CREW HEALTH AND PERFORMANCE SYSTEM PROBABILISTIC RISK ASSESSMENT (CHP-PRA): PROOF-OF-CONCEPT APPROACH

Human Factors Webcast (Virtual)
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AGENDA AND GOALS

AGENDA:

- Introduce the scope and challenges to CHP-PRA model development
- Touch on approach to adoption of risk metrics: Long-Term Health

GOAL:

- Demonstrate Proof-of-concept approach (not even a prototype!)
- Elicit feedback from gathered SME's to improve approach leading to operational use

FROM PPBE24: CHP-PRA

- CHP Trade Space Visualization
  - CHP-PRA to address state-of-the-art resource requirements and PRA estimates
  - BEST EFFORT for Mars CHP
    - M/V/P utilizing today's knowledge
    - PRA with Sensitivity analysis
    - HRP Investments contribute to risk reduction
  - Long Term Health Metric
    - Propose quantifiable metric(s)
    - Illustrate quantifying this metric is influenced by HRP risk reduction investments

PRA REQUIREMENTS IN 3001

V1 3003: In-Mission Preventive Health Care   NASA-STD-3001 V1 B (2022-01-05)

Statement:

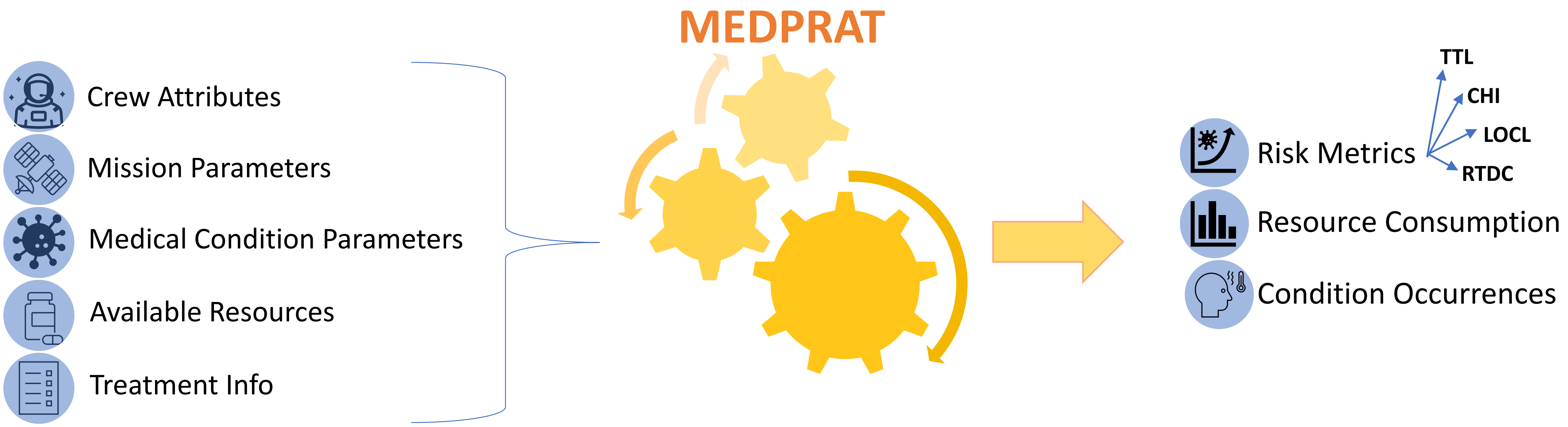
All programs shall provide training, in-mission capabilities, and resources to monitor physiological and psychosocial well-being and ***enable delivery of in-mission preventive health care, based on epidemiological evidence-based probabilistic risk assessment (PRA) that takes into account the needs and limitations of each specific design reference mission (DRM),*** and parameters such as mission duration, expected return time to Earth, mission route and destination, expected radiation profile, concept of operations, and more.

INITIAL CHALLENGES

- **Determine the CHP-PRA customers (HRP, CHPO's, OCHMO, etc.) and maintain frequent feedback/collaboration**
- **Understand the scope and context for CHP-PRA questions**
- Ascertain CHP system and prioritize sub-components of interest
- Define applicable approaches to model CHP system and sub-system components
- State model concept and implementation process
- **Identify the knowledge and data types best suited for CHP-PRA**
- **Understand LTH Risk and how it differs from in-mission risk**
- **Explore background information on LTH metric concepts**
- Bring review of potential LTH metric approaches and correlate with customer's needs
- Determine how a new LTH metric is informed and implemented in the CHP-PRA trades

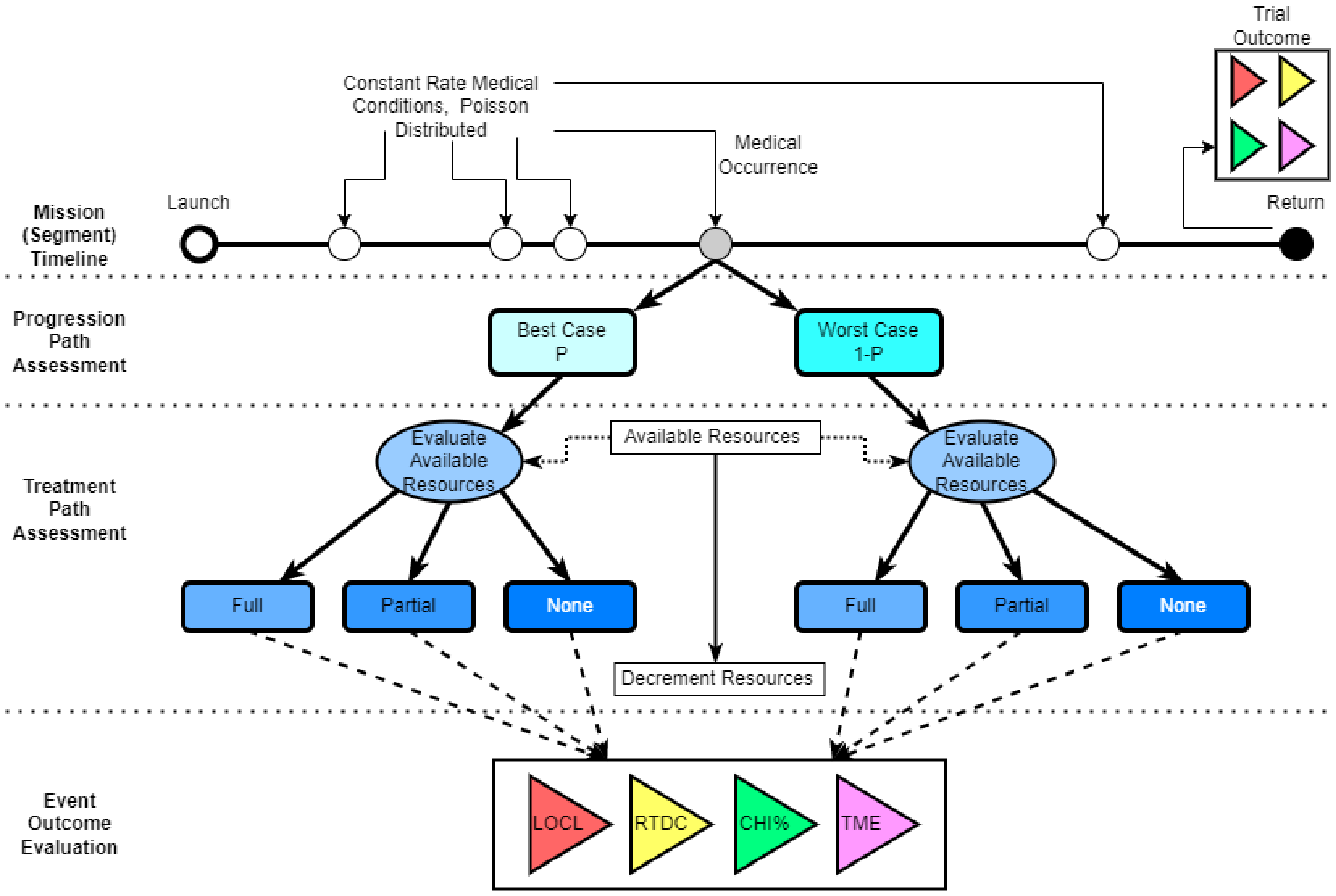
SUCCESSFUL MODEL DEVELOPMENT HISTORY (MEDPRAT)

- MEDPRAT is a computational PRA (probabilistic risk assessment) model for quantifying spaceflight medical risk
- An evolution of IMM – shares the basic functionality of IMM, but with a new underlying software architecture and many new features
- The computational model in ExMC's IMPACT tool suite

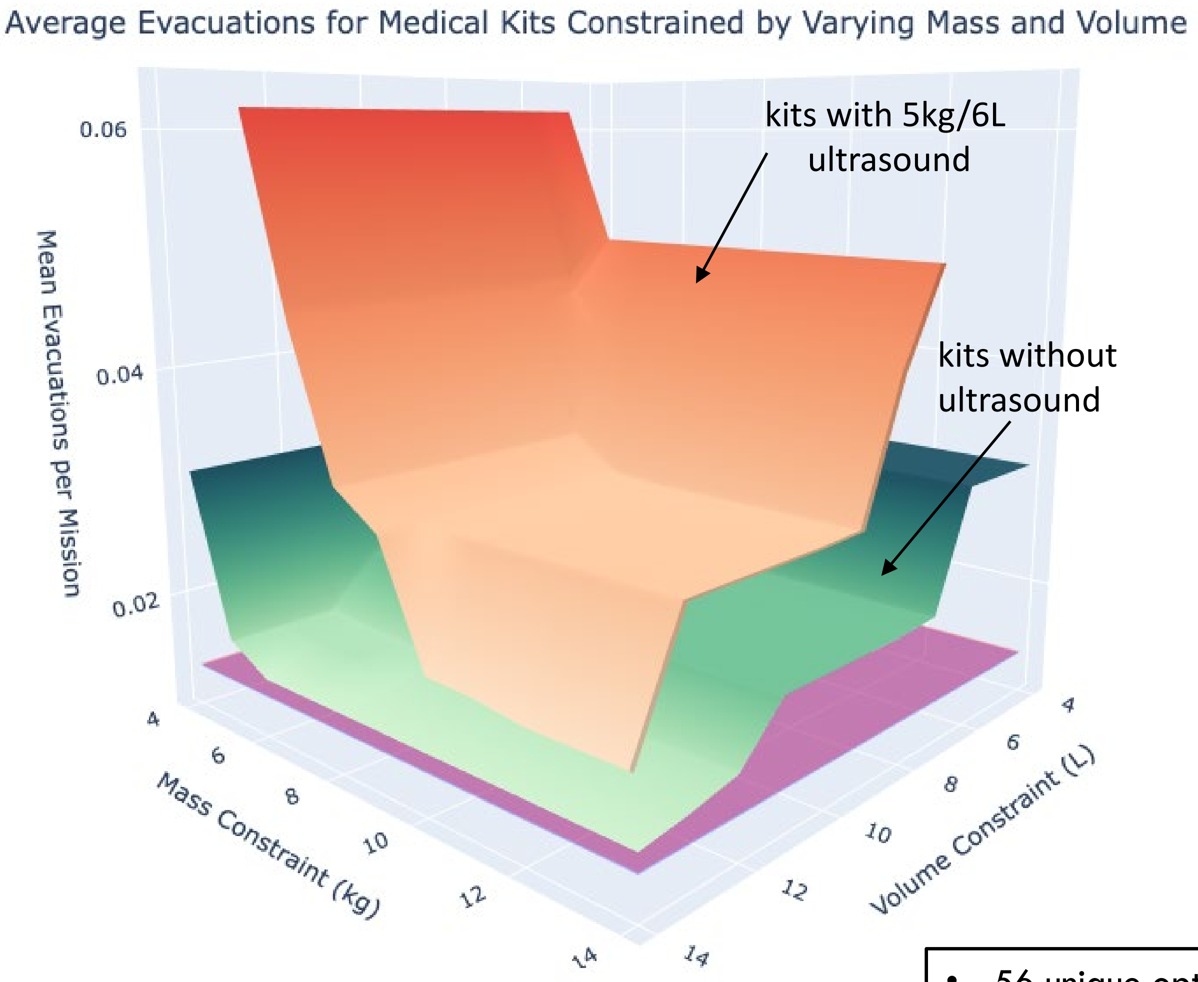


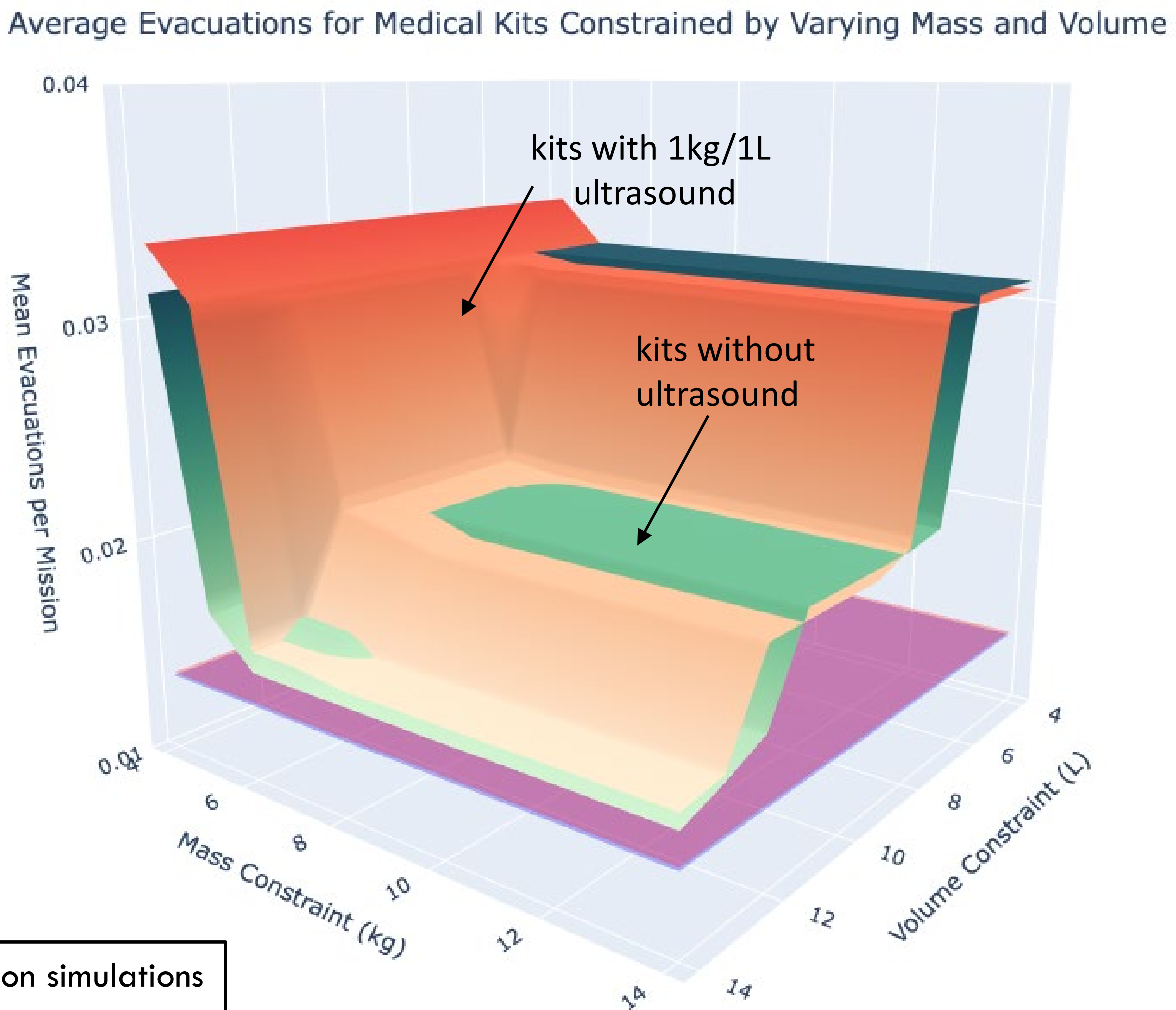
MEDPRAT

- Provides IMM-like risk estimates on a larger scale, with additional functionality, robustness, and flexibility
  - Unique Mission segments
  - Resource Combinations
  - Dependent Conditions
  - High fidelity
- High degree of computational efficiency allows for exploration of parameter spaces



