Spaceflight Decompression Sickness Contingency Plan

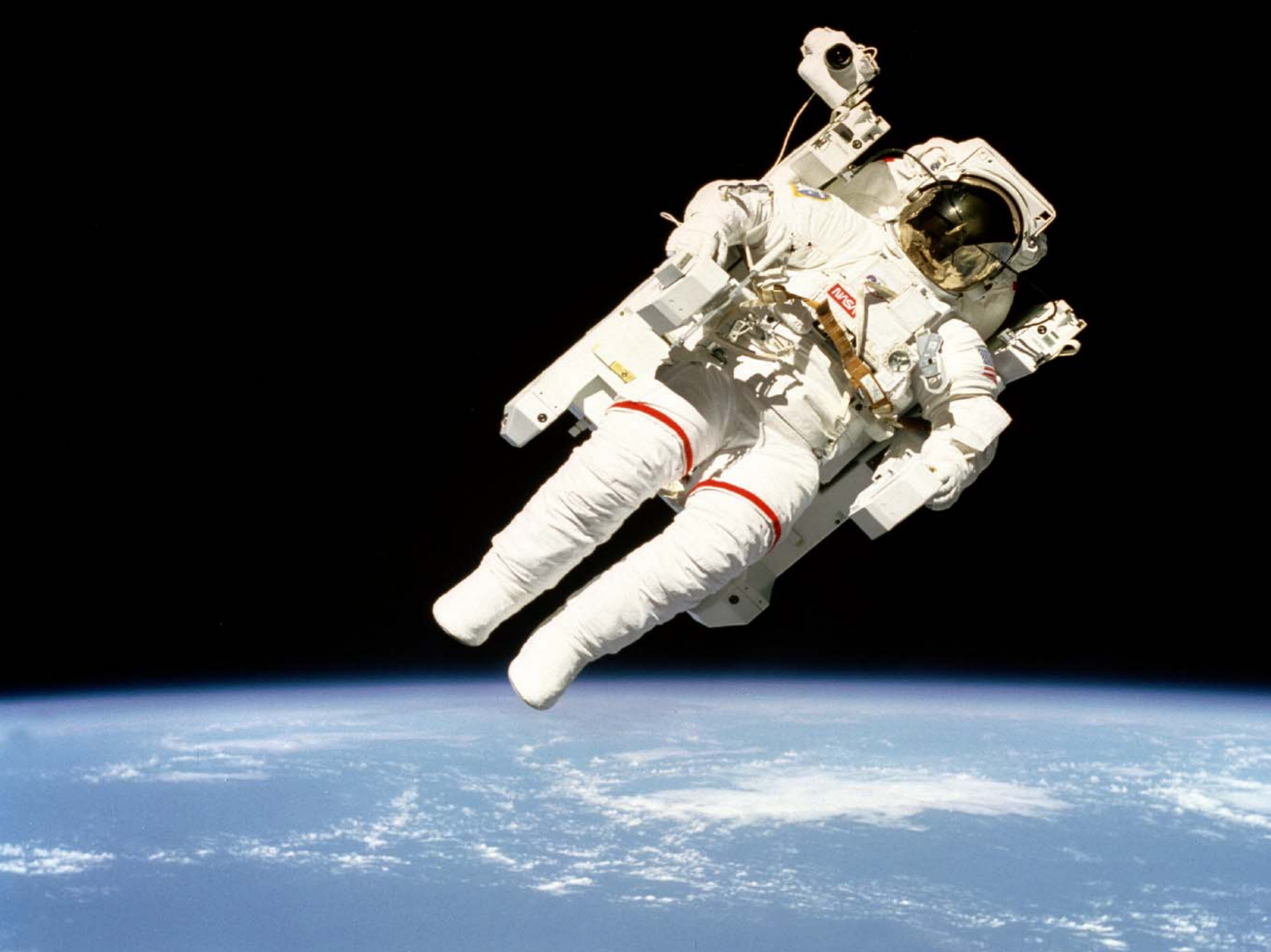
Joe Dervay, M.D.

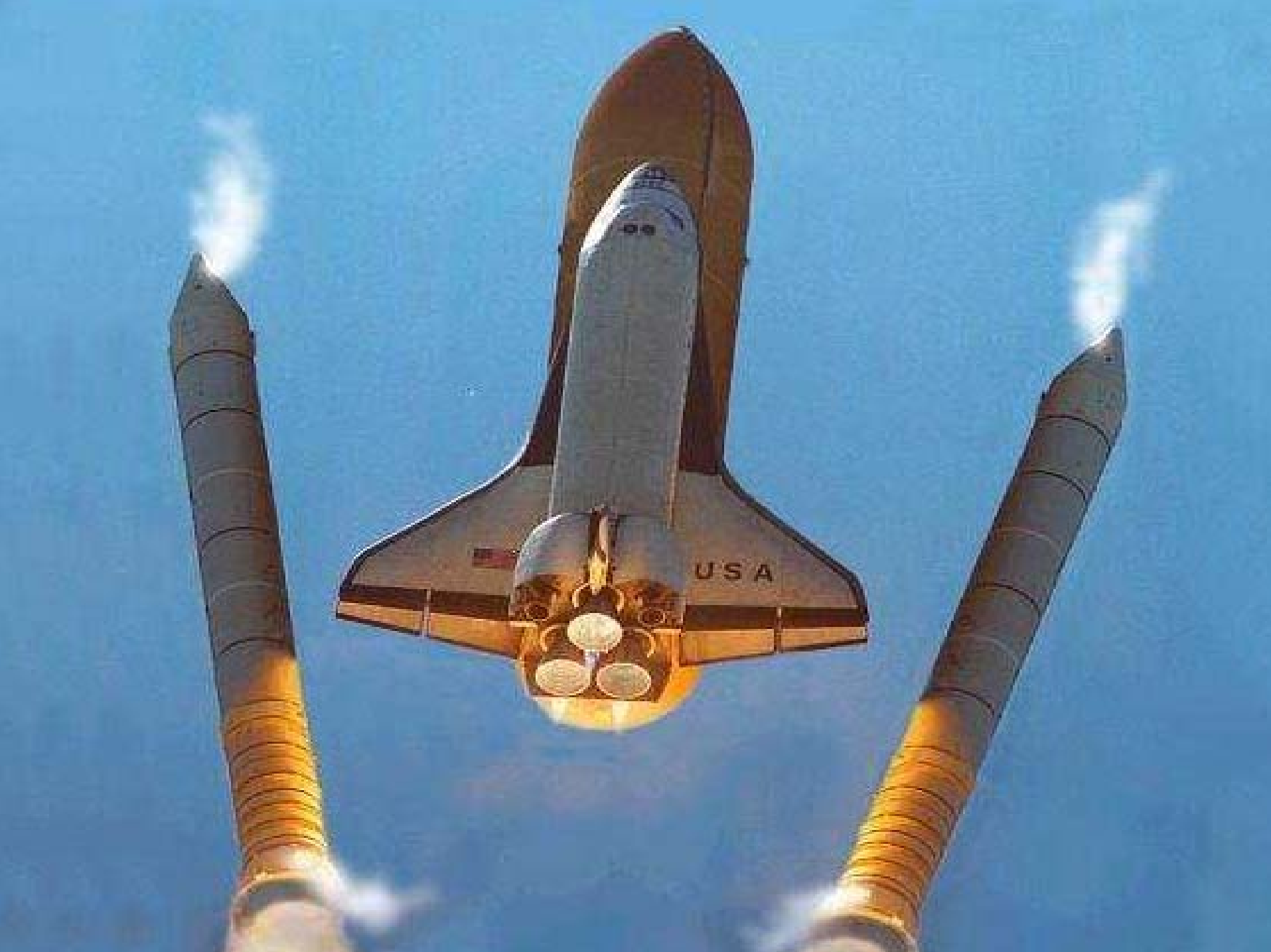
Spaceflight Decompression Sickness Contingency Plan

