



UPDATES TO NASA'S BREAK-IN-PREBREATHE RULES DUE TO TYPE II DECOMPRESSION SICKNESS RISK CONSIDERATIONS

ANDREW F. J. ABERCROMBY¹, ALEJANDRO GARBINO², MATTHEW MAKOWSKI³, JASON NORCROSS⁴, ROBERT SANDERS¹

¹ NASA JOHNSON SPACE CENTER, HOUSTON, TX

² GEOCONTROL SYSTEMS, NASA JOHNSON SPACE CENTER, HOUSTON, TX

³ UNIVERSITY OF TEXAS MEDICAL BRANCH, NASA JOHNSON SPACE CENTER, HOUSTON, TX

⁴ KBR, NASA JOHNSON SPACE CENTER, HOUSTON, TX



Disclosure Information

93rd Annual Scientific Meeting

Andrew Abercromby

I have no financial relationships to disclose.

I will not discuss off-label use and/or investigational use in my presentation

Background

- NASA routinely conducts suited ground vacuum chamber tests for training and hardware testing purposes
- NASA's EVA Integrated Product Team (IPT) investigated a serious Type II DCS event at Johnson Space Center
- A **late break in prebreathe** (2-3 minute break breathing ambient air, 13 minutes pre-depress) was identified as a **credible cause or factor in the Type II DCS case**
- NASA prebreathe protocols were followed
 - Existing policies allowed breaks-in-prebreathe of up to 10 minutes with 2:1 "payback"
 - No additional or different payback rules for late breaks



Information on Type II DCS case or the specifics of the chamber run will not be discussed due to attributability and medical privacy



Rationale for Re-evaluating Ground & Flight Rules

- Late break-in-prebreathe not definitively shown to be a cause or factor in the Type II DCS case, but was considered credible
- Unlike nominal prebreathe protocols, break-in-prebreathe flight rules not based on any significant empirical data
- Concern that late breaks may be higher risk than earlier breaks
- Flight prebreathe protocols are validated through extensive ground testing – **no concern with nominal flight protocols**





Approach

Flight Rule
Documentation

Consulting with
previous SMEs

Published
Literature

Relevant Data
Sets

Operational
Experience

Models

- Initial focus on retrieval and review of documentation and rationale for existing flight rules
 - Several subject matter experts (SMEs) involved in flight rules had since retired from NASA
- Literature & previous operational experience with breaks-in-prebreathe also reviewed
- NASA's DCS risk models not applicable or validated for estimating DCS risk due to break-in-prebreathe but offer some insight



Documentation of BiP Flight Rule

Flight Rule Documentation

Consulting with previous SMEs

Published Literature

Relevant Data Sets

Operational Experience

Models

- **Limited documentation** on rationale for existing Break-in-Prebreathe flight rules
 - Contrasts with exhaustive documentation and data supporting nominal protocols
 - External Committee (1980) supported 2:1 payback – unable to retrieve report
- **Email exchanges and meeting minutes (2004)** provide some insight
 - SME 1: *“I think that the 2:1 payback is appropriate”*
 - SME 2: *“...we don't break at the end to avoid even the discussion about Type II.” “I feel 2:1 is conservative enough...”*
 - SME 3: *“...suspect that break in prebreathe is not that important **as long as you do at least another 60 minutes of prebreathe after the break.** However, that is only an intuitive opinion and no substitute for getting real data on the subject, which has been part of our integrated plan.”*
- **Contacted SMEs that have since left NASA**
 - *“Not based on any significant empirical data”*
 - *[poorly understood and the approach has been mostly analytical and expert opinion]*
 - *[Other factors] drove 2:1*



Recent Literature & Data on BiP

Flight Rule Documentation

Consulting with previous SMEs

Published Literature

Relevant Data Sets

Operational Experience

Models

- Unaware of published studies since 2010 study by USAF ¹
 - NASA collaborated on the study
 - Data not directly applicable - aimed at U2 pilots
 - Very high DCS stress (75-84% DCS) incl. 25% Type II
 - Included 10, 20, 60 min breaks but all followed by 30 mins additional prebreathe
 - No change to NASA payback rules based on results
- EVA-focused Break-in-Prebreathe research study proposed circa 2005 but not funded
- Forward work to include more extensive review of recent literature

¹ Pilmanis AA, Webb JT, Balldin UI, Conkin J, Fischer JR. Air break during preoxygenation and risk of altitude decompression sickness. Aviat Space Environ Med. 2010 Oct;81(10):944-50. doi: 10.3357/ asem.2819.2010. PMID: 20922886.