MEDPRAT

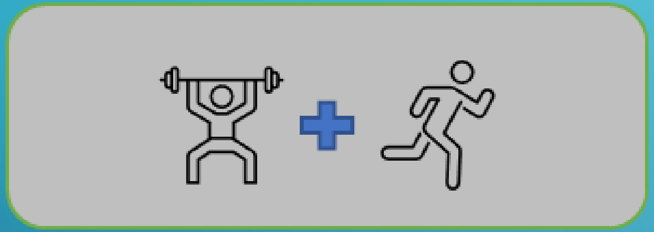


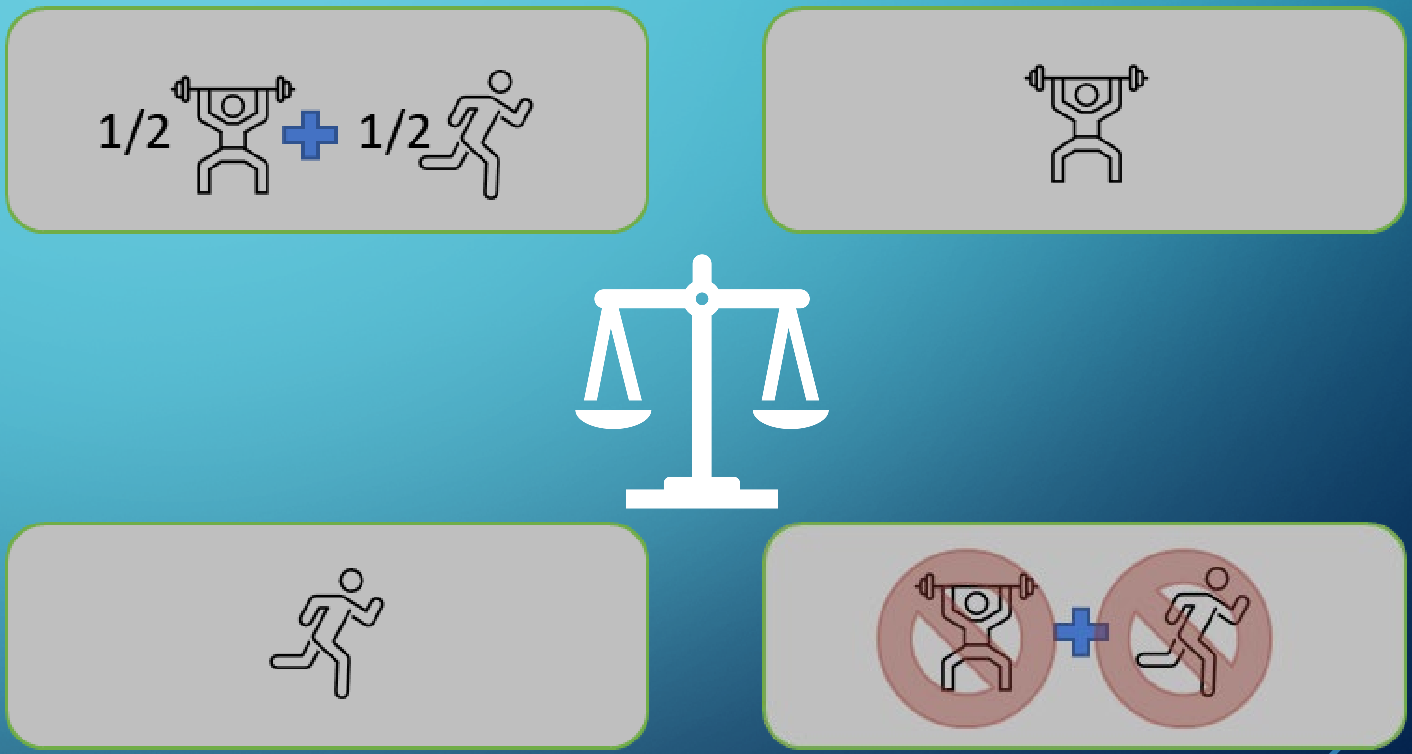


- 56 unique optimization simulations
- ~1.5 day run time

CONSIDER THIS CHP-PRA SCENARIO

What Risk is Incurred to Reduce Mass and Volume (M&V) of CHP System





Could Be Any CHP Resource or Capability, e.g. Exercise Countermeasure

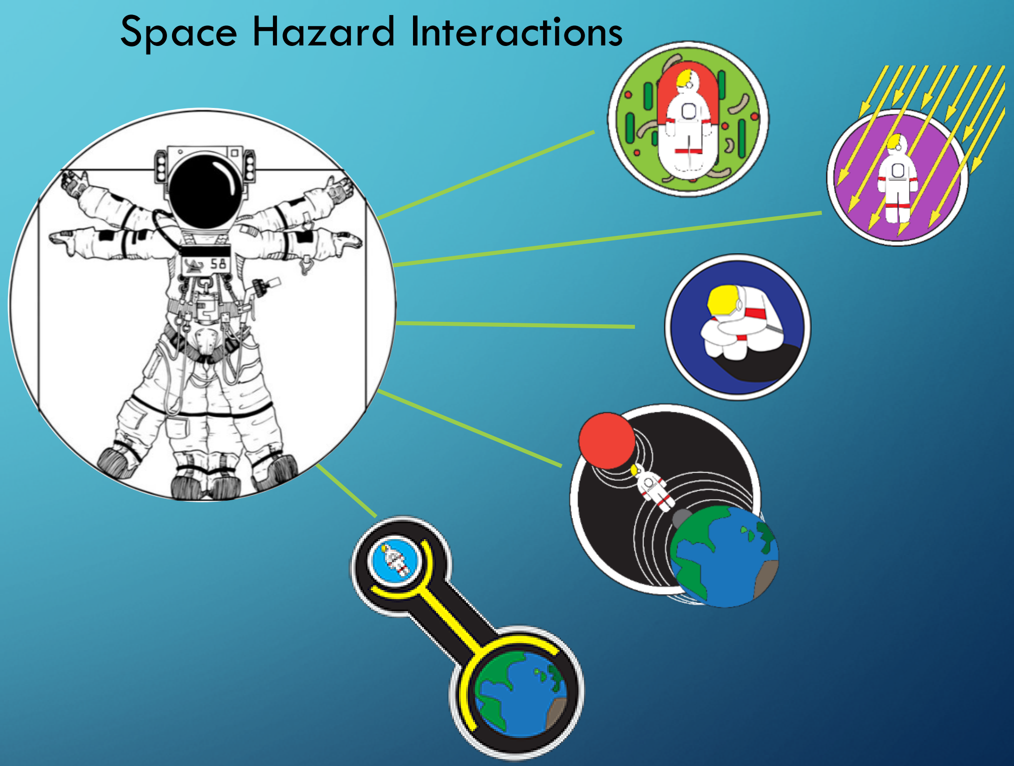
MANY FACTORS TO WEIGH

30+ Human Spaceflight Risks

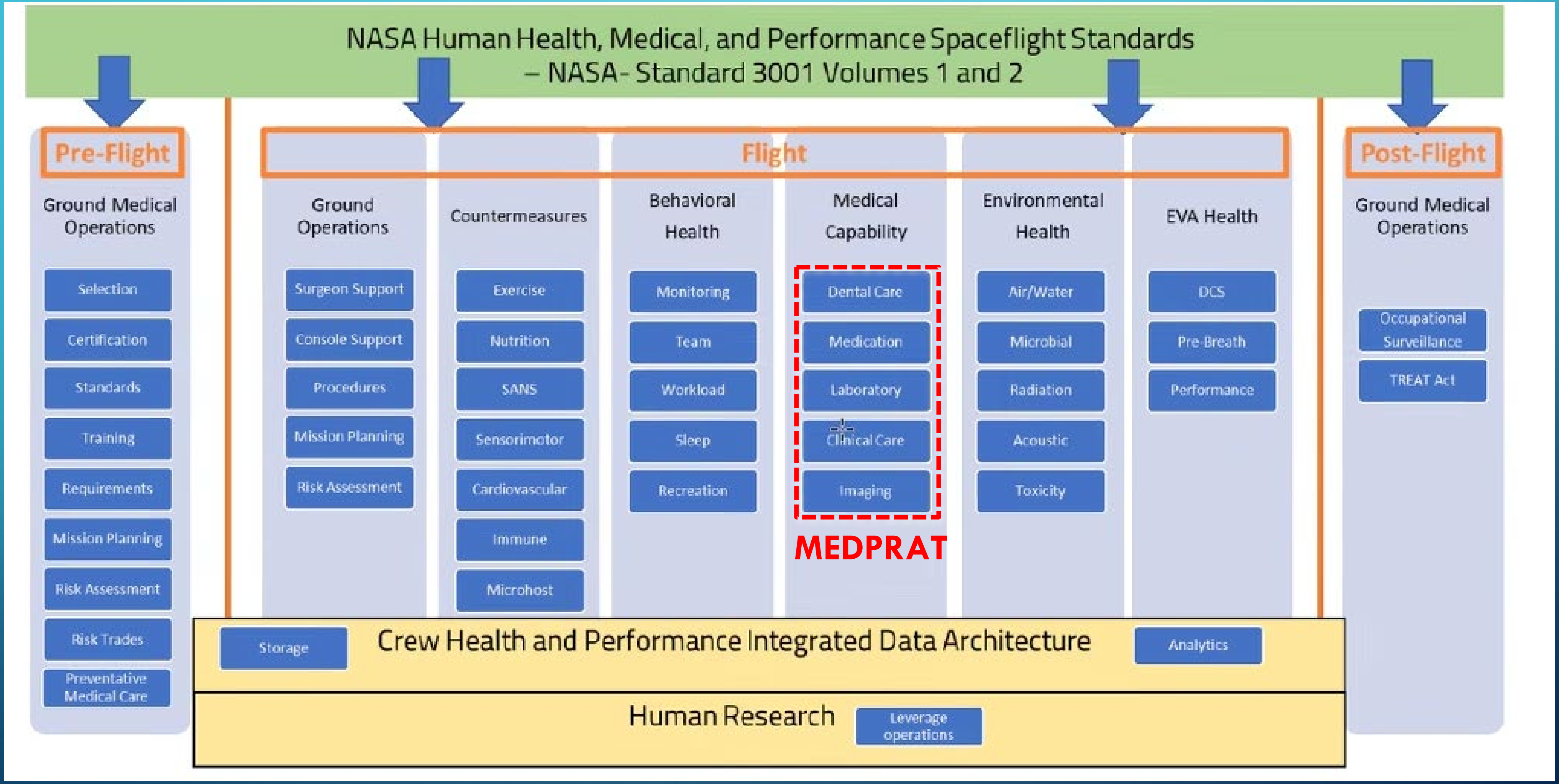
Vehicle Constraints and Mission Objectives

Health and Performance Standards

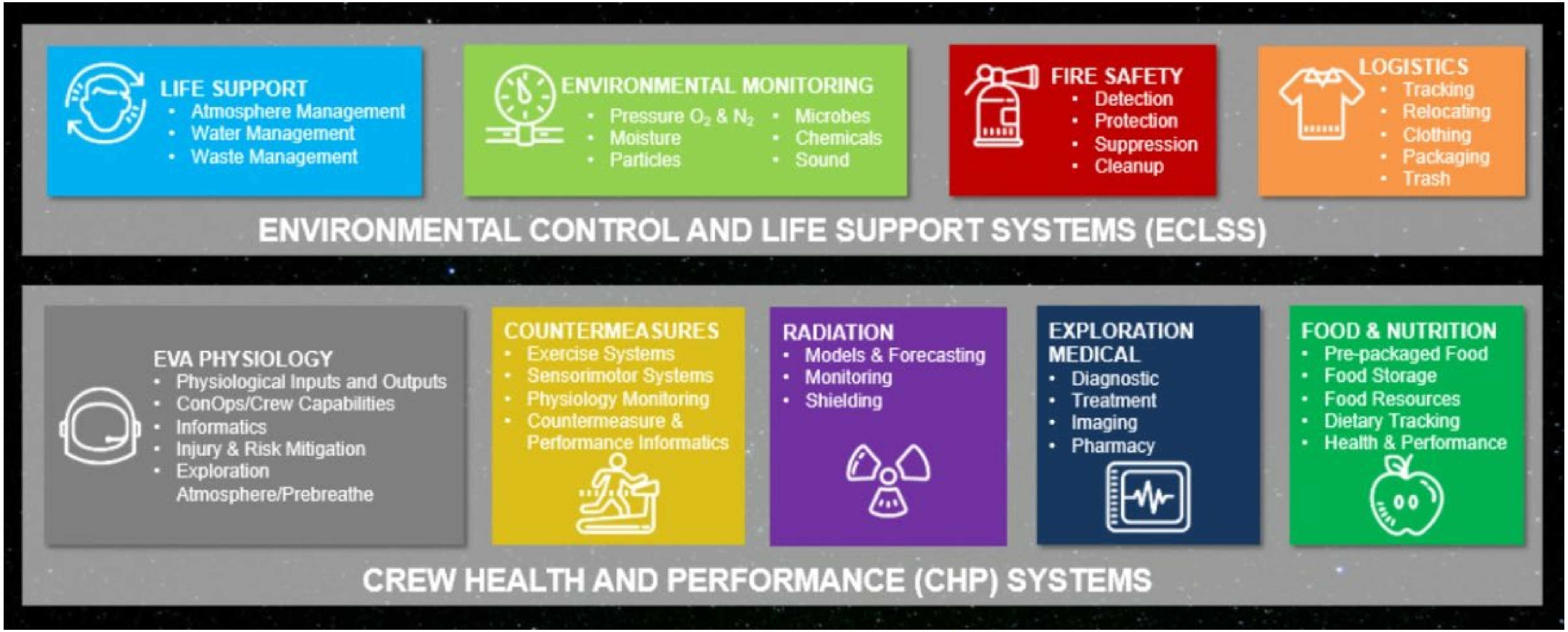
Crew Training and Skill Mix



CREW HEALTH & PERFORMANCE SYSTEM: HRP MENTAL MODEL



ECLSS-CHP SLT : CAPABILITY AREAS



ECLSS-CHP SCLT Capability Areas and Capabilities Lists

GATEWAY CHP SYSTEM SPECIFICATION

Revision: A	Document No: GP 10016
Release Date: January 12, 2023	Page: 11 of 167
Title: Gateway Program Subsystem Specification for Crew Health and Performance (CHP)	