Medical Operations

Dr. Joe Dervay

- 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


NASA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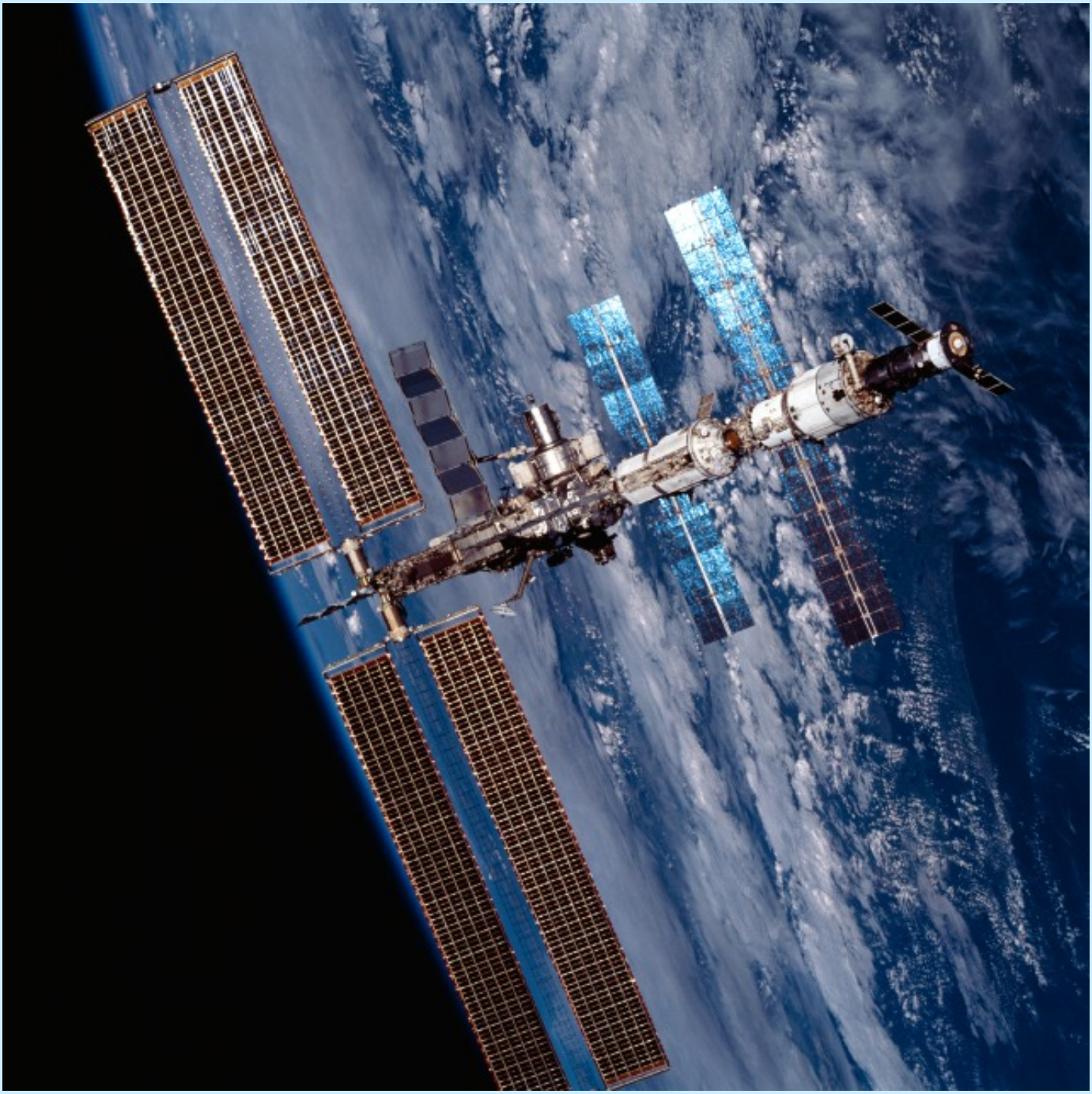

