National Aeronautics and Space Administration

Lyndon B. Johnson Space Center
2101 NASA Parkway
Houston, TX 77058-3696

October 27, 2022

Reply to Attn of: SA-22-065

TO: Human System Risk Directed Acyclic Graph Working Group

FROM: Chair, Human System Risk Board
Deputy Chair, Human System Risk Board

SUBJECT: Demonstration of the Relationships Between Human System Risks via Directed Acyclic Graphs (DAGs)/TP NF-1676 20220015709

The Human System Risk Board (HSRB) is responsible for the management of a portfolio of 30 human system risks that NASA tracks and configuration manages to mitigate for future crewed exploration missions. Starting in January 2020, the board has developed and managed the concept of causal diagrams (in the form of DAGs) as an approach to creating knowledge graphs for each risk to enable shared mental models of causal flow from spaceflight hazards to mission outcomes among HSRB Stakeholders. These diagrams are intended to improve insight and communication of risk across the myriad subject matter experts and management interested in human system risk reduction. This includes program managers, systems engineers, and operators in addition to the Human Health and Performance Directorate.

With the completion of the Configuration Management of all 30 human system risk DAGs, we requested preparation of a NASA Technical Publication suitable for public dissemination that contains:

1. Guidance on how to construct and interpret the DAGs
2. Shared definitions of all the terms within the DAGs
3. DAGs for each of the Human System Risks
    a. Including their narrative description
4. Code appropriate for easy replication of the Human System DAGs by interested parties

One function of this technical publication is to release the DAGs to the public domain, the official NASA versions of DAGs, their narratives, and the definitions of the terms within the DAGs will be version last configuration managed by the HSRB. It is understood and desired that the public and research community will add detail and complexity to the DAGs for each

user's purpose, but the version of the DAGs on the HSRB NASA website will always be the official one for NASA risk management purposes and will supersede any non-HSRB configuration managed versions.

We look forward to the receipt of this material and hope the external community can expand and respond to this publication in ways that characterize and mitigate the risks to human health and performance of exploration spaceflight.

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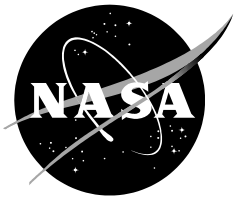
NASA/TP-20220015709



Directed Acyclic Graphs: A Tool for Understanding the NASA Human Spaceflight System Risks

Human System Risk Board

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October 2022

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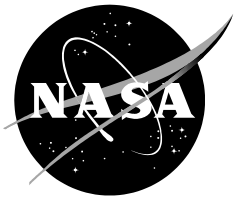

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This report is available in electronic form at http://

Abstract

For over a decade, the National Aeronautics and Space Administration (NASA) has tracked and configuration-managed approximately 30 risks to astronaut health and performance that occur before, during and after spaceflight. The Human System Risk Board (HSRB), a Health and Medical Technical Authority (HMTA) Board at NASA Johnson Space Center, is the entity responsible for identifying, assessing, analyzing, and monitoring the official understanding of the risk or risk posture for each of the Human System Risks and determining – based on evaluation of the available evidence – when that risk posture changes. The ultimate purpose of tracking and researching these risks is to find ways to reduce the risk that astronaut crews face during spaceflight. Historically, research, development and operations relevant to one risk have been conducted in isolation from other risks; these individual risk 'silos' enabled initial characterization of each specific risk. In spaceflight however, the impact of exposure to risk for astronaut crews is cumulative, and not independent of exposures or other risks, as all the adverse effects of the spaceflight environment begin at launch, continue throughout the duration of the mission and in some cases across the lifetime of the crews. In January of 2020, the HSRB at NASA embarked on a pilot project designed to assess the potential value of causal diagramming as a tool to facilitate understanding of these cumulative and interdependent effects as applied within Human System Risk management. This process uses directed acyclic graphs as a means of formalizing a shared mental model of the causal flow of risk among Risk Board stakeholders. Initially this model was to improve communication among those stakeholders, but the potential value exceeds communication alone. The causal diagrams are formulated as directed acyclic graphs (DAGs) to function as a type of knowledge graph for reference for the board and its stakeholders.

This document is a sister document to NASA/TM 20220006812 Directed Acyclic Graph Guidance Documentation (1). In that document, the basic guidance for creating and standardizing directed acyclic graphs as tools for cross-risk analysis is provided. This document contains the initial configuration managed DAGs that were created as a result of applying those principles. These initial versions were accepted by the HSRB in January of 2022. Each of the Human System Risks are represented by a DAG that has been reviewed by the larger Human Health and Performance community at NASA including life scientists, physical scientists, physicians, nurses, pharmacists, exercise specialists and more. These results show the starting point for Human System Risk DAGs as shared mental models and communication aids across the boundaries of the various expertise needed to understand and mitigate the human risks in spaceflight. Because they are a starting point, each of these DAGs can be expected to change over time as new or refined evidence becomes available. The process for updating these DAGs can be found in the JSC-66705 Human System Risk Management Plan (2) that is publicly available on the NASA Technical Reports Server.

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Overview

For the Human System Risk Board (HSRB), a Directed Acyclic Graph (DAG) is a visual tool that is used to capture knowledge and enhance communication across all the stakeholders of human system risks. The knowledge captured is the Human Health and Performance community's knowledge about the causal flow of a human system risk. They are intended as a high-level resource for understanding the complex relationships between factors that contribute to increased risk within and across the Human Spaceflight System Risks. They are not intended to provide detailed insight into subject matter expert (SME) domains of deep knowledge, but rather to provide the high-level scaffolding to which SMEs can attach more detailed visuals to clearly relay their importance to Mission Level Outcomes. The DAGs documented here are current as of May 13, 2022.

- The DAGs are dynamic and will change.
- Any major changes will be captured, and configuration managed at the HSRB.
- Any DAGs not configuration managed at the Board are considered notional.

For context, the interested reader can download JSC-66705 Human System Risk Management Plan (2) and NASA/TM 20220006812 Directed Acyclic Graph Guidance Documentation (1).

The formal definition of each node in the DAG network can be found in Appendix A.

The Human System Risk DAGs were created using DAGitty 3.0 (3) a publicly available browser-based environment for creating, editing, and analyzing causal diagrams. DAGitty formatting files for each Risk are included in Appendix B. Note that there are dotted lines in some DAGs connecting nodes. These indicate weak or speculative evidence support for the causal connection drawn and are explained more in the supporting documentation listed above. These are not a feature of the DAGitty program. Each of those found DAGs shown here were added in post-processing and as such are not captured in the DAGitty formatted files. These are intended to be captured in future software capabilities.

Guidance for DAGs

- All causal flow is acyclic, no loops are allowed.
- All flow starts with a Hazard(s) and ends with a Mission Level Outcome(s).
- Arrows to outbound Risks have been removed for visual clarity. They are shown as inbound arrows in the applicable Risks.
- Some nodes are "nested" to collapse like categories.
- Configuration Management of the DAGs is performed by the HSRB at NASA. The HSRB configuration managed DAGs represent the official position of the NASA Human Health and Performance community and the Health and Medical Technical Authority (HMTA).
- The DAGs shown here are 'Narrative' DAGs. These are intended to capture the high-level community agreement on causal flow. They are accompanied by narrative slides that explain in words the visualized representation. They include nodes that can represent grouped concepts for clarity and visual simplification.
- 'Detailed' DAGs can be made by individual users that show some of these concepts unpacked into multiple additional nodes or can add additional detail that is relevant to a specific problem. These are not configuration managed by the HSRB. Variations used

within NASA are expected to show fidelity to the Narrative DAG and are subject to HSRB administrative review.

- Users of DAGs may encounter more detailed DAGs that have been created by modifying or adding detail to the Narrative DAGs. Please note that these may not have been approved by the HSRB and as such may not reflect an official position of the NASA community. The user is responsible for determining whether the DAG is an HSRB configuration managed version or has been derived from an HSRB configuration managed version.
- HSRB Management would appreciate any comments on what level of detail or logistics need to be considered in this delineation of products. Please email your comments to jsc-dl-hsrb@mail.nasa.gov.
- Substantive changes to the Narrative DAGs may be proposed with any board update for the associated risk. This is to ensure discussion of the evidence considered in proposing updates to the DAGs. Anyone wishing to propose a DAG update must send a From-To visualization with rationale for recommending the causal changes. NASA is under no obligation to respond or accept suggested changes but will consider them within available resources.
- Processes for validating the structure of the DAGs using existing evidence are in development and the reader can learn more here Validating Causal Diagrams of Human Health Risks for Spaceflight: An example using bone data from rodents can be found here, Validating Causal Diagrams of Human Health Risks for Spaceflight: An Example Using Bone Data from Rodents (4)

Standardization Process

The DAG Guidance Document (1) provides a detailed explanation of the standardization guidelines for making HSRB approved DAGs. This is to ensure that visual representation of concepts and node terminology used is applicable across the many different fields of expertise that contributed to making the DAGs for the HSRB. The goal is to create a repeatable and systematic process for creating and updating DAGs to demonstrate consistency across all DAGs and ensure usability for the future.

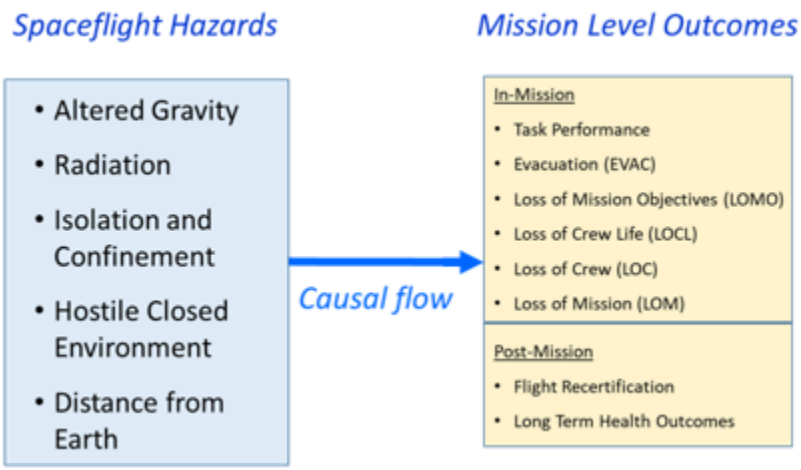


Figure 1: Each DAG starts with one or more of the known Hazards in human spaceflight and proceeds through nodes and edges to one or more of the Mission Level Outcomes that define risk for the astronauts and NASA.

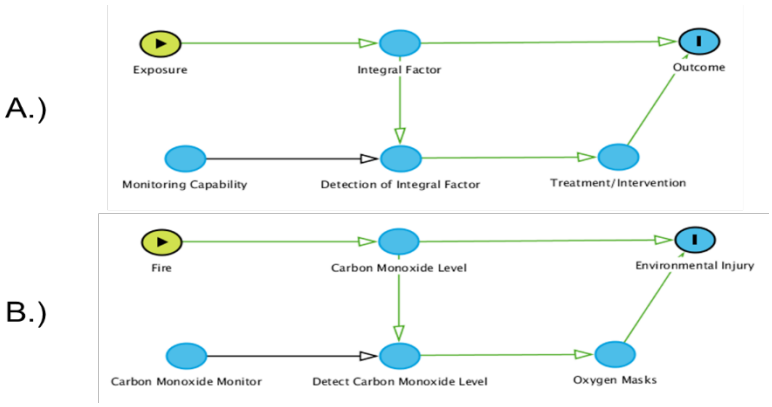


Figure 2: Example of standardization of visual representation. In this case, monitoring, detection, and the resulting intervention or treatment are shown in a consistent way across all DAGs. A. shows the general approach and B. shows a specific use case.

- Common Start and End Points.
- Common representations of concepts – See monitoring example in Figure 2.
- Harmonized Terminology - Ensuring that terms referring to the same concept are named the same in order to facilitate risk-risk interaction mapping. This is accomplished by reviewing all the DAGs together and creating a terminology list. When official DAGs are updated the Risk Custodian Teams responsible are asked to choose terms from the official list for any new nodes. If there is not an applicable term in the database, then the team needs to submit a definition for the proposed node along with an update to the narrative of how that node contributes to the causal story of risk shown in the affected DAG(s).
- Below is the legend for the DAGs visualized with the current DAGitty (http://www.dagitty.net) capabilities. Future software will enable different representations.

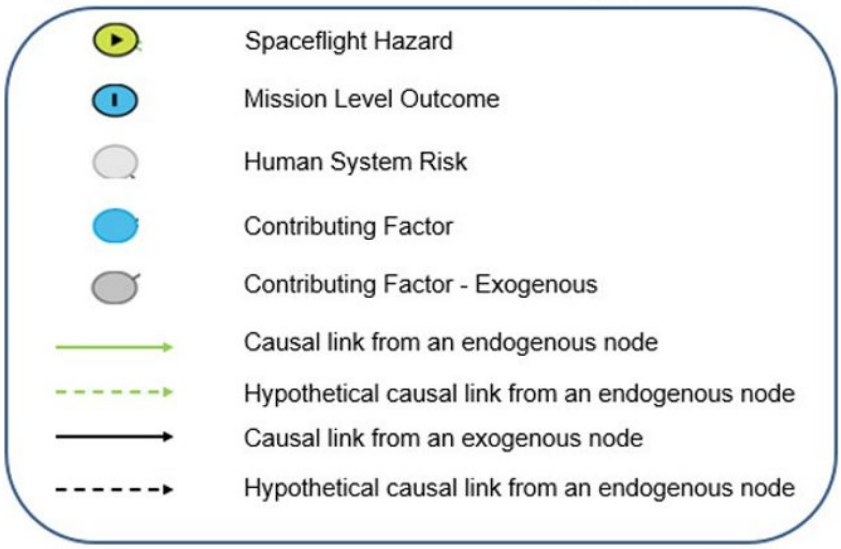


Figure 3: For DAGs created with the DAGitty software, this legend identifies the types of nodes and edges found in the DAGs in this document. Dotted lines are not part of the DAGitty capabilities and were added manually.

Common Terms

This is a list of some of the common terms found in multiple DAGs with description:

- **Hazards** – Set hazards defined in the Risk Management Plan (Altered Gravity, Radiation, Isolation and Confinement, Hostile Closed Environment, Distance from Earth).
- **Mission Level Outcomes** – Set outcomes defined in the Risk Management Plan (Task Performance, Evacuation, Loss of mission objectives, Loss of Crew Life, Loss of Crew, Loss of Mission, Flight Recertification, Long Term Health Conditions, and Long-Term Health Quality.)
- **Crew Capability** - represents the ability/readiness of the entire crew to perform a task. This includes functional capacity and knowledge, skills, and abilities.
- **Individual Readiness** - the level to which a crewmember is prepared mentally and physically to perform necessary tasks.
- **Task Performance** – likelihood of successful performance of a task based on factors such as response time, efficiency, or accuracy.
- **Astronaut Selection** - the narrowing down of the pool of individual applicants to the most suitable for spaceflight.
- **Individual Factors**
  - The influence that each crewmember will have on biologic variability (e.g., physical, physiological, or behavioral) affecting risk. This node as a category is broken out into two types:
    - Modifiable (lifestyle choices, smoking status, exercise habits, etc.).
    - Non-modifiable (age, sex, genetic predispositions, etc.).
    - Astronaut Selection processes affect what Individual Factors are present in any given crew.
      - Reduces pre-existing Medical Conditions and affects multiple risks.
      - May be different for commercial/private astronauts in the future.

Important Note: This node as shown in Figure 4 illustrates the concept of Nesting that is discussed in more detail in the DAG Guidance Document (1). Briefly this means that in telling the high-level story of causal flow it is sometimes helpful to group together some detailed causes/effects into a single node. That node must faithfully represent the contributions of all the sub-nodes to the DAG. This applies here to Individual Factors as well as Total Medical Events and Crew Health and Performance System below.

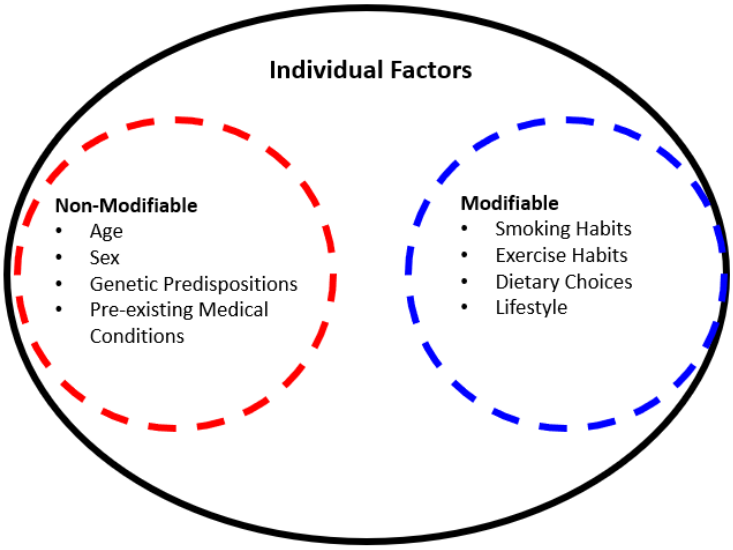


Figure 4: Individual Factors node is a category node that includes potential sub-nodes within it. It can be split into Modifiable Individual Factors and Non-Modifiable Individual Factors. Within those sub-nodes there are further potential divisions as shown by the bulleted lists of factors.

- **Total Medical Events**
  - Traumatic Injury - any injury that occurs as a result of acute or chronic loading of a part of the body including penetrating and blunt.
  - Environmental Injury - any non-traumatic injury that is the direct result of a known environmental exposure including burns.
  - Medical Illness - any illness that is not specifically caused by the above.
- **Physiologic Changes**
  - Category node that includes physiologic changes, measurable variances in cellular, tissue, organ, or body function, that are specific to a given risk. Used in Narrative DAGs for visual clarity.
- **Crew Health and Performance (CHP) System**
  - Vehicle system including the following capabilities that provides health and performance support to crew.
    - Prevention Capability- to address health conditions using onboard therapeutics, crewmembers, and ground-based resources and provide and preventive countermeasures.
    - Medical Treatment Capability - to address health conditions using onboard therapeutics, crewmembers, and ground-based resources and provide treatment countermeasures.
    - Monitoring Capability - to periodically or continuously observe, record, and systematically review the status of vehicle, habitat, spacesuit or human systems.
    - Detection Capability – to identify, measure and report changes that occur during a space flight mission to assist in determining the need for intervention or treatment.

- **Surveillance**
  - Monitoring and diagnostic services available to active and retired astronauts to facilitate early detection of health conditions that may be associated with exposures incurred during space flight or space flight training.

Description of Sections and Appendices

The section immediately following this shows the HSRB approved DAGs and their narrative descriptions as of May 2022. Following that there is more information in this document.

