



20 years

Long-term Health Risk Quantification

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Agenda

- Long-term Health (LTH) Risk Overview
- Lifetime Surveillance of Astronaut Health (LSAH) Epidemiological Studies
- Quantification Challenges
- LTH Risk Quantification Applications
- Conclusions

LTH Risk Overview

- NASA's Human System Risk Board (HSRB) maintains Long-term Health (LTH) Risks in addition to in-mission risks

Human Spaceflight Risks	In Mission Risk - Operations								Post Mission Risk - Long Term Health							
	Low Earth Orbit		Lunar Orbital		Lunar Orbital + Surface		Mars		Low Earth Orbit		Lunar Orbital		Lunar Orbital + Surface		Mars	
	< 30 D	30 D - 1 Y	< 30 D	30 D - 1 Y	< 30 D	30 D - 1 Y	< 1 Y	730-1224D	< 30 D	30 D - 1 Y	< 30 D	30 D - 1 Y	< 30 D	30 D - 1 Y	< 1 Y	730-1224D
EVA Risk	Accepted 4x2	Accepted 4x2	Accepted with Optimization 4x3	Accepted with Optimization 4x3	Requires Mitigation 5x4	Requires Mitigation 5x4	Accepted with Optimization 4x3	Requires Mitigation 5x4	Accepted with Optimizati... 5x2	Accepted with Optimization 5x2	Accepted with Optimization 5x2	Accepted with Optimization 5x2	Accepted with Optimization 5x2	Accepted with Optimization 5x2	Accepted with Optimization 5x2	Accepted with Optimizati... 5x2
Medical Conditions Risk	Accepted 3x2	Accepted 4x2	Accepted 4x2	Requires Mitigation 5x3	Requires Characteriz... 4x3	Requires Mitigation 5x4	Requires Mitigation 5x4	Requires Mitigation 5x4	Accepted 3x2	Accepted 4x2	Accepted 3x2	Requires Characteriz... 4x2	Requires Characteriz... 4x2	Requires Characteriz... 4x4	Requires Characteriz... 4x4	Requires Characteriz... 5x4
Dynamic Loads Risk	Accepted with Optimization 4x3	Accepted with Optimization 4x3	Accepted with Optimization 4x3	Requires Mitigation 4x3	Accepted with Optimization 4x4	Requires Mitigation 4x4	Requires Mitigation 4x3	Requires Mitigation 4x4	Accepted 3x2	Accepted 3x2	Accepted with Optimization 3x2	Requires Mitigation 3x2	Accepted with Optimization 3x4	Requires Mitigation 4x4	Requires Mitigation 3x2	Requires Mitigation 4x4
Food and Nutrition Risk	Accepted with Monitoring 2x2	Accepted with Optimization 5x2	Accepted with Optimization 5x2	Requires Mitigation 5x3	Requires Mitigation 5x3	Requires Mitigation 5x4	Requires Mitigation 5x4	Requires Mitigation 5x5	Accepted 1x1	Accepted with Monitoring 3x2	Accepted with Monitoring 3x2	Requires Mitigation 4x2	Accepted with Monitoring 3x2	Requires Mitigation 4x3	Requires Mitigation 5x3	Requires Mitigation 5x3
SANS Risk	Accepted 4x1	Accepted with Monitoring 4x3	Accepted 4x1	Accepted with Monitoring 4x3	Accepted 4x1	Accepted with Monitoring 4x3	Accepted with Monitoring 4x3	Requires Mitigation 4x4	Accepted 2x2	Requires Mitigation 4x3	Accepted 2x2	Requires Mitigation 4x3	Accepted 2x2	Requires Mitigation 4x3	Requires Mitigation 4x3	Requires Mitigation 4x5
Muscle Risk	Accepted with Optimization 5x1	Requires Characteriz... 5x1	Accepted with Optimization 5x1	Requires Characteriz... 5x1	Requires Characteriz... 5x2	Requires Mitigation 5x3	Requires Mitigation 5x2	Requires Mitigation 5x4	Accepted 3x1	Accepted with Optimization 5x2	Accepted 3x1	Accepted with Optimization 5x2	Accepted with Optimization 3x1	Requires Characteriz... 5x2	Requires Characteriz... 5x2	Requires Mitigation 5x3
Renal Stone Risk	Accepted with Monitoring 1x4	Accepted with Monitoring 3x4	Accepted with Monitoring 1x4	Accepted with Monitoring 3x4	Accepted with Monitoring 1x4	Accepted with Monitoring 3x4	Requires Mitigation 3x4	Requires Mitigation 4x4	Accepted with Monitoring 1x3	Accepted with Monitoring 2x3	Accepted with Monitoring 1x3	Accepted with Monitoring 2x3	Accepted with Monitoring 1x3	Accepted with Monitoring 2x3	Requires Mitigation 3x4	Requires Mitigation 4x4