Operational Experience

Flight Rule
Documentation

Consulting with
previous SMEs

Published
Literature

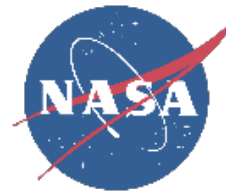
Relevant Data
Sets

Operational
Experience

Models

- Only ~7 BiP in 20 years of operations
- 2 breaks-in-prebreathe in 72 EVAs since the start of current ISS prebreathe protocol (ISLE) in 2011
 - 144 crewmembers have suited up
- US EVA 38: Metox removed for 13 seconds while EMU Fan on
 - 4 minute break assumed
 - Resulted in 20 minute delay for depress
 - **59 minutes before depress start**
- US EVA 73: Helmet removed to swap comm caps
 - 6 minute break
 - Resulted in 24 minute delay for depress
 - **81 minutes before depress start**
- No reported DCS





Models

Flight Rule
Documentation

Consulting with
previous SMEs

Published
Literature

Relevant Data
Sets

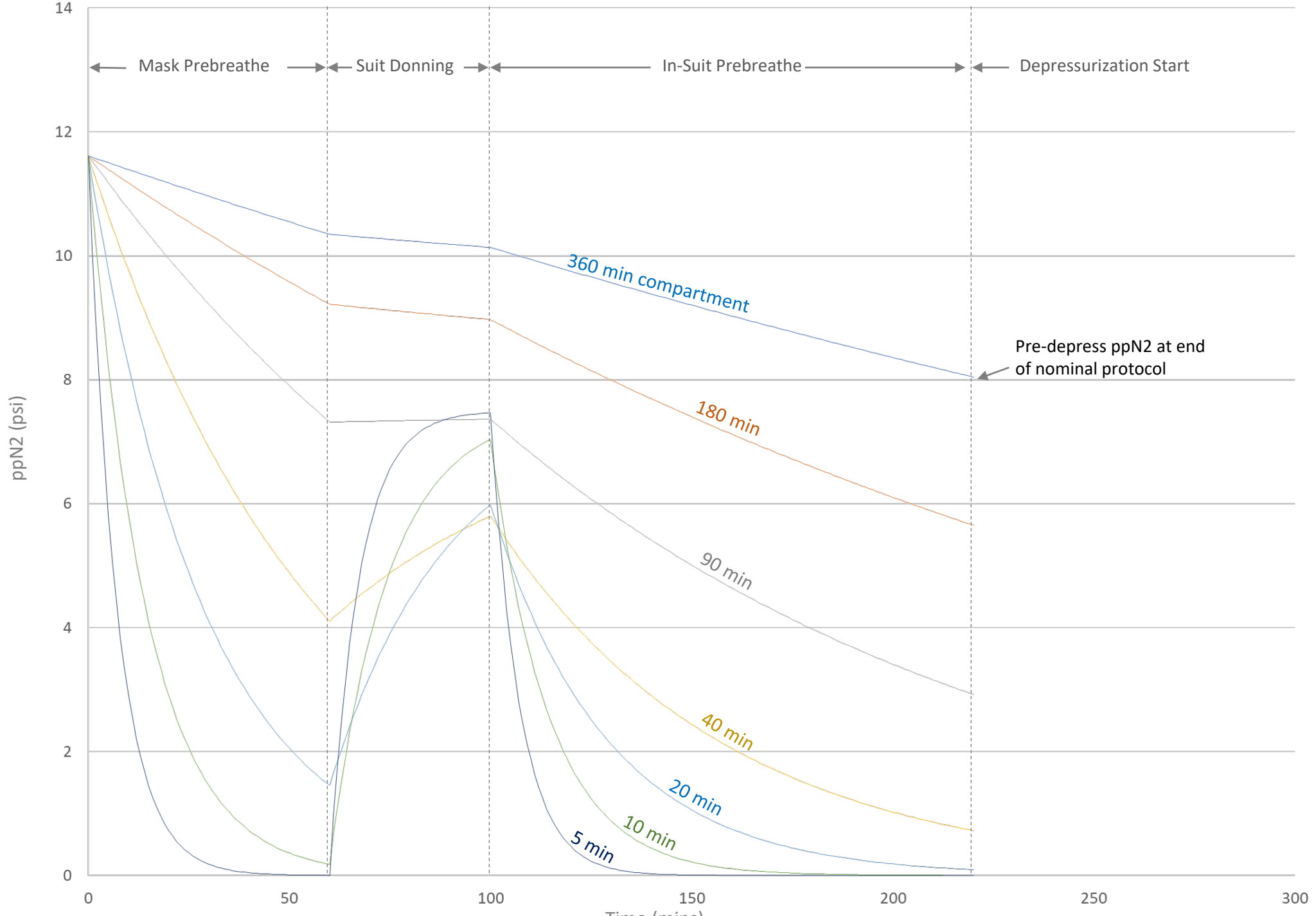
Operational
Experience

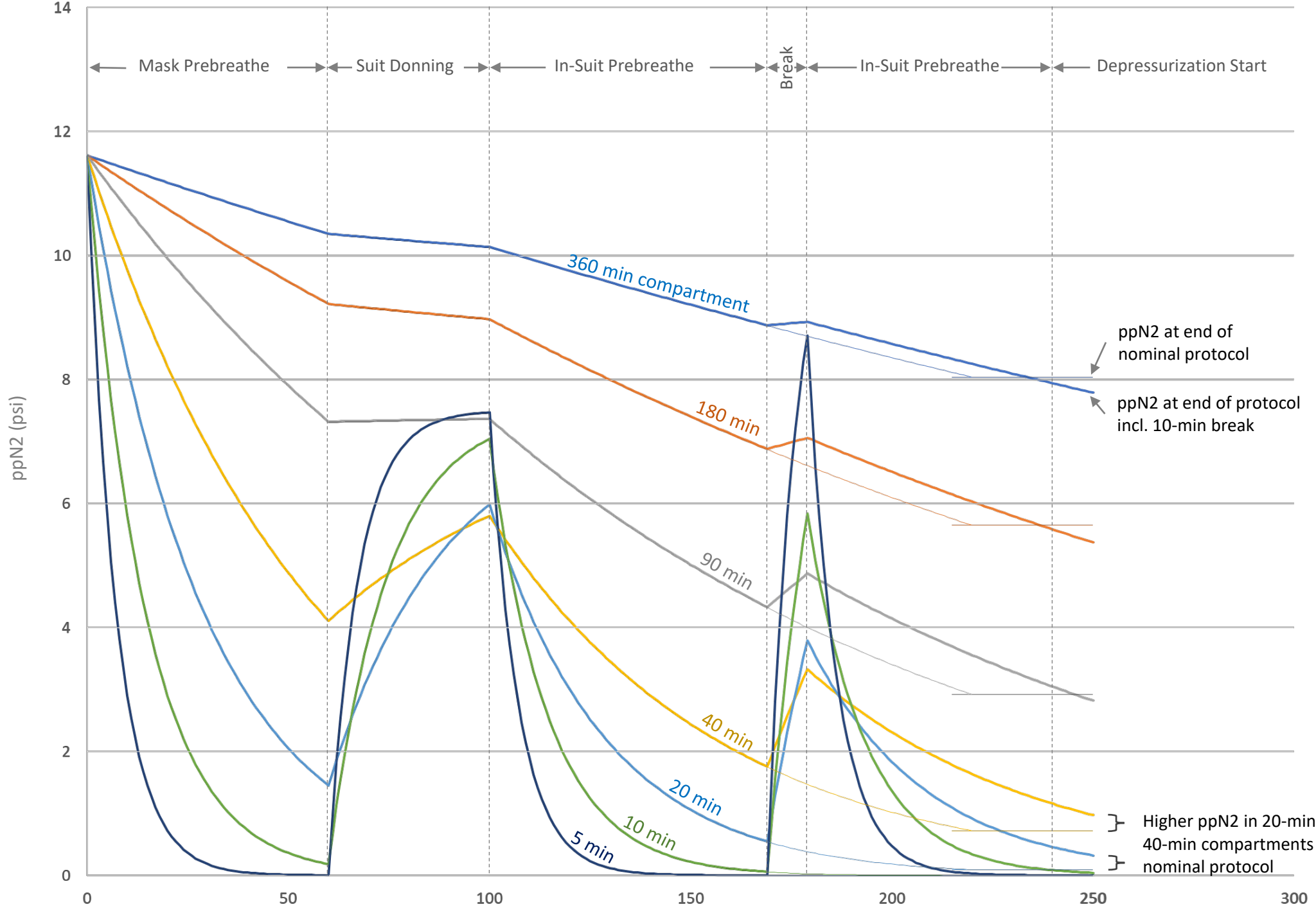
Models

- NASA's DCS risk models not applicable or validated for estimating DCS risk due to break-in-prebreathe but offer some insight
- Exponential on-gassing and off-gassing assumptions mean later a break-in-prebreathe may have higher predicted tissue N₂ at EVA start

Later breaks in prebreathe → Faster Renitrogenation & Slower Denitrogenation

- “Faster” tissues most affected – associated with prediction of Type II DCS