Appendix A is called the ‘Dagtionary’. This is a listing of all the node names and closely related terms used in this domain by the NASA HHP community. This list of definitions was reviewed by the HSRB and the definitions formally approved in August 2022. The main reason for this step is that working with risk and countermeasures in the human health and performance domain of spaceflight requires collaboration across many different specialty fields such as medical, engineering, life sciences, and more. Each of these domain experts can have slightly different definitions that they use for the terms provided. In order to provide a standardized, community wide common language, the HSRB reviewed, and configuration managed these definitions. This section seeks to provide an adjudication point for terminology that may be used differently by experts who need to work together.

Appendix B is the mapping of all the nodes used in the Narrative DAGs to the various risks. This is provided as a short cut to give the reader insight into where common items are expected to affect the causal path for multiple risks. One overly simplistic measure of importance of nodes to the larger risk network could be how many risks it touches. However, analytics of risk networks are complicated and deriving useful information from a network like this requires more thorough consideration. This is the goal of future work using these DAGs.

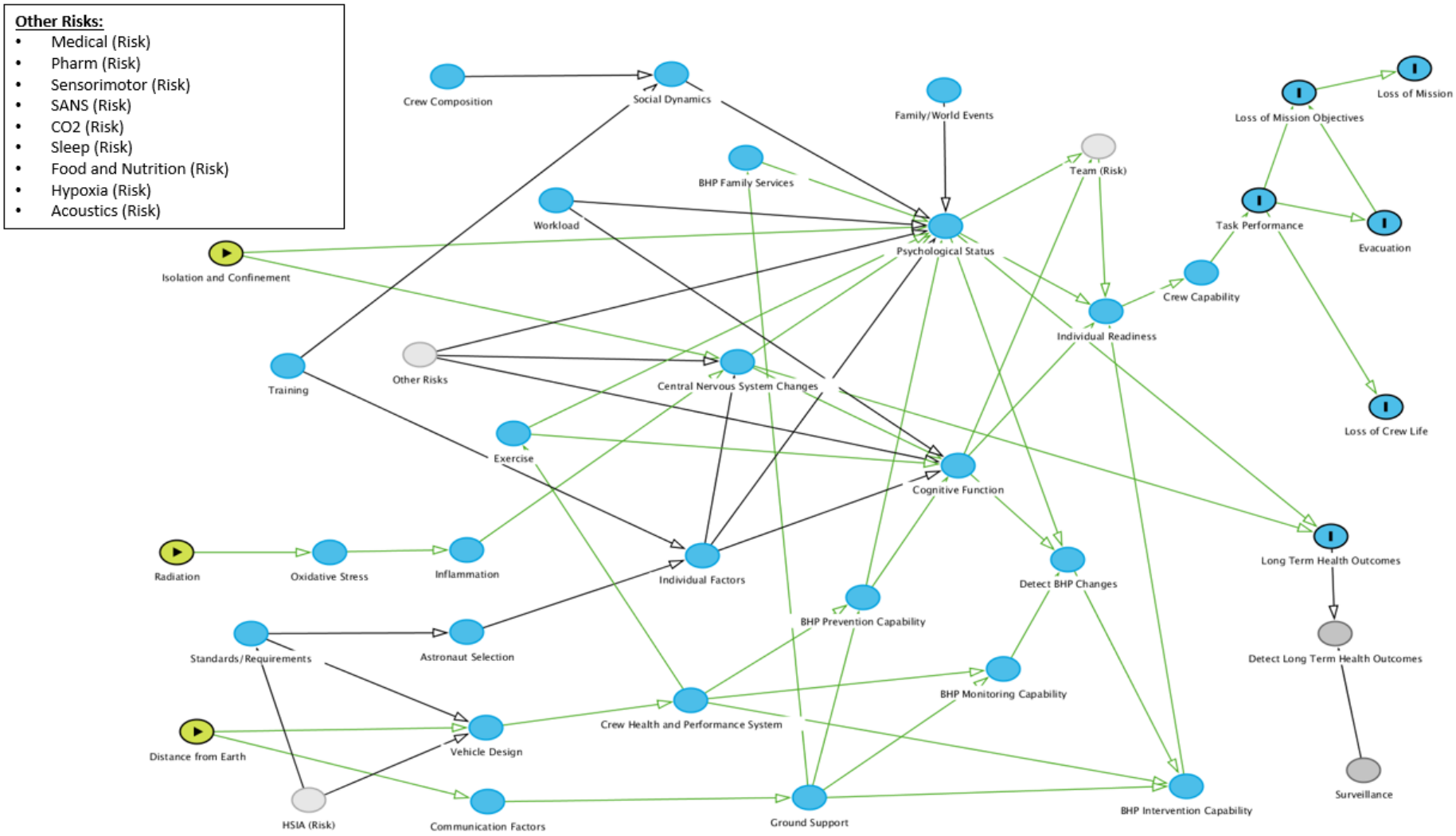
Appendix C is the Risk Formatting Instructions from DAGitty 3.0. The structure of the DAGs shown here is captured in DAGitty and made available so that reconstructing it does not need to be done manually. However, these instructions do not capture all of the information shown in the official DAGs. Dotted lines that show weakly hypothetical causal links (as opposed to strongly hypothetical causal links represented by solid lines) are not captured in these files and the user must take care to cross reference the file output with the DAG images shown in this paper if the basic Level of Evidence supporting the assertion of a link is important to them.

Directed Acyclic Graphs and Descriptive Writeups

Pages 12-87 contain the visual depiction of the causal flow in the DAG followed by a narrative description for each of the 29 HSRB risk and the one concern. Each of these are the HSRB approved versions that are current as of May 2022.

Note: The Muscle and Aerobic risks have been combined into one DAG.

Adverse Cognitive or Behavioral Conditions and Psychiatric Disorders (Behavioral Med. Risk)

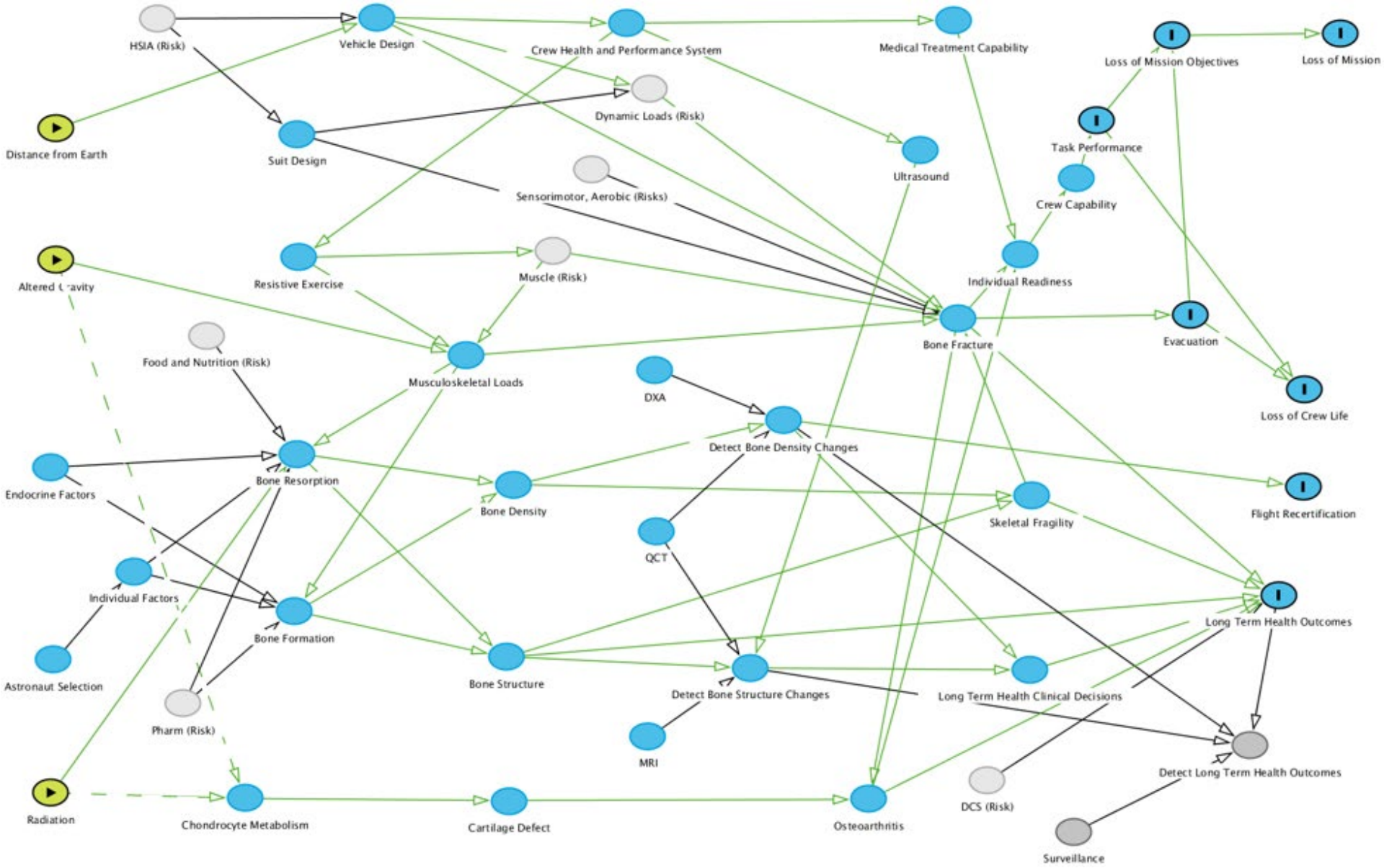


Behavioral Med. Risk DAG Narrative

- The primary spaceflight hazard for the Behavioral Risk is exposure to the **Isolation and Confinement** of spaceflight which can result in decrements in cognitive and behavioral functioning centered around two nodes, **Psychological Status** and **Cognitive Function;** secondary Hazards include **Distance from Earth** and **Radiation**.
- **Psychological Status** refers to the mood and psychological state of the crew at any given time during a mission. These factors can directly affect **Individual Readiness**, **Crew Capability** by decreasing an individual's readiness for **Task Performance** if crew are distracted, preoccupied, dysregulated, unmotivated, or uncooperative. This also affects the **Team (Risk).**
  - The equilibrium that is present in **Psychological Status** for an individual astronaut is affected by:
    - **Family/World Events** that can occur while an astronaut is on a long mission. These can include deaths and loss that provoke grief and affect mood and motivation for example.
    - **Social Dynamics** with the rest of the crew are dependent on **Crew Composition**. NASA typically does not select crews for their compatibility, but this may be required in longer duration exploration missions.
    - Central Nervous System Changes that can occur as a result of Isolation and Confinement or can occur because of Other Risks including Medical (Risk), Pharm (Risk), Food and Nutrition (Risk), Sensorimotor (Risk), SANS (Risk), Sleep (Risk), CO2 (Risk), Hypoxia (Risk), Immune (Risk), and Acoustics (Risk) changes. This can also be affected by Oxidative Stress and Inflammation as a result of Radiation and other causes.
    - **Individual Factors** including Age, Sex, Genetic Predispositions and more affect the resilience of individual astronauts and the magnitude of impact to **Psychological Status** that may occur.
- **Cognitive Function** refers to the astronaut's attributes like planning, reasoning/decision-making, attention, memory, cognitive speed, and other thought processes that can be affected by a variety of factors in the spaceflight environment. Disruption in **Cognitive Function** can also directly affect **Crew Capability** and decrease readiness for **Task Performance** required for a variety of mission objectives. This can affect the **Team (Risk)** by requiring other team members to compensate for the individual's deficits.
  - The equilibrium that is present in **Cognitive Function** for an individual astronaut is affected by:
    - Central Nervous System Changes as described above can affect Cognitive Function.
    - **Workload** can affect ability to focus and general cognitive function.
    - **Individual Factors** including Age, Sex, Genetic Predispositions and more affect the resilience of individual astronauts and the magnitude of impact to **Cognitive Function** that may occur.
- Countermeasures to issues with **Psychological Status** and **Cognitive Function** can occur pre-flight or in-mission and in some cases must be included in **Vehicle Design** allocations and the **Crew Health and Performance System** in order to realize risk reduction. These include:
  - **Selection** of crew who are resilient to decrements in **Psychological Status** and **Cognitive Function**.
  - **Training** historically has occurred pre-flight and enables crews to develop individual resilience as well as team cohesion. This may need to be included in-flight as well in future missions.
  - **Exercise** has a strong connection with mood and motivation of the crew affecting both **Psychological Status** and **Cognitive Function** in positive ways.

  - **BHP Prevention Capability** could include **Exercise** as above, but there are other preventive measures that are performed including care packages, family conferences, private psychological conferences, and more.
  - **BHP Monitoring Capability** enables the crew to identify when there are changes to **Psychological Status** or **Cognitive Function** and determine appropriate times to implement **BHP Intervention Capability**. This includes regular assessments of **Cognitive Function** and evaluations during **Private Medical Conferences** as well as **Private Psychological Conferences**.
  - **BHP Intervention Capability** includes as clinically indicated Private Psychological Conferences, Private Family conferences, and ground-based family support services. Intervention by other crewmembers, and other BHP interventions that may include medications if warranted.
- Most of the current countermeasures are dependent on real-time communication and resupply. As **Communication Factors** change with **Distance from Earth**, access to **Ground Support** that enables successful **BHP Monitoring Capability** and **BHP Intervention Capability** becomes strained or non-existent.
- **Central Nervous System Changes** and **Psychological Status** of an individual astronaut throughout a mission both have the possibility of causing **Long Term Health Outcomes**. **Surveillance** post-flight and post-career enables us to **Detect Long Term Health Outcomes** of interest and better characterize the long-term risk to astronauts.

Risk of Bone Fracture due to Spaceflight-induced Changes to Bone (Bone Fracture Risk)



Bone Fracture Risk DAG Narrative

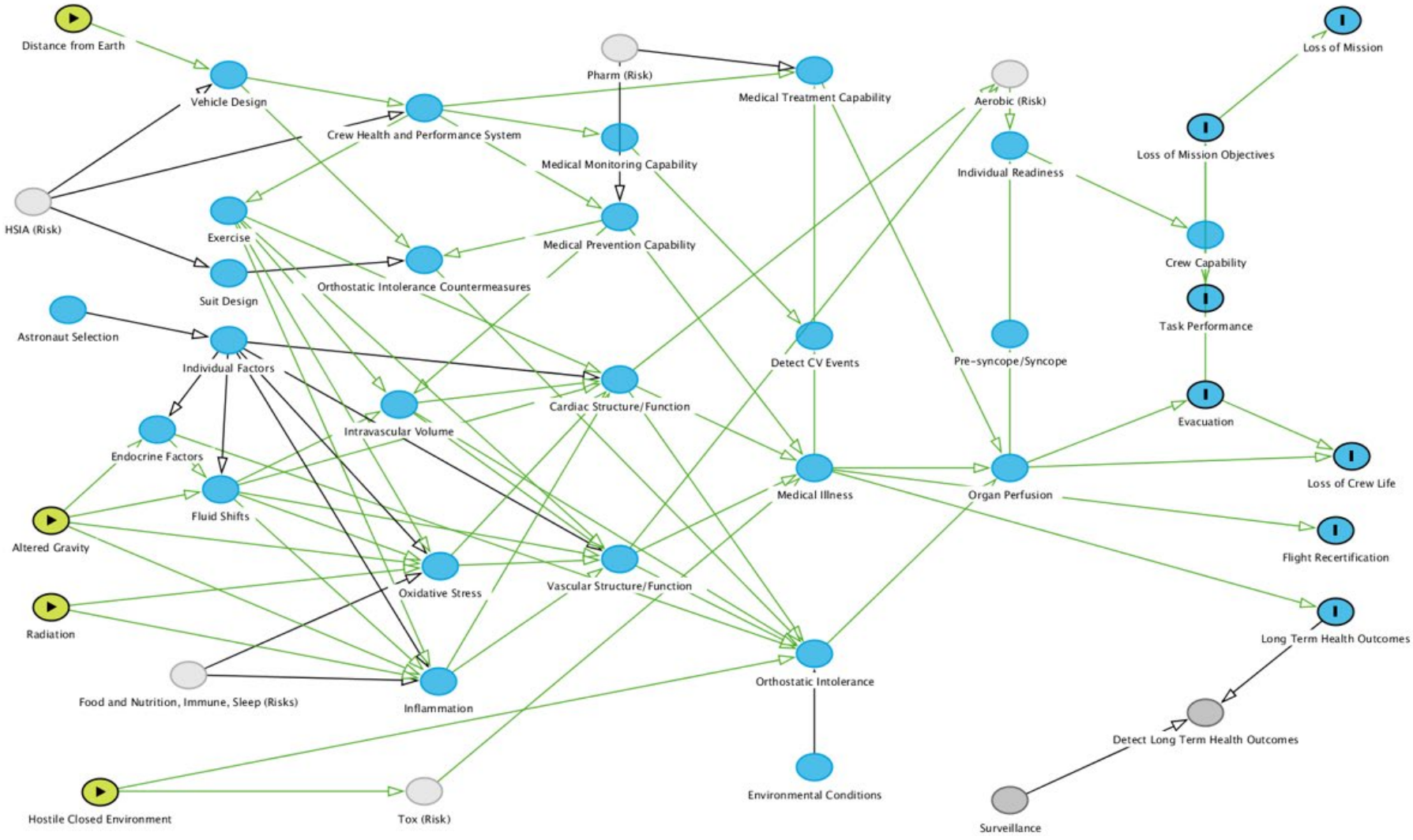
The Bone Fracture DAG centers around the **Bone Fracture** node that has two types of inputs. Those that affect the loads that the bone experiences, and those that make the bone more fragile i.e., **Skeletal Fragility**.