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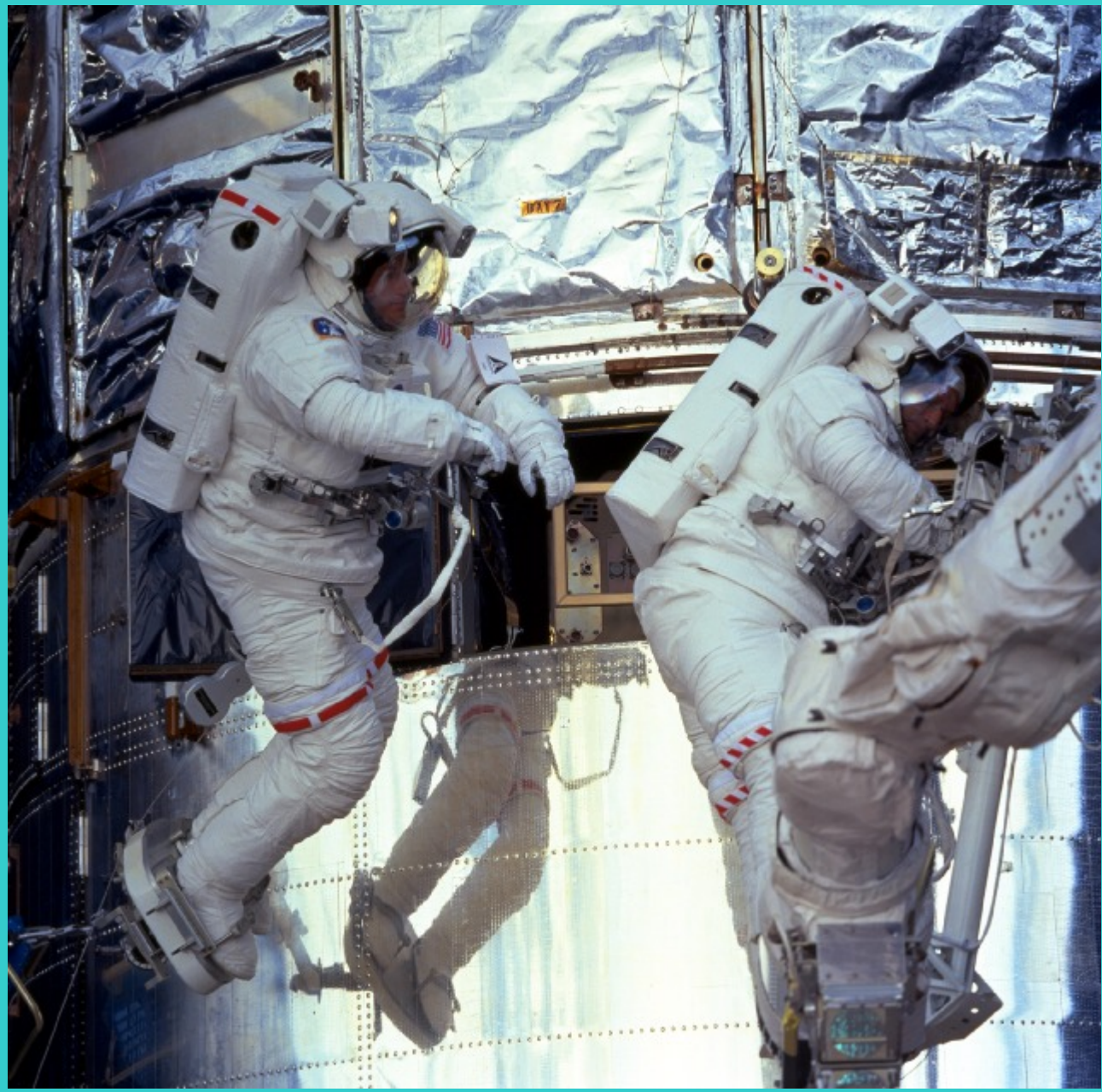
DAY 2


NASA

Mission Support

On-orbit Flight Control Room (FCR) Staffing

Surgeon Console - FCR

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- **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) $\leq$ 15 % at 95% CL**
    - » **Grade 4 Venous Gas Emboli (VGE) $\leq$ 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**

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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

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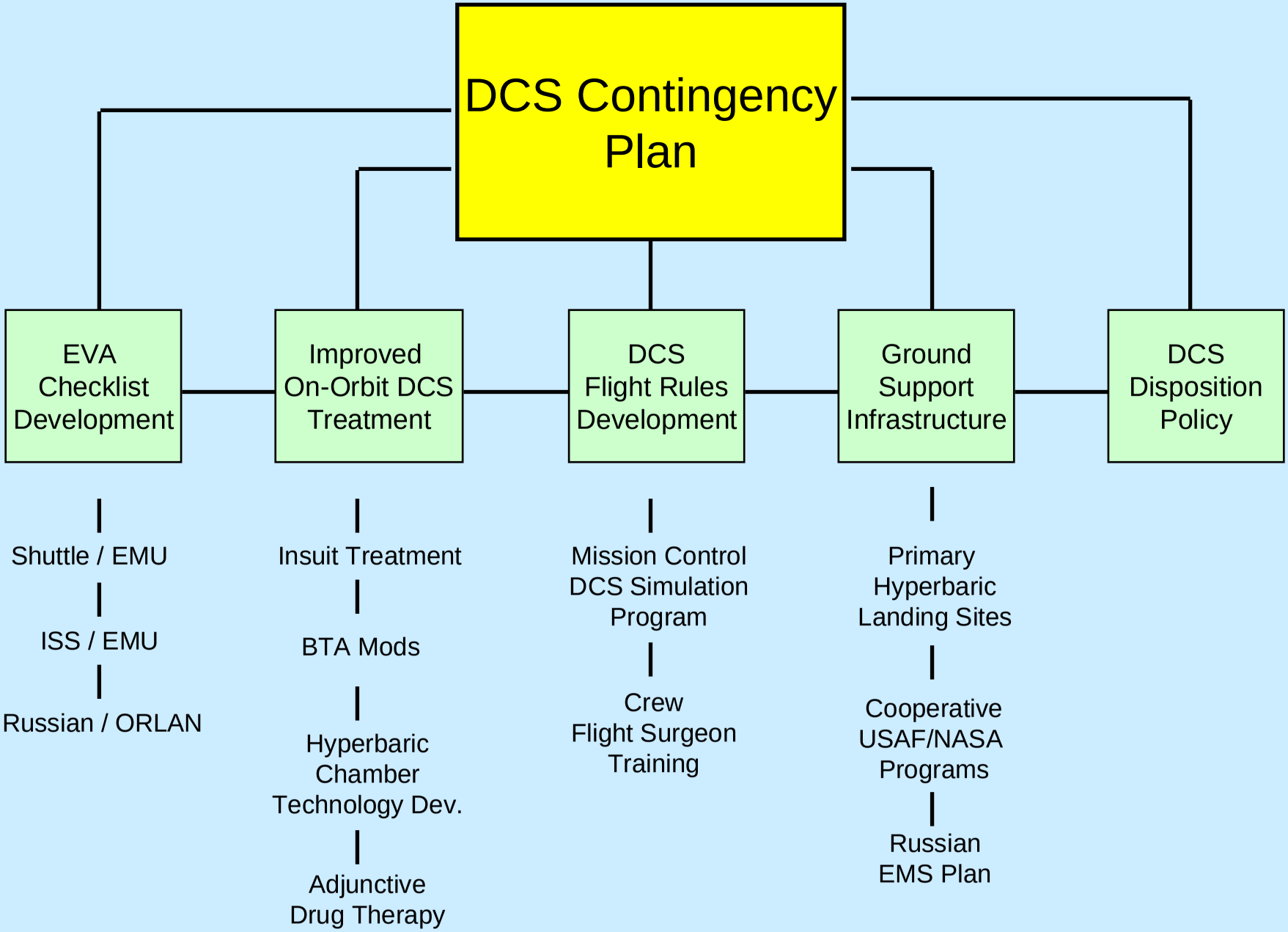
APPROACH:

- 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)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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

Cuff Class	Symptoms	Response	Rationale
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 PMC. No future EVA impact.	1-8
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.)

Cuff Class	Symptoms	Response	Rationale
3	**Severe cuff 1 symptoms** or migratory, trunkal or multiple site paresthesia, unusual headache.	Terminate EVA. Assisted return of affected crew member to airlock, buddy perform worksite safing, then airlock repress. Set up PMC.	12,13
4	Serious symptoms – Central neurological, cardiopulmonary.	Abort EVA. Crew assisted return to airlock. Repress affected crew member. Buddy perform worksite safing, then airlock depress, repress. Set up PMC.	14-19

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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

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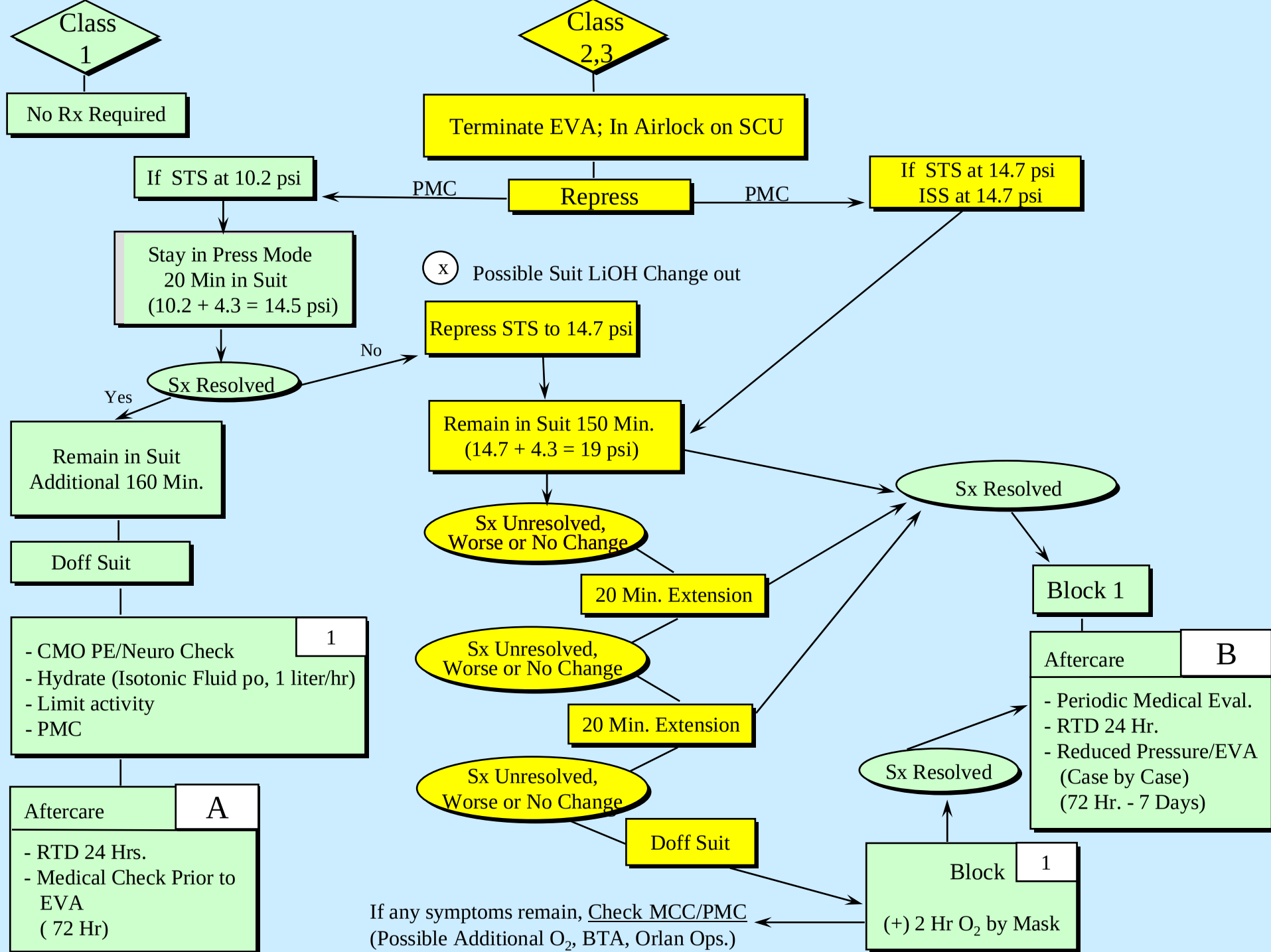
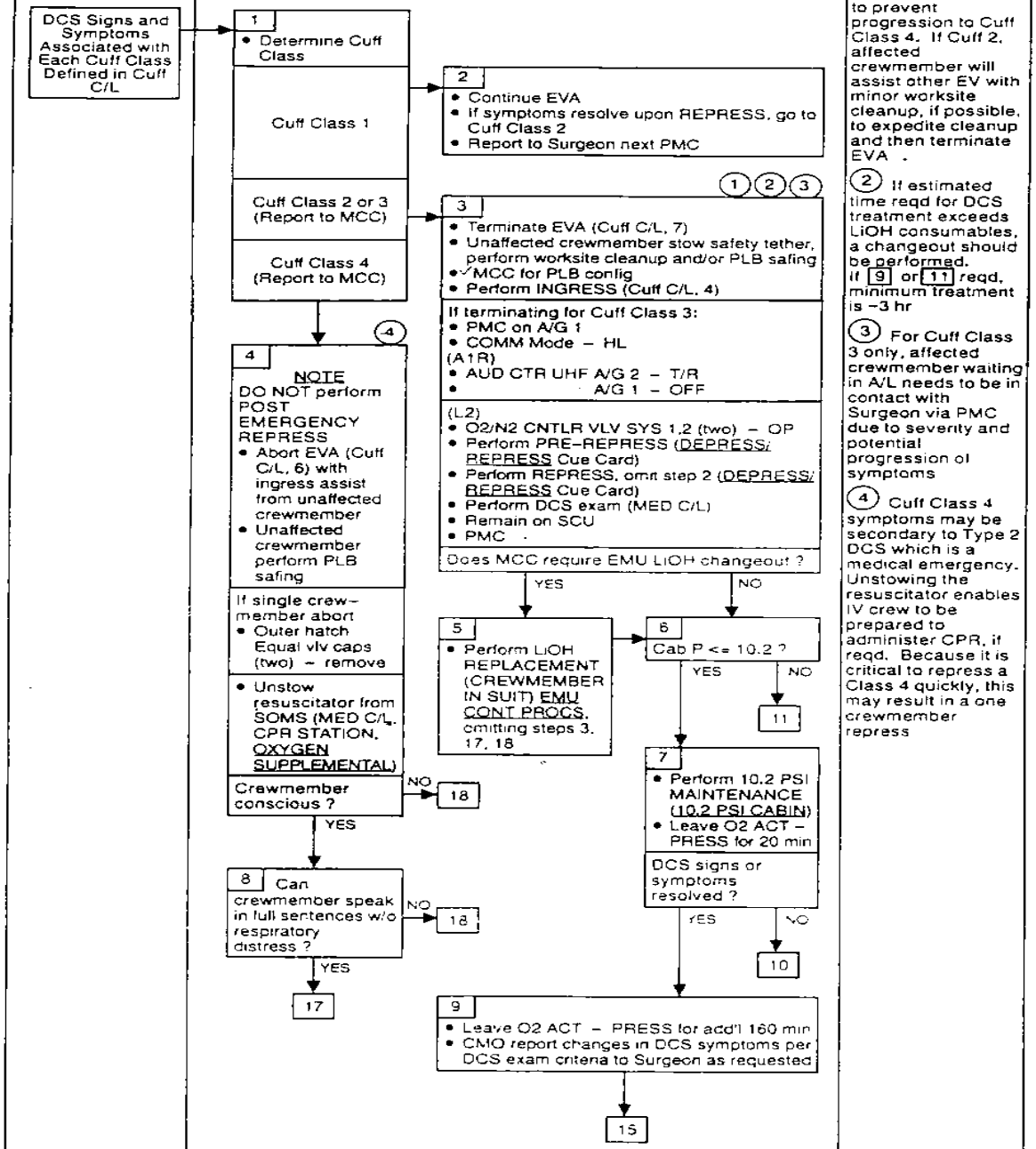
TREATMENT PHILOSOPHY:

- 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”


Class 1
No Rx Required
Class 2,3
Terminate EVA; In Airlock on SCU
Repress
PMC
PMC
If STS at 10.2 psi
If STS at 14.7 psi
ISS at 14.7 psi
Stay in Press Mode
20 Min in Suit
(10.2 + 4.3 = 14.5 psi)
X
Possible Suit LiOH Change out
Repress STS to 14.7 psi
No
Sx Resolved
Yes
Remain in Suit
Additional 160 Min.
Remain in Suit 150 Min.
(14.7 + 4.3 = 19 psi)
Sx Resolved
Sx Unresolved,
Worse or No Change
20 Min. Extension
Block 1
Doff Suit
1
- CMO PE/Neuro Check
- Hydrate (Isotonic Fluid po, 1 liter/hr)
- Limit activity
- PMC
Sx Unresolved,
Worse or No Change
Aftercare
B
- Periodic Medical Eval.
- RTD 24 Hr.
- Reduced Pressure/EVA
(Case by Case)
(72 Hr. - 7 Days)
20 Min. Extension
Sx Resolved
Aftercare
A
- RTD 24 Hrs.
- Medical Check Prior to
EVA
(72 Hr)
Sx Unresolved,
Worse or No Change
Doff Suit
Block
1
(+) 2 Hr O2 by Mask
If any symptoms remain, Check MCC/PMC
(Possible Additional O2, BTA, Orlan Ops.)

20.1 DCS TREATMENT



(1) EVA terminated to prevent progression to Cuff Class 4. If Cuff 2, affected crewmember will assist other EV with minor worksite cleanup, if possible, to expedite cleanup and then terminate EVA .

(2) If estimated time reqd for DCS treatment exceeds LiOH consumables, a changeout should be performed. If 9 or 11 reqd, minimum treatment is ~3 hr

(3) For Cuff Class 3 only, affected crewmember waiting in A/L needs to be in contact with Surgeon via PMC due to severity and potential progression of symptoms

(4) Cuff Class 4 symptoms may be secondary to Type 2 DCS which is a medical emergency. Unstowing the resuscitator enables IV crew to be prepared to administer CPR, if reqd. Because it is critical to repress a Class 4 quickly, this may result in a one crewmember repress

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DCS Neurological exam:

- Simple exam to asses 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

Facial Nerves											
16	**Facial Muscles:** Crewmember raises eyebrows, squeezes eyes shut and puffs up cheeks without difficulty.	AB NL	AB NL	AB NL	AB NL	AB NL	AB NL	AB NL	AB NL	AB NL	AB NL
Strength											
17	**Arm Bending Strength:** Crewmember bends elbow, with palm towards face and holds for two seconds against examiner resistance. Repeat both sides.	AB NL	AB NL	AB NL	AB NL	AB NL	AB NL	AB NL	AB NL	AB NL	AB NL
18	**Leg Bending Strength:** Crewmember bends knee and holds for two seconds against examiner resistance. Repeat both sides.	AB NL	AB NL	AB NL	AB NL	AB NL	AB NL	AB NL	AB NL	AB NL	AB NL
Coordination Functions											
19	**Finger-to-Finger:** Starting with hands wide apart, Crewmember easily and accurately touches fingertips together with eyes closed.	AB NL	AB NL	AB NL	AB NL	AB NL	AB NL	AB NL	AB NL	AB NL	AB NL
Sensory Function											
20	**Gross Sensation:** Examiner squeezes Crewmember's forearms, feet and knees through suit. Crewmember should feel squeezing of the forearms, feet and legs.	AB NL	AB NL	AB NL	AB NL	AB NL	AB NL	AB NL	AB NL	AB NL	AB NL