Partial view of the HSRB risk chart

For more information about HSRB risks:

<https://hsp.sp.jsc.nasa.gov/sadocs/hsrb/risktool/Pages/Home.aspx> (NASA Internal)

<https://www.nasa.gov/directorates/esdmd/hhp/human-system-risk-board/> (Public Website)

LTH Risk Overview

- Astronaut LTH risk covers a continuum, including:
 - Preflight training
 - Immediately post-flight
 - Through the rest of the astronaut's career
 - Through retirement
 - Until death
- Unique prior, during, and post astronaut experiences introduce individual variability
- LTH risk includes several types of consequences:
 - Return to baseline timeline and intervention needed
 - Number, severity, and level of care required for career related medical conditions
 - Impact on quality of life and amount of support needed to perform activities of daily living
 - Changes to life expectancy

Long-term Health Risk Timeline

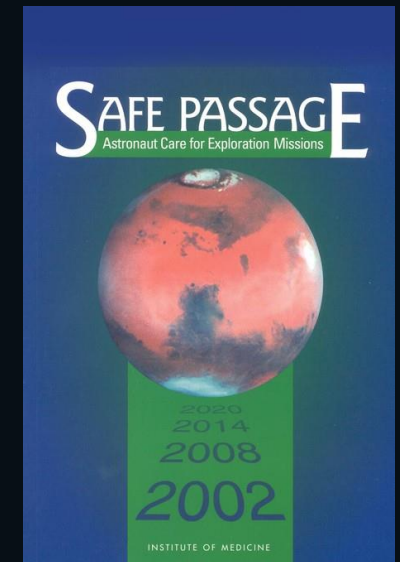
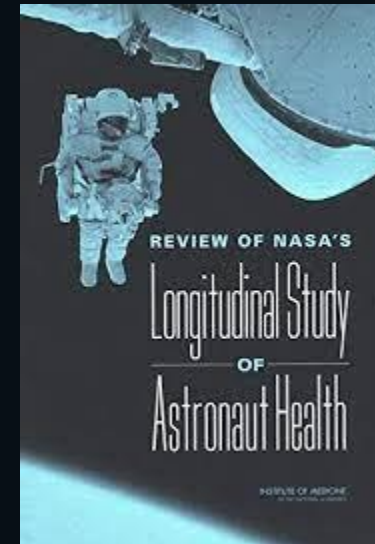
Birth	Before selection/ Astronaut training	Mission(s)	Post-flight recovery	Post mission/ Retirement	Death
	Astronaut selection Preflight training	Mission characteristics: <ul style="list-style-type: none"> Vehicle shielding Mission length Mission location Number of EVAs performed CHP System capabilities: <ul style="list-style-type: none"> In-flight monitoring In-flight medical system Physiological countermeasures 	Recovery from in-mission medical events <ul style="list-style-type: none"> Clinical phase 3 effects persisting into post-flight Recovery from spaceflight induced physiological changes <ul style="list-style-type: none"> Amount of time required to return to baseline 	Changes in morbidity: Medical conditions that occur with a higher incidence rate or with more severity because of spaceflight experiences	Changes in life expectancy

LIKELIHOOD RATING			L x C Matrix					Time frame	
In-Mission	Flight Recertification	Long Term Health	5	10	16	20	23	25	Expected Need for Mitigation
5 Very High	More likely to happen than not during the mission or probability (P) >10%	Very likely to happen. Controls are insufficient or P >10%							Near 0 < 2 Years
4 High	Likelihood is during the mission or 10%-P10%	Likely to happen. Controls have significant limitations or uncertainties or 10%-P10%	5	7	13	18	22	24	Mid 2-7 Years
3 Moderate	May happen during the mission or 0.1%-P12%	Not likely to happen. Controls exist with some limitations or uncertainties or 0.1%-P12%	3	4	9	15	19	21	Far > 7 Years
2 Low	Unlikely to happen during the mission or 0.1%-P0.1%	Not expected to happen. Controls have minor limitations or uncertainties or 0.1%-P0.1%	2	2	6	11	14	17	
1 Very Low	Nearly certain to not occur in mission or P < 0.1%	Extremely remote possibility that it will happen. Strong controls in place or P < 0.1%	1	1	3	5	8	12	
			1	2	3	4	5		
			CONSEQUENCE						
MISSION	Crew Health Impact	1	2	3	4	5			
	Mission Objectives Impact	1	2	3	4	5			
	Crew Flight Recertification Status	1	2	3	4	5			
LONG TERM HEALTH	Health Outcomes OR	1	2	3	4	5			
	Quality of Life	1	2	3	4	5			