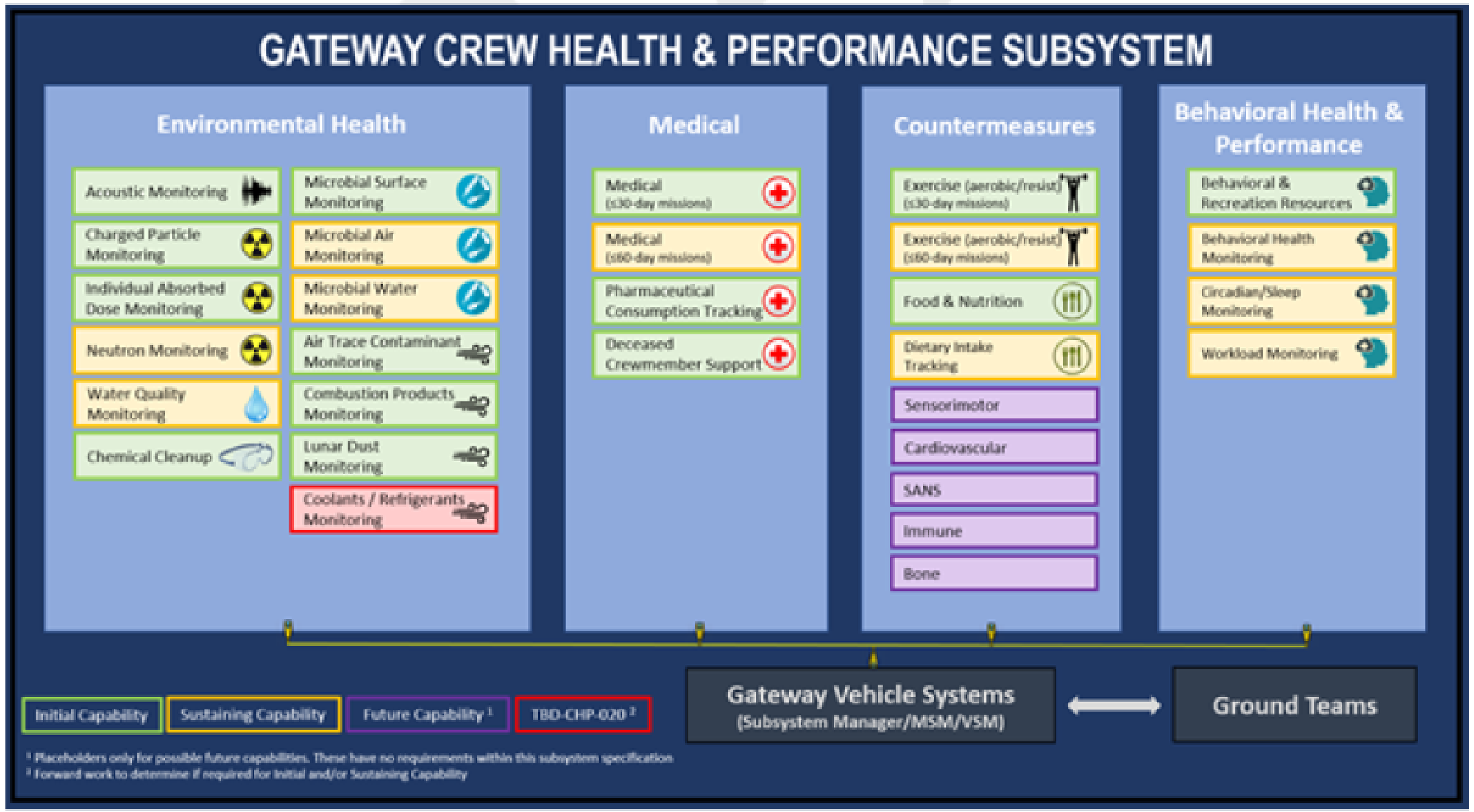
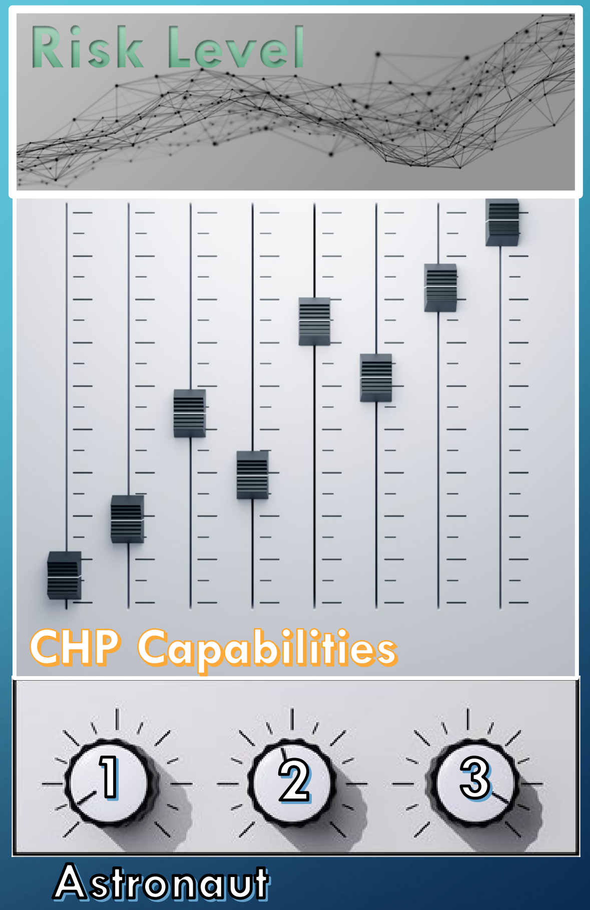


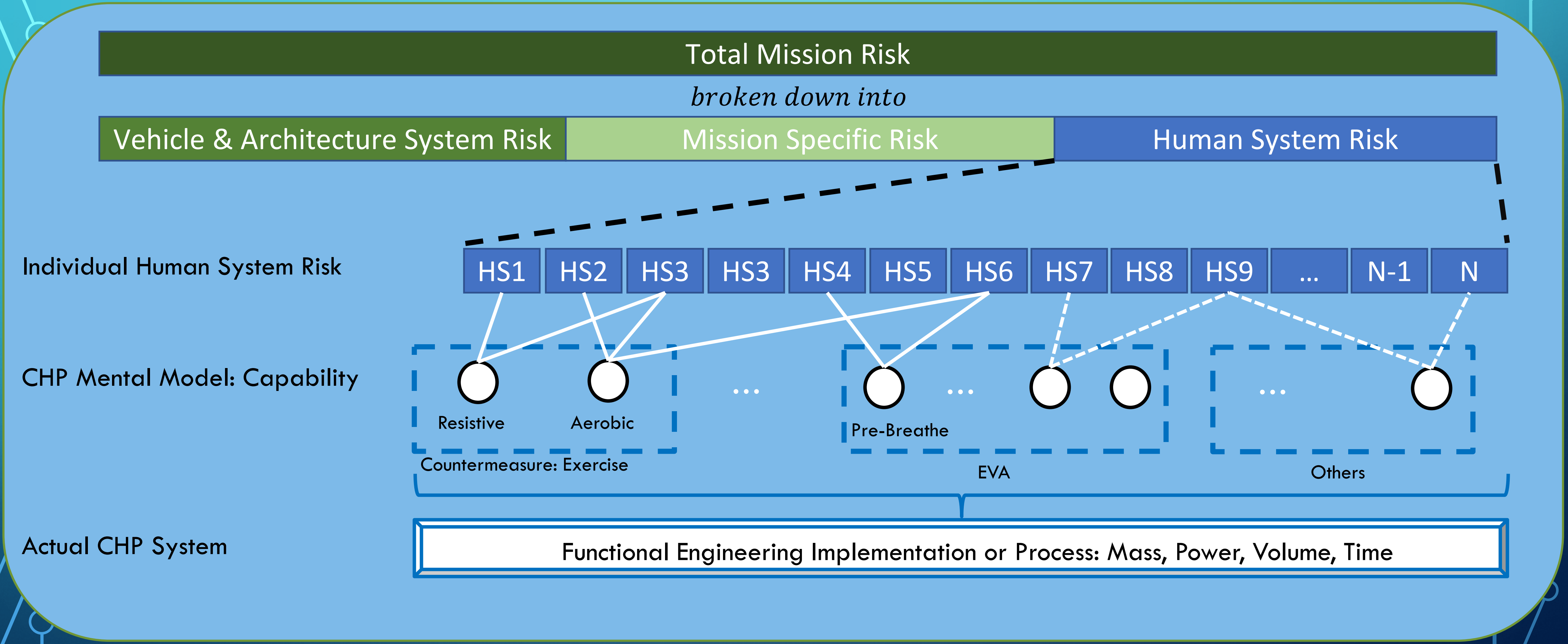
FIGURE 3.1.1-1 SUMMARY OF GATEWAY CHP SUBSYSTEM CAPABILITIES

POC: CREW HEALTH AND PERFORMANCE PRA

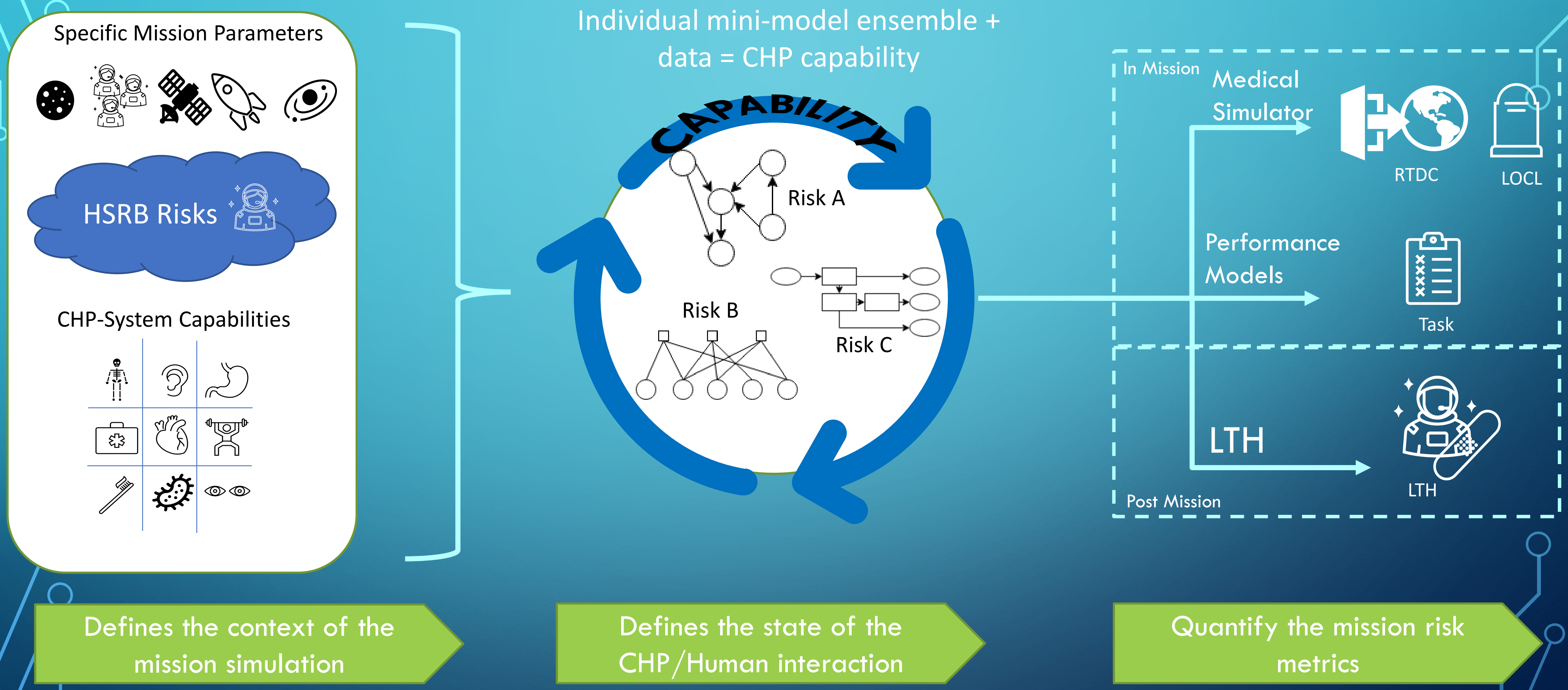
- “Comprehensive Model”
- “Series of Knobs”
- “Leverage HSRB DAGs” when practical
- “Keep it Simple”
- Order of Magnitude Estimates = Good Enough