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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


United States

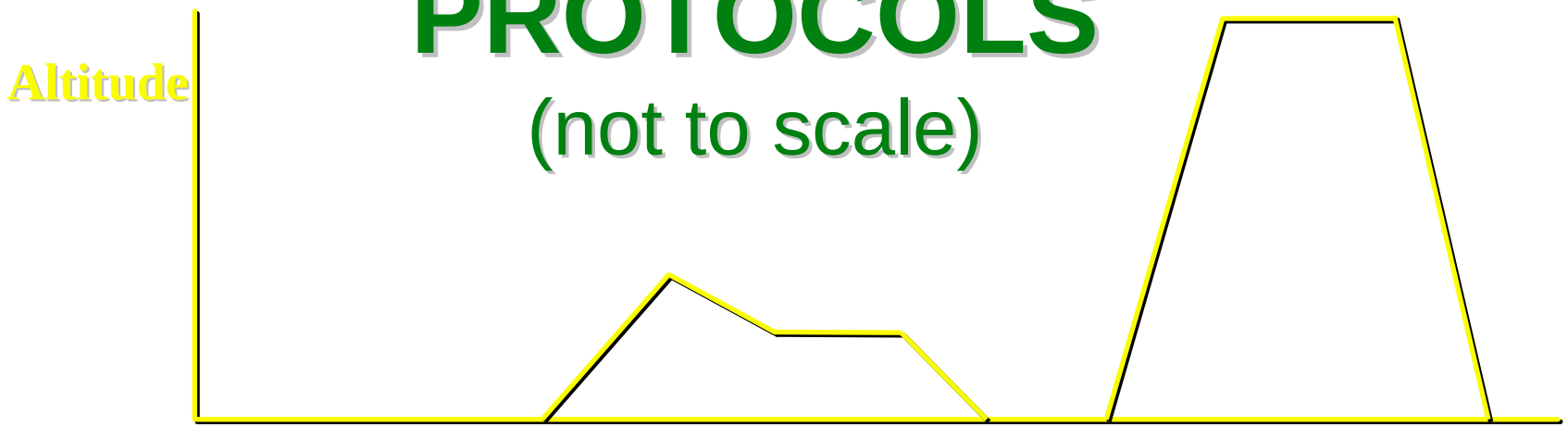
PRP EXERCISE STRATEGIES

Upright dual arm and leg cycle exercise (ALE)

Semi-recumbent intermittent light exercise simulating astronaut tasks (ILE)

RESULTS: 2 HOUR PROTOCOLS

(not to scale)