- Nodes that affect the loads the bone experiences include:
  - **Musculoskeletal Loads** is dependent in part by **Altered Gravity**, the **Resistive Exercise** designed into the **Crew Health and Performance System**, and the effects of **Muscle (Risk)** on the bone.
  - **Vehicle Design** and **Suit Design**.
  - **Dynamic Loads (Risk)** governs the loads experienced in landing scenarios for planetary surfaces. This is heavily influenced by **Vehicle Design** and **Suit Design** as well.
  - **Sensorimotor** and **Aerobic (Risks)** can influence the likelihood of experiencing high loads from falling or operational errors.
  - **Muscle (Risk)** includes the muscular loads on the bone and muscular support that change with muscular atrophy. This is dependent on the **Resistive Exercise** designed into the **Crew Health and Performance System**.
- Nodes that affect **Skeletal Fragility** include:
  - **Bone Density** refers to mass and mineral density within the bone.
  - **Bone Structure** refers to changes in the trabecular structure internal to the bone and areal structure of the bone.
  - Changes to both of these occur as a result of unbalanced **Bone Remodeling** here shown as two sub-nodes:
    - **Bone Resorption** performed by Osteoclast cells and dependent on **Musculoskeletal Loads**, **Endocrine Factors** such as estrogen, **Individual Factors**, medications used here represented by **Pharm (Risk)**, and **Nutrients** here represented by **Food and Nutrition (Risk).**
    - **Bone Formation** performed by Osteoblast cells and dependent on all of the same nodes as above *except* for **Food and Nutrition (Risk)**.
- It is hypothesized that **Chondrocyte Metabolism** may be affected by **Altered Gravity** and **Radiation.** These connections are shown as dotted lines because of the paucity of evidence supporting this assertion. If so, this can lead to **Cartilage Defects** and **Osteoarthritis** that can contribute to **Individual Readiness** and **Crew Capability** for example, when dealing with joint pain. **Osteoarthritis** can also occur in some cases of **Bone Fracture**.
- **Skeletal Fragility** if permanent can cause osteoporosis and contribute to **Long Term Health Outcomes**. Similarly chronic joint pain such as arthritis can contribute to **Long Term Health Outcomes**.
- Monitoring countermeasures that can be performed before and after flights such as **DXA**, **QCT**, and **MRI** enable us to **Detect Bone Density Changes** and **Detect Bone Structure Changes**. Detecting these can lead to **Long Term Health Clinical Decisions** such as orthopedic interventions or medication use that can decrease the likelihood or severity of **Long Term Health Outcomes.** Currently there is no arrow connecting **Detect Bone Structure Changes** to **Flight**

Recertification because we do not have a clinical trigger that is identified. However, research into both technology and clinical validation is in progress.

- Ultrasound may provide an option to **Detect Bone Structure Changes** occurring in flight if the capability is designed into the **Crew Health and Performance System**.

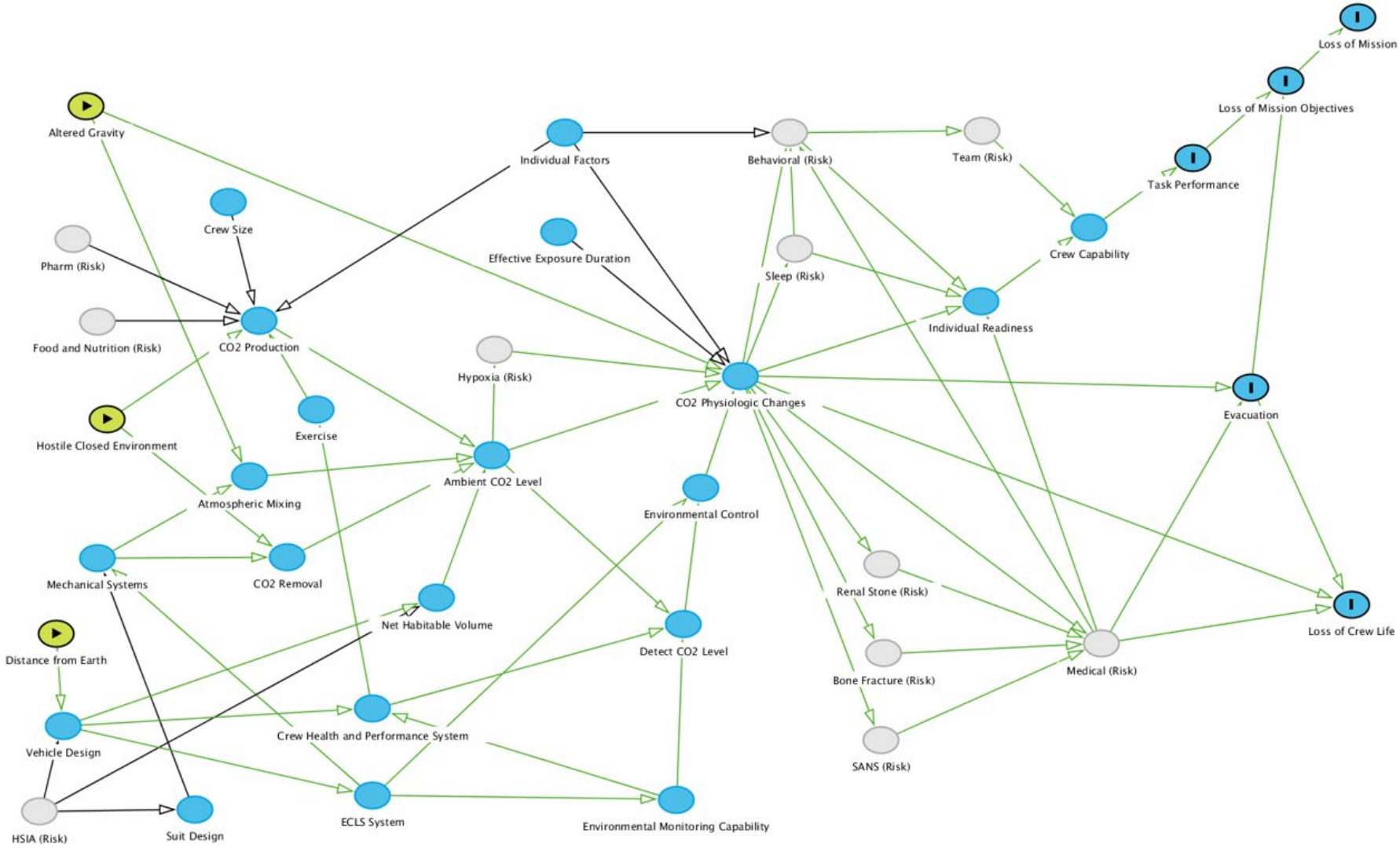
Risk of Cardiovascular Adaptations Contributing to Adverse Mission Performance and Health Outcomes (Cardiovascular Risk)



Cardiovascular Risk DAG Narrative

- The **Cardiovascular (Risk)** incorporates three former risks into a single risk to the cardiovascular system itself. The new risk is organized around the ability of the heart and blood vessels to successfully perfuse the organs (supply needed oxygen and nutrients).
- In-mission risk is dependent on aerobic fitness (captured here as the **Aerobic (Risk)**) and **Organ Perfusion**. **Aerobic Fitness** and **Pre-syncope/Syncope** (underperfusion of the brain) represent the performance pathway to affecting mission level outcomes. The health pathway is shown by **Medical Illness** which is a category node that includes a number of medical conditions including dysrhythmias (electrical system of the heart, formerly represented by the Arrythmia Risk), myocardial infarction (damage to the pumping capability of the heart), and vascular conditions (the integrity of the pipes that deliver oxygen and nutrients from the heart).
- These are preceded by the **Cardiac** and **Vascular Structure/Function** which are both affected by **Exercise, Individual Factors, Fluid Shifts, Endocrine Factors, Intravascular Volume**, **Oxidative Stress,** and **Inflammation**. **Oxidative Stress** and **Inflammation** are in particular affected by **Radiation** (formerly part of the Radiation Risk as **Tissue Degeneration**).
- Finally, **Orthostatic Intolerance** can cause changes in **Organ Perfusion** (especially the brain) and is shown affected by multiple factors as well as **Orthostatic Intolerance** countermeasures which includes compression garments, fluid loading, salt tablets, and more.
- The **Crew Health and Performance System** design specifically includes **Exercise**, **Medical Prevention Capabilities** like medications, **Medical Monitoring Capabilities** like EKG and **Ultrasound**, and **Medical Treatment Capabilities** like medications and defibrillators depending on DRM needs and priorities.
- Note that if these are not designed into the vehicle, they will not be available for risk mitigation in mission.

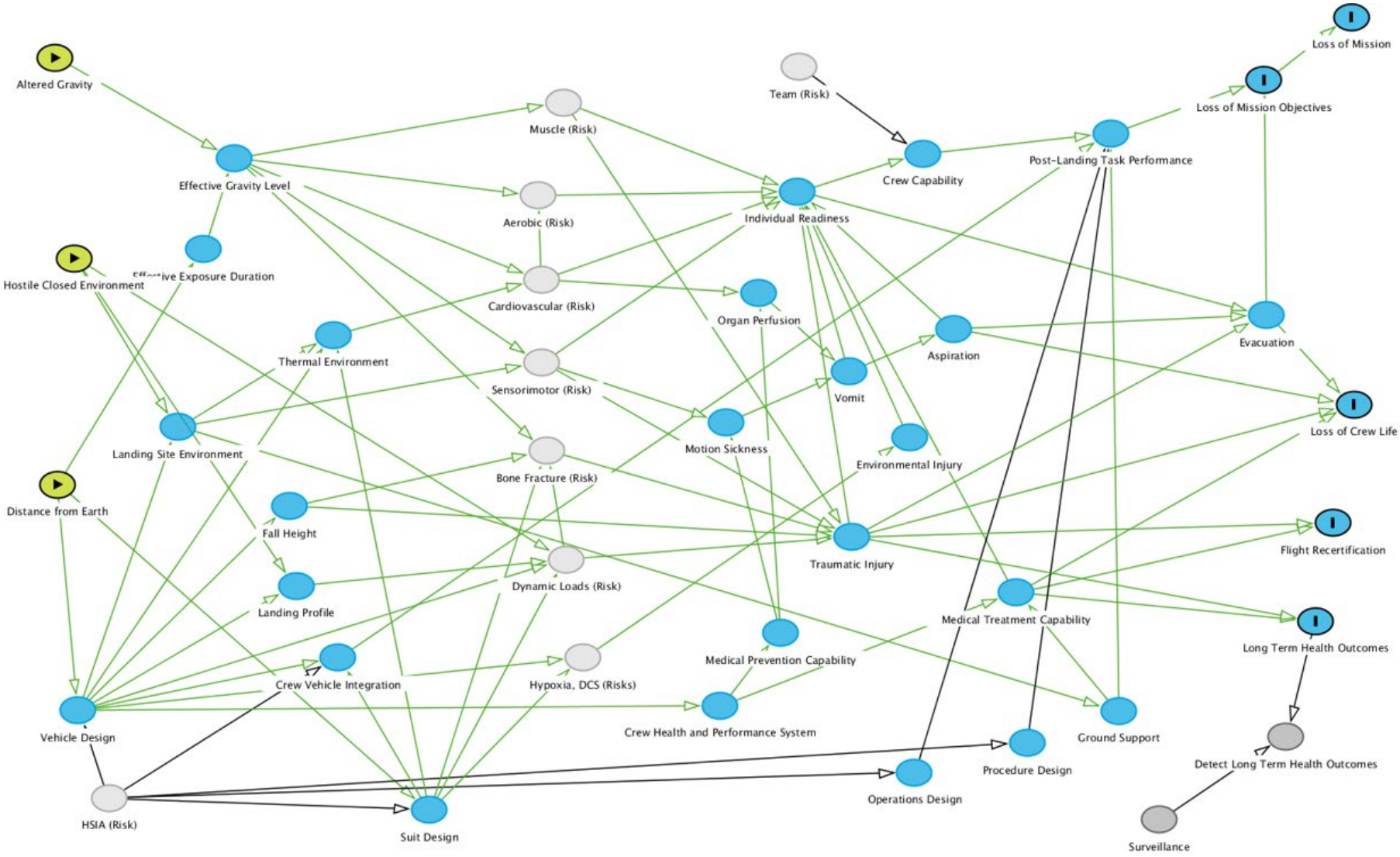
Risk of Nominal Acute and Chronic Ambient Carbon Dioxide Exposure in Crewed Vehicles (CO2 Risk)



CO_2 Risk DAG Narrative

- The CO_2 concentration in the closed spacecraft environment is a balance between production (primarily crew) and Environmental Control and Life Support (ECLS) scrubbing.
- When the balance is impacted by vehicle capability (limited ECLS mass/power, for example) or production influences (exercise, for example), the CO_2 concentration will increase and may result in several different physiological changes.
- Monitoring is essential to understand the levels and possible outcomes.
  - Ambient cabin level averaging is currently relied upon almost exclusively.
  - Ambient local/area monitoring also possible via the carbon dioxide monitor (CDM) and personal CO_2 monitors (pCO_2m).
  - Periodic individual monitoring (inspired CO_2 or other, for example) is not currently available.
- Levels that are elevated significantly and/or chronically may lead to adverse mission outcomes, including loss of mission objectives or loss of mission (evacuation). Unexpectedly high acute levels may lead to loss of crew life, but the likelihood of this event is very low.

Risk to Vehicle Crew Egress Capability and Task Performance as Applied to Earth and Extraterrestrial Landings (Crew Egress Risk)

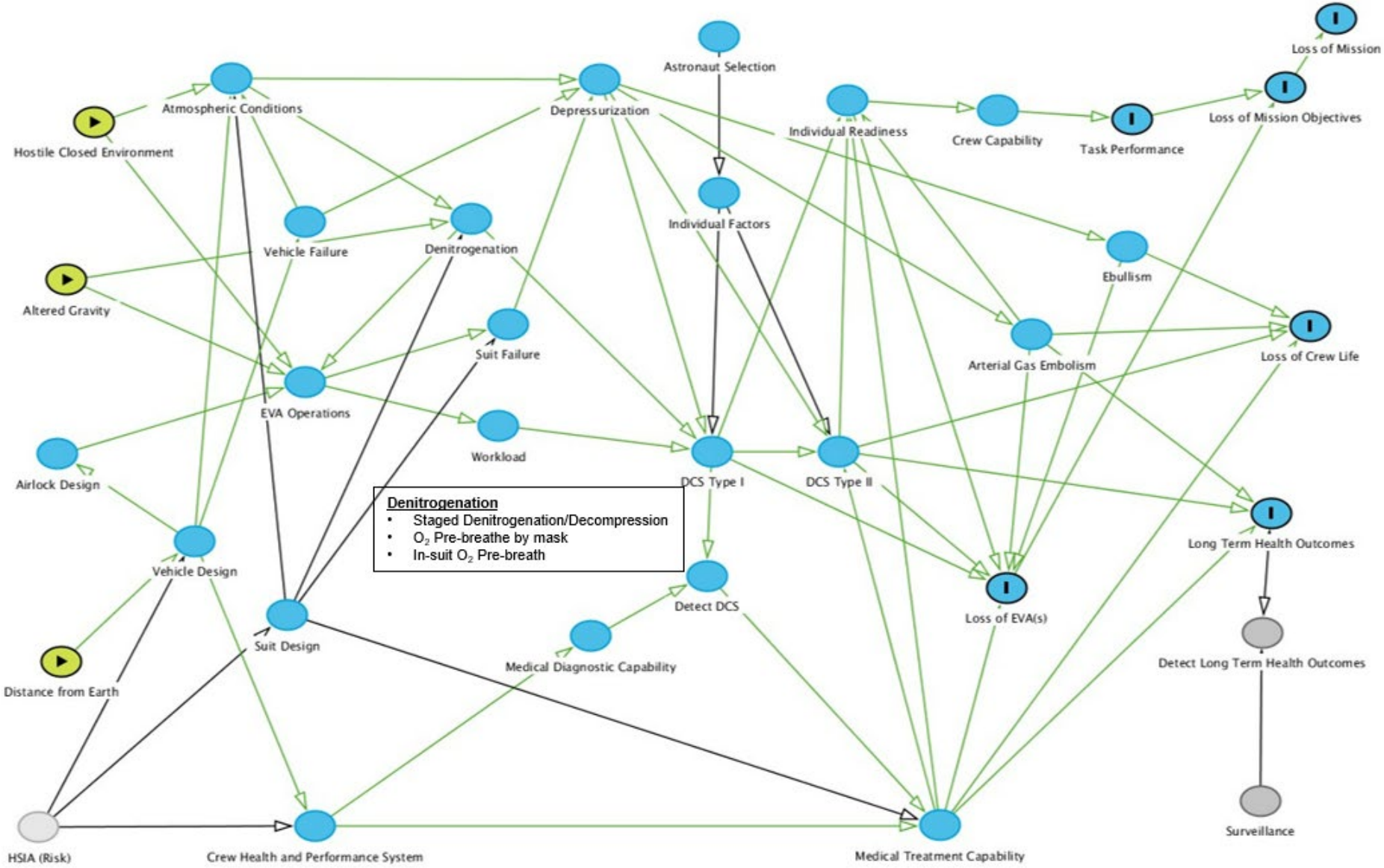


Crew Egress Risk DAG Narrative

- **Altered Gravity** across all DRM categories includes microgravity, lunar gravity, Mars gravity and Earth gravity. This affects **Effective Gravity Level** which is mission dependent.
- The **Hostile Closed Environment** here refers to the **Landing Site Environment** (including waves for water landings) and accelerations that are experienced in the **Landing Profile** that affect the **Dynamic Loads (Risk).**
- **Distance from Earth** determines the mass and volume allocations for **Vehicle Design** and **Suit Design** and affects the **Effective Mission Duration**.
- **Individual Readiness** and the **Crew Capability** to perform **Post-Landing Tasks Performance** is strongly dependent on several other Human System risks as well as the **Effective Exposure Duration** to whatever **Effective Gravity Level** is encountered as these factors determine the extent of deconditioning crew will face. This can range from microgravity (0g) to lunar gravity (1/6g) to Mars gravity (3/8g) to Earth Gravity (1g). **Post Landing Tasks** include egress from the vehicle, safing the vehicle, and more. As mission duration increases, the confluence of other risks can lead to a variety of issues.
- Those risks include **Muscle (Risk), Aerobic (Risk), Cardiovascular (Risk), Sensorimotor (Risk), Bone Fracture (Risk), Dynamic Loads (Risk), DCS** and **Hypoxia (Risks)** serve to decondition crew depending on **Effective Exposure Duration**.
- **HSIA (Risk)** varies depending on **Distance from Earth** and effective implementation of standards, requirements and HSI Processes in vehicle and mission design.
- The **Muscle (Risk), Aerobic (Risk), Sensorimotor (Risk),** and **Cardiovascular (Risk)** can all directly affect **Crew Capability** and through that Task Performance. Effective exercise can help reduce these risks.
- Medical issues that can lead to reduced **Individual Readiness** and **Crew Capability** include:
  - **Organ Perfusion** can be decreased because of orthostatic intolerance which is represented by the **Cardiovascular (Risk)**. One outcome of this is higher likelihood of **Vomiting** as well as crew passing out and these can be exacerbated by the **Thermal Environment** of the landing vehicle.
  - **Motion Sickness** can lead **to Vomiting** and **Aspiration** which may lead to **Loss of Crew Life** in cases where crew cannot turn their head, remove a helmet quickly, or otherwise cannot protect their airway. This can be exacerbated by the **Landing Site Environment**, particularly if there is a water landing with waves.
- **Traumatic Injury** likelihood can be increased through several means:
  - **Sensorimotor (Risk)** changes affecting balance and proprioception can lead to an increased likelihood of falls in a deconditioned state.
  - **Dynamic Loads (Risk) - Landing Profiles,** which are the accelerations/deceleration profiles that the crew experience in re-entry determine the loads that crew experience and affect the likelihood of traumatic injuries that will occur. The design of occupant protection measures such as restraints and seat designs are included in the vehicle and spacesuits.
  - **Bone Fracture (Risk)** changes due to spaceflight may result in an increased chance of fracture when traumatic injuries are sustained. Bone changes that predispose to fracture are minimized by effective exercise in mission.