- Unable to provide quantitative risk estimates of Type I or Type II DCS
- Possible that BiP risk is not explained by simple gas kinetics





ppN2 at end of nominal protocol
ppN2 at end of protocol incl. 10-min break

} Higher ppN2 in 20-min and 40-min compartments vs. nominal protocol



EVA IPT Discussion Points

Flight Rule Documentation

Consulting with previous SMEs

Published Literature

Relevant Data Sets

Operational Experience

Models

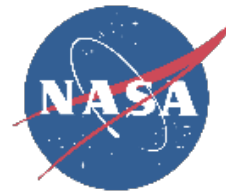
- Late BiP a credible cause or factor in recent Type II DCS case
- Unable to identify / retrieve documentation on rationale for existing FR
- Documented uncertainty among SMEs in early 2000s regarding late breaks and apparent lack of consensus on sufficiency of 2:1 payback
 - *Existing FR “not based on any significant empirical data”*
 - *Recognized as gap in data / knowledge*
- Simplistic unvalidated model of gas kinetics suggests increased risk following late breaks
- Very few instances (2 out of 72 EVAs) of ISLE breaks-in-prebreathe; no breaks later than 59 minutes pre-depress

Consensus recommendations – no dissenting opinions



Recommendations

ID	Recommendation	Rationale	Anticipated Impact