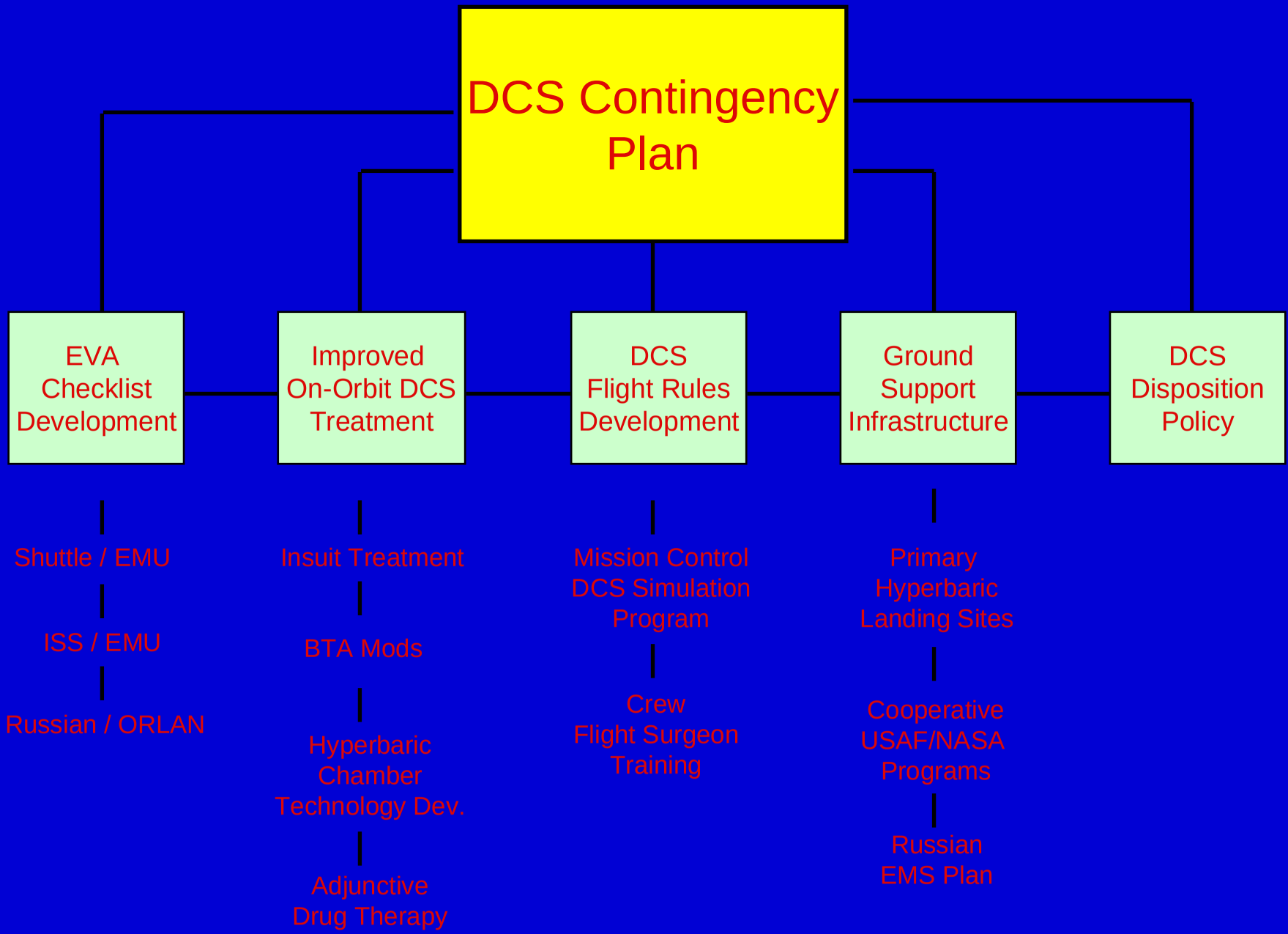


Time (min) 0 100 110 150 170 180 210 215 250 280 520 525

Phase I	Rest		10 min			9 DCS/47 trials = 19%				4 hr		
Phase II	Rest		75% $VO_{2\ peak}$			40 min		0/45 = 0%		EVA		
Phase III	Rest					Light Work		2/10 = 20% (1 cerebral DCS)		Simu-		
Phase IV	Rest		95 min Light Work					8/57 = 14%		lation		

Mission Support

- Extravehicular Activity (EVA) Monitoring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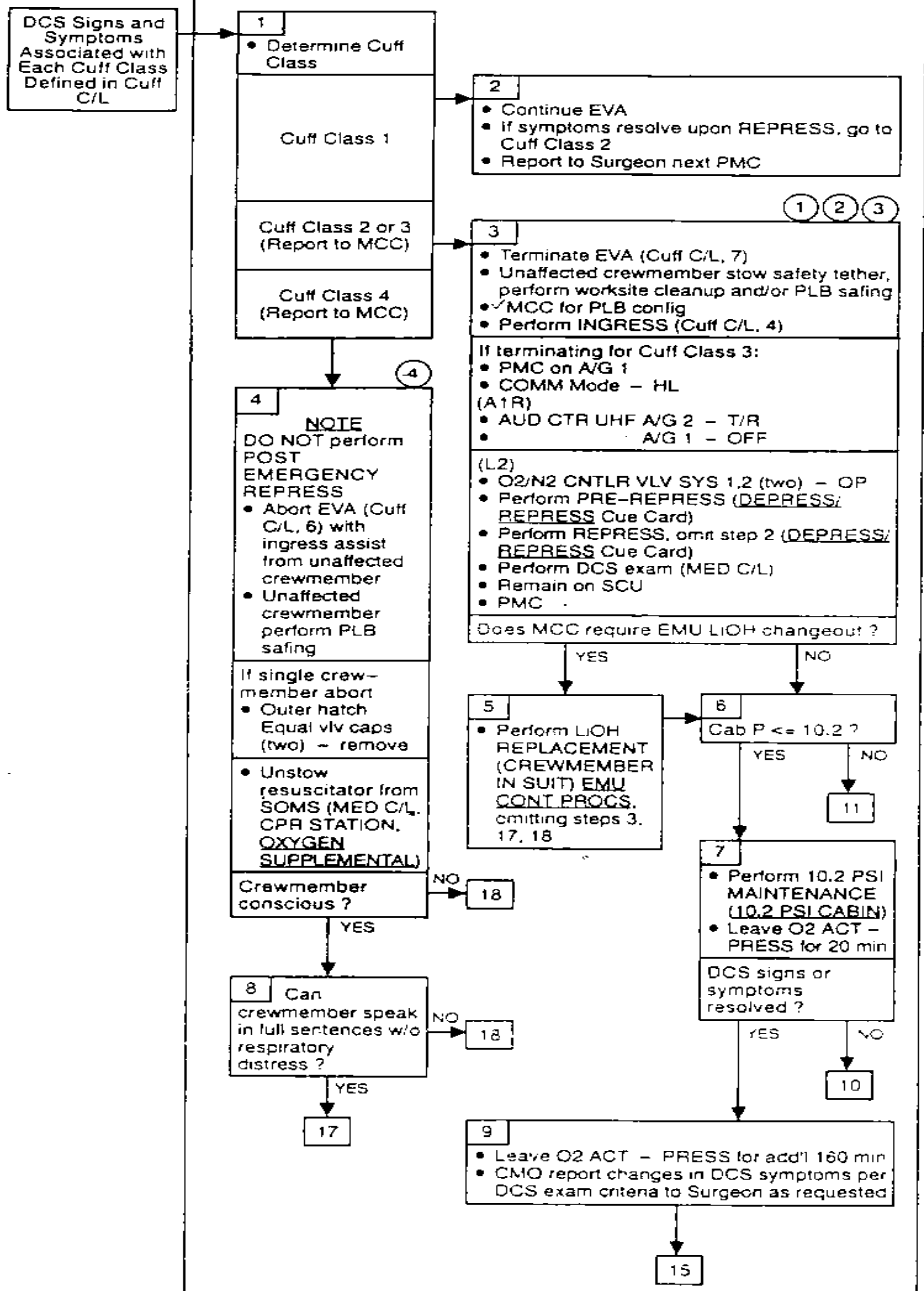
20.1 DCS TREATMENT