  - **Fall Height** is a factor that can affect the likelihood of **Traumatic Injury** including in lander designs, ladder heights, and tasks that crew may be asked to perform as part of Post-Landing Tasks.
  - **Traumatic Injuries** that are incurred can result in issues with **Flight Recertification** or **Long Term Health Outcomes**. **Occupational Surveillance** ensures that we **Detect Long Term Health Outcomes** of our astronauts.
- **DCS and Hypoxia (Risks)** contribute to possible **Environmental Injuries** that may occur depending on the use of staged denitrogenation prior to landings and EVAs on the surface of the Moon or Mars.
- Medical Issues can be in part mitigated through capabilities designed into the **Crew Health and Performance System** or, in the case of Earth landings, brought along by **Ground Support**.
  - **Medical Prevention Capability** such as medications to prevent motion sickness and vomiting, and fluid loading to prevent orthostatic intolerance.
  - **Medical Treatment Capability** such as pain medications to treat pain, nausea and other medical treatments as needed.
- In the special case of Earth landings, the medical capability that is brought by **Ground Support** also serves to mitigate risk but is unavailable for lunar or Mars landings.
- **HSIA (Risk)** influences the level of **Crew Capability** and likelihood of successful **Post-Landing Task Performance** in several ways:
  - **Vehicle Design**, **Suit Design**, and **Crew Vehicle Integration** all affect the ability of astronauts to perform the tasks they have been given. These affect adequate exit paths, hatch openings, restraint during landing, ability to remove restraints in an emergency, potential **Fall Height**, and more.
  - **Operations Designs** including appropriate flight rules or overly complicated **Procedure Designs** can also enhance or adversely affect successful **Post Landing Task Performance**.

Risk of Decompression Sickness (DCS Risk)

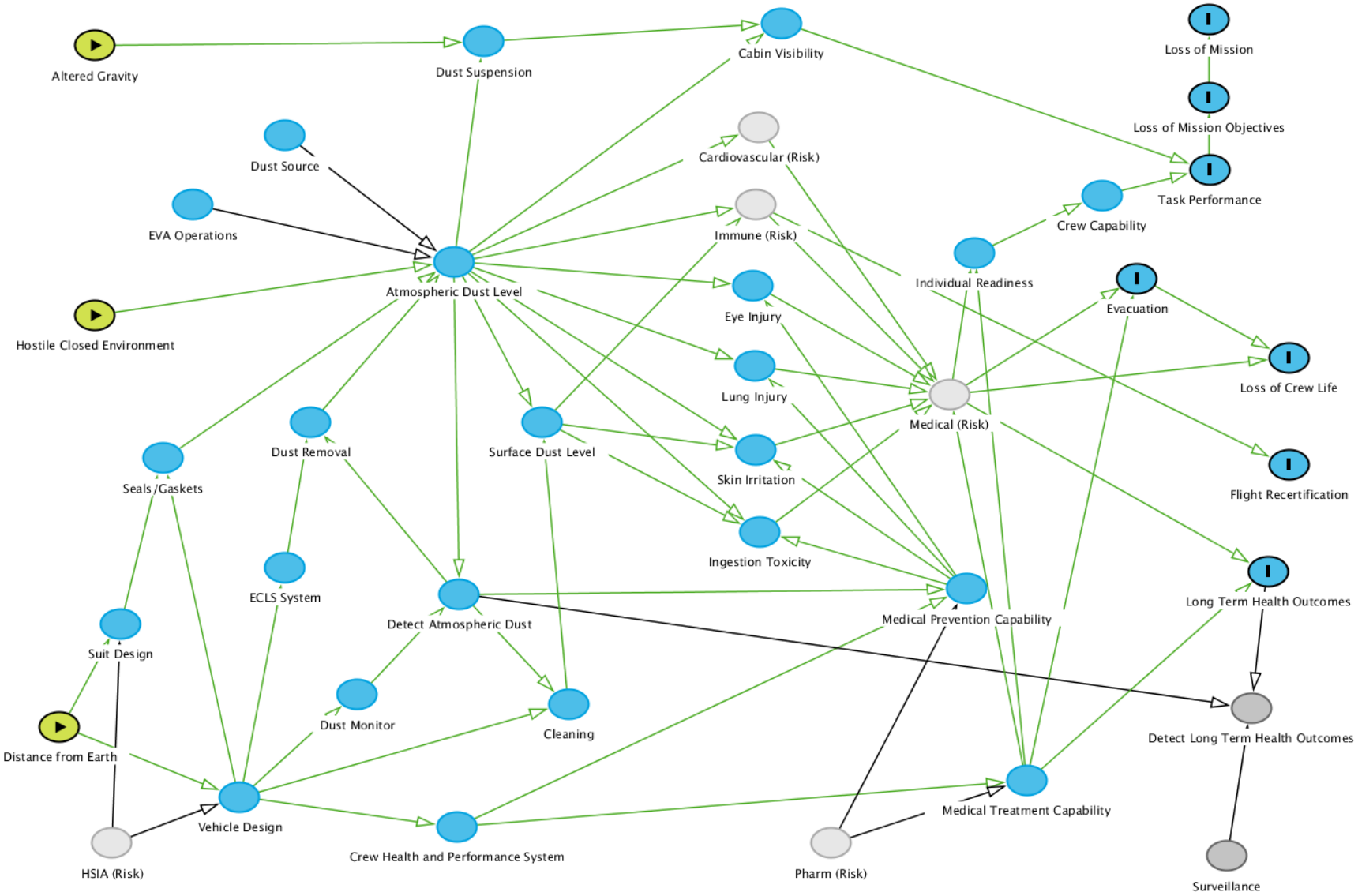


DCS Risk DAG Narrative

The Risk of Decompression Sickness (DCS) is broken into two nodes – **DCS Type I** which is mild **Environmental Injury**, and **DCS Type II** which is severe **Environmental Injury**. It is possible for **DCS Type I** to progress to **DCS Type II**.

- Either of these types can impact **Individual Readiness** and **Crew Capability** by introducing functional impairments and can lead to **Loss of EVAs**. **DCS Type II**, **Arterial Embolism**, and **Ebullism**, if they occur, can lead to **Loss of Crew Life** or permanent **Long Term Health Conditions**.
- The likelihood of experiencing DCS is dependent on physical exertion captured here as **Workload**. This is dependent on **EVA Operations** which as a category node includes **EVA Frequency**, **EVA Duration**, **Planned EVA Content**, **EVA Task Timeline**, **EVA Decision Support** (These are explicitly shown in the EVA Risk DAG).
- **EVA Operations** are directly affected by the **Denitrogenation** (including Pre-Breathe time) that is dependent on **Atmospheric Conditions**. For example, Exploration Atmospheres are altered **Atmospheric Conditions** designed to decrease **Denitrogenation** time while keep the risk of DCS low.
- **Vehicle Design** determines:
  - **Atmospheric Conditions.**
  - **Airlock Design**.
  - **Crew Health and Performance System** which determines the level of **Medical Diagnostic Capability** and **Medical Treatment Capability**. The **Medical Diagnostic Capability** is important to distinguish between mild DCS symptoms and other injuries. **Medical Treatment Capability** depends in part on **Suit Design**. For example, on International Space Station (ISS) treatment is provided by the Space Suit which is capable of some over-pressurization.
- The likelihood of **Vehicle/Suit Failure** which can lead to **Depressurization** is affected by **Vehicle Design** and **Suit Design**.
- The likelihood of **Loss of Crew Life** is dependent on the likelihood of **DCS Type II, Arterial Embolism**, **Ebullism**, and the effectiveness of the **Medical Treatment Capability** that is provided in mission.

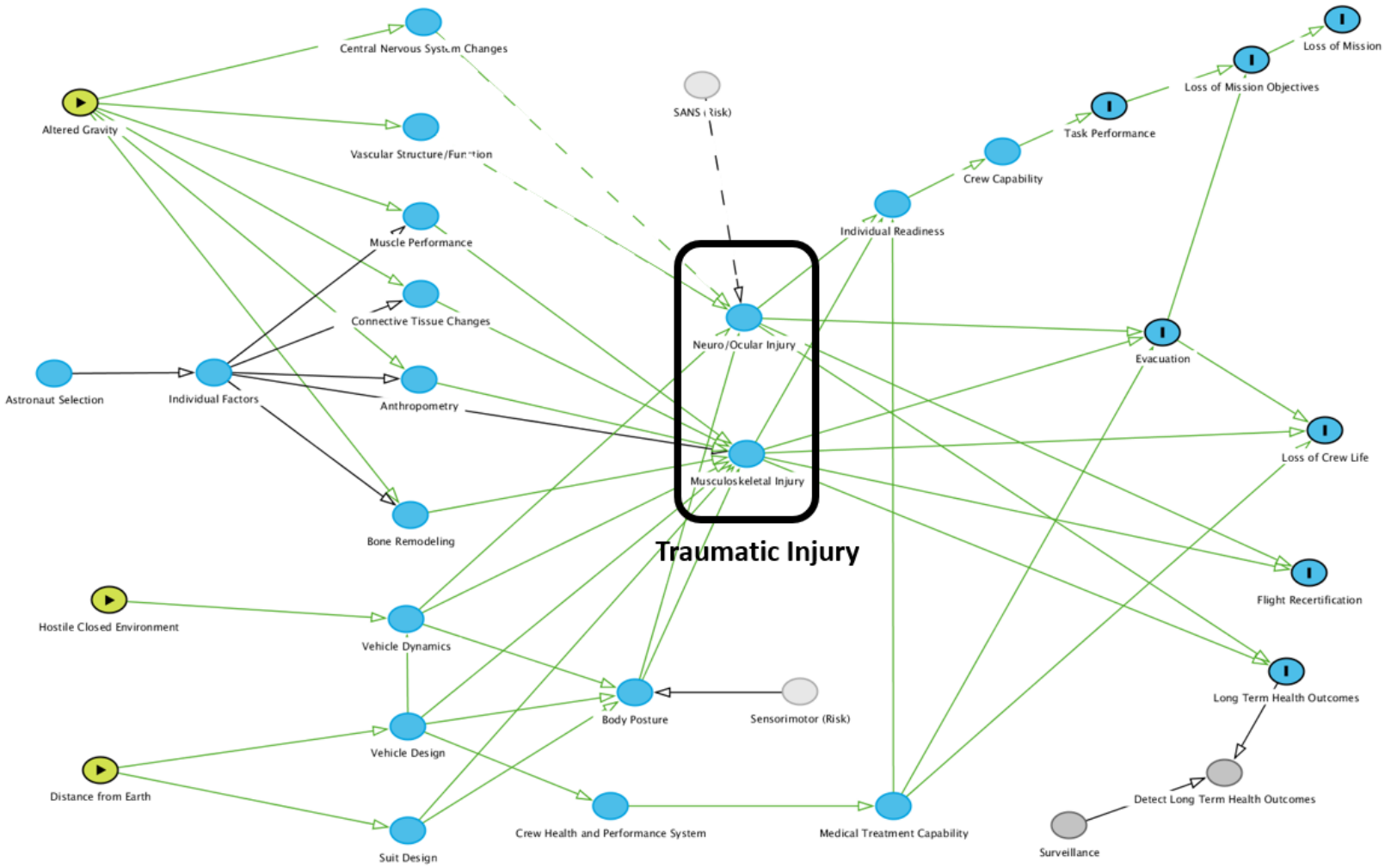
Risk of Adverse Health & Performance Effects of Celestial Dust Exposure (Dust Risk)



Dust Risk DAG Narrative

- This DAG centers around **Atmospheric Dust Levels** that can occur within vehicles after Extravehicular Activity **(EVA) Operations** on celestial bodies. During **EVA Operations, Dust Sources** from the lunar or Martian surface can result in dust being carried back into a vehicle or habitat, potentially on space suits. The extent to which this will occur depends on **Vehicle Design, Suit Design,** and the **Seals/Gasket** designs that are included to prevent dust entry into a vehicle.
- If dust gets into a vehicle or habitat, then the extent of exposure that crews face depends on several factors:
  - The level of **Dust Suspension** that occurs in the vehicle atmosphere.
  - The **Surface Dust Level** that builds up when dust settles from the atmosphere onto vehicle surfaces.
- The capability for **Dust Monitoring** that enables crews to **Detect Atmospheric Dust** levels must be included in the Environmental Control and Life Support (**ECLS) System** in order to determine the appropriate contamination levels that should prompt **Dust Removal** (filtration) and **Cleaning** of surfaces.
- Inappropriate levels of **Dust Suspension** in the atmosphere can lead to issues with **Cabin Visibility** affecting performance when piloting vehicles, especially on return to microgravity. This can also lead to several health challenges that affect **Crew Capability**.
- Dust exposure can lead to **Eye Injury**, **Lung Injury** and **Skin Irritation** which can all progress to affect the **Medical (Risk)**. Most evidence suggests that the medical issues are likely to be minor in mission.
- Dust that gets into food or pharmaceuticals may lead to **Ingestion Toxicity**, especially in the case of Martian dust with perchlorates.
- There is some evidence that the **Cardiovascular (Risk)** and **Immune (Risk)** may be affected by celestial dust exposures, but this remains at the speculative level currently.
- Countermeasures can include:
  - **Medical Prevention Capabilities** such as artificial tears, skin coverings, etc.
  - **Medical Treatment Capabilities** including creams and ointments to treat skin irritation as well as medical eye drops to address eye irritation or injury. Antibiotics may be required if secondary infection develops.
- **Long Term health Outcome** may include pneumonoconiosis, hypersensitivity conditions, autoimmune disorders, and cancers, but the level of evidence is currently low that these will occur. Surveillance post flight and post-career for these types of conditions can enable us to **Detect Long Term Health Outcomes** and better characterize the magnitude of risk in the Long-Term Health domain.

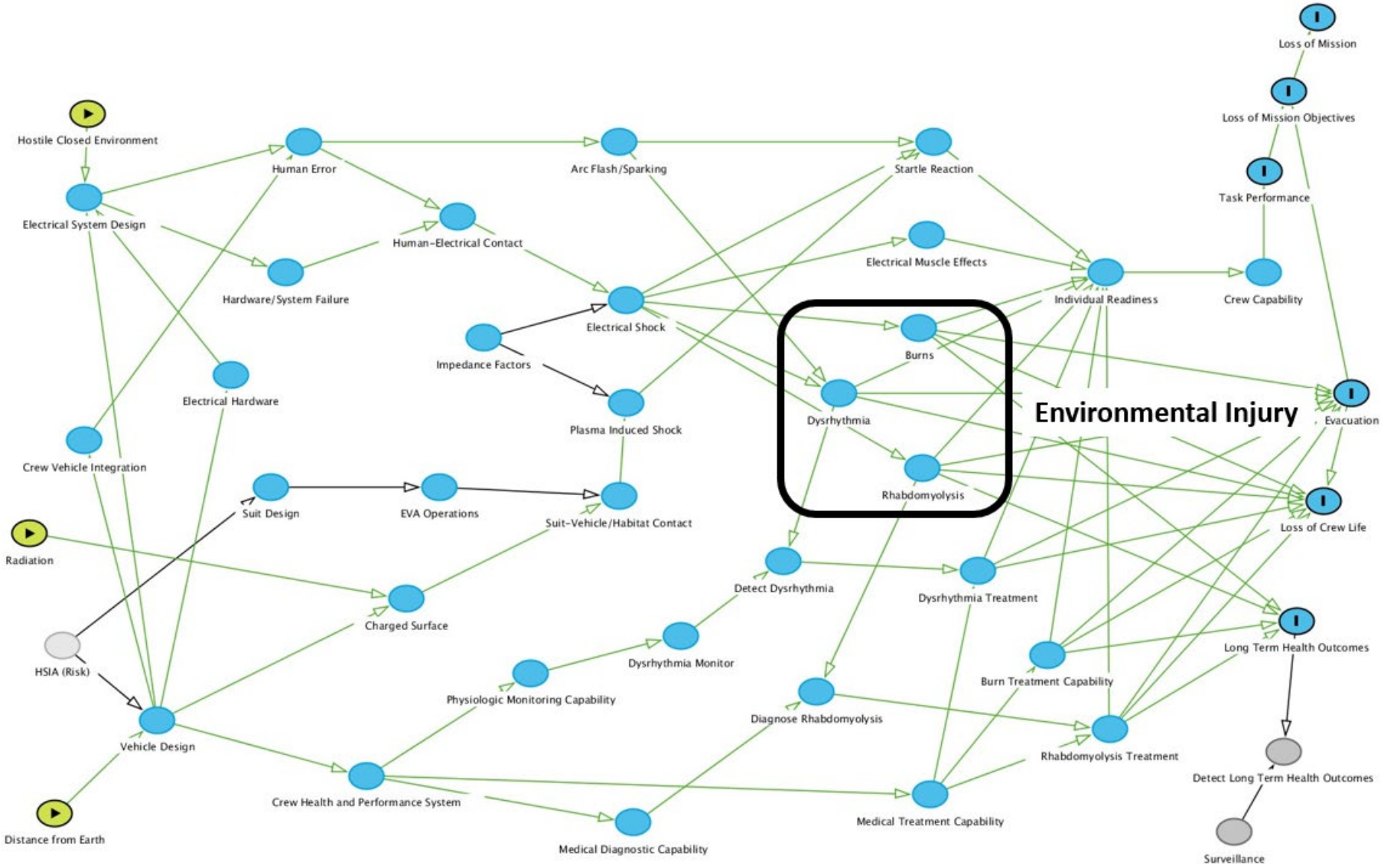
Risk of Injury from Dynamic Loads (Dynamic Loads Risk)



Dynamic Loads Risk DAG Narrative

- The central issue in the Dynamic Loads Risk is the **Traumatic Injuries** that are caused by acceleration/deceleration forces.
- Two categories of traumatic injuries are shown here – **Musculoskeletal Injury** and **Neuro/Ocular Injury**.
- Evidence shown in the risk package supports the occurrence of **Musculoskeletal Injuries** after landings in the Soyuz and other vehicles.
- The dotted lines to **Neuro/Ocular Injury** show a speculative concern given these have not been experienced to date. Predisposing factors for **Neuro/Ocular Injuries** may include **Central Nervous System Changes** and **Vascular Structure/Function** as well as **Vehicle Dynamics** and **Body Posture**.
- Predisposing factors for **Musculoskeletal Injuries** include **Muscle Performance**, **Connective Tissue Changes**, **Anthropometry** and **Bone Remodeling** as well as **Vehicle Dynamics** and **Vehicle and Suit Designs**.
- Restraints and occupant protection measures are included in **Vehicle Design**.
- The **Sensorimotor (Risk)** influences **Body Posture** through Postural Control and Locomotion.
- Given Design Reference Mission (DRM) categories that include Lunar and Martian Landings, the pathway through **Crew Health and Performance System -> Medical Treatment Capability** is shown to illustrate that the consequences of inadequate medical system planning will be felt in **Crew Capability**, likelihood of **Evacuation**, and potentially **Loss of Crew Life**. Any **Neuro/Ocular** or **Musculoskeletal Injuries** incurred have the potential to affect **Flight Recertification** of crew as well as **Long Term Health Conditions**.