1	<p>For all <u>ground-based</u> suited operations, require full restart of prebreathe in the event of a break-in-prebreathe (e.g. helmet removal, visor opening, opening the Body Seal Closure, hatch opening in exploration EMU).</p> <p>Note 1: Nominal Metox changeout is not considered a break-in-prebreathe. Boot bladder manipulations and glove removal remain acceptable with purge/payback as per existing test rules.</p>	<p>Break-in-prebreathe a credible cause or contributing factor in Type II DCS case. Existing payback rules and allowance for late breaks in prebreathe may be insufficient to control DCS risk.</p>	<p>Temporary restriction believed unlikely to significantly impact operations.</p> <p>Updated recommendation based on additional review of historical data, literature, and models may enable less restrictive break-in-prebreathe rules.</p>



Recommendations

ID	Recommendation	Rationale	Anticipated Impact
2	<p>Prohibit ground prebreathe protocols involving mask-to-suit transitions.</p> <p>Note: Mask-to-mask transitions with breath-hold and exhalation purge is acceptable.</p>	<p>Break-in-prebreathe is a potential cause or contributing factor in the Type II DCS case. NASA does not utilize mask-to-suit prebreathe protocols for ground-based testing, but current NASA policies do not preclude the practice.</p>	<p>No anticipated impact to current NASA operations.</p>