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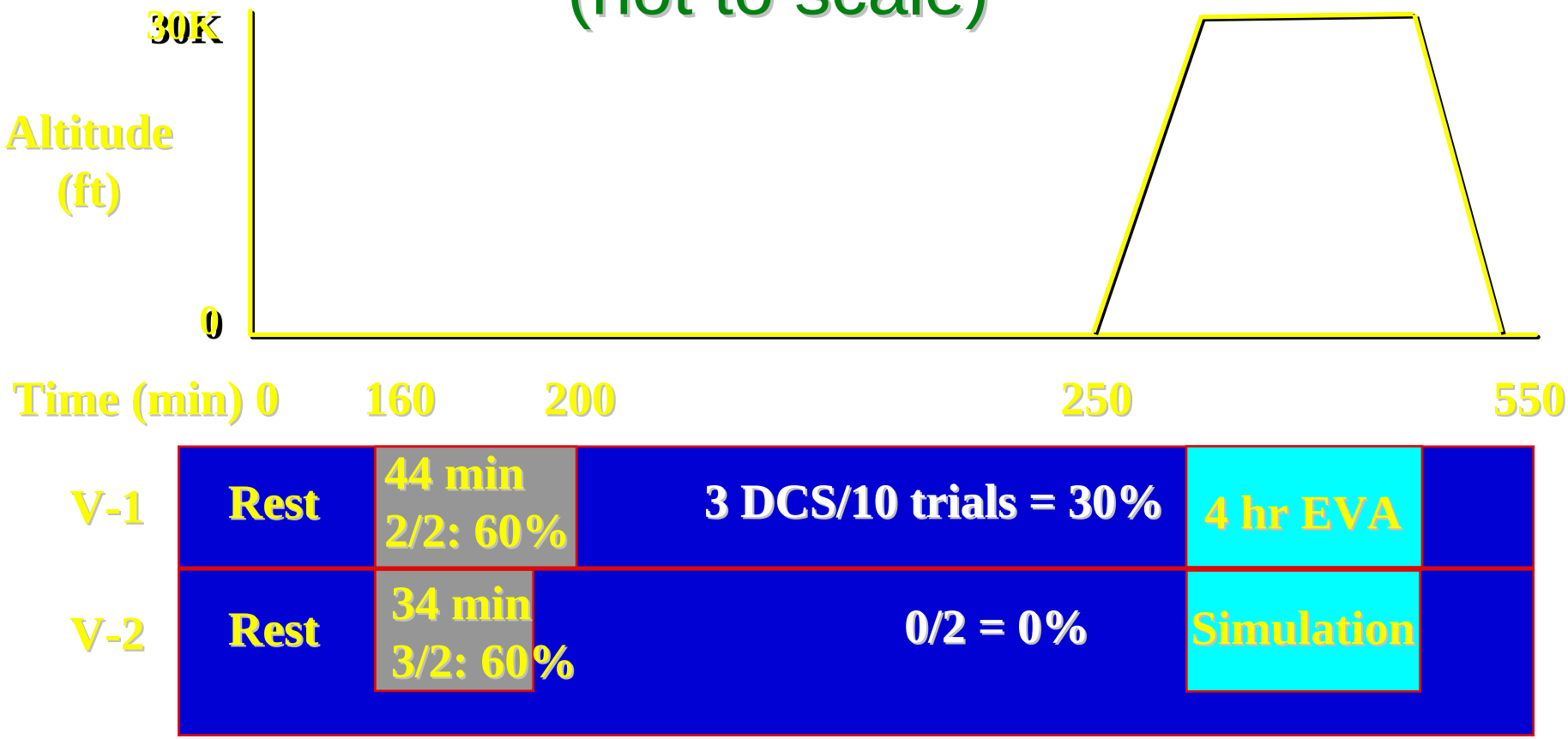
RESULTS: 90 MIN PROTOCOLS

(not to scale)



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4 hr In-suit Protocol Timeline

(Note: Pre-sleep time not shown)

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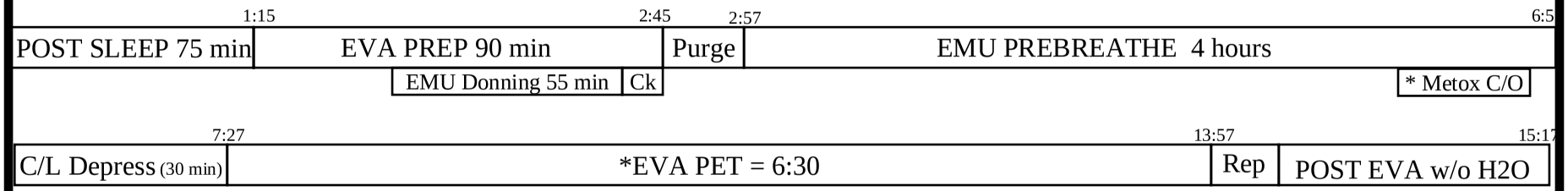

* It is possible to perform METOX Change-Out (manned) to allow for maximum EVA PET capability. Provided that Crew Day Length violations can be approved, we could support a 6:30 EVA PET.

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)

Spaceflight Decompression Sickness Contingency Plan

CEVIS Exercise Protocol Timeline

(Note: Breakfast not shown)

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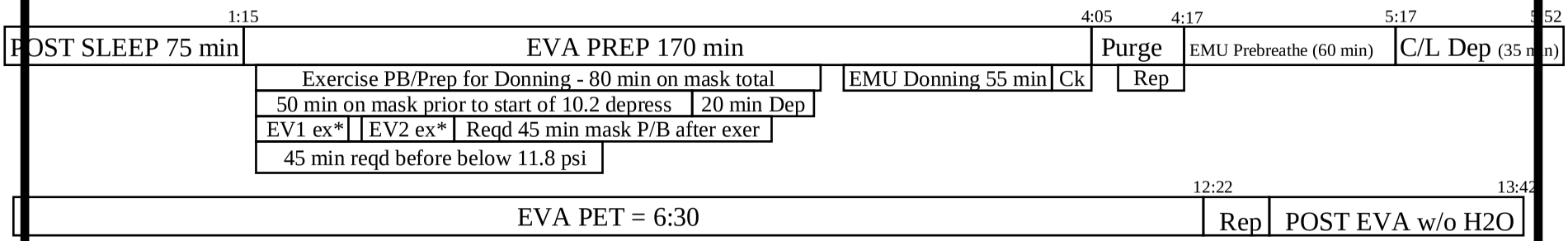

* EV1 must start exercise within 10 min after PB initiate, EV2 must start exercise within 25 min after PB initiate to maintain 45 minute of mask time after exercise per FR

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**.

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)**

Spaceflight Decompression Sickness Contingency Plan

Shuttle 10.2 PSI Staged Protocol Timeline

(Note: Sleep time not shown)

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60 min Mask PB	*12 HOURS AT 10.2 psi	POST SLEEP 75 min	EVA PREP 90 min	Purge	EMU PREBREATHE 75 min**
10.2 Dep			EMU Donning 55 min	Ck	
45 min before 12.5					
1:15			2:45	2:53	4:0

A/L Dep (15 min)	EVA PET = 6:30	Rep	POST EVA w/o H2O
4:23		10:53	12:13

* 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, **STS Crew Day length = 14:17**.

INITIAL PREBREATHE	TIME AT 10.2 PSI	FINAL PREBREATHE
60 MINUTES	24 HOURS	40 MINUTES
60 MINUTES	20 HOURS	50 MINUTES
60 MINUTES	16 HOURS	60 MINUTES
60 MINUTES	12 HOURS	75 MINUTES

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

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

*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.