Risk to Crew Health Due Electrical Shock (Electrical Shock Risk)



Electrical Shock Risk DAG Narrative

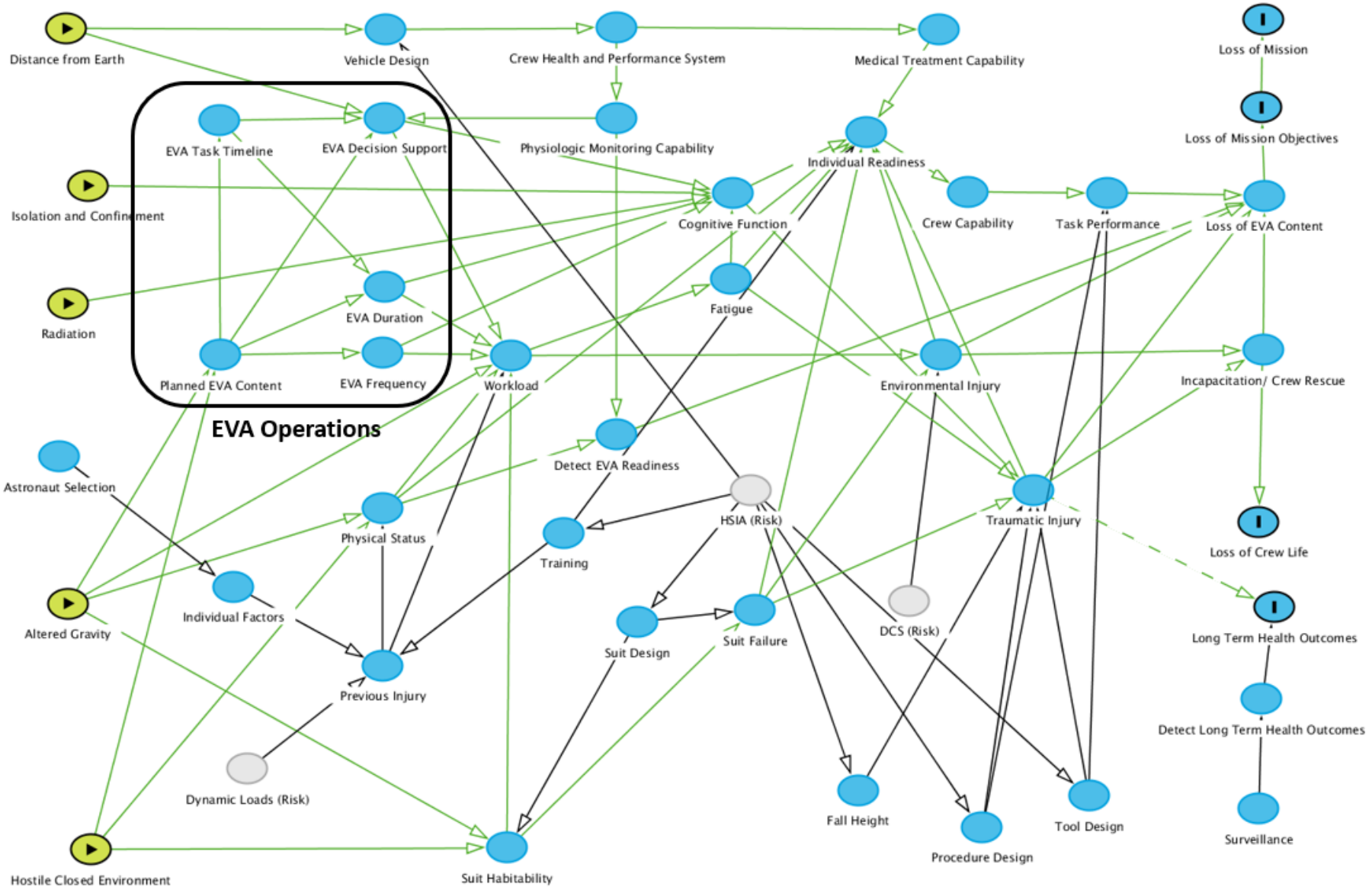
- The Hostile Closed Environment feeds directly into Electrical System Design which is impacted by Vehicle Design and Electrical Hardware.
- **Electrical Shock** centers around three nodes:
  - **Arc Flash/Sparking** occurs when there is a voltage difference between hardware inside the spacecraft and either a crewmember or other hardware. When a spark jumps to a crewmember this can lead to a **Dysrhythmia** or a **Startle Reaction**.
  - **Electrical Shock** describes when **Human-Electrical Contact** occurs inside the spacecraft and may occur without sparking. Small current can result in **Startle Reaction** or **Electrical Muscle Effects** such as tetany. Higher current passing through crewmembers can result in **Burns**, **Dysrhythmia**, or damage to muscles leading to **Rhabdomyolysis**. In rare circumstances, **Dysrhythmia** could lead to **Loss of Crew Life.**
  - **Plasma Induced Shock** can occur during **EVA Operations. Radiation** impacts on the spacecraft can result in **Charged Surfaces** and if there is **Suit-Vehicle/Habitat Contact** then a shock may occur. The expected current levels suggest mainly **Startle Reaction** as the likely result which can affect crew operations during the EVA.

- Crew Capability is affected by the severity of the shock that occurs in all three of the above categories. Consequences can range from minor annoyance to severe disease that results in functional impairments of the crew.
  - The severity of **Electrical Shock** and **Plasma Induced Shock** both depend on **Impedance Factors** that can include insulation of clothing and shoes as well as amount of sweat on the body.
- **Human Electrical Contact** may occur for several reasons:
  - **Electrical System Design** can be done well or poorly. Poor design can result in **Hardware/System Failure**. Poor **Crew-Vehicle Integration** can result in increased likelihood of **Human Errors** that result in inadvertent contact with charged hardware and is influenced by the **HSIA (Risk).**
  - Electrical System Design is dependent on the needed Electrical Hardware and Vehicle Design and is influenced by the HSIA (Risk).
  - Likewise, **Suit Design** influences the **EVA Operations** including timeline and likelihood of **Suit-Vehicle/Habitat Contact** and is influenced by the **HSIA (Risk)**.
- The **Crew Health and Performance System** provides monitoring and treatment capabilities needed to respond to an injury that occurs.
  - Physiologic Monitoring Capability includes Dysrhythmia Monitors required to Detect Dysrhythmias and provide Dysrhythmia Treatment when appropriate.
  - **Medical Diagnostic Capability** includes appropriate laboratory testing to **Diagnose Rhabdomyolysis** and initiate **Rhabdomyolysis Treatment** such as IV Fluids when appropriate.

    - The Medical Treatment Capability that is fielded must consider whether to include treatments such as Dysrhythmia Treatment, Rhabdomyolysis Treatment, or Burn Treatment Capability to respond to these Environmental Injuries.

- Lack of appropriate **Monitoring**, **Diagnostic**, and **Treatment Capabilities** can lead to impacts to **Crew Capability**, **Evacuation** for injured crewmembers, or **Loss of Crew Life**. In the cases of **Burns** and **Rhabdomyolysis**, failure to treat in mission can result in **Long Term Health Outcomes** including skin constrictions and kidney failure. **Surveillance** performed post-mission and post career can **Detect Long Term Health Outcomes** and better characterize the magnitude of risk.

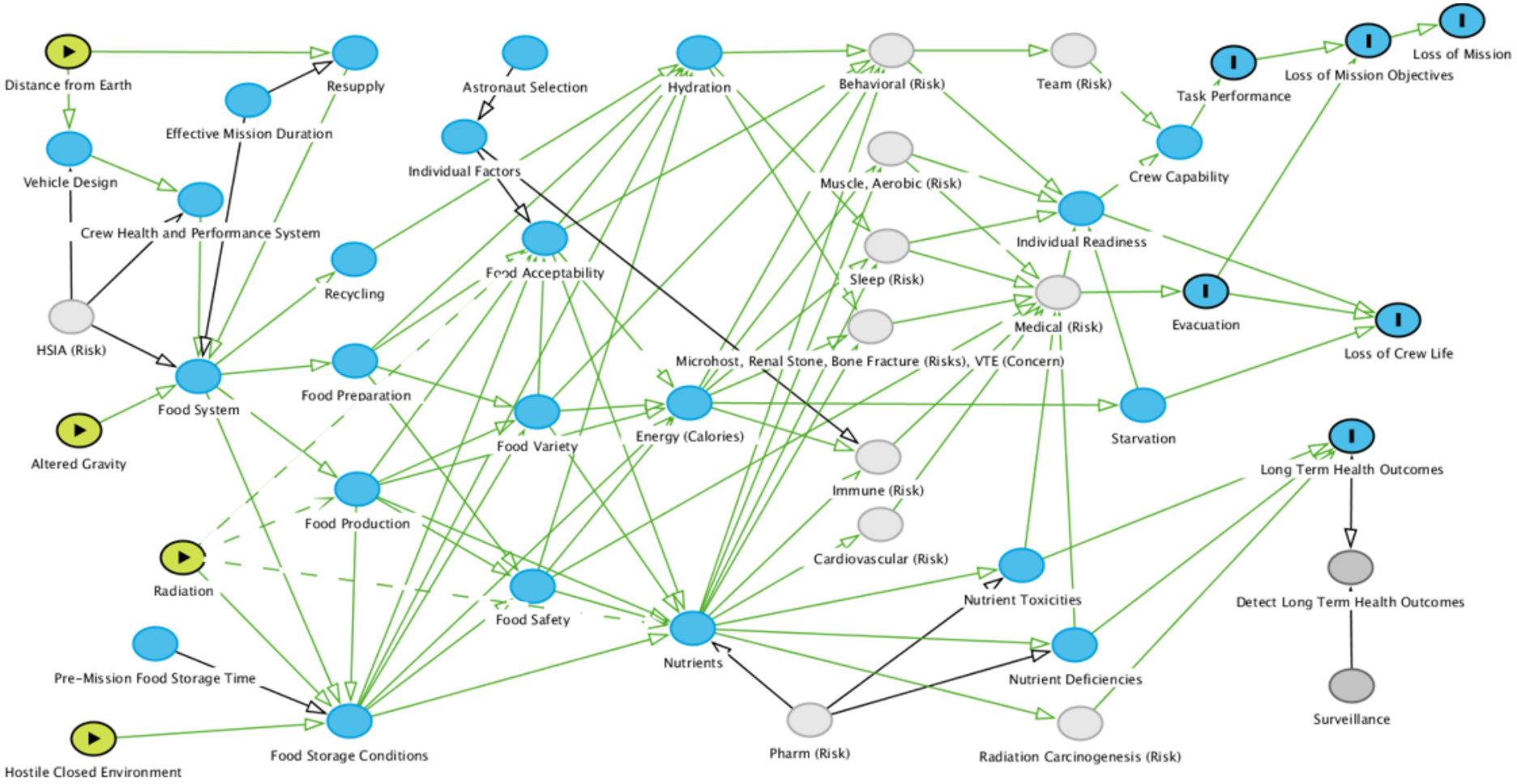
Risk of Injury and Compromised Performance Due to EVA Operations (EVA Risk)



EVA Risk DAG Narrative

- The Risk of EVA Injury focuses on **Environmental Injuries** and **Traumatic Injuries** on the right side of the DAG. The numbers, types, and severities of injuries that occur during EVA affects **Individual Readiness** and **Crew Capability** by introducing functional impairments that can affect **Task Performance**. These categories of injuries are explicit in the Medical Risk DAG and **Medical Treatment Capability** provided in mission determines the extent to which the consequences of these injuries can be mitigated in-mission.
- Contributing factors to **Environmental Injuries** are **Suit Failure** and Decompression Sickness – **DCS (Risk)**.
- Contributing factors to **Traumatic Injuries** includes **Suit Failure**, **Fall Height** (either from poor vehicle design or mission task attributes), **Tool Design** (such as in Apollo missions where many astronauts complained of hand injuries), and **Procedure Design**. All of these are affected by the **HISA (Risk)**.
- When severe, these injuries can lead to **Loss of EVA Content** which increases the likelihood of **Loss of Mission Objectives**, especially in short duration missions. Additionally, they can lead to **Incapacitation/Crew Rescue** during an EVA which increases the likelihood of **Loss of Crew Life**.
- **Individual Readiness** and **Crew Capability** are also affected by both design and operational decisions and their consequences. **Cognitive Function** and **Fatigue** are dependent on:
  - **Planned EVA Content** and **EVA Task Timeline** (are they feasible and appropriate?).
  - **EVA Duration** (how long do they last?), **EVA Frequency** (how many and how often?), and **EVA Decision Support** (is decision support effective at cognitive unloading?).
  - All of the above contribute to the **Workload** that crews experience during their EVAs.
- Note that **EVA Task Timeline** and **EVA Duration** may both be affected by **Radiation** issues such as solar particle events.
- **Workload** is also affected by the **Altered Gravity** environment (microgravity, lunar or Martian), their **Physical Status**, and any **Previous Injuries** – either old or incurred during prior EVAs.
- **Effective Training** can affect the likelihood of having **Previous Injuries** as well as **Crew Capability** through a practiced understanding of movement and exertion limitations during an EVA. **Dynamic Loads (Risk)** also influences the likelihood of incurring a **Previous Injury** during a landing phase prior to EVA activity.
- **Distance from Earth** affects the mass, power, volume and data bandwidth available to the **Crew Health and Performance System** that enables **Medical Treatment Capability**, **EVA Decision Support** and **Physiologic Monitoring** – such as the ear exams done to ensure crew can effectively clear prior to starting an EVA – that enable **Detect EVA Readiness** giving crew the green light to begin an EVA.
  - The **HSIA (Risk)** interfaces at many places including **Vehicle Design**, **Suit Design**, **Training**, **Fall Height**, **Tool Design**, and **Procedure Design**. Inadequate attention to Human System Integration at the Mission, Vehicle and Suit level is expected to have a strong effect on the risk of EVA Injury.

Risk of Performance Decrement and Crew Illness Due to Inadequate Food and Nutrition (Food and Nutrition Risk)



Food and Nutrition Risk DAG Narrative

The central issue in the Food and Nutrition Risk encompasses six nodes in the center of the diagram that highlight the contribution of food to human health and performance.

- **Energy (Calories)** - this is the amount of energy that food supplies to crew to enable them to live and perform. Insufficient energy in the diet leads to body mass loss, muscle loss, bone loss, oxidative stress, and cardiovascular deconditioning, and ultimately starvation and death.
- **Nutrients** - this includes macro and micronutrients that are a critical part of our diet and without which we develop nutrient deficiency diseases and other pathophysiologies. The term nutrition also encompasses thousands of phytochemicals that when adequate can provide anti-inflammatory, anticarcinogenic, and other benefits. There is some evidence that food may be degraded by **Radiation** but the few studies to date have used higher levels of radiation than expected in human spaceflight. The dotted line indicates the low amount of evidence in this area.
- **Hydration** – hydration status is determined by total water intake and exit from the body. Dehydration can affect multiple other risks, including cardiovascular, renal stone, cognition, performance, and more.
- **Food Acceptability** – if food is not acceptable it does not matter if it has the required nutrition – they will not consume enough to get adequate nutrition. This is affected by **Individual Factors** such as food preferences and allergies which are part of the **Immune (Risk)**. **Astronaut Selection** affects the extent of those factors present in a given crew.
- **Food Variety** – variety is part of acceptability – a nutritional variety of foods needs to prevent menu fatigue and provide choice to prevent risk of underconsumption and undernutrition.
- **Food Safety** – if food is not safe it does not matter if it has the required nutrition – it will be a major risk to crew health and loss of mission.

In conflict with this is another critical concept - resources. To date, nutrition, energy, acceptability, and variety have been cut by programs, regardless of unknown risk, when resources are not available. Mass/volume and power are limited by the **Vehicle Design**, **Crew Health and Performance System**, and highly dependent on **Distance from Earth** as well as the **HSIA (Risk)**. This is also dependent on **Resupply**. Resources also impact:

- **Food Preparation** includes items such as a water heater, food warmer, and other equipment that can determine the amount of time that preparation activities add to the schedule as well as the acceptability and safety of the food for the astronauts. This is key to acceptability.
- **Food Storage Conditions** includes refrigeration and packaging of food. This is key to nutrition and acceptability and is affected by **Pre-Mission Food Storage Time** which historically has ranged from weeks to years. **Recycling** primarily includes water.
- **Food Production** which, if designed into the system may include necessary equipment for growing food and ensuring safety, and capability such as salad crops may be critical for acceptability on long duration missions with no resupply of fresh provisions. There is some evidence that **Radiation** may affect seed viability. Dotted line indicates the low amount of evidence in this area.