Recommendations

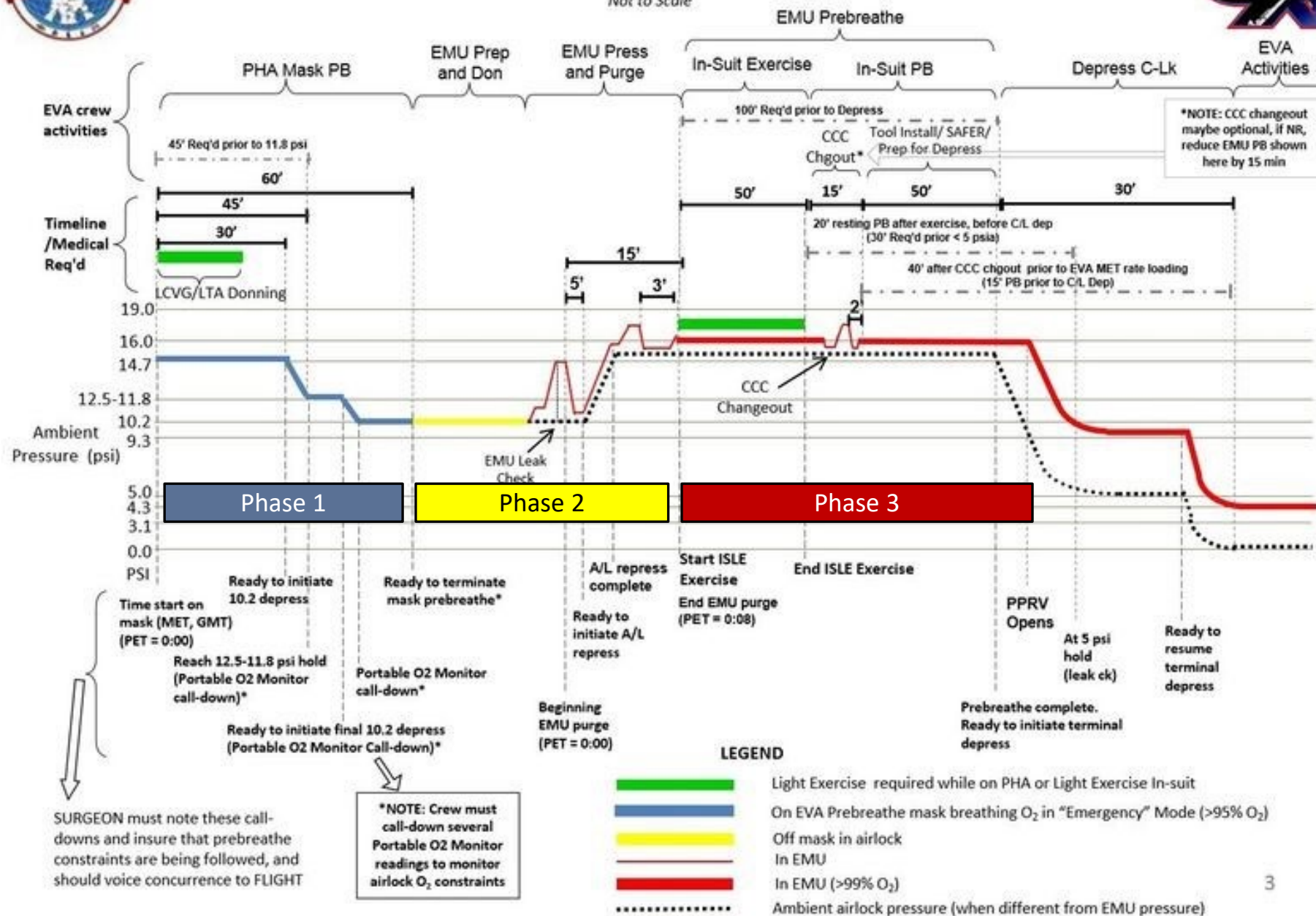
ID	Recommendation	Rationale	Anticipated Impact
3	Complete a high-priority EVA IPT assessment of EVA flight rule adequacy regarding break in prebreathe based on review of historical data, literature, and model analyses.	Break-in-prebreathe a credible cause or contributing factor in Type II DCS case. Successful history of break-in-prebreathe 2:1 “payback” in flight; however, flight rules allow for late breaks-in-prebreathe, thus reconsideration is warranted.	Future recommendations – if any – affecting break-in-prebreathe flight rules may impact ISS and future Exploration EVA operations. Interim recommendation [following slides] to be provided prior to completion of comprehensive review.