LSAH Epidemiological Studies

- NASA's Lifetime Surveillance of Astronaut Health (LSAH) investigates incidences of acute and chronic astronaut morbidity and mortality
- To determine whether their unique occupational exposures are associated with increased morbidity and mortality risk

[Review of NASA's Longitudinal Study of Astronaut Health | The National Academies Press](#)
[Safe Passage: Astronaut Care for Exploration Missions | The National Academies Press](#)



LSAH Epidemiological Studies

- Several studies have been performed investigating astronaut morbidity and mortality
- Comparisons have been made between astronauts vs. the general population and astronauts vs. appropriately matched comparison cohorts
- The studies have focused primarily on cardiovascular disease and cancer outcomes
- The studies have found no or only modest increases in astronaut morbidity or mortality

Workplace
Original research

Cancer incidence and mortality in the USA Astronaut Corps, 1959–2017

Robert Reynolds^{1, 2}, Mark P Little³, Steven Day¹, Jacqueline Charvat^{2, 4}, Steven Blattnig⁵, Janice Huff⁵, S Patel^{2, 4}

Correspondence: rreynolds@mayoclinic.org

[ORIGINAL ARTICLE](#)

Long-term Cardiovascular Risk in Astronauts: Comparing NASA Mission Astronauts With a Healthy Cohort From the Cooper Center Longitudinal Study

[ORIGINAL RES](#)


Jacqueline M. Charvat, PhD; David Leonard, PhD; Carolyn E. Barlow, PhD; Laura F. DeFina, MD; Benjamin L. Willis, MD, MPH; Stuart M.C. Lee, PhD; Michael B. Stenger, PhD; Sarah F. Mercaldo, PhD; and Mary Van Baalen, PhD

Incidence Rate of Cardiovascular Disease End Points in the National Aeronautics and Space Administration Astronaut Corps

Carl J. Ade, PhD; Ryan M. Broxterman, PhD; Jacqueline M. Charvat, PhD; Thomas J. Barstow, PhD

LTH Risk References

Author	Journal	Volume(Issue):Page	Date
Peterson, et al.	Radiat Res	133(2):257-64	1993
Hamm et al.	Aviat Space Environ Med	69(2):142-4	1998
Hamm et al.	Aviat Space Environ Med	71(6):564-70	2000
Reynolds and Day	Aviat Space Environ Med	81(11):1024-7	2010
Ade et al.	J Am Heart Assoc	6(8):e005564	2017
Reynolds and Day	Aerosp Med Hum Perform	88(5):492-6	2017
Reynolds and Day	Occup Environ Med	76(2):114-7	2019
Reynolds et al.	Sci Rep	9(1):8583	2019
Reynolds et al.	Occup Environ Med	78(12):869-75	2021
Charvat et al.	Mayo Clin Proc	97(7):1237-46	2022