In order to mitigate risk, crew must intake an appropriate amount of **Energy (Calories), Nutrients**, and **Hydration**. The system must provide the necessary **Food Acceptability**, **Food Variety**, and **Food Safety** that supports adequate intake. Too little of these and **Nutrient Deficiencies**, **Starvation**, or medical conditions such as dehydration can occur. Too much causes **Nutrient Toxicities** or other medical conditions such as polydipsia, hyponatremia, etc. Optimal nutrition can provide additional

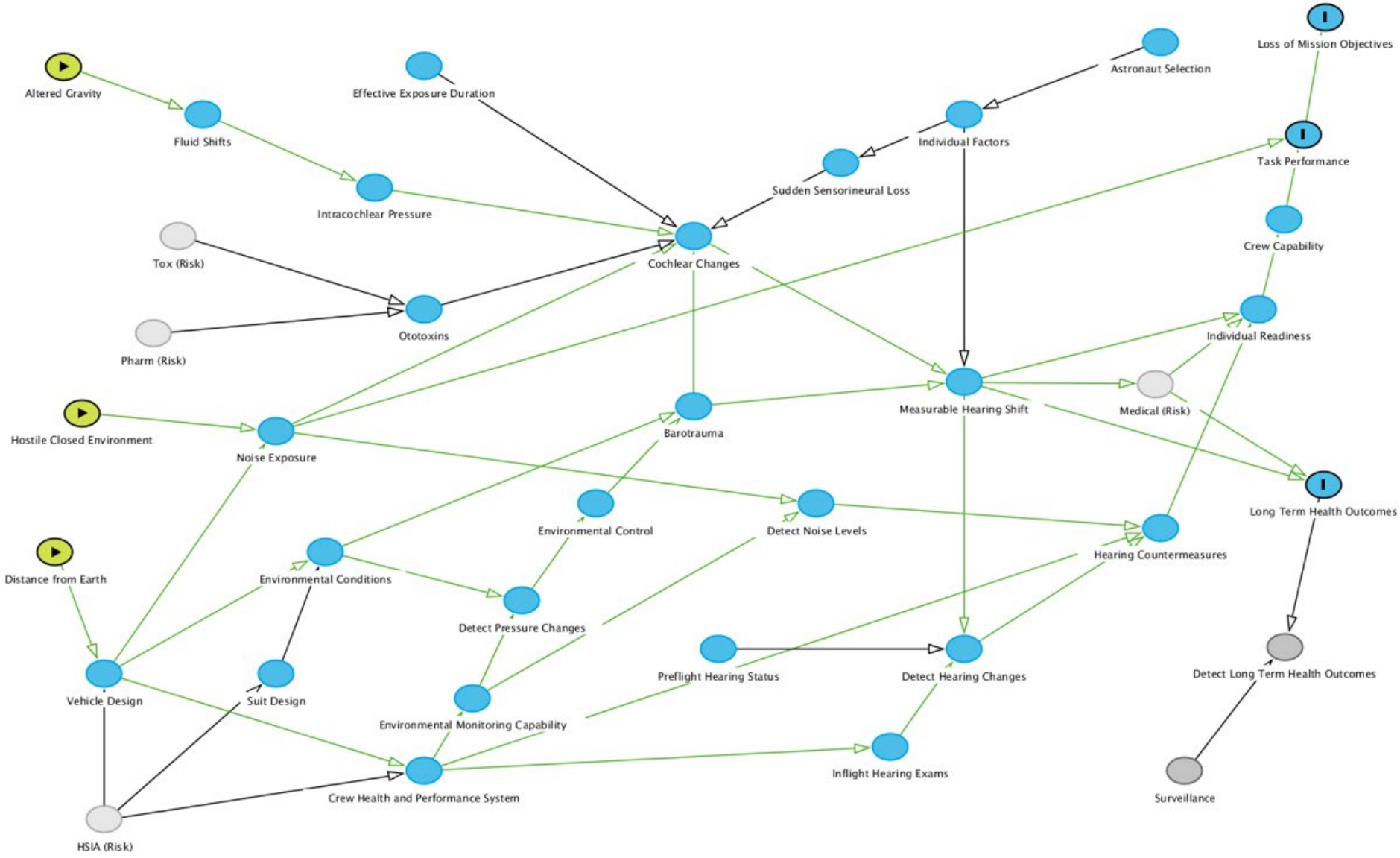
benefits, including anti-inflammatory (**Immune Risk**) and anticarcinogenic effects (**Radiation Carcinogenesis Risk**), which can be a key countermeasure to prevent disease on long duration missions. This balance affects other risks listed below that all contribute to non-optimal **Individual Readiness**, **Crew Capability** and through that affect **Task Performance**. Through the **Medical (Risk)** or through **Starvation**, **Nutrient Toxicities** or **Nutrient Deficiencies** these can also affect the likelihood of other Mission Level Outcomes including **Evacuation**, **Loss of Crew Life**, and **Long Term Health Outcomes**.

Food system (including nutrient deficiencies and/or toxicities) directly affects the likelihood of other risks listed below:

- **Behavioral (Risk)** affects factors such as mood and cognitive function.
- **Muscle** and **Aerobic (Risks)** fitness levels including stamina and strength can be affected.
- **Sleep (Risk)** affects factors such as mood and cognitive function.
- **Microhost, VTE, Renal Stone, and Bone Fracture (Risks)** – all have nutritional underpinnings and can lead to specific medical conditions occurring in mission.
- **Immune (Risk)** system dysregulation can occur as a result of inadequate energy. This also includes hypersensitivity reactions like food allergies which are affected by **Individual Factors**.
- **Cardiovascular (Risk)** function and **SANS (Risk)** through vitamin issues or other single nutrient deficiencies.
- **Nutrient Toxicities** occur when too much of a required nutrient is ingested. These can include vitamin and mineral toxicities if astronauts consume too much in-mission and affect **Long Term Health Outcomes** (e.g., liver damage from Vitamin A overconsumption).
- **Nutrient Deficiencies** occur when too little of a required nutrient is ingested. Scurvy from a lack of vitamin C or rickets from a lack of vitamin D are historic examples that can lead to **Long Term Health Outcomes**.
- Antioxidants and other nutrients may play a role in affecting **Radiation Carcinogenesis** likelihood and **Long Term Health Outcomes** for long missions.

Surveillance enables us to detect **Long Term Health Outcomes** and better characterize the risk as we gather more evidence.

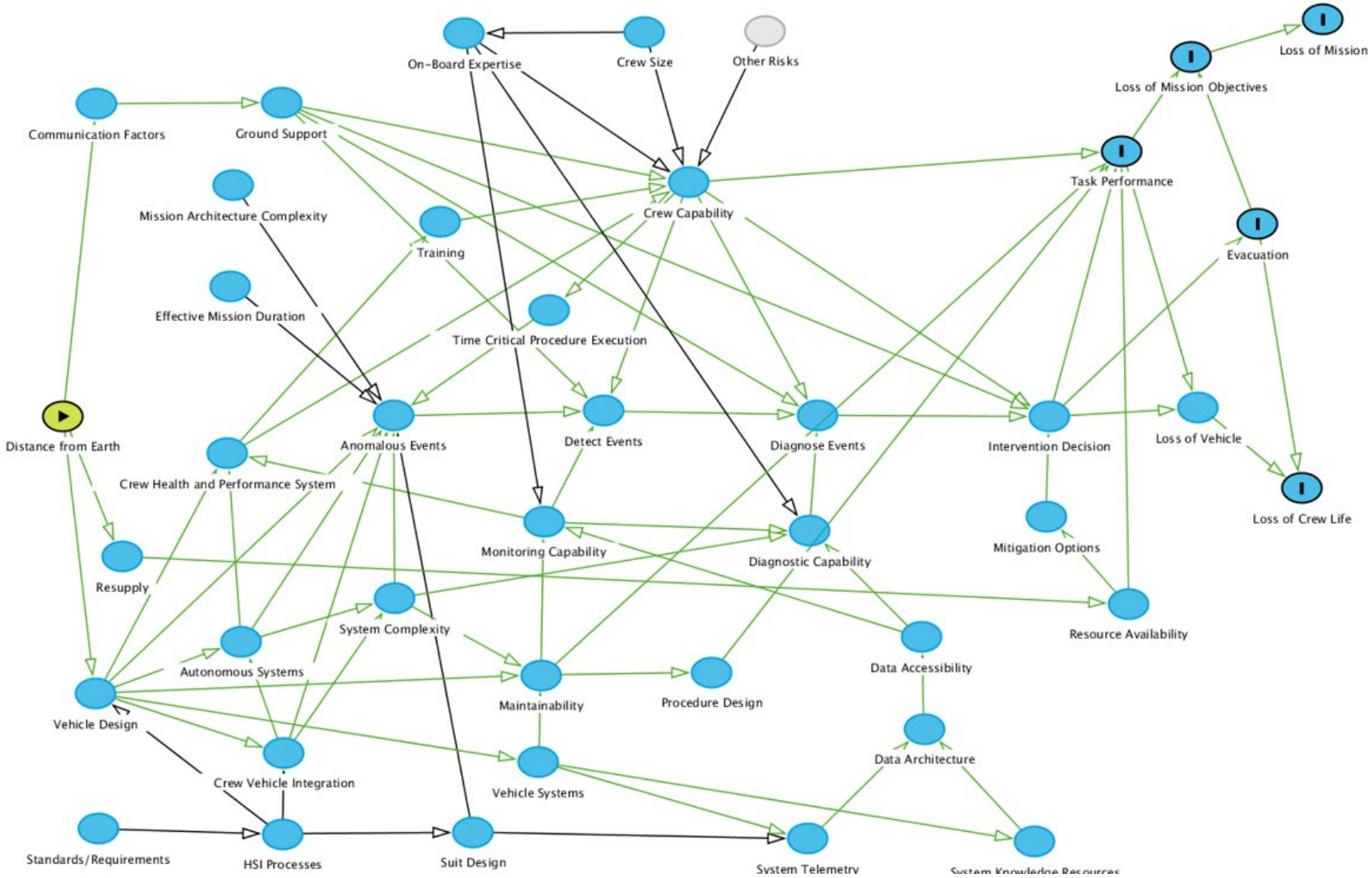
Risk of Hearing Loss and Performance Decrements Due to Acoustics Issues in Space (Hearing Loss Risk)



Hearing Loss Risk DAG Narrative

- From a health perspective this DAG centers around **Cochlear Changes** which are changes inside the inner ear that can lead to issues with hearing. These culminate in effects on **Individual Readiness** and **Crew Capability**. This can be influenced by changes in:
  - Noise Exposure which includes Noise Intensity Level, Noise Exposure Duration, and Noise Spectrum.
  - **Ototoxins** in the environment or in medications.
  - **Sudden Sensorineural Hearing Loss** which is dependent on **Individual Factors** and has been recorded in some astronauts.
  - **Intracochlear Pressure** caused by **Fluid Shifts** in **Altered Gravity** environments. In this case the **Effective Exposure Duration** accounts for the cumulative effect that the exposure will have for different Design Reference Missions.
  - **Barotrauma** that can result from changes in pressure represented here by **Environmental Conditions**. This can result in Inner Ear Barotrauma that affects **Cochlear Changes** or Middle Ear Barotrauma that affects **Measurable Hearing Shifts** without affecting the cochlea. This is affected by **Suit Design.**
- From a performance perspective, **Noise Exposure** leads directly to **Task Performance** showing that the noise environment can affect performance by impacting effective communications without degrading astronaut health.
- Vehicle Design and the Crew Health and Performance System enable Noise Monitoring and In-Flight Hearing Exams if these are designed into the system. When designed into the system, they enable Detect Noise Levels and Detect Hearing Changes. Inflight Hearing Exams must be coupled with Pre-Flight Hearing Status to enable detection of changes. Detection of either inappropriate Noise Levels or actual hearing changes can prompt crews to use Hearing Countermeasures such as hearing protection, which must also be designed into the Crew Health and Performance System to enable risk mitigation.
- From the **Barotrauma** perspective, **Environmental Monitoring Capability** enables us to **Detect Pressure Changes**. Standards require that crew have **Environmental Control** over the rate of depressurization that can minimize the likelihood of experiencing **Barotrauma**.
- Measurable Hearing Shifts and Hearing Countermeasures both affect Individual Readiness and Crew Capability. In some cases, Measurable Hearing Shifts can lead to medical problems like Hearing Loss both In-Mission as well as Long Term Health Conditions.

Risk of Adverse Outcomes Due to Inadequate Human Systems Integration Architecture (HSIA Risk)



HSIA Risk DAG Narrative

The central issue in the Human Systems Integration Architecture Risk is that **Anomalous Events** occur in human spaceflight, and the chain of steps that takes place after an **Anomalous Event** occurs is affected by known factors. The chain includes:

- **Anomalous Event** with one or more vehicle systems occurs.
- The crew (or **Ground Support**) must be able to **Detect Events** that have occurred or there will be no further steps.
- The crew (or **Ground Support**) must be able to accurately **Diagnose Events** that have occurred or they will not be able to intervene appropriately to resolve the event.
- Once diagnosed, the crew (or **Ground Support**) must make an **Intervention Decision** based on the **Mitigation Options** available.
- The **Intervention Decision** could lead to tasks required to fix a problem. Successful completion of these is **Task Performance**. If the **Diagnosis** and **Intervention Decision** were correct, then the anomaly will be resolved. If it was incorrect, then the anomaly will not be addressed. Failure to resolve vehicle system **Anomalous Events** or inadequate **Mitigation Options** can force **Intervention Decisions** that can lead to **Loss of Mission Objectives**, **Evacuation**, or **Loss of Vehicle**.

Crew Capability denotes the functional capacity of the crew as well as their knowledge, skills and abilities. This is affected by:

- The level and type of **Ground Support** available. This is dependent on **Communication Factors** including latency related to **Distance from Earth**.
- **Training** performed before and during a mission.
- **On-Board Expertise** that exists within the crew. This is also a function of **Crew Size**.
- Crew deterioration experienced by the cumulative impact of all of the **Other Risks** (Human System Risks). These contribute through **Individual Readiness** and **Team Functionality.**
- Effectiveness of the **Crew Health and Performance System** in offsetting the deterioration from **Other Risks**.

Task Performance is the degree of success the entire crew has in performing mission tasks. Inadequate **Task Performance** in the case of repairs can lead to **Loss of Vehicle** or **Loss of Mission Objectives** These are affected by:

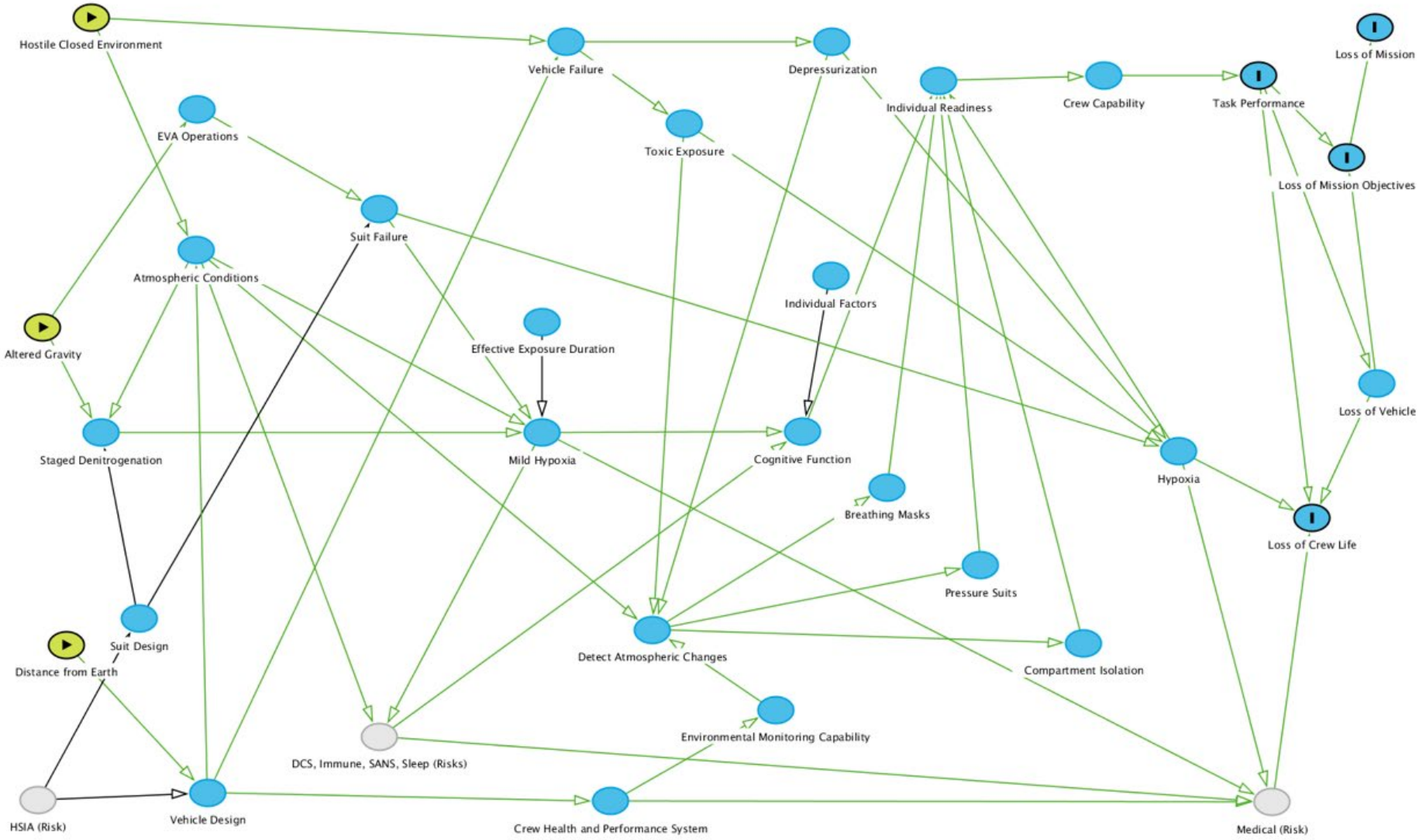
- **Crew Capability** as represented above. Note that a 100% functional crew may not be able to perform some tasks because of the following factors.
- **Procedure Design** which denotes the design of procedures that respects human limitations in terms of strength, reach, complexity, etc.
- **Maintainability** which includes accessibility for maintenance and repairs and tool dependence and availability is dependent on **Vehicle Design** and the design of **Vehicle Systems**.
- **Resource Availability** such as availability of necessary spare parts is dependent on **Resupply** related to **Distance from Earth**.

The rest of this narrative focuses on what can affect the success of each of these factors in the central chain.

- The number any type of **Anomalous Events** are affected by **Vehicle Design**, the level of **Crew-Vehicle Integration** achieved, contributions from **Autonomous Syste**ms, **System Complexity**, **Mission Architecture Complexity** (single vehicle, multiple vehicles, docking, planetary landings, etc.), and Effective **Mission Duration**. In cases of EVA, **Suit Design** also influences **Anomalous Events**. It is also affected by **Time Critical Procedure Execution** when performed by crew with reduced **Crew Capability** In other words, crew with functional impairments or insufficient knowledge, skills and abilities can make mistakes that lead to **Anomalous Events** in vehicle systems.
- The ability to **Detect Events** is dependent on **Crew Capability**, **Ground Support**, and **Monitoring Capability** present in the vehicle.
- The ability to **Diagnose Events** is dependent on **System Complexity**.
- **Monitoring Capability** and **Diagnostic Capability** are heavily data dependent and are both affected by **Data Accessibility**. This is provided by the **Data Architecture** within the vehicle that makes available to crew **System Telemetry** and **System Knowledge Resources** needed for diagnosis and monitoring of the **Vehicle Systems** as determined by **Vehicle Design**. In the case of EVA, **System Telemetry** from the space suite is affected by the **Suit Design**.

As **Distance from Earth** increases, the available mass, power, volume and data bandwidth become more restricted. The **Standards/Requirements** and **HSI Processes** that are used to influence **Vehicle Design**, **Suit Design**, and **Crew-Vehicle Integration** will functionally determine what vehicle and systems are fielded, how complex and maintainable they are, and how information on system state is provided back to crew and ground support. The ability to detect, diagnose, and effectively intervene on **Anomalous Events** that occur ultimately determines how much HSIA Risk the mission will carry.