ISLE Pressure Profile (Without Data Collection)

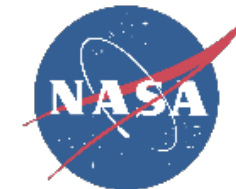


Not to Scale

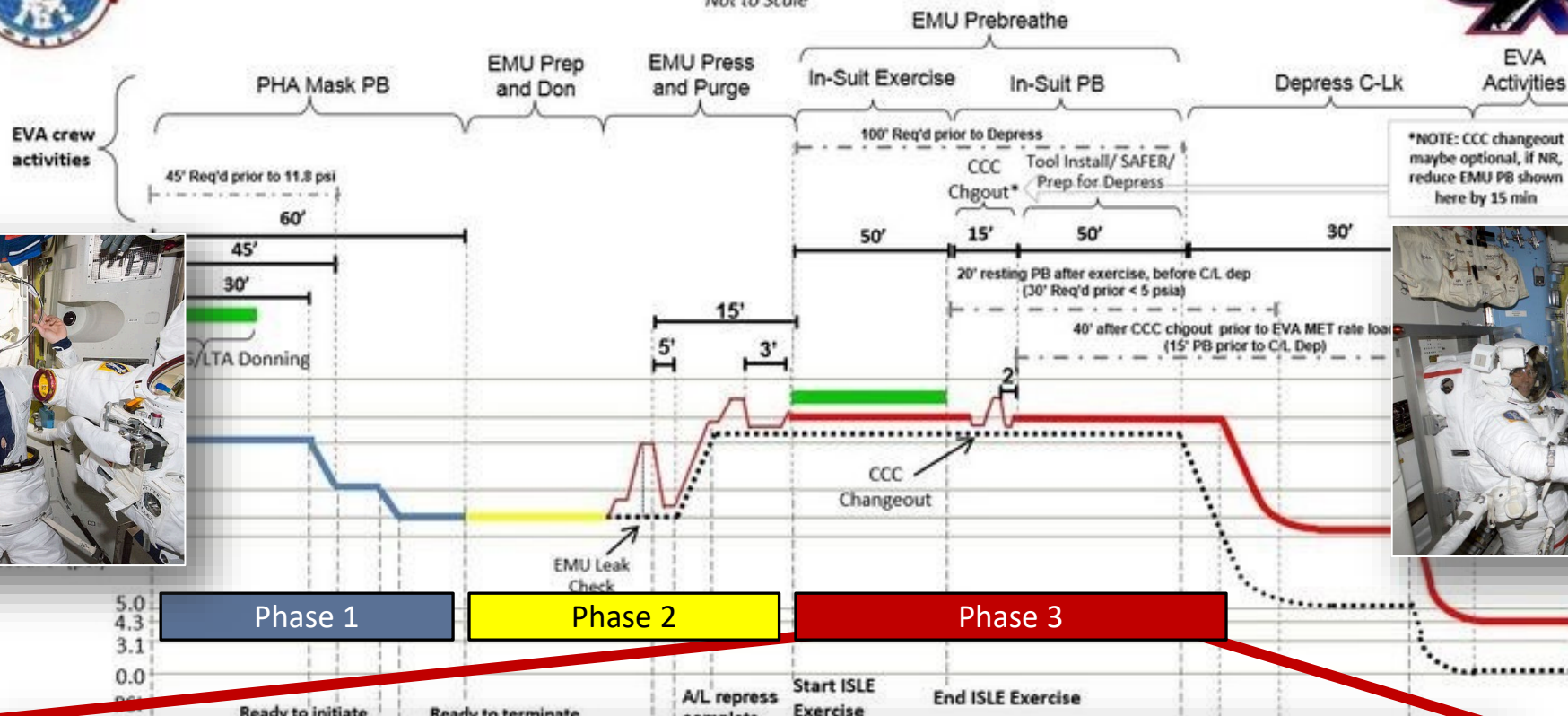




ISLE Pressure Profile (Without Data Collection)