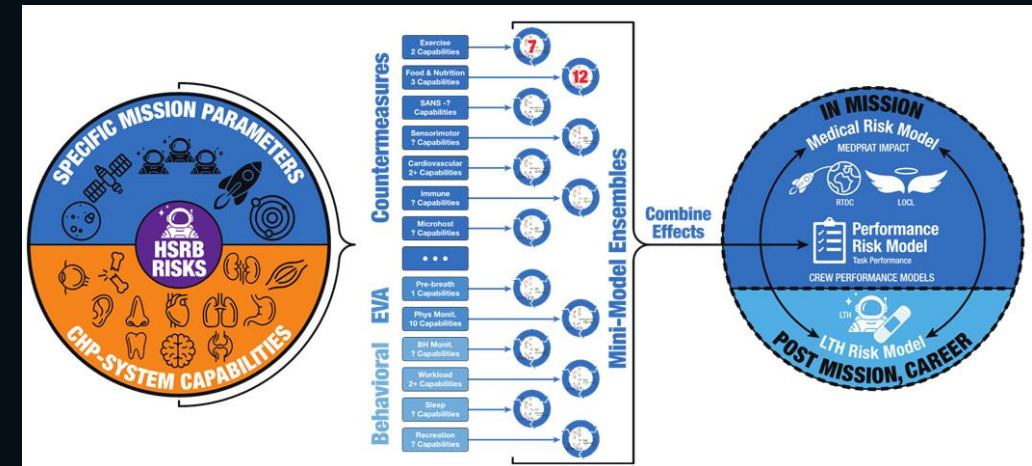
Quantification Challenges

- The lack of LTH risk outcome identification thus far should not alleviate the concerns:
 - LSAH has identified 144 medical conditions associated with LTH risk
 - Increases in astronaut morbidity and mortality have been investigated for only a small portion of the conditions
 - Possible findings may be detected for conditions not yet studied
 - LTH risk outcome analysis suffers from limited data points
 - Limited numbers of astronauts overall
 - Even smaller numbers of astronauts who have reached an age where LTH concerns may begin to manifest
 - Possible findings may be detected as more shuttle and ISS astronauts begin to age

LTH Risk Quantification Applications


- Risk metric quantification is used within trade studies for countermeasure decision making, for example:
 - What combination of medical resources results in the lowest risk
 - How much lower is the risk when exercise capabilities are included on a mission

Crew Health and Performance – Probabilistic Risk Assessment (CHP-PRA) Conceptual Diagram. In development by the Human Research Program’s Science Integration Office.



LTH Risk Quantification Applications

- Ground-based countermeasures to astronaut LTH outcomes include:
 - Astronaut selection process and screening requirements
 - Access to continuous medical monitoring and health care before, during, and after their missions
- In-mission countermeasures tied to astronaut LTH outcomes include:
 - Availability and level of in-mission medical care
 - Availability and type of countermeasures to physiological decrements



Guide to Becoming an Astronaut



TREAT Astronauts Act

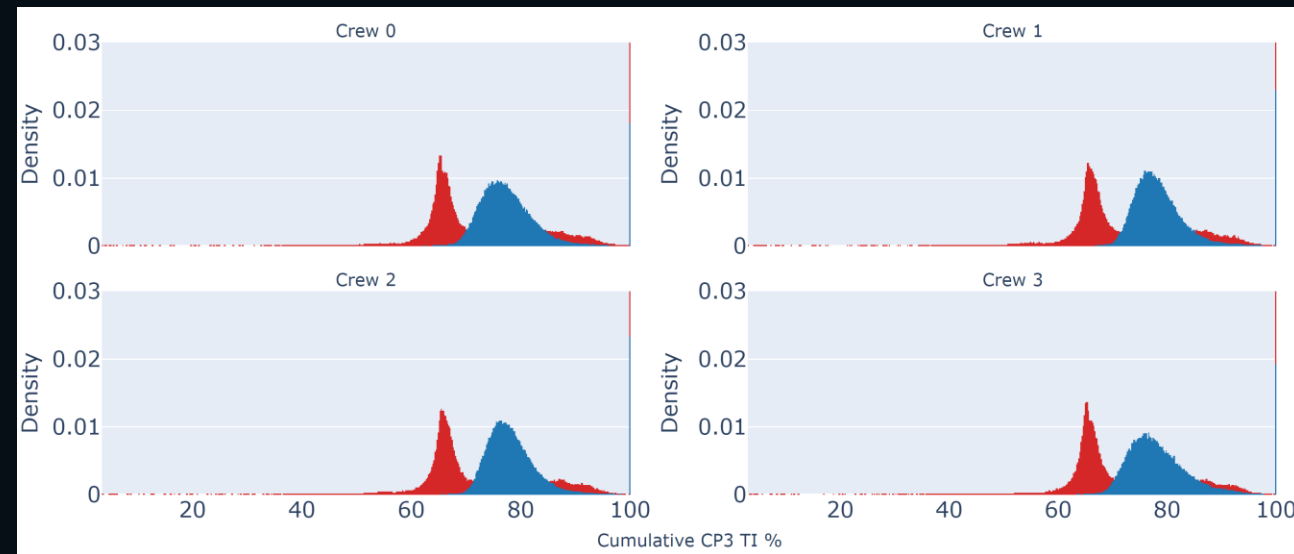
The TREAT Astronauts Act authorizes NASA to monitor, diagnose, and treat medical and psychological conditions associated with spaceflight.