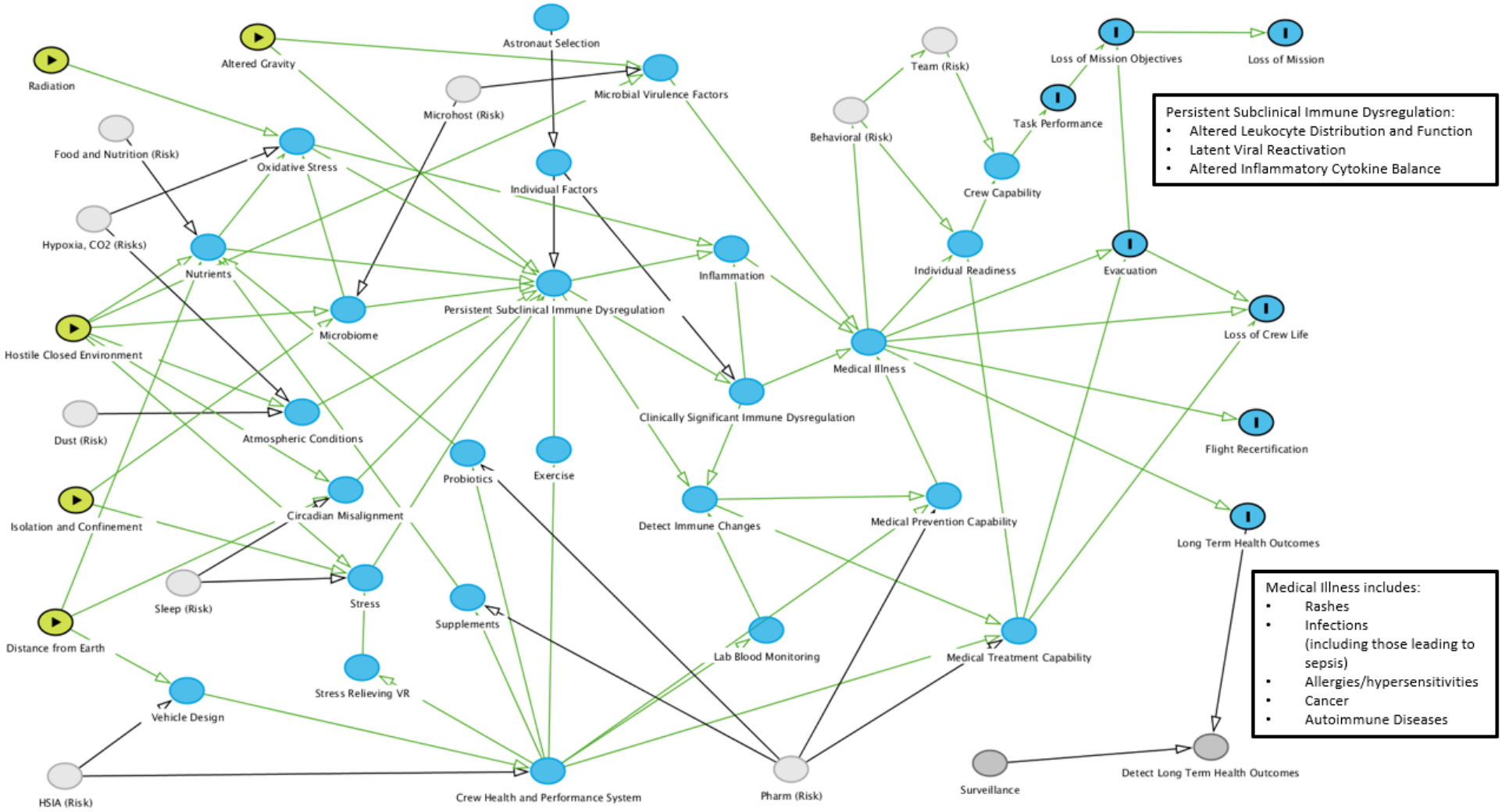
Risk of Reduced Crew Health and Performance Due to Hypoxia (Hypoxia Risk)



Hypoxia Risk DAG Narrative

- There are two levels of **Hypoxia** stemming from different sources that are concern in spaceflight. The **Hypoxia** node represents more severe hypoxia that can occur as a result of a **Suit Failure**, **Toxic Exposure**, or **Depressurization** from **Vehicle Failure**. This severity of hypoxia can lead to **Loss of Crew Life** or can impact **Individual Readiness** and **Crew Capability**.
- **Mild Hypoxia** is a different concern that can lead to issues with **Cognitive Function**, **Medical (Risk)** conditions such as acute mountain sickness, and issues addressed by other Human System Risks including **Sleep (Risk)** and **Immune (Risk)**.
- **Mild Hypoxia** is of concern when considering Exploration Atmospheres for example, where changes to **Atmospheric Constituents** during **Staged Denitrogenation** can expose astronauts to physiologic hypoxia that is at a low level and chronic over time. **Suit Failures** that are not catastrophic can also induce **Mild Hypoxia** and these can be caused by either **Suit Design** issues or **EVA Operations**. The level of hypoxia experienced is also dependent on the **Effective Exposure Duration**.
- **Distance from Earth** affects the available Mass, Power, Volume and Bandwidth available to a Crew Health and Performance System. The **Crew Health and Performance System** enables **Environmental Monitoring Capability** that can **Detect Atmospheric Changes**. In cases where those changes warrant, countermeasures such as **Breathing Masks, Pressure Suits**, and **Compartment Isolation** can be implemented to protect **Individual Readiness**, **Crew Capability**, and health.
- Historically pilots and astronauts are exposed to hypoxic conditions prior to flight so that they can understand how their unique symptoms are expressed. This is because the insidious onset of hypoxia can affect **Individual Readiness** and **Crew Capability** severely enough that **Task Performance** for critical tasks like piloting a vehicle may be affected and **Loss of Vehicle** can occur.

Risk of Adverse Health Event Due To Altered Immune Response (Immune Risk)



Immune Risk DAG Narrative

The central issue in the Immune Risk is the progression from Persistent Subclinical Immune Dysregulation -> Clinically Significant Immune Dysregulation -> Medical Illness. Oxidative Stress, Persistent Subclinical Immune Dysregulation and Clinically Significant Immune Dysregulation can affect Inflammation levels in the body that contribute to Medical Illness.

- **Subclinical Immune Dysregulation** refers to changes in cellular proliferation and function that does not have a known clinical issue directly following it.
- **Clinically Significant Immune Dysregulation** refers to the threshold at which those cellular issues have a known prognostic indication for impending disease.
- The **Medical Illnesses** that can result are a function of both hypoactive and hyperactive immune dysregulation.
- Hypoactive dysregulation predisposes astronauts to increased probability of infections.
- Hyperactive dysregulation predisposes astronauts to increased probably of hypersensitivity reactions like rashes and autoimmune disease.

Increasing probability of **Medical Illnesses** contributes to deterioration of **Individual Readiness** and **Crew Capability** which affects **Task Performance**, likelihood of **Evacuation** for medical reasons, and in severe cases can contribute to **Loss of Crew Life**. Persistent medical issues post flight and post career may affect **Flight Recertification** and **Long Term Health Outcomes**.

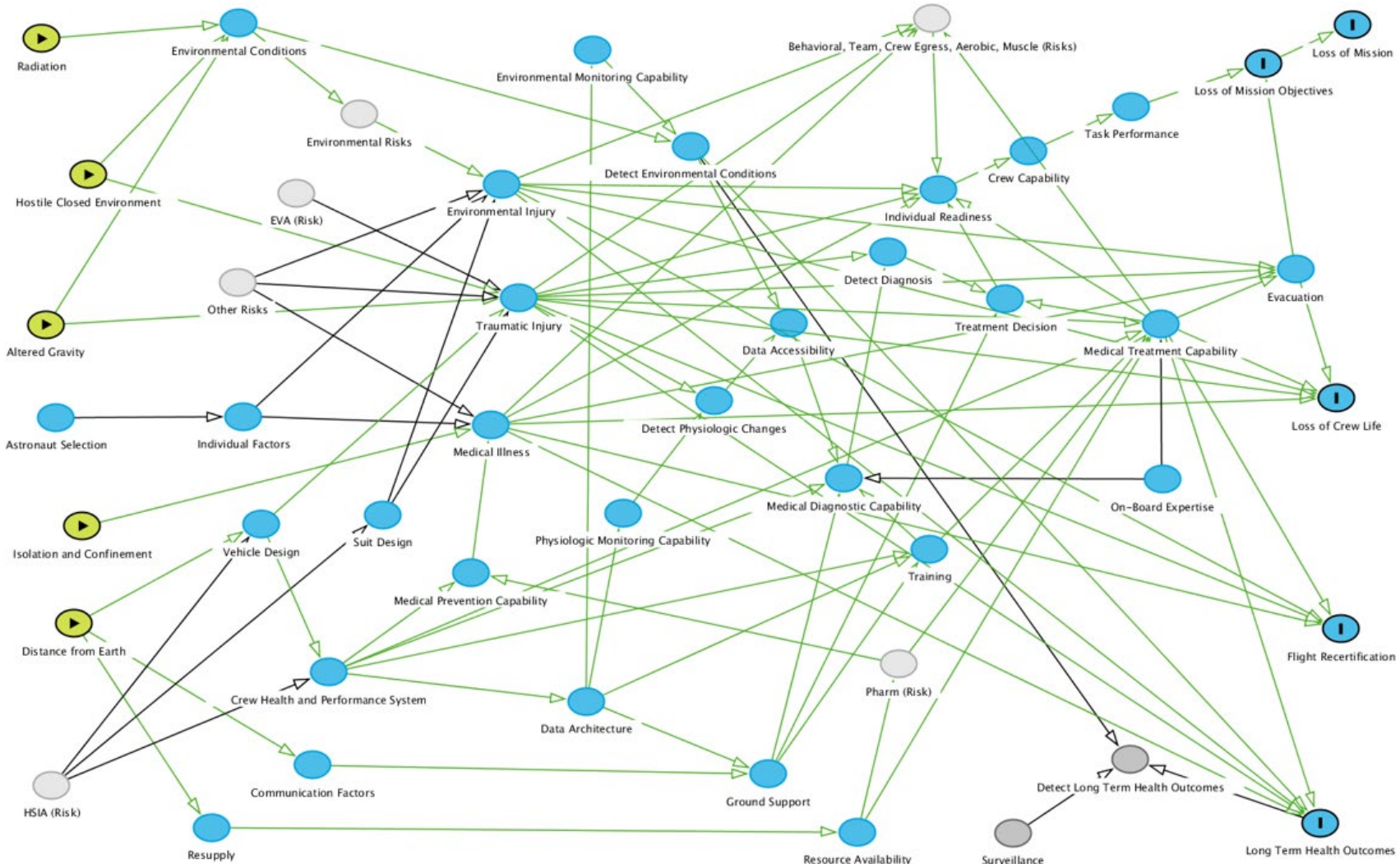
- Contributors to the start of this chain of events include:
- **Radiation** exposure leads to **Oxidative Stress** that can contribute to immune dysregulation.
- **Nutrients** which are dependent on safe and acceptable **Food and Nutrition (Risk)**.
- The **Microbiome** which is dependent on the status of the **Microhost (Risk)**.
- **Atmospheric Conditions** including airborne content affected by the **Hypoxia**, **CO2**, **Dust (Risks).**
- **Circadian Misalignment** associated with the **Sleep (Risk)** is known to affect immune function.
- **Stress** associated with the **Behavioral (Risk)** is known to affect immune function.

Countermeasures that affect immune system function must be included in the **Crew Health and Performance System** and accommodated in **Vehicle Design**. These are affected by the **HSIA (Risk)** and include:

- Countermeasures that may prevent Persistent Subclinical Immune Dysregulation.
- **Probiotics** and **Supplements** which are dependent on the **Pharm (Risk)** and may require different storage modalities.
- Other stress relieving techniques such as **Stress Relieving** Virtual Reality **(VR)**.
- **Exercise** has been shown to improve Subclinical changes in the immune system.
- **Lab Blood Monitoring** enables the ability to **Detect Immune Changes** that are either subclinical or clinically significant. When detected, these can enable further interventions including:
  - **Medical Prevention Capability** such as evaluations by the crew medical officer that can help reduce the causes of immune dysfunction.

  - **Medical Treatment Capability** that responds to the infections or hypersensitivity reactions that occur and seek to minimize the consequences of those medical conditions.
  - Both of these are dependent on the **Pharm (Risk)** as medications used are subject to stability and pharmacokinetic (PK)/pharmacodynamic (PD) issues.
- The likelihood of infectious diseases (**Medical Illness**) in a mission is also affected by **Microbial Virulence Factors** which have been shown to change in spaceflight.
- **Long Term Health Outcomes** that may occur as a result of immune dysregulation must be included in **Surveillance** post flight and post-career in order to effectively **Detect Long Term Health Outcomes** and characterize the magnitude of this risk in the Long Term Health domain. These can include hypersensitivity conditions, autoimmune disorders, and cancers.

Risk of Adverse Health Outcomes and Decrements in Performance Due to Medical Conditions that occur in Mission, as well as Long Term Health Outcomes Due to Mission Exposures (Medical Risk)



Medical Risk DAG Narrative

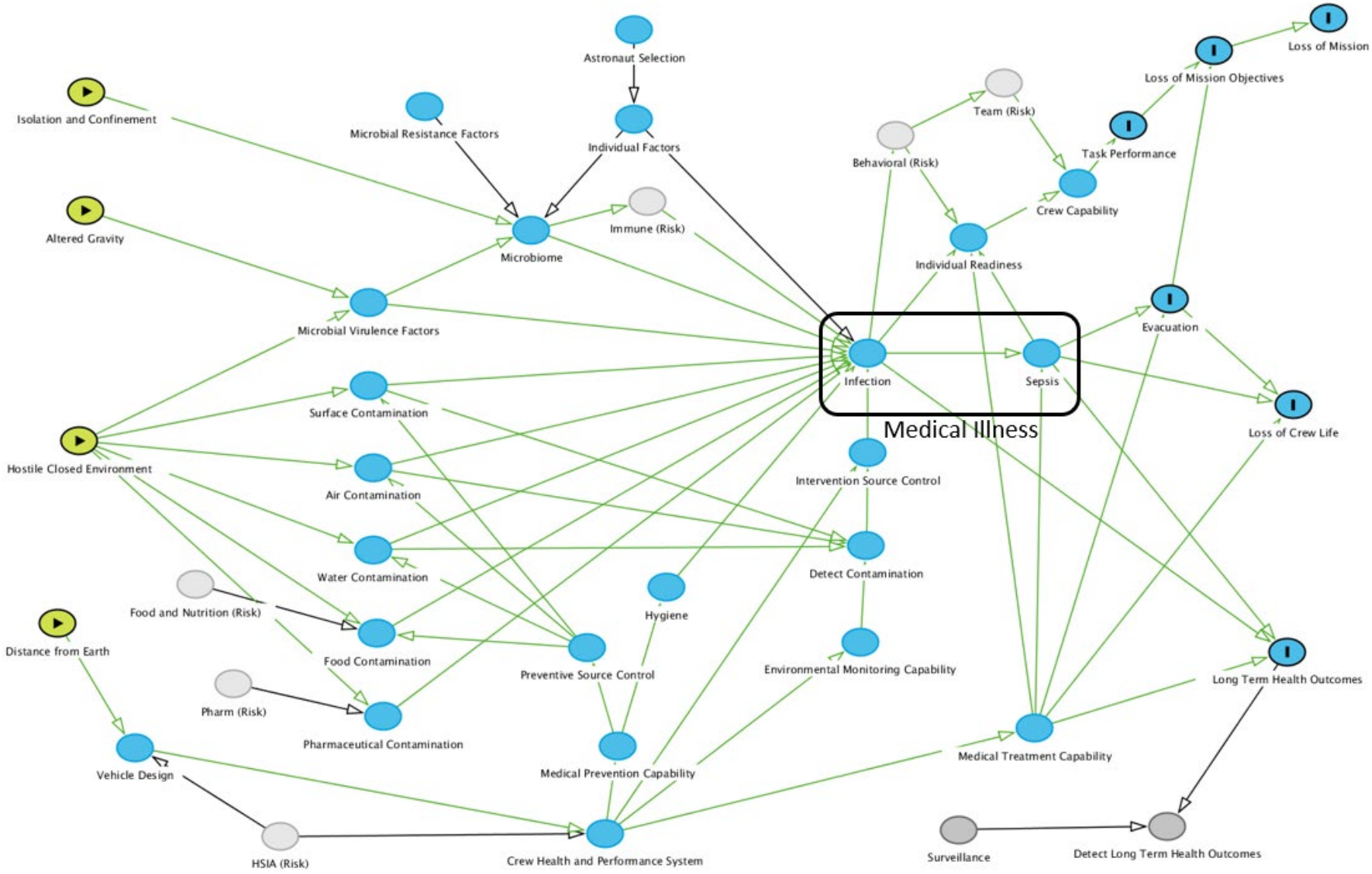
The Medical Risk boils down to two parts – First, what medical conditions/events are going to happen in a given mission. Second, what can be done to decrease the likelihood (prevention) or the consequence (treatment) of those events.

- For the first part: Total Medical Events are made up of three categories – Environmental Injuries, Traumatic Injuries, and Medical Illnesses.
  - **Environmental Injury** likelihood is affected by Environmental Conditions (and other Environmental Risks), EVAs, and **Vehicle** and **Suit Designs**. **Individual Factors** inform the bio-variability in response to environmental insults.
  - Traumatic Injury likelihood is affected by EVAs, Vehicle and Suit Designs, and other risks (Bone fracture, Dynamic Loads, Crew Egress, Muscle and Aerobic (Risks)).
  - **Medical Illness** likelihood is affected by other risks and **Individual Factors**.

Each of these categories can affect mission level outcomes, especially if not planned for. This is why there is a second part – What can we do about it?

- For the second part: The **Crew Health and Performance System** provides for a variety of capabilities intended to mitigate medical risk. These include **Medical Prevention Capabilities** (designed to decrease likelihood of conditions) and **Medical Treatment Capabilities** (designed to decrease the consequence of conditions that have occurred). Deciding on what treatment to provide is an information dependent process that requires **Physiologic** and **Environmental Monitoring Capabilities** and **Diagnostic Capabilities**. These are closely linked to a **Data Architecture** and depend on **Data Accessibility** to inform the correct **Treatment Decision**. If an incorrect **Treatment Decision** is reached, risk is not mitigated, and it may be increased. **Diagnostic** and **Treatment Capabilities** are dependent on the **On-Board Expertise**, **Ground Support**, **Training**, **Resource Availability**, and **Data Architecture** provided by the **Crew Health and Performance System**.
- **Resource Availability** is dependent on **Resupply**. **Ground Support** is dependent on **Communication Factors** including communications delay. Both of these are dependent on **Distance from Earth**.