Not to Scale



Current Flight Rule

PHASE THREE	Ready to initiate	Ready to terminate	A/L repress complete	Start ISLE Exercise	End ISLE Exercise
	PRESSURE BETWEEN CONTROL ZONE AND 14.7 PSI/760 MMHG	≤ 10-MINUTE INTERRUPTION (SINGLE OR CUMULATIVE)	MAKE UP O ₂ TIME IN SUIT. [1] [5] [7] [9]	MAKEUP RATIO: 2:1	
	PRESSURE BETWEEN CONTROL ZONE AND 14.7 PSI/760 MMHG	> 10-MINUTE INTERRUPTION (SINGLE OR CUMULATIVE)	REPEAT IN-SUIT LIGHT EXERCISE PREBREATHE PROTOCOL OR CONSIDER ALTERNATE PREBREATHE PROTOCOL. [4] [7]	ON MCC CALL	
			CREW SCHEDULING CONSTRAINTS MAY NECESSITATE SHORTENING OR RESCHEDULING THE EVA.		

..... Ambient airlock pressure (when different from EMU pressure)



Recommended Interim Updates

No changes recommended to Phase 1 or 2

Recommended Phase 3 changes:

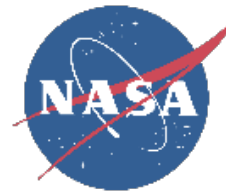
- 1) For ANY break in PB above the control zone **<10 mins**
 - *Repeat the full 100 minute in-suit PB with exercise*

- 2) For a break >10 minutes *EITHER*
 - a. Return to control zone prior to the break and go to 3)

OR

 - b. Repeat *entire* ISLE protocol or consider alternate PB protocol

- 3) For any break *within* the control zone: repeat full 100 minute in suit PB with exercise cycles



Recommended Interim Updates

No changes recommended to Phase 1 or 2

Recommended Phase 3 changes:

Earlier breaks (pre-Phase 3) have slower on-gassing, faster off-gassing, and provide sufficient time (with 2:1 payback) to reduce estimated tissue N₂ to equivalent levels as no-break

- 1) For ANY break in PB above the control zone <10 miles
 - Repeat the full 100 minute in-suit PB with exercise

- 2) For a break >10 minutes *EITHER*
 - a. Return to control zone prior to the break and go to 3)

OR

 - b. Repeat *entire* ISLE protocol or consider alternate PB protocol

- 3) For any break *within* the control zone: repeat full 100 minute in suit PB with exercise cycles



Recommended Interim Updates

No changes recommended to Phase 1 or 2

Recommended Phase 3 changes:

- 1) For ANY break in PB above the control zone **<10 mins**
- *Repeat the full 100 minute in-suit PB with exercise*

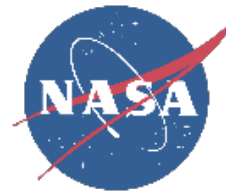
Repeating Phase 3 avoids late BiP and ensures tissue N2 equivalent to no-break protocol

- 2) For a break >10 minutes *EITHER*
 - a. Return to control zone prior to the break and go to 3)

OR

- b. Repeat *entire* ISLE protocol or consider alternate PB protocol

- 3) For any break *within* the control zone: repeat full 100 minute in suit PB with exercise cycles



Recommended Interim Updates

No changes recommended to Phase 1 or 2

Recommended Phase 3 changes:

- 1) For ANY break in PB above the control zone **<10 mins**
 - *Repeat the full 100 minute in-suit PB with exercise*

- 2) For a break >10 minutes *EITHER*
 - a. Return to control zone prior to the break and go to 3)