MODEST CUMULATIVE RISK APPROACH

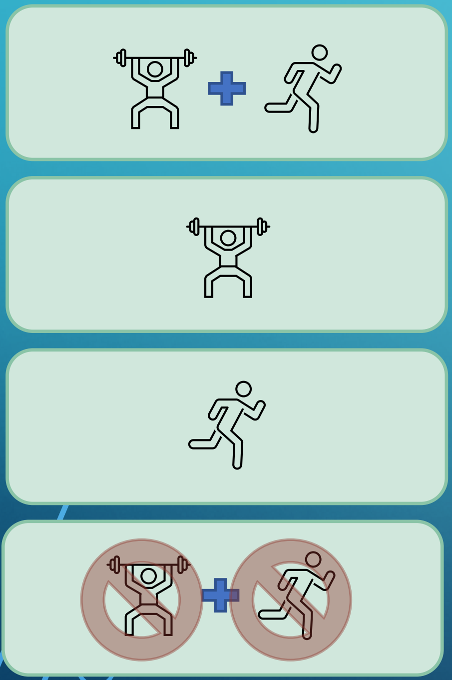


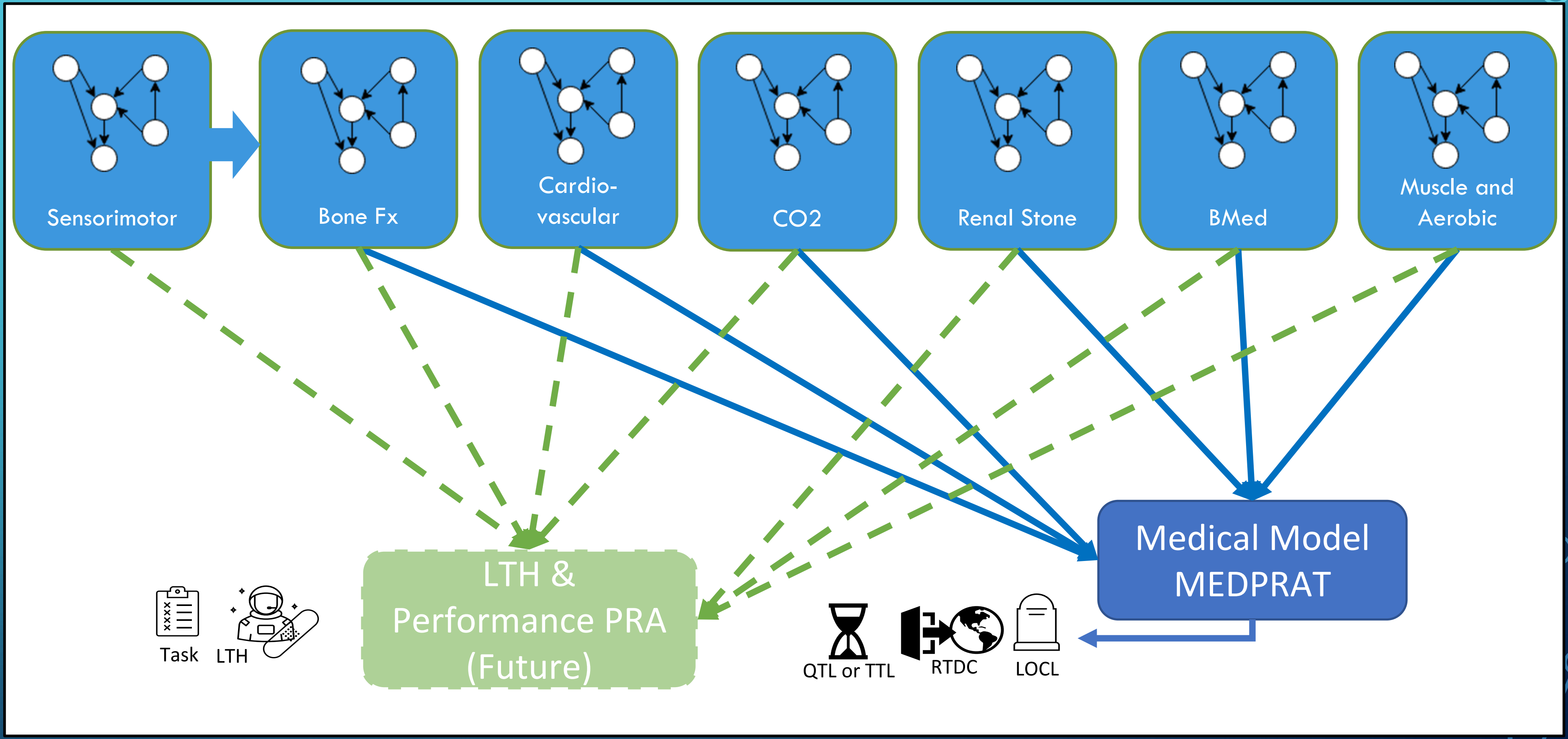
STRATEGY FOR AN EARLY CHP-PRA CONCEPT



BACK TO CHP-PRA-POC: EFFECT OF REDUCING A CAPABILITY TO SAVE M OR V

Options for Evaluation

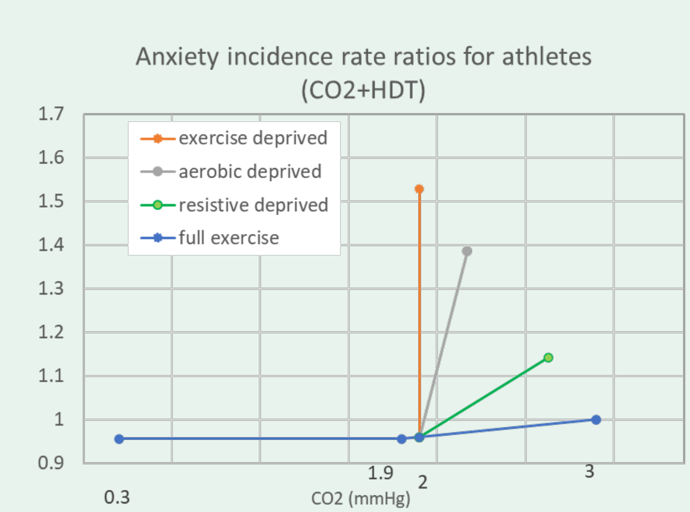


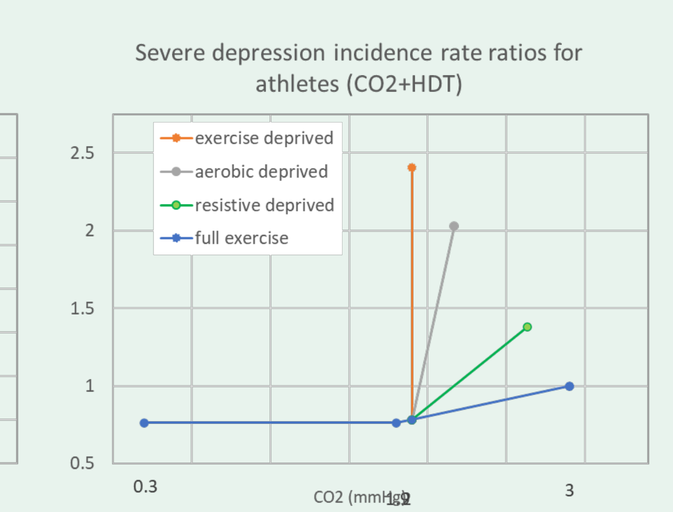


ANXIETY AND SEVERE DEPRESSION ACCOUNTING FOR AEROBIC VS RESISTIVE EXERCISE

- Data from HSRB file: 2021-09-09_HSRB_Ryder,V, Alexander,A._CO2 Risk_(CR SA-04044 Decisional)
- Morris et. al, 1990
- Basner 2021, *Continuous and Intermittent Artificial Gravity as a Countermeasure to the Cognitive Effects of 60 Days of Head-Down Tilt Bed Rest*

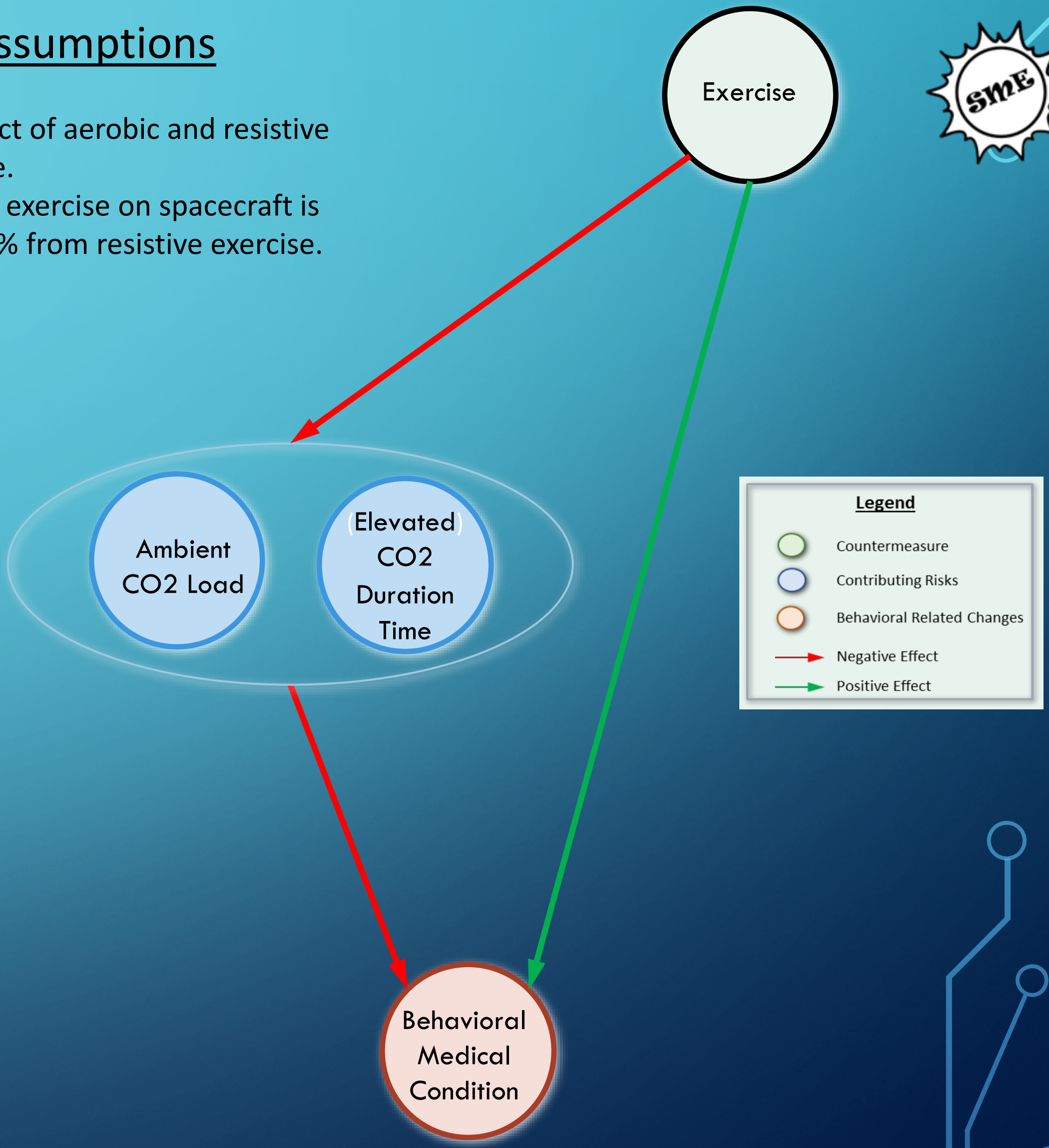
CO2 Levels – CO2 Mini-Model and ISS Observation	mmHg
With exercise	3
No exercise	2
CO2 productions for aerobic + resistive CM:	1
CO2 productions for aerobic CM:	0.73
CO2 productions for resistive CM:	0.27



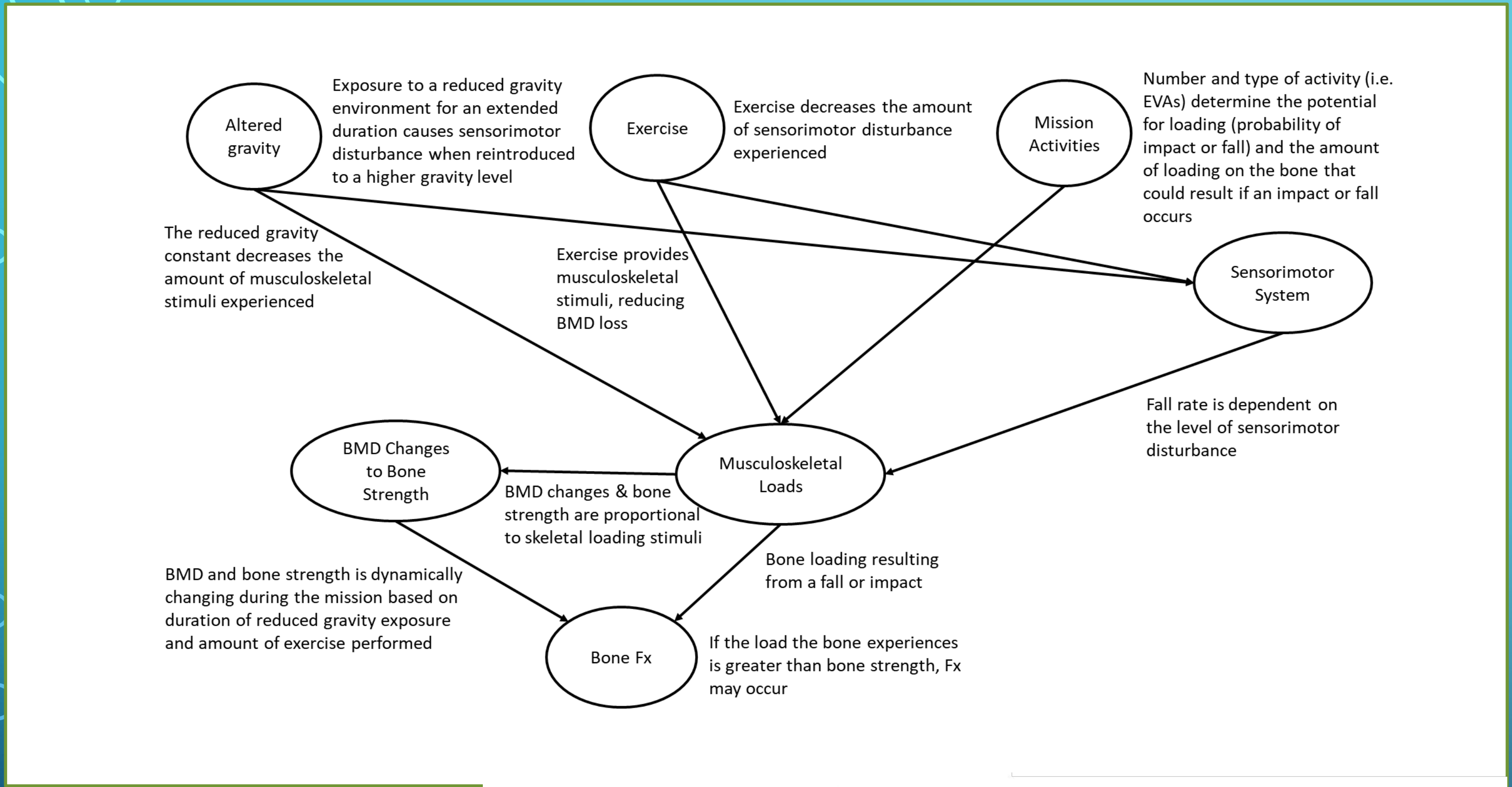


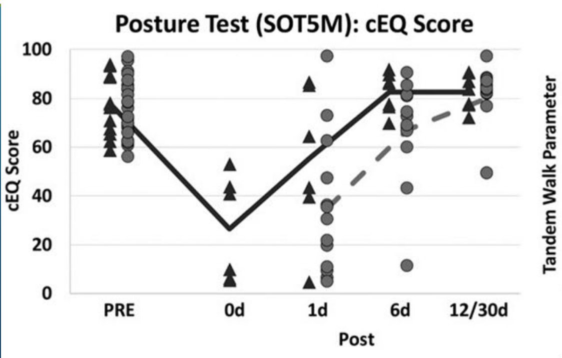
Model assumptions

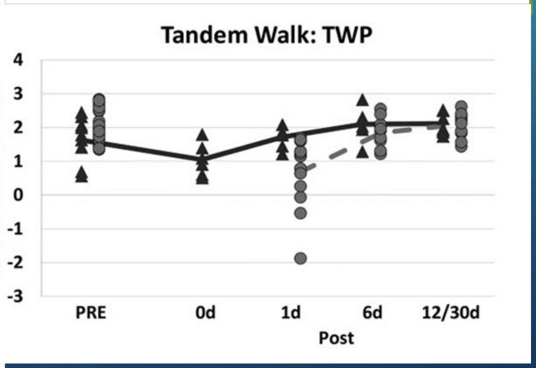
- We assume the effect of aerobic and resistive exercise are additive.
- We assume that full exercise on spacecraft is 73% aerobic and 27% from resistive exercise.