LTH Risk Quantification Applications

- The availability and level of in-mission medical care influences the End of Mission Health Status (Cumulative CP3 TI*) of the astronaut

LTH Risk

- The **cumulative task impairment** at the end of the mission due to the occurrence of in-mission medical events **increases** as the amount of available **in-mission medical resources decreases**

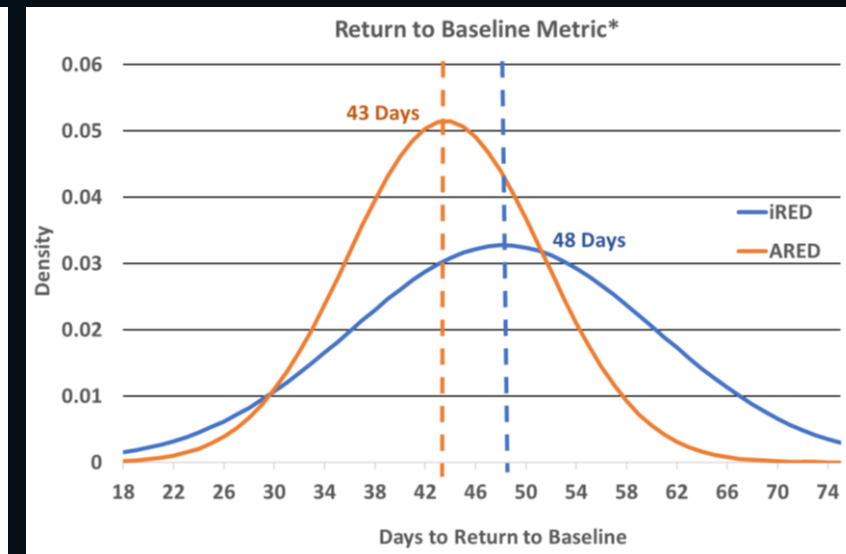
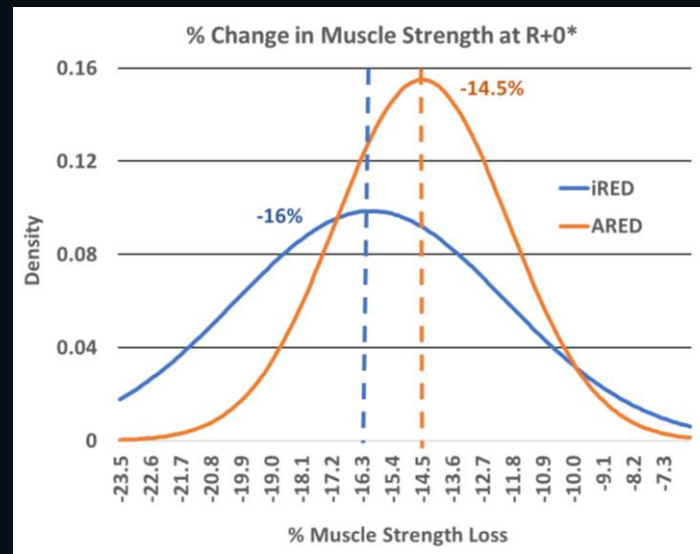


■ Limited treatment
■ Untreated

**See poster: M. Prelich et al., Proof-of-concept for a long-term health metric to quantify end of mission health status in astronauts, 2025 HRP IWS, Galveston, TX.*

LTH Risk Quantification Applications

- The availability and type of in-mission exercise capabilities influences the time it takes for the astronaut to restore their physiological status
- The time to return to preflight physiological status after a mission **decreases** as the effectiveness of available in-mission exercise devices **increases**



*K.L. English et al., *Isokinetic Strength Changes Following Long-Duration Spaceflight on the ISS*, *Aerosp Med Hum Perform*, 86(12), 2015.



Conclusions

- The LTH risk space is vast and only a small portion of it has been investigated
- Astronaut selection and screening processes and access to continuous medical monitoring and health care have to date been effective countermeasures to LTH risk
- CHP-PRA proof-of-concept models demonstrate the quantification of potential LTH risk metrics that are influenced by in-mission interventions and countermeasures
- Values for “End of Mission Health Status” and “Time to Return to Preflight Physiological Status” can be provided as an output of CHP-PRA along with in-mission risk metric values
- Identification of additional LTH risk metrics and maturation of the current LTH proof-of-concept models can occur as more epidemiological studies are completed and upon stakeholder request



Thank You!!