Spaceflight Decompression Sickness Contingency Plan

Joe Dervay, M.D.
<table>
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<tr>
<th>Medical Operations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dr. Joe Dervay</td>
</tr>
</tbody>
</table>

- 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

Dr. Joe Dervay
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
    
    » 12-16 hr stay at 10.2 --- 20 Final PB 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)
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
# EVA Cuff Classifications

<table>
<thead>
<tr>
<th>Cuff Class</th>
<th>Symptoms</th>
<th>Response</th>
<th>Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td><strong>Mild pain</strong>, at single or multiple sites and/or single extremity paresthesia. Difficult to distinguish from suit pressure points. <strong>Symptoms do not interfere with performance.</strong></td>
<td>Report in post EVA PMC. No future EVA impact.</td>
<td>1-8</td>
</tr>
<tr>
<td>2</td>
<td><strong>Moderate cuff 1 symptoms that interfere with performance.</strong></td>
<td>Terminate EVA for both crew members, perform worksite clean-up only, minimize activity of affected crew member. Perform repress. Set up PMC post repress.</td>
<td>3,6 9-10</td>
</tr>
</tbody>
</table>
### 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><strong>Severe cuff 1 symptoms</strong> 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><strong>Serious symptoms – Central neurological, cardiopulmonary.</strong></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>
</tbody>
</table>
RATIONALE:

- Spacesuit itself creates pressure points, joint pains, and local paresthesias

- Majority of pain symptoms (86%) in historic database improved or remained the same with time

- Low risk of mild or moderate symptoms progressing to serious

- Worksite safing important for potential Shuttle de-orbit as well as Station operations

- May require 30-45 min. transit to airlock from worksite location

- With serious symptoms, may need to repress affected crewmember ASAP while solo crewmember completes clean-up tasks
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”
If STS at 10.2 psi
Stay in Press Mode
20 Min in Suit
(10.2 + 4.3 = 14.5 psi)
Yes
Sx Resolved
No
Remain in Suit 150 Min.
(14.7 + 4.3 = 19 psi)
Sx Unresolved, Worse or No Change
20 Min. Extension
Sx Unresolved, Worse or No Change
Sx Unresolved, Worse or No Change
Doff Suit

If any symptoms remain, Check MCC/PMC
(Possible Additional O₂, BTA, Orlan Ops.)

If STS at 14.7 psi
ISS at 14.7 psi
Repress STS to 14.7 psi
Repress

Possible Suit LiOH Change out

Remain in Suit 160 Min.
Additional 160 Min.

 PMC

Stay in Press Mode
20 Min in Suit
(10.2 + 4.3 = 14.5 psi)

No Rx Required

Aftercare
- Periodic Medical Eval.
- RTD 24 Hr.
- Reduced Pressure/EVA (Case by Case)
(72 Hr. - 7 Days)

Block 1

A

B

Sx Resolved

Sx Resolved

Doff Suit

20 Min. Extension

20 Min. Extension

Block 1

- CMO PE/Neuro Check
- Hydrate (Isotonic Fluid po, 1 liter/hr)
- Limit activity
- PMC

Aftercare
- RTD 24 Hrs.
- Medical Check Prior to EVA
(72 Hr)
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>Facial Muscles: Crewmember raises eyebrows, squeezes eyes shut and puffs up cheeks without difficulty.</th>
<th>AB</th>
<th>AB</th>
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<tbody>
<tr>
<td>16</td>
<td></td>
<td>NL</td>
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<td>NL</td>
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<tr>
<td>Strength</td>
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<td>AB</td>
<td>AB</td>
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<tr>
<td>17</td>
<td>Arm Bending Strength: Crewmember bends elbow, with palm towards face and holds for two seconds against examiner resistance. Repeat both sides.</td>
<td>AB</td>
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</tr>
<tr>
<td>18</td>
<td>Leg Bending Strength: Crewmember bends knee and holds for two seconds against examiner resistance. Repeat both sides.</td>
<td>AB</td>
<td>AB</td>
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<td>NL</td>
<td>NL</td>
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<tr>
<td>Coordination Functions</td>
<td></td>
<td>AB</td>
<td>AB</td>
<td>AB</td>
<td>AB</td>
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<td>AB</td>
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<tr>
<td>19</td>
<td>Finger-to-Finger: Starting with hands wide apart, Crewmember easily and accurately touches fingertips together with eyes closed.</td>
<td>NL</td>
<td>NL</td>
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<td>NL</td>
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<td>NL</td>
<td>NL</td>
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<tr>
<td>Sensory Function</td>
<td></td>
<td>AB</td>
<td>AB</td>
<td>AB</td>
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<td>AB</td>
<td>AB</td>
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<tr>
<td>20</td>
<td>Gross Sensation: Examiner squeezes Crewmember’s forearms, feet and knees through suit. Crewmember should feel squeezing of the forearms, feet and legs.</td>
<td>AB</td>
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</tbody>
</table>
Medical Operations