EXERCISE CONTRIBUTIONS TO SENSORIMOTOR AND BONE-FX







Nelson et al., "Development and validation of a predictive bone fracture risk model for astronauts," Ann Biomed Eng, 37(11), pp. 2337–2359, Nov. 2009

Lewandowski & Myers, "Forecasting Postflight Hip Fracture Probability Using Probabilistic Modeling," J Biomech Eng, 141(1), Jan. 2019

Scheuring et al., "Musculoskeletal injuries and minor trauma in space: Incidence and injury mechanisms in U.S. astronauts," Aviat Space Environ Med, 80(2), pp. 117–124, Feb. 2009

C. A. Miller et al., "Functional task and balance performance in bed rest subjects and astronauts," Aerosp Med Hum Perform, vol. 89, no. 9, pp. 804–815, Sep. 2018

- Modulates BFxRM by adjusting mission specific external load opportunities
  - Falls on EVA
- Synergistically influence Fx Risk with change in bone demineralization rate

GENERALIZED EFFECTS ON MEDICAL CONDITIONS

Condition	Parameter	Baseline	Aerobic Only	Resistive Only	No Exercise
Anxiety	IRR	1	1.139	1.375	1.514
Depression	IRR	1	1.124	1.336	1.46
	Worst Case Probability	0.08	0.095	0.113	0.122
Lumbar Spine Fracture	IRR	1	1.564	1	1.5645
Hip/Proximal Femur Fracture	IRR	1	1.360	1	1.3603
Headache (CO_2 induced)	IRR	1	0.8585	0.6093	0.4678
Acute Sinusitis	IRR	1	0.8583	0.3914	0.4668
Allergic Reaction (mild to moderate)	IRR	1	0.8513	0.8513	0.7027
Diarrhea	IRR	1	1.1883	1.1883	1.3767
Eye Infection	IRR	1	0.8465	0.8465	0.6931
Gastroenteritis	IRR	1	1.1636	1.1636	1.3272
Herpes Zoster Reactivation (shingles)	IRR	1	0.7803	0.7803	0.5606
Influenza	IRR	1	1.3409	1.3409	1.6818
Mouth Ulcer	IRR	1	1.3308	1.3308	1.6616
Pharyngitis	IRR	1	1.3305	1.3305	1.6611

Condition	Parameter	Baseline	Aerobic Only	Resistive Only	No Exercise
Respiratory Infection	IRR	1	1.2841	1.2841	1.5682
Skin Infection	IRR	1	1.1350	1.1350	1.2700
Skin Rash	IRR	1	1.1519	1.1519	1.3039
Urinary Tract Infection - Female	IRR	1	1.2873	1.2873	1.5747
Urinary Tract Infection - Male	IRR	1	1.1305	1.1305	1.2611
Back Sprain/Strain	IRR	1	0.8115	0.8115	0.623
Shoulder Sprain/Strain	IRR	1	0.8115	0.8115	0.623
Ankle Sprain/Strain	IRR	1	0.8115	0.8115	0.623
Elbow Sprain/Strain	IRR	1	0.8115	0.8115	0.623
Neck Sprain/Strain	IRR	1	0.8115	0.8115	0.623
Knee Sprain/Strain	IRR	1	0.8115	0.8115	0.623
Wrist Sprain/Strain	IRR	1	0.8115	0.8115	0.623
Hip Sprain/Strain	IRR	1	0.8115	0.8115	0.623
Skin Abrasion	IRR	1	0.9785	0.9785	0.957
Skin Laceration	IRR	1	0.982	0.982	0.964
Nephrolithiasis	IRR	0.9358	1.1486	0.9358	1.1486

30 Conditions, 31 Parameters

CAUTION WITH THESE RESULTS

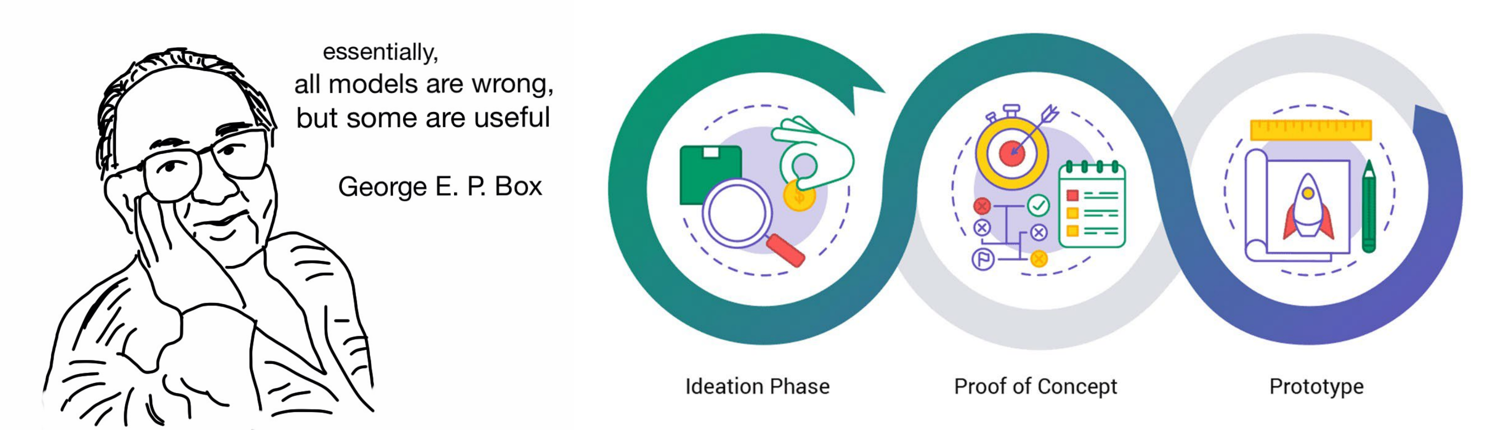
The Model is:

- **<u>Not currently inclusive of all health and performance metrics influenced by ECM functionality</u>**

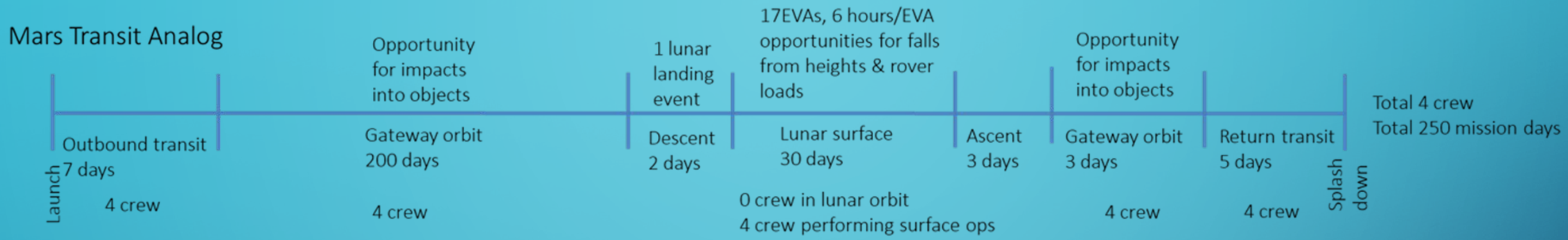
- Not been reviewed by appropriate SME's
- Not meant for decision making, but to elicit discussion and feedback supporting targeted development

This Model is:

- A proof of concept illustrating CHP-PRA construction
- An illustration of multiple "primary" paths of influence on one aspect of health and performance
- Informed by publicly available data.

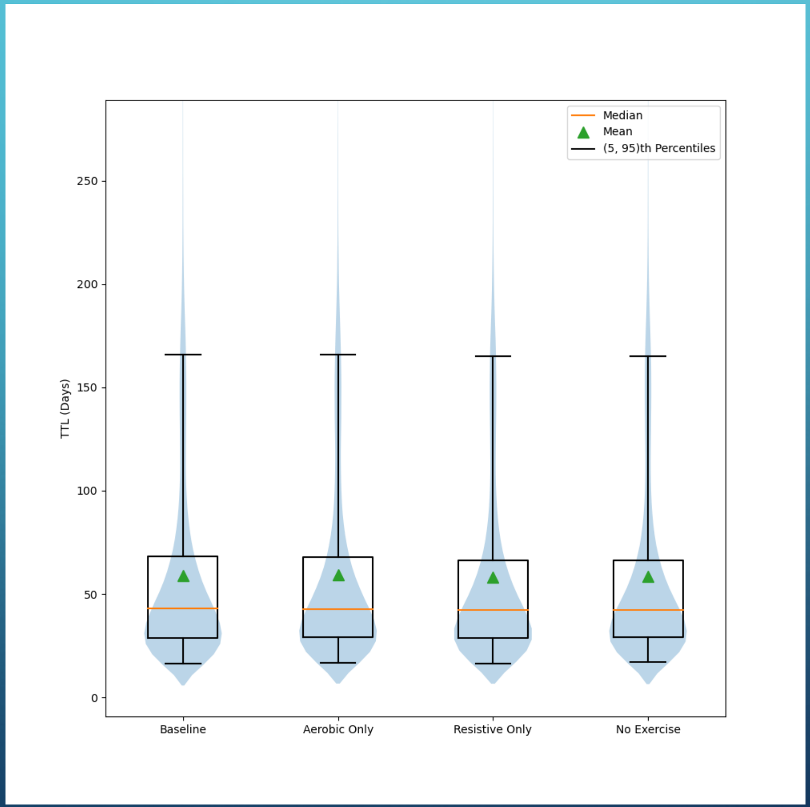


MARS TRANSIT ANALOGUE – LIMITED TREATMENT



Simulation Details

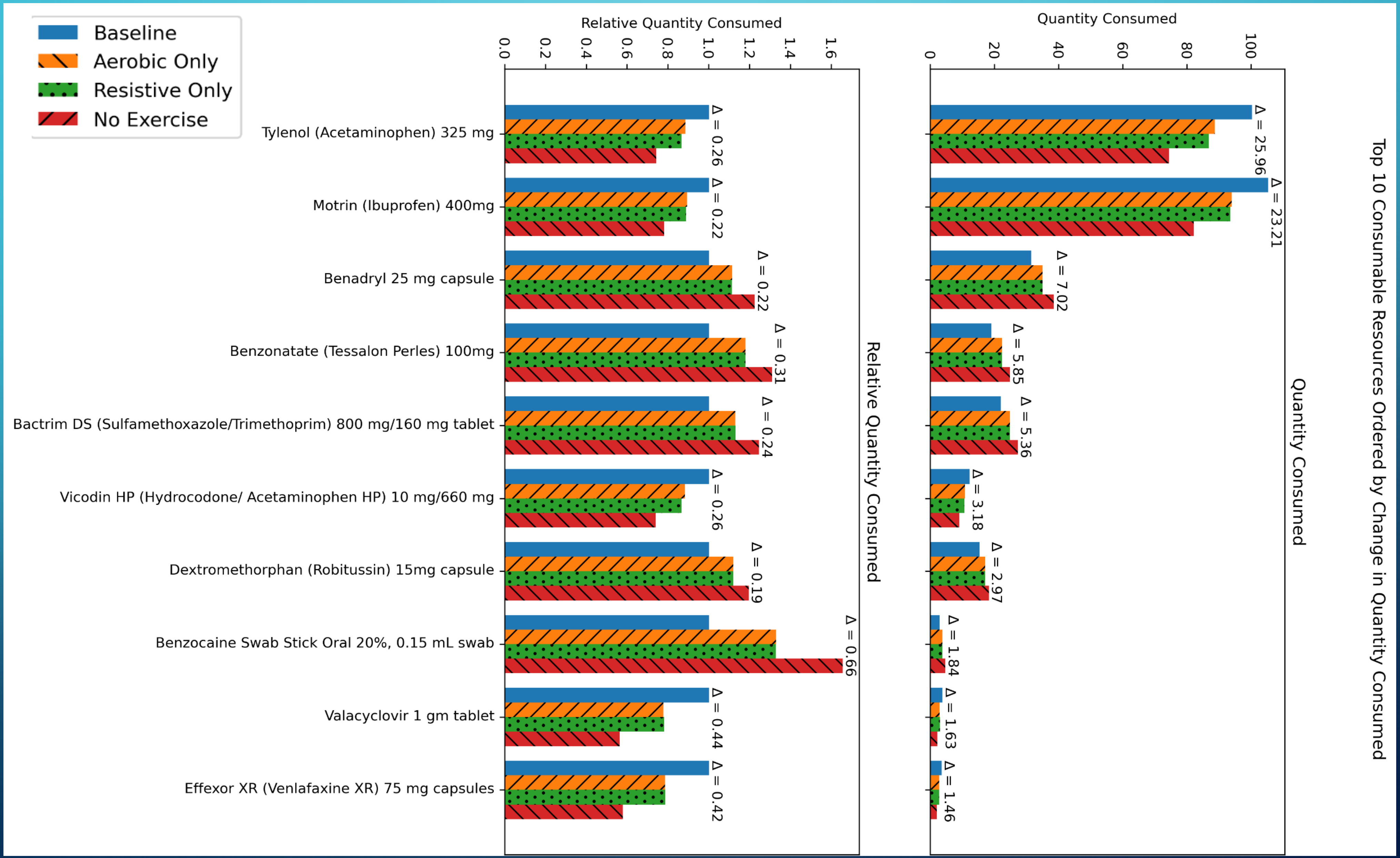
- Database: iMED
- Diag/Treatment: ISS Equiv.



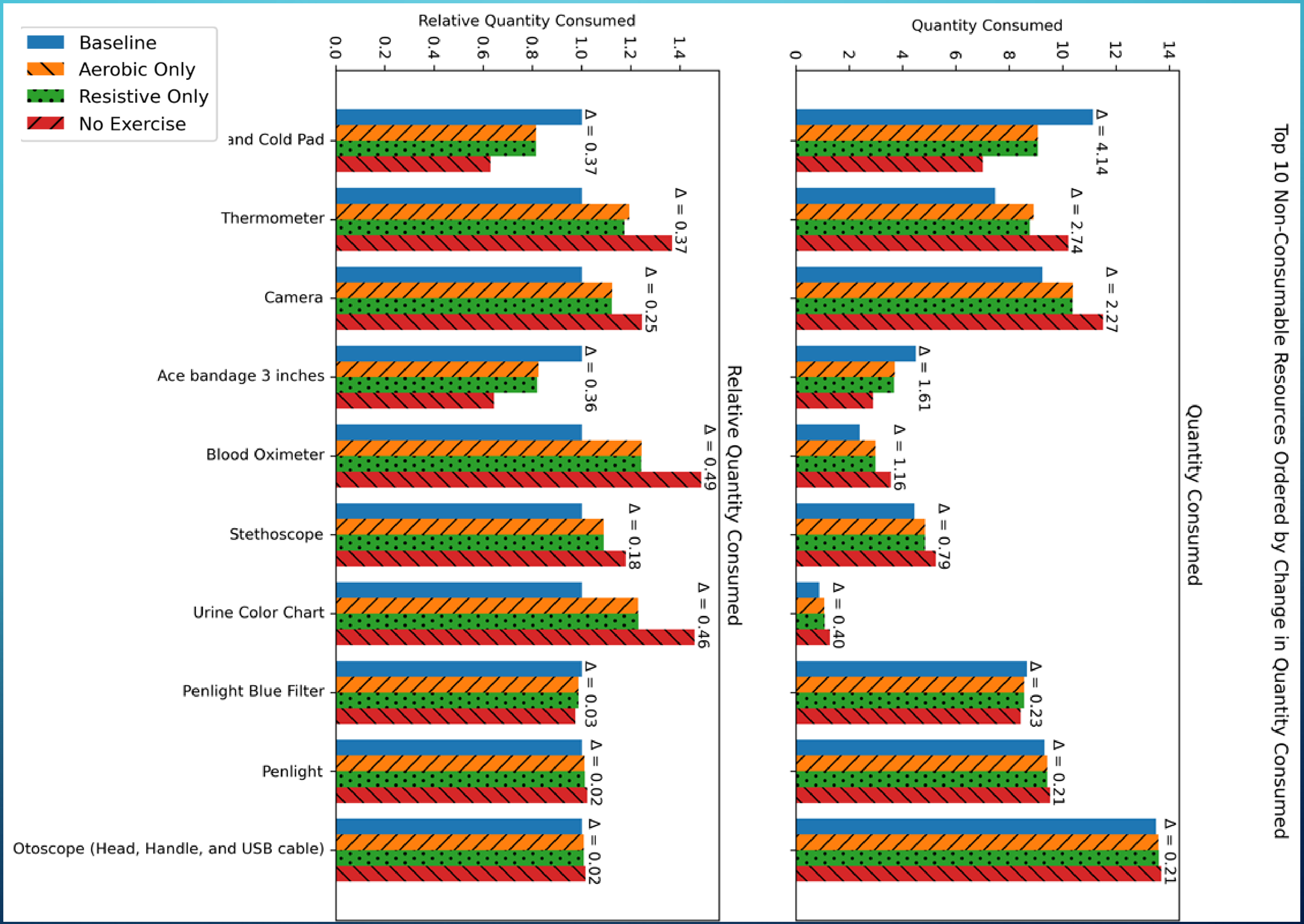
~1 day change in mean TTL (QTL)

Similar minor changes to LOCL and RTDC (not shown)