Risk of Adverse Health Effects Due to Host-Microorganism Interactions (Microhost Risk)

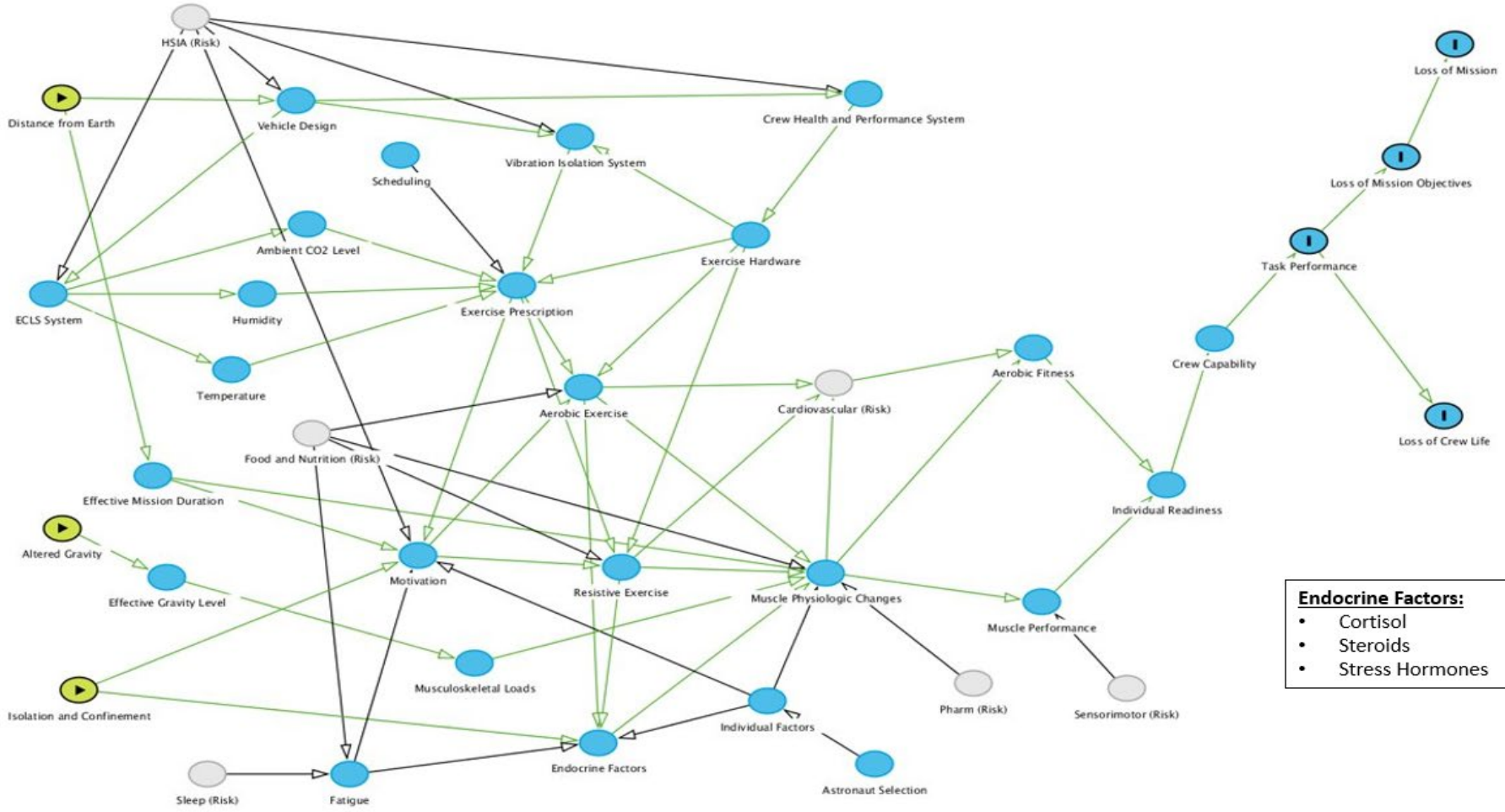


Microhost Risk DAG Narrative

- The **Microhost Risk** centers around the possibility for microbial contamination leading to **Infections** that if left inadequately treated could become **Sepsis.** Both **Infections** and **Sepsis** can lead to deterioration of **Individual Readiness** and **Crew Capability** which affects **Task Performance**, likelihood of **Evacuation** for medical reasons, and in severe cases can contribute to **Loss of Crew Life**. They can also lead to **Long Term Health Outcomes** if inadequately treated and post-mission/career **Surveillance** enables **Detection of Long Term Health Outcomes** to understand the magnitude of the problem.
- The cause of infections can come from various sources:
  - **Microbial Virulence Factors** – evidence that the virulence of certain microbes change in response to spaceflight environment.
  - This may lead to an increased risk of infections.
  - Can indirectly lead to infections through changes in **Microbiome**.
  - **Immune (Risk) -** the strength of the immune system determines how well individuals fight off infections.
  - **Surface Contamination** - microbes on surfaces are found regularly on ISS, cleaning procedures can decrease impact on crew.
  - **Air Contamination** – good air quality and filtration can limit likelihood of airborne and droplet-based infections among crew.
  - **Water Contamination** - water quality monitoring and cleaning helps limit infections in crew.
  - **Pharmaceutical Contamination** - repackaged pharmaceuticals are susceptible to contamination increasing risk for infection among crew.
  - **Food Contamination** – inadequate packaging and storage conditions for crew food could lead to infections including gastroenteritis.
- Countermeasures that affect microbial levels must be included in the **Crew Health and Performance System** and accommodated in **Vehicle Design**. These are affected by the **HSIA (Risk)** and include: Countermeasures include the storage conditions which if compromised could increase contamination of food and pharmaceuticals; the storage conditions are also impacted by the food system available which is represented in the DAG by the **Food and Nutrition (Risk)**.
  - **Preventive Source Control** includes monitoring, regular cleaning, filtration and other modes of limiting spread of microbes.
  - **Hygiene** includes personal hygiene such as regular showers, dental hygiene, and other personal cleaning that limits the development of **Infection**.
  - **Environmental Monitoring Capability** is necessary to **Detect Contamination** levels in the air, water, and surfaces. This enables **Intervention Source Control** measures like cleaning or maintenance of filtration systems.
  - **Medical Treatment Capability** includes antibiotics, antifungal, and antiviral medications, as well as other supportive care, intended to minimize consequence of infection and prevent the development of sepsis.

- **Infections** and **Sepsis** affect cognitive function, mood and performance and therefore affect **Behavioral (Risk)** and **Team (Risk)** which negatively impacts **Individual Readiness** and **Crew Capability.**

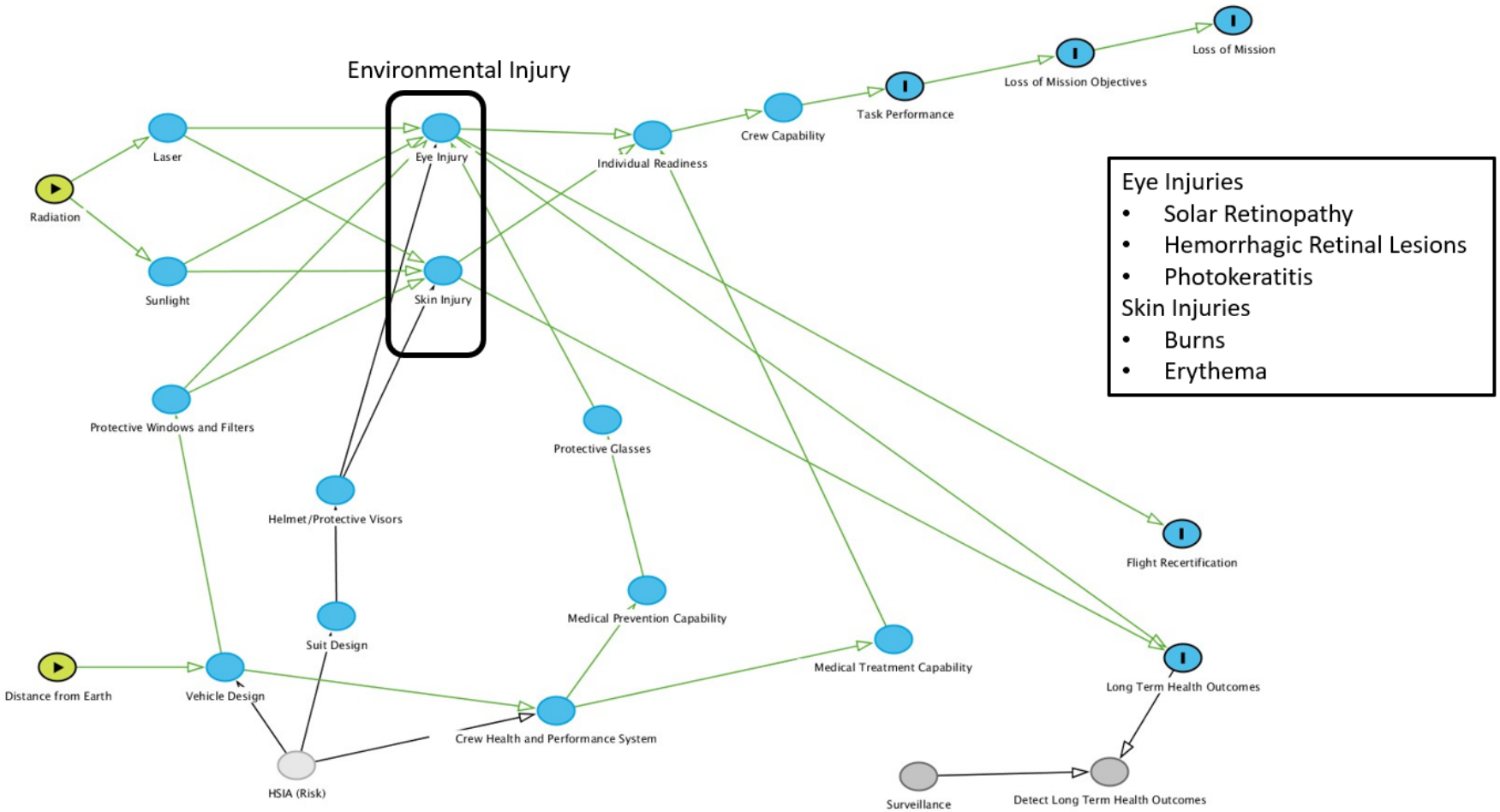
Risk of Impaired Performance Due to Reduced Muscle Size, Strength, and Endurance (Muscle Risk) and Risk of Reduced Physical Performance Capabilities Due to Reduced Aerobic Capacity (Aerobic Risk)



Muscle and Aerobic Risks DAG Narrative

- **Altered Gravity** across all DRMs includes microgravity, lunar gravity, Mars gravity and Earth Gravity. This affects **Effective Gravity Level** experienced by crew and through that **Musculoskeletal Loads**.
- **Isolation and Confinement**, especially over long **Effective Mission Durations** can induce monotony and anhedonia affecting the **Motivation** to perform needed exercise.
- **Distance from Earth** determines the mass and volume allocations for **Vehicle Design** and **Suit Design** and affects the **Effective Mission Duration**.
- The central focus of the Muscle and Aerobic Risk DAG is on **Aerobic Fitness** and **Muscle Performance** levels being adequate for crew to do the tasks that are expected of them (**Task Performance**). These directly influence **Individual Readiness** and crew readiness or fitness for duty (**Crew Capability**).
- When these nodes are negatively affected, the performance of EVAs - **EVA (Risk)** - and the performance of post-landing tasks – **Crew Egress (Risk)** may be threatened.
- **Aerobic Fitness** and **Muscle Performance** are directly affected by the **Muscle Physiologic Changes** that occur at the level of cardiac, smooth, and skeletal muscle throughout the body as a result of the duration of exposure to the spaceflight environment. **Aerobic Fitness** is also directly dependent on the functionality of the Cardiovascular system (**Cardiovascular Risk**).
- These **Physiologic Changes** are the result of several contributing factors:
  - **Musculoskeletal Unloading** that occurs as a result of the **Altered Gravity** Environment.
  - Endocrine Factors that are related to the Isolation and Confinement experienced.
- Countermeasures to these include:
  - Resistive Exercise.
  - Aerobic Exercise.
  - Medications - Pharm (Risk).
  - Nutrients - Food and Nutrition (Risk).
- Other contributing factors can include the **Motivation** to exercise which is impacted by **Fatigue** through the **Sleep (Risk)** and **Food and Nutrition (Risk), Effective Mission Duration** that can induce monotony, design and maintenance challenges from the **HSIA (Risk)**.
- The exercise capability that protects **Aerobic Fitness** and **Muscle Performance** is the result of the **Vehicle Design** process, the **HSIA (Risk)**, and the fielded **Crew Health and Performance System**. These define and limit the presence and reliability of the **Exercise Hardware** that is available in a mission. The **Exercise Prescription** that can be accomplished by crew is limited by the **Schedule**, **Vibration Isolation System**, **Previous Injury**, and environmental factors such as **Temperature**, **Humidity**, and **CO2 (Risk)** that are a function of the **ECLS System**.

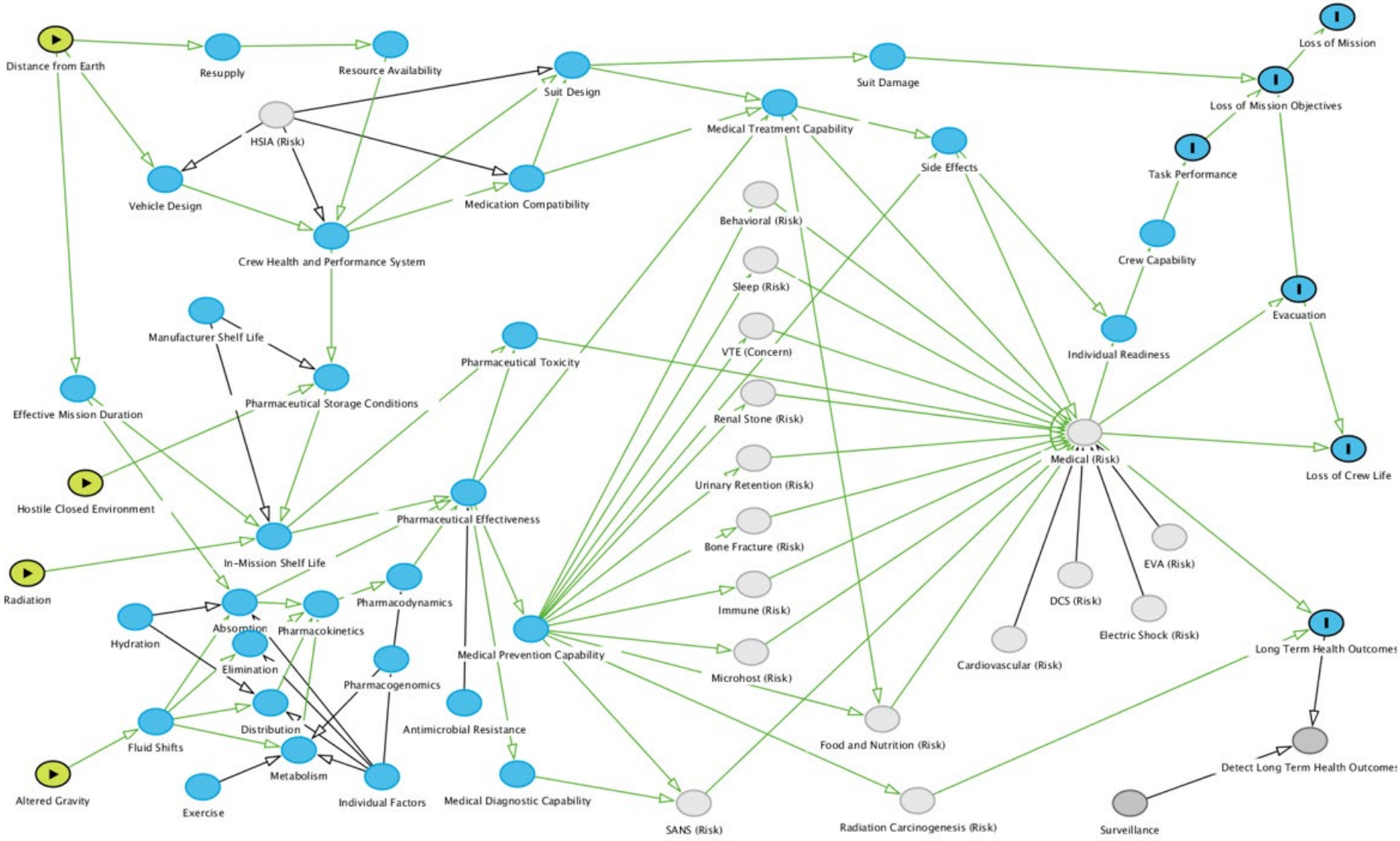
Risk of Adverse Health Outcomes and Performance Decrements resulting from Non-Ionizing Radiation during Spaceflight (Non-Ionizing Radiation Risk)



Non-Ionizing Radiation Risk DAG Narrative

- The central risk for Non-ionizing Radiation is in **Eye Injuries** and **Skin Injuries** that can result from **Sunlight** or **Laser Exposure**.
- If these occur, they can create functional impairments that affect **Individual Readiness** and **Crew Capability** in mission, especially in loss of vision.
- Protection from these exposures occurs through **Protective Windows and Filters** that are designed into the vehicle, **Helmet/Protective Visors** that are designed into the suits, and the provision of **Protective Glasses** for crew as needed.
- **Crew Health and Performance System -> Medical Treatment Capability** captures any treatments that need to be planned into the system, possibly including pain medications, ocular drops, skin creams for burns, etc.
- If **Eye Injuries** do occur from these exposures, then there is a chance that they will affect **Flight Recertification** of crew and possibly include **Long Term Health Conditions** like debilitating visual defects.

Risk of Ineffective or Toxic Medications During Long-Duration Exploration Spaceflight (Pharm Risk)



Pharm Risk DAG Narrative

DAG: Nodes Directly Affecting Pharmacokinetics.

- **Absorption**: How a drug enters the body.
  - Intestinal Absorption – For oral medications, most absorption occurs in the small intestine.
  - Gastric Emptying Time – The rate-limiting step of oral absorption.
- **Distribution:** The journey of the drug through the bloodstream to various tissues of the body.
  - Changes in total body water or Intravascular Volume.
  - Plasma protein binding.
- **Metabolism**: How the drug is biotransformed (broken down) in the body.
  - Hepatic Function, Hepatic Enzymes.
  - Other organs (e.g. Lungs, kidney, gastrointestinal (GI), skin).
- **Elimination**: How a drug is removed from the body.
  - Renal Function.
  - Hepatic Function.
  - Minor Pathways.