Spaceflight Decompression Sickness Contingency Plan

Dr. Joe Dervay
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
Medical Operations

Spaceflight Decompression

Sickness Contingency Plan

Dr. Joe Dervay
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)

<table>
<thead>
<tr>
<th>Time (min)</th>
<th>0</th>
<th>100</th>
<th>110</th>
<th>150</th>
<th>170</th>
<th>180</th>
<th>210</th>
<th>215</th>
<th>250</th>
<th>280</th>
<th>520</th>
<th>525</th>
</tr>
</thead>
<tbody>
<tr>
<td>Altitude</td>
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</table>

**Phase I**
- Rest
- 10 min

**Phase II**
- Rest
- 75% VO₂ peak
- 40 min

**Phase III**
- Rest
- Light Work

**Phase IV**
- Rest
- 95 min Light Work

**Results**
- 9 DCS/47 trials = 19%
- 0/45 = 0%
- 2/10 = 20%
  - (1 cerebral DCS)
- 8/57 = 14%

**4 hr**
- EVA
- Simulation
Mission Support

- Extravehicular Activity (EVA) Monitoring
Medical Operations
Spaceflight Decompression
Sickness Contingency Plan

Dr. Joe Dervay

DCS Contingency Plan

DCS Disposition Policy

Ground Support Infrastructure

EVA Checklist Development

Improved On-Orbit DCS Treatment

DCS Flight Rules Development

Mission Control DCS Simulation Program

Primary Hyperbaric Landing Sites

Cooperative USAF/NASA Programs

Russian EMS Plan

Insuit Treatment

BTA Mods

Crew Flight Surgeon Training

Hyperbaric Chamber Technology Dev.

Adjuvant Drug Therapy

Shuttle / EMU

ISS / EMU

Russian / ORLAN
EVA “CUFF CLASSIFICATION” SYSTEM:

- Simple operational classification of DCS symptoms relevant to EVA crewmember
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- Defines actions required to place payload in safe configuration and repress affected crewmember
- Sensible system to encourage symptom reporting
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- Documents Cuff Classes, deorbit requirements to Primary Hyperbaric Care site (3 CONUS, Hickam, Guam), deorbit within 10 hrs. for unresolved Type II symptoms
RESULTS: 90 MIN PROTOCOLS

(not to scale)

Altitude (ft)

30K

0

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>
<thead>
<tr>
<th>Spaceflight Decompression Sickness Contingency Plan</th>
<th>Medical Operations</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Dr. Joe Dervay</td>
</tr>
</tbody>
</table>
4 hr In-suit Protocol Timeline
(Note: Pre-sleep time not shown)

**Medical Operations**

Dr. Joe Dervay

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**Spaceflight Decompression**

**Sickness Contingency Plan**

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**POST SLEEP 75 min**

**EVA PREP 90 min**

**Purge**

**EMU PREBREATHE 4 hours**

**EMU Donning 55 min**

**Ck**

---

**C/L Depress (30 min)**

**EVA PREP = 6:30**

**Rep**

**POST EVA w/o H2O**

---

* 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)
Medical Operations

Dr. Joe Dervay

CEVIS Exercise Protocol Timeline

Spaceflight Decompression
Sickness Contingency Plan

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)

* EV1 must start exercise within 10 min after PB initiate, EV2 must start exercise within 25 min after PB initiate to maintain 45 minute of mask time after exercise per FR

Note: Assume depress pump and EMERG MPEV & AL VAJ; 40 min C-Lk depress with built in hold at 5psi PET = 25. With 2 hours of Pre-sleep, **STS Crew Day length = 15:42.**
Spaceflight Decompression
Sickness Contingency Plan

Dr. Joe Dervay

A/L Dep (15 min)

NOTE: Assume depress with AIRLK DEPRESS vlv; 15 min. With 2 hours of Pre-sleep, STS Crew Day length = 14:17.

A/L Dep (15 min)

EVA PET = 6:30

1:15

2:45

2:53

4:0

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)
## Table 1

### Prebreathe Protocols- Observed and Estimated Risks

<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><strong>EXERCISE (CEVIS)</strong></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>
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<tr>
<td><strong>CAMPOUT (ISS)</strong></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>2.8% (≤5.9% @ 95% cl)#</td>
<td>1 / 936 (1/656 – 1/1635 cl)#</td>
<td></td>
</tr>
<tr>
<td>Grade IV VGE</td>
<td></td>
<td>5.8% (≤19.0% @ 95% cl)#</td>
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</tr>
<tr>
<td><strong>10.2 PSIA STAGED</strong></td>
<td></td>
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<td></td>
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<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.