TOP 10 CONSUMABLE RESOURCES BY CHANGE IN QUANTITY CONSUMED



TOP 10 NON-CONSUMABLE RESOURCES BY CHANGE IN FREQUENCY UTILIZED



WHAT WE LEARNED

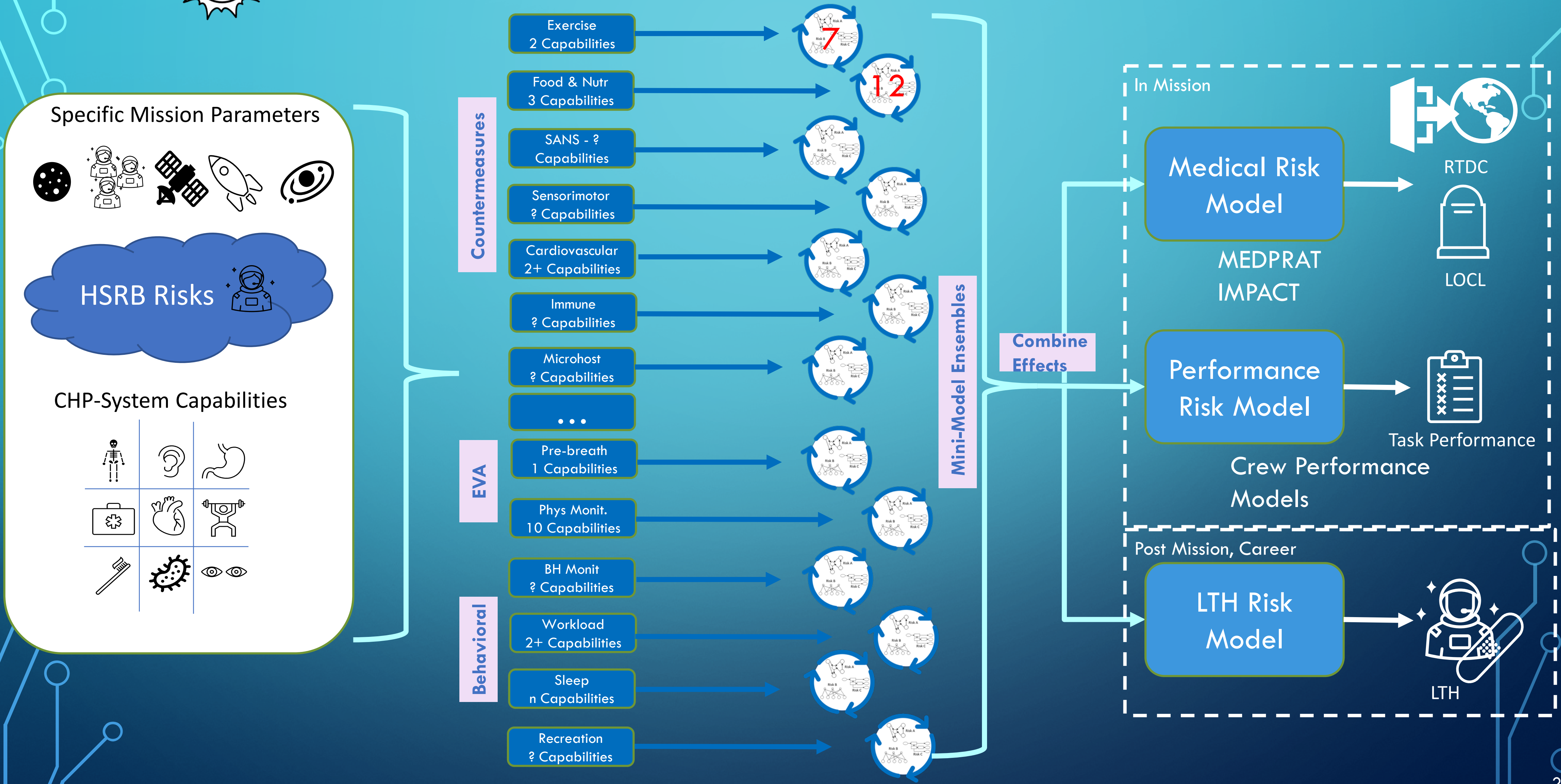
The Good

- PoC approach is viable
- Combines effects along multiple <u>primary</u> paths
- Using existing tools for mission granularity
- Mini-models unique wrt capability
- HSRB DAGs good starting point

The Bad

- Diminishing returns “chasing” all paths
- Does not propagate all known uncertainty
- Does not account for all interactions of CHP sub-systems
- Not all Med Conditions of interest in iMED or EL
- HSRB DAGs lack sub-system definition and priority proportion

FUTURE CHP-PRA CONCEPT



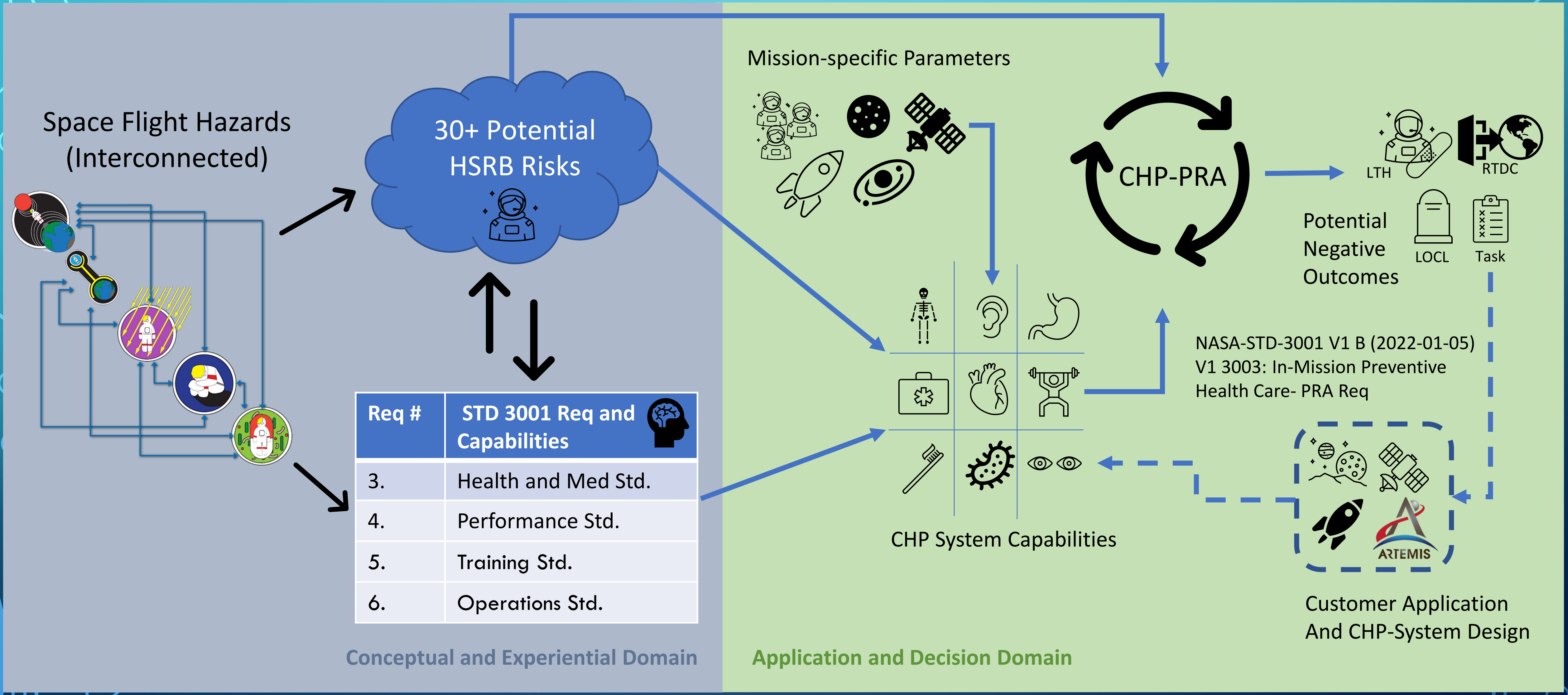
ESTABLISHING COLLABORATIONS AND INTEGRATIONS

Moving focus beyond medical to include performance and long-term health to allow enhanced trades across the rest of the CHP capabilities and functionalities.

Example: Give physiologist another avenue to communicate the importance of research and development products on mitigating humans space flight risk using quantifiable metrics consistent with engineering methods and trades.

Subject Area	SME Sources
Performance Models and Metrics (agent based, Sleep/circadian, strength, coordination)	BHP, NSL, ABF, EPC
Capability: Physiological Monitoring	D&Sw, EPC, AIP, BHP, CVL
In-Dev Countermeasures (SANS etc)	CVL, AIB, ABF, NSL, Nutrition
Larger CHP Components – Overlap with other vehicle systems	Nutrition and Biochem, ABF, BHP, EPC
Latest information	All Labs
More as collaborations develop….	

PRA POTENTIAL TO INFLUENCE THE DESIGN PATH



Req #	STD 3001 Req and Capabilities
3.	Health and Med Std.
4.	Performance Std.
5.	Training Std.
6.	Operations Std.

NEXT STEPS

- Evaluate the methods needed to combine capability effects
  - Ex: No exercise CM & No ultrasound device
- COCEI call to crowd source specific functionality
- Identify a 1st Generation Performance Model
- Ex: SCREAM: Space-based Cognitive Reliability Error Analysis Method: Boyer et al 2019.

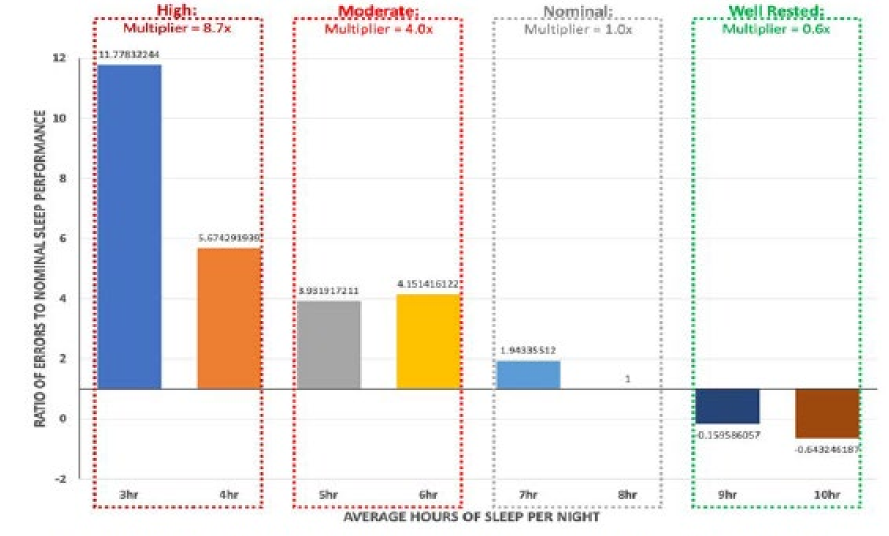


Figure 3. Ratio of Performance Effects at Different Levels of Sleep Deprivation to Performance with Normal Sleep.

LONG TERM HEALTH METRIC DEVELOPMENT EFFORTS

- Understanding spaceflight LTH risks
- Existing LTH Metrics with potential spaceflight applications
- Understanding NASA's need for LTH metric(s)
- Understanding existing efforts within and outside of NASA
- Develop a plan for incorporation of LTH metric(s) into CHP-PRA efforts

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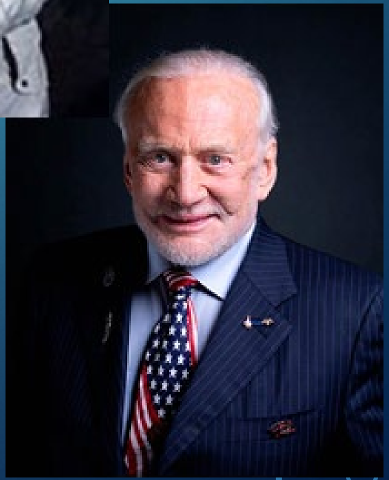


https://www.nasa.gov/content/national-space-council-users-advisory-group/membership_roster_b_aldrin/

LONG TERM HEALTH RISK

- HSRB maintains LTH risks in addition to in-mission risks
  - Exposure to spaceflight hazards increases the incidence rate or severity of medical issues experienced by the astronaut later in life
    - Decreases quality of life or life expectancy
    - Examples:
      - Dementia
      - Cancer
      - Cardiovascular disease
  - Medical conditions occurring during spaceflight have long lasting effects which limit astronaut capability post-flight
    - Decreases quality of life or increases disability adjusted life years
    - Examples:
      - Musculoskeletal disabilities
      - Kidney failure

Consequence

Long Term Health (post mission) (LTH)

High	• Unknown and improbable return to baseline (requires drastic intervention surgery & therapy) • Major impact on quality of life (permanent reduced function, premature death)
Medium	• Return to near baseline requires extended medical intervention w/ known clinical methods/technologies (pharmaceuticals, etc.) • Moderate impact on quality of life
Low	• Return to baseline values within 1 year with nominal intervention (time, exercise, nutrition, lenses) • Negligible effect on quality of life
Very Low	• Return to baseline values within 3 months with limited intervention • No effect on the quality of life

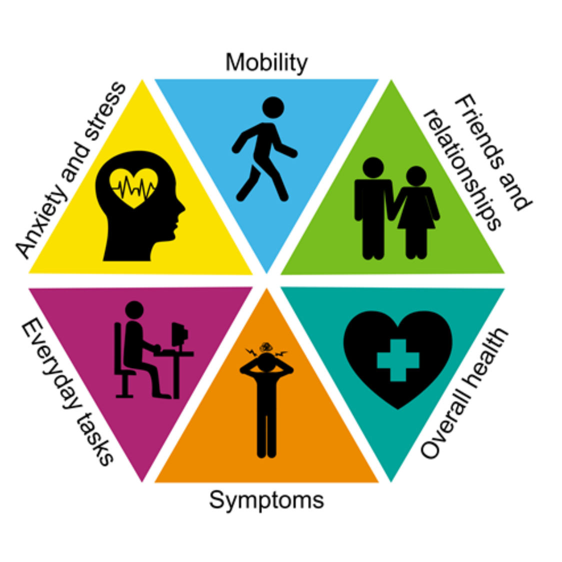
Quality of Life is defined as impact on day to day physical and mental functional capability and/or lifetime loss of years

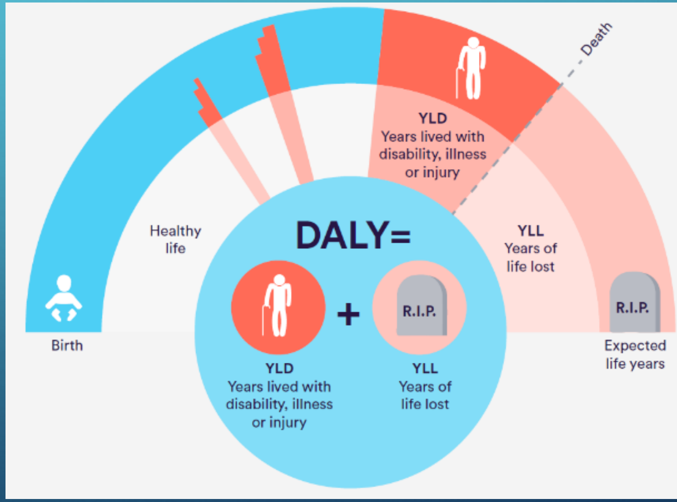
LTH Outcomes	LTH Risks
Cognitive impairment	Behavioral Medicine SANS Radiation carcinogenesis
Long term psychological effects	Behavioral Medicine
Vision impairment	SANS Dynamic Loads Non-ionizing radiation
Hearing impairment	Hearing loss
Early onset osteoporosis and/or debilitating arthritis	Bone Fracture
Musculoskeletal disability	Crew Egress Dynamic Loads
Skin constrictions	Electric Shock
Long term complications from spaceflight medical conditions	Medical
Long term complications from malnutrition	Food
Kidney disease	Renal stone Urinary Retention Electric Shock Toxic Exposure
Long lasting effects from DCS or arterial gas embolism	Decompression Sickness
Long lasting/debilitating rashes, autoimmune disorders	Dust Immune
Cancer	Radiation carcinogenesis Immune
Effects from untreated infections or sepsis	Microhost Urinary Retention
Chronic cardiopulmonary disease, Pneumonoconiosis	Toxic Exposure Dust