OR

- b. Repeat *entire* ISLE protocol or *control zone* protocol

On-gassing in CZ is slow and adequately counteracted during completion of full Phase 3

- 3) For any break *within* the control zone: repeat full 100 minute in suit PB with exercise cycles



Recommended Interim Updates

No changes recommended to Phase 1 or 2

Recommended Phase 3 changes:

1) For ANY break in PB above the control zone **<10 mins**

- *Repeat the full 100 minute in-suit PB with exercise*

2) For a break >10 minutes *EITHER*

a. Return to control zone prior to the break and go to 3)

OR

No change to current flight rule

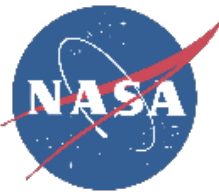
b. Repeat *entire* ISLE protocol or consider alternate PB protocol

3) For any break *within* the control zone: repeat full 100 minute in suit PB with exercise cycles

Conclusions

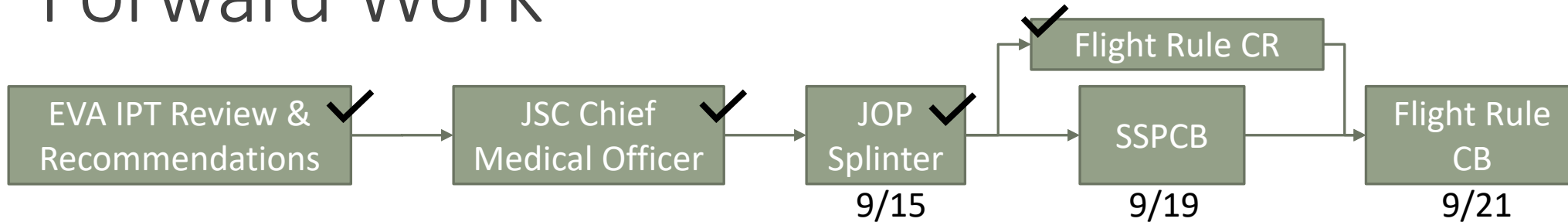
- Late break-in-prebreathe may or may not have been the cause of the Type II DCS case
- Planned breaks-in-prebreathe avoided since 1980s, but policies did not preclude them
- Conservative response avoids the possibility of late breaks-in-prebreathe
- Infrequent occurrence of breaks and ability to reschedule ground chamber tests and most ISS EVAs if required make current operational implications tolerable
- Exploration missions with higher frequency EVAs and highly constrained mission timelines may be more significantly impacted by conservative protocols
- Work ongoing to identify additional data sources and evaluate less conservative protocols





Questions

Forward Work



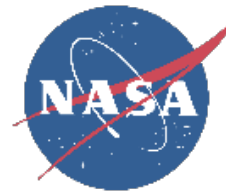
Interim recommendation provided in time for October EVAs

- **9/15: Recommended wording for interim flight rule update submitted to workflow**
 - Directed to submit Flight Rule CR vs. CHIT / Flight Note
 - Reviewed and concurred by EVA JOP prior to submission
- **9/19: Informational SSPCB review of draft updates**
- **9/21: FRCB Review**

FY24 Q2: Updated recommendations based on additional review of literature, data, models, and documentation

FY25+: Dedicated hypobaric chamber testing for ground-based validation of Break-in-Prebreathe flight rules for ISS and Exploration

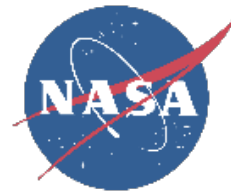
- To be proposed to HRP within scope of AETHER project (Aerospace Estimation Tool for Hypobaric Exposure Risk)



Background: Decompression Sickness (DCS)

- Type I DCS: Joint pain; single extremity tingling or numbness; mild skin symptoms
 - No reports of untreatable Type I altitude DCS symptoms
- Type II DCS: Central neurological or cardiopulmonary symptoms; can be life-threatening
- Denitrogenation via Oxygen prebreathe reduces DCS risk





History of BiP Flight Rule