LONG TERM HEALTH						
	Health Outcomes	Career related short term self-resolving medical conditions	Career related medical conditions manageable with outpatient medical treatments	Treatable career related medical condition that requires hospitalization for management	Chronic career related medical condition requiring intermittent hospitalization or nursing care	Career related premature death or permanent disability requiring institutionalization
	OR					
	Quality of Life	No impact on quality of life OR independence in activities of daily living	Minor, short-term impact on quality of life OR rare support required for activities of daily living	Moderate long-term impact on quality of life OR may require some time-limited support for activities of daily living	Major long-term impact on quality of life OR requires intermittent support for activities of daily living	Chronic debilitating impact on quality of life OR requires continuous support for activities of daily living

CANDIDATE LTH METRICS

- Existing metrics that may be candidates for quantifying the consequences of spaceflight LTH risk:
  - Quality of life
  - Life expectancy
  - Quantity and level of health care needs
  - Ability to perform activities of daily living independently
  - Disability adjusted life years





- Other government agencies and industries have vast experience in developing and using LTH metrics that can likely be leveraged

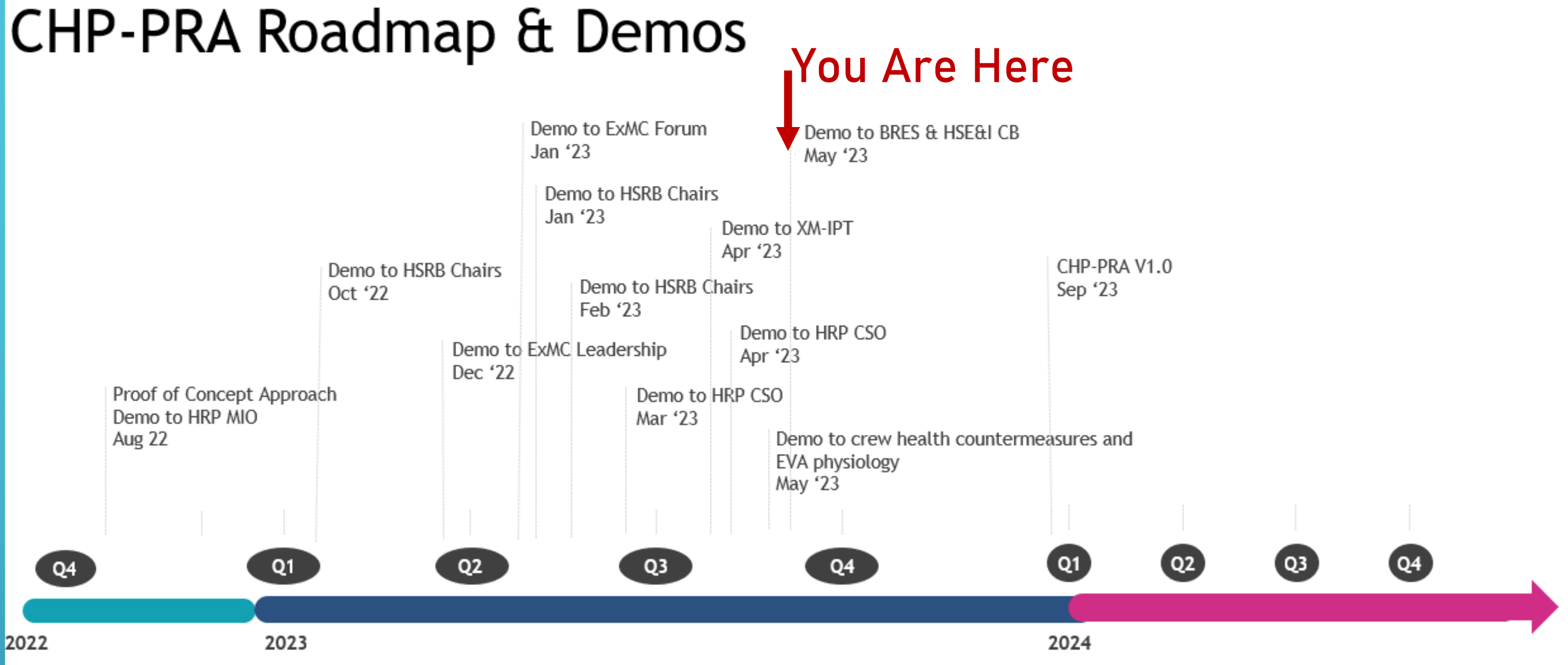
LTH METRIC DEVELOPMENT ROADMAP

- Identify NASA stakeholders:
  - Human System Risk Board
  - Human System Risk Custodians
  - NASA Crew Health and Safety
    - Maintains the Lifetime Surveillance of Astronaut Health Database
    - Using the IMPALA platform and 60 years' worth of data to visualize and understand the most likely LTH outcomes – target completion is 2024
  - The Multi-model Ensemble Risk Assessment (MERA) Project
    - Determining incidence rates for LTH outcomes for space radiation, behavioral health and cardiovascular risks
- Determine what type of LTH risk trades stakeholders might need to make
- FY23 Deliverable: LTH Metric Development Summary Report:
  - Compilation of background work
  - Summary of findings from TIMs
  - Recommendations for CHP-PRA incorporation
  - Forward plan for FY24

Lifetime Surveillance of Astronaut Health

Task	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Collect Background Information for LTH Metric(s)					x							
On HSRB risks and from within NASA Organizaitons	x	x										
On relevant programs within other government agencies			x									
On metrics used within relevant industries				x								
Literature search												
Collect Background Information for Performance Metric(s)				x								
On HSRB risks and from within NASA Organizaitons	x	x										
On relevant programs within other government agencies		x										
On metrics used within relevant industries		x										
Literature search			x									
Summary and discussion with CHP-PRA team				x								
Meet with Stakeholders												
Preliminary meetings		x	x							x		
TIM #1					x							
TIM #2								x				
Briefing to IMPACT									x			
Identify candidate metrics and link astronaut LTH risk to the metric(s)												x
Develop recommendations on candidate metrics										x		
Write a SOW for further identification/proof of concept demonstration											x	
Summary of findings reports												x
Interim findings for PPBE25 planning						x						
Final report												x

FREQUENT FEEDBACK WELCOME



Goal: Elicit feedback from gathered SME's to improve approach leading to operational use

Questions ?

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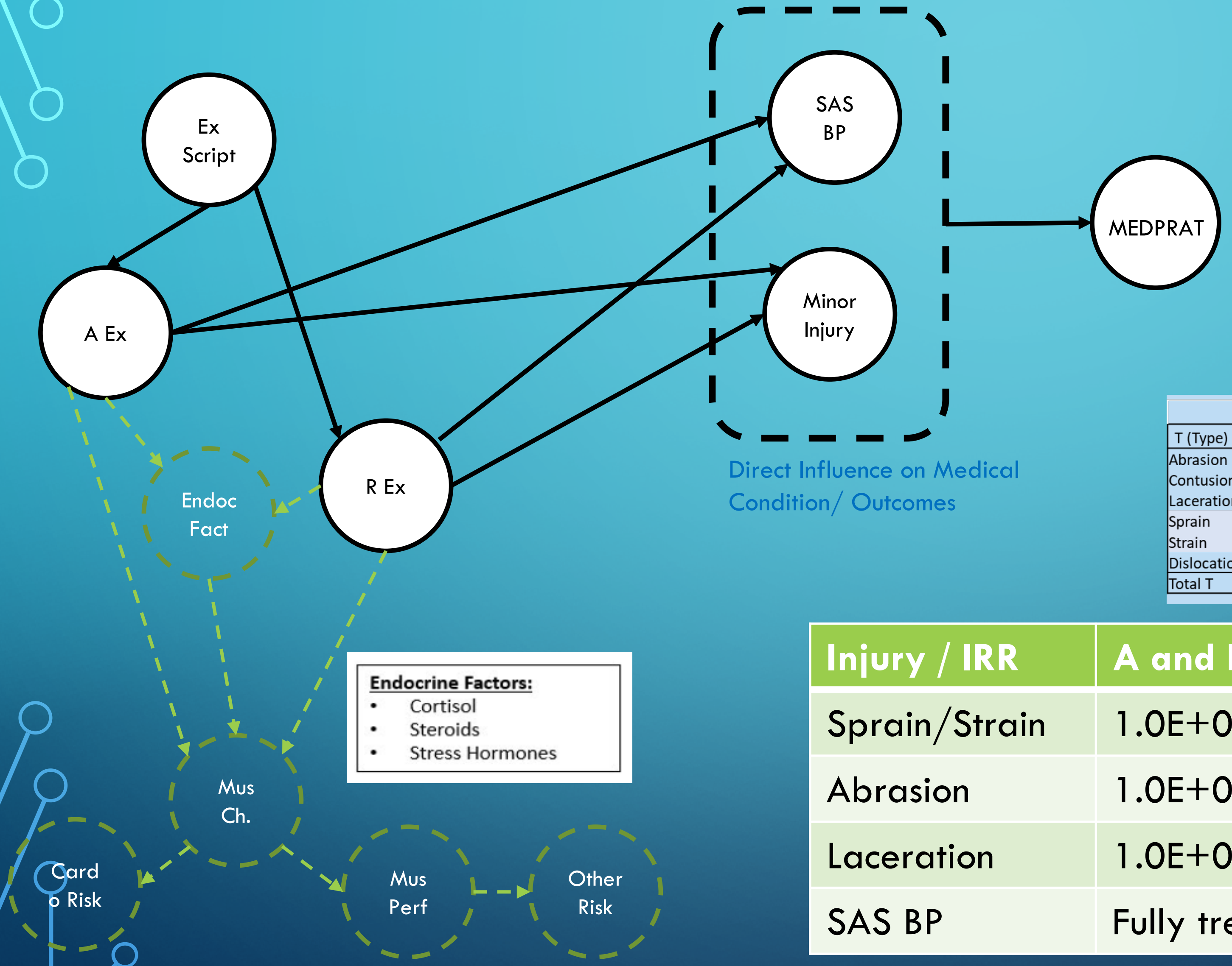
BACKUP SLIDES

MUSCLE AND AEROBIC, MINOR INJURY EFFECTS



Primary References
Kerstman EL, Scheuring RA, Barnes MGMG, et al (2012) Space adaptation back pain: A retrospective study. Aviat Sp Environ Med 83:2–7. https://doi.org/10.3357/ASEM.2876.2012

Scheuring RA, Mathers CH, Jones JA, Wear ML (2009) Musculoskeletal injuries and minor trauma in space: incidence and injury mechanisms in U.S. astronauts. Aviat Space Environ Med 80:117–24

Count of different types of injuries by different methods (From Scheuring 2009)

T (Type) \ M (Method)	Crew Activity	Egress	EVA Activity	EVA Suit	Exercise	Experiment	LES	Unknown	Total M
Abrasion	34	1	1	21	3			10	70
Contusion	12			23	10	6	12	4	67
Laceration	17	2		2	1		2	4	28
Sprain	1				3				4
Strain	17		4	2	17		6	3	49
Dislocation	1								1
Total T	82	3	5	48	34	6	20	21	219

Injury / IRR	A and R	A or R	Not A or R
Sprain/Strain	1.0E+00	8.1E-10	6.2E-01
Abrasion	1.0E+00	9.8E-01	9.6E-01
Laceration	1.0E+00	9.8E-01	9.6E-01
SAS BP	Fully treated when A available		

CO2 HEADACHE AND ACUTE SINUSITIS

MEDICAL SUPPORT FOR ISS CREWMEMBER TRAINING IN STAR CITY, RUSSIA

(nasa.gov)

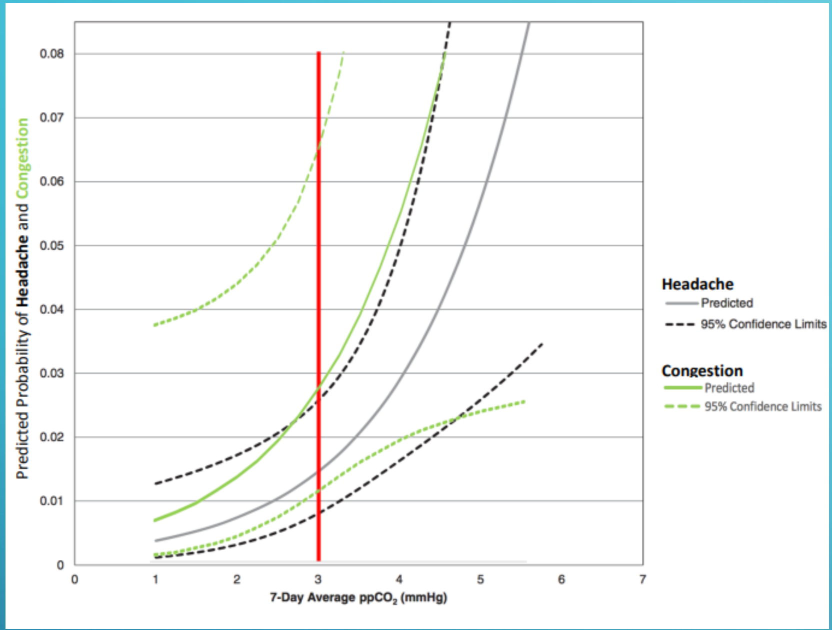
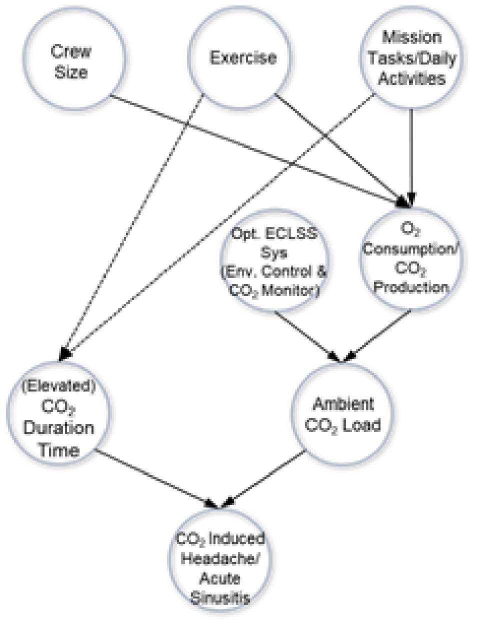


Table 4. Cardiorespiratory parameters before and after long-duration spaceflight with standard of care exercise or Sprint exercise prescription.

	CON			SPRINT		
	Preflight	R + 3	R + 30	Preflight	R + 1	R + 30
VO_{2peak} (L min^{-1})	3.36 ± 0.19	3.12 ± 0.19*	3.32 ± 0.19	3.22 ± 0.23	2.91 ± 0.23*	3.23 ± 0.23
VO_2peak (mL kg^{-1} min^{-1})	41.8 ± 1.6	39.7 ± 1.6*	41.8 ± 1.6	41.6 ± 1.9	38.2 ± 1.9*	42.0 ± 1.9
Ventilatory threshold (L min^{-1})	2.22 ± 0.15	1.97 ± 0.15*	2.25 ± 0.15	2.08 ± 0.16	1.79 ± 0.18*	2.00 ± 0.18
Peak workload (W)	302 ± 14	281 ± 14*	304 ± 14	269 ± 17	256 ± 17*	288 ± 17
Peak heart rate (beats min^{-1})	173 ± 3	174 ± 3	174 ± 3	178 ± 4	176 ± 4	176 ± 4

Data are mean ± SE and were collected approximately 50 days preflight (L-50) and 1 (Sprint) or 3 (CON) days and 30 days postflight (R + 1/R + 3 and R + 30). No group × time interaction effects were detected ($P > 0.05$). *CON* control group that performed the ISS standard of care exercise prescription, *SPRINT* experimental group that performed a high intensity/lower volume exercise prescription.
*Simple main effect for time relative to preflight ($P < 0.05$).

*: *English et al., NPJ Microgravity, 2020.*



Assumption: Health risk and incidence rate ratios are equivalent			
Change in probability of headache due to increase in CO2 (aerobic+resistive Ex CM):	0.022	±	0.024
Change in probability of headache due to increase in CO2 (resistive Ex CM):	0.016	±	0.017
Change in probability of headache due to increase in CO2 (aerobic Ex CM):	0.006	±	0.006
Headache incidence risk ratio due to CO2 (aerobic Ex CM):	**0.609**	**±**	**0.029**
Head incidence risk ratio due to CO2 (resistive Ex CM):	**0.859**	**±**	**0.025**
Headache incidence risk ratio due to CO2 (no Ex CM):	**0.468**	**±**	**0.024**

Assumption: Health risk and incidence rate ratios are equivalent.			
Change in probability of congestion due to increase in CO2 (aerobic+resistive Ex CM):	0.041	±	0.161
Change in probability of congestion due to increase in CO2 (resistive Ex CM):	0.030	±	0.118
Change in probability of congestion due to increase in CO2 (aerobic Ex CM):	0.011	±	0.031
Congestion (acute sinusitis) incidence risk ratio due to CO2 (aerobic Ex CM):	**0.609**	**±**	**0.200**
Congestion (acute sinusitis) incidence risk ratio due to CO2 (resistive Ex CM):	**0.858**	**±**	**0.164**
Congestion (acute sinusitis) incidence risk ratio due to CO2 (no Ex CM):	**0.467**	**±**	**0.161**

IMMUNE – CHANGES

- Compiled immune-related iMED data for “w/o-” and with-exercise ISS periods.
- Sepsis number is likely from general population, not ISS.
- Preserved sex difference for UTI; also combined male and female for total UTI.
- Vaginal yeast infection events and person_years are inconsistent with others.

Medical_Condition	Events/Person-Years "w/o" Exercise	Events/Person-Years with Exercise	%Δ due to "w/o" Exercise	Crucian et al., 2016
ALLERGIC REACTION (TO MODERATE)	0.402	0.572	29.7	0.100
DIARRHEA	1.206	0.879	-37.2	
EYE INFECTION	0.183	0.264	30.7	
GASTROENTERITIS	0.146	0.110	-33.0	
HERPES ZOSTER REACTIVATION (SHINGLES)	0.037	0.066	44.6	0.300
INFLUENZA	0.037	0.022	-66.3	
MOUTH ULCER	0.329	0.198	-66.3	
PHARYNGITIS	0.402	0.242	-66.3	0.100
RESPIRATORY INFECTION	1.206	0.769	-56.8	1.000
~~SEPSIS~~	~~0.002~~	~~0.002~~	~~0.0~~	
SKIN INFECTION	0.475	0.374	-27.1	0.300
SKIN RASH	3.436	2.635	-30.4	1.100
URINARY TRACT INFECTION - FEMALE	1.348	0.856	-57.5	
URINARY TRACT INFECTION - MALE	0.169	0.134	-26.2	
URINARY TRACT INFECTION - TOTAL	1.517	0.990	-53.3	0.100
VAGINAL YEAST INFECTION	0.065	0.386	83.3	

- Herpes data of Crucian et al. includes all latent herpes viruses, not just zoster (VZV).
- Excluded sepsis as its numbers are likely from general population, not ISS.
- Urinary tract infection data of Crucian et al. is likely dominated by male astronauts.
- Excluded vaginal yeast infection due to inconsistency.
- Incidence rates used here compare reasonably to data reported by Crucian et al.

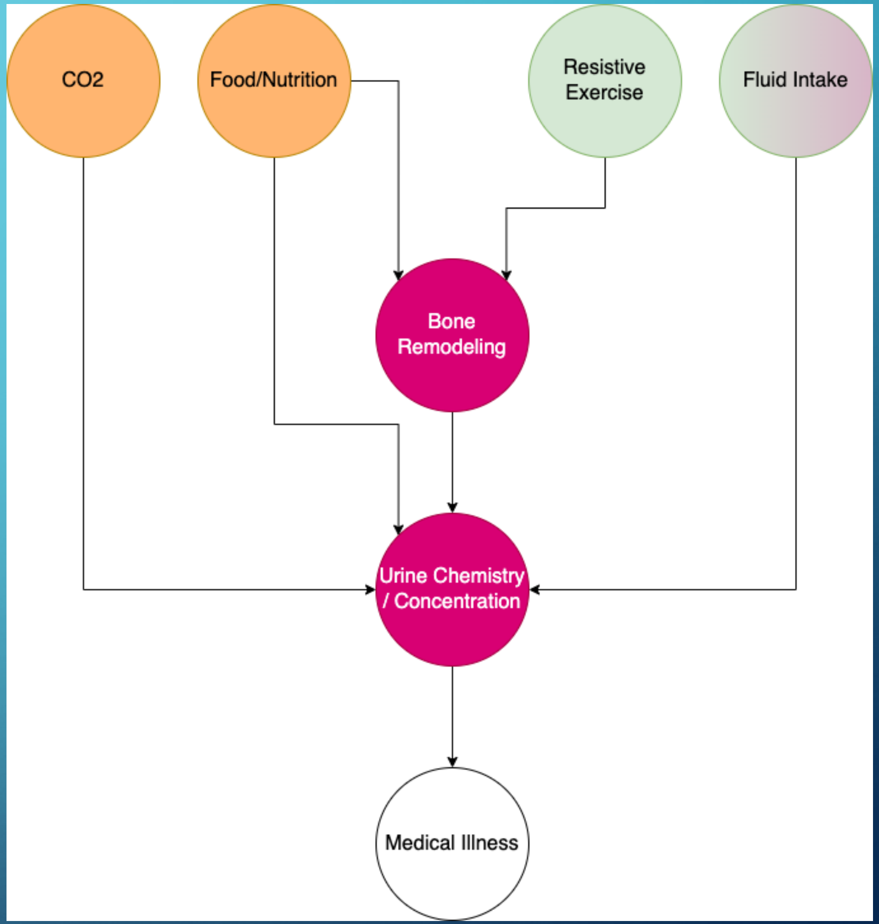
EXERCISE EFFECTS ON RENAL STONE IR

- Pre-flight and In-flight Urine Chemistry: Goodenow-Messman, D.A., Gokoglu, S.A., Kassemi, M. *et al*. Numerical characterization of astronaut CaOx renal stone incidence rates to quantify in-flight and post-flight relative risk. *npj Microgravity* **8**, 2 (2022). https://doi.org/10.1038/s41526-021-00187-z
- BMD Loss Rates:
- English, K.L., Downs, M., Goetchius, E. *et al*. High intensity training during spaceflight: results from the NASA Sprint Study. *npj Microgravity* **6**, 21 (2020). https://doi.org/10.1038/s41526-020-00111-x
- Keyak JH, Koyama AK, LeBlanc A, et al (2009) Reduction in proximal femoral strength due to long-duration spaceflight. Bone 44:449–453. doi: 10.1016/j.bone.2008.11.014
- Leblanc A, Matsumoto T, Jones J, Shapiro J, Lang T, Shackelford L, Smith SM, Evans H, Spector E, Ploutz-Snyder R, Sibonga J, Keyak J, Nakamura T, Kohri K, Ohshima H. Bisphosphonates as a supplement to exercise to protect bone during long-duration spaceflight. Osteoporos Int. 2013 Jul;24(7):2105-14. doi: 10.1007/s00198-012-2243-z. Epub 2013 Jan 19. PMID: 23334732.

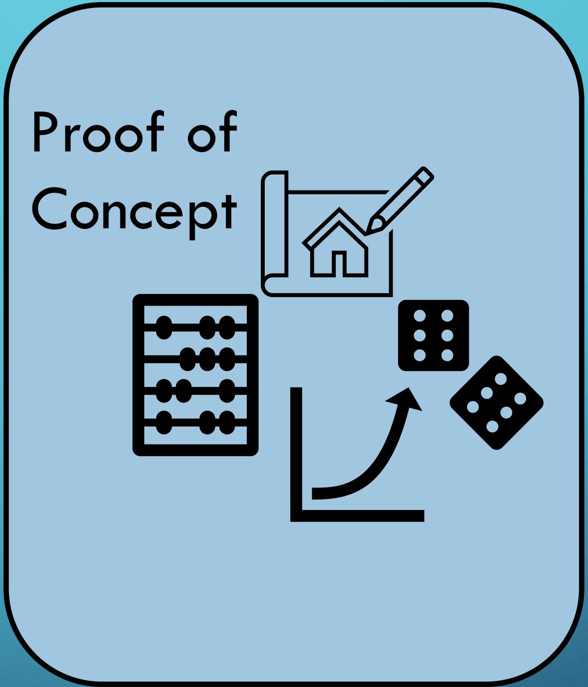
Urine Calcium levels:

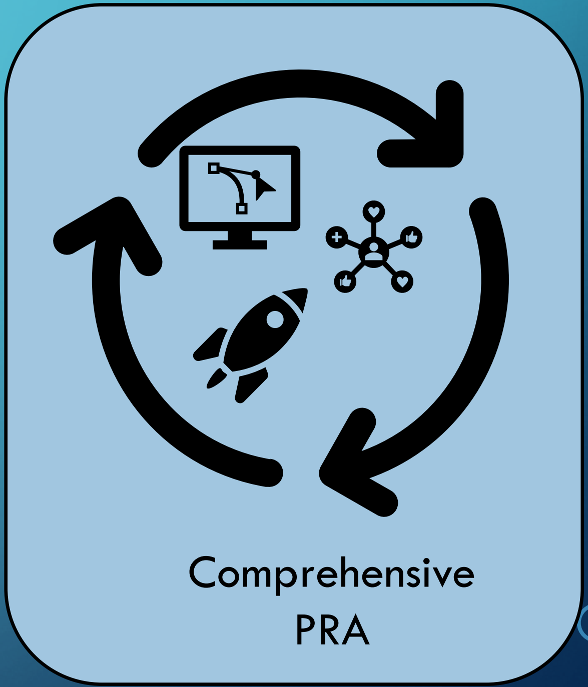
Without effective resistive exercise (mean): 367.0 mg/day
With effective resistive exercise (mean): 241.5 mg/day
Intermediate levels of resistive effectiveness are linearly interpolated.

These calcium levels are then fed to the Renal Model (Goodenow-Messman, et al.) for an IRR for renal stones.

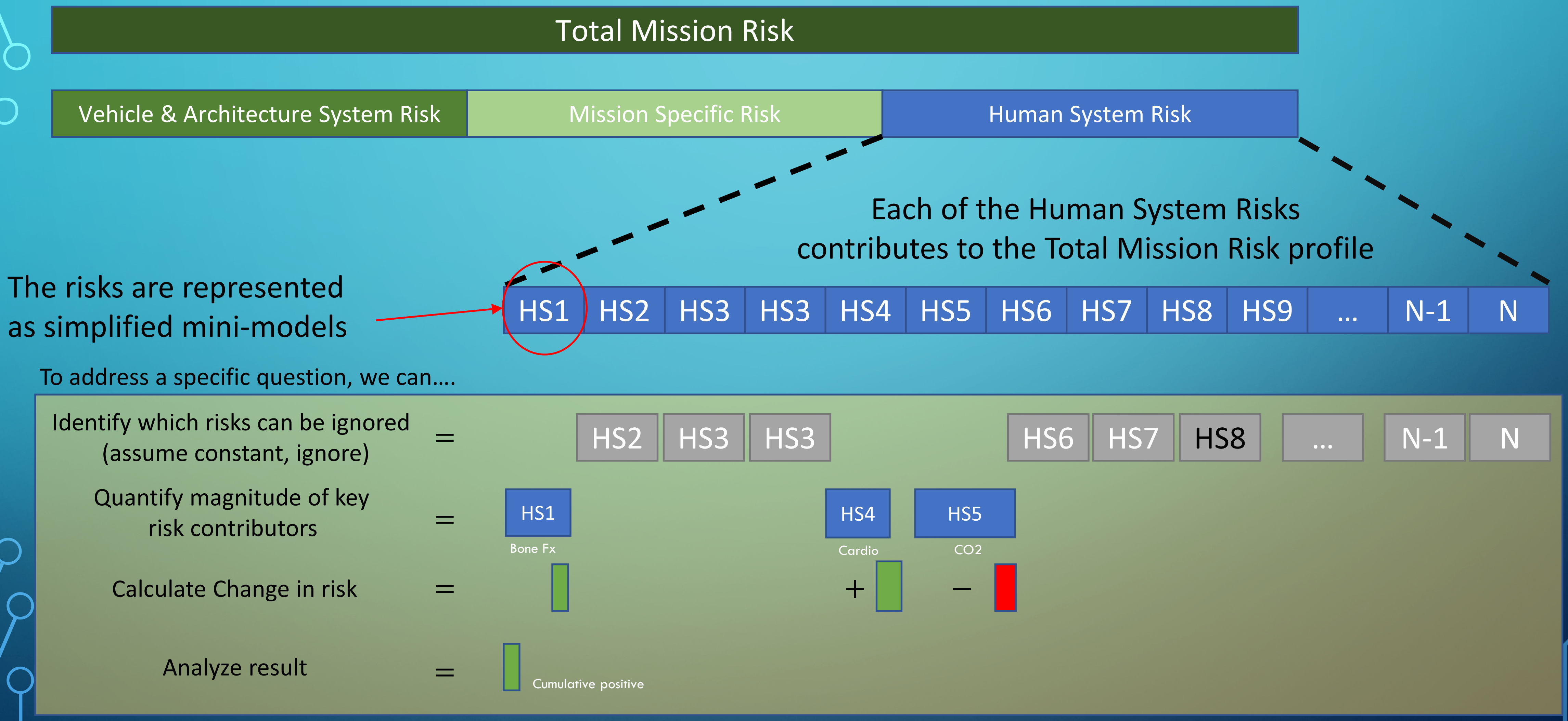


REACHING OUR GOAL



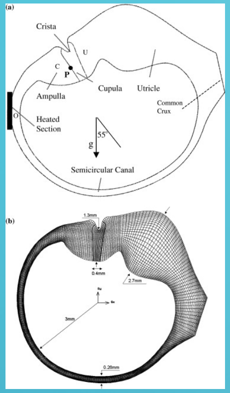


MATHEMATICAL APPROACH



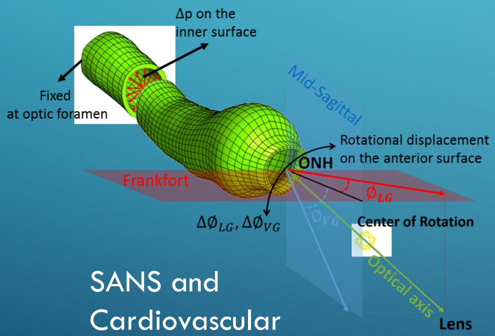
COLLABORATIONS AND INTEGRATIONS

Radiation+ Long-Term Health Models



Vestibular Performance Models

Agent-Based Models for Team and Behavior



SANS and Cardiovascular Related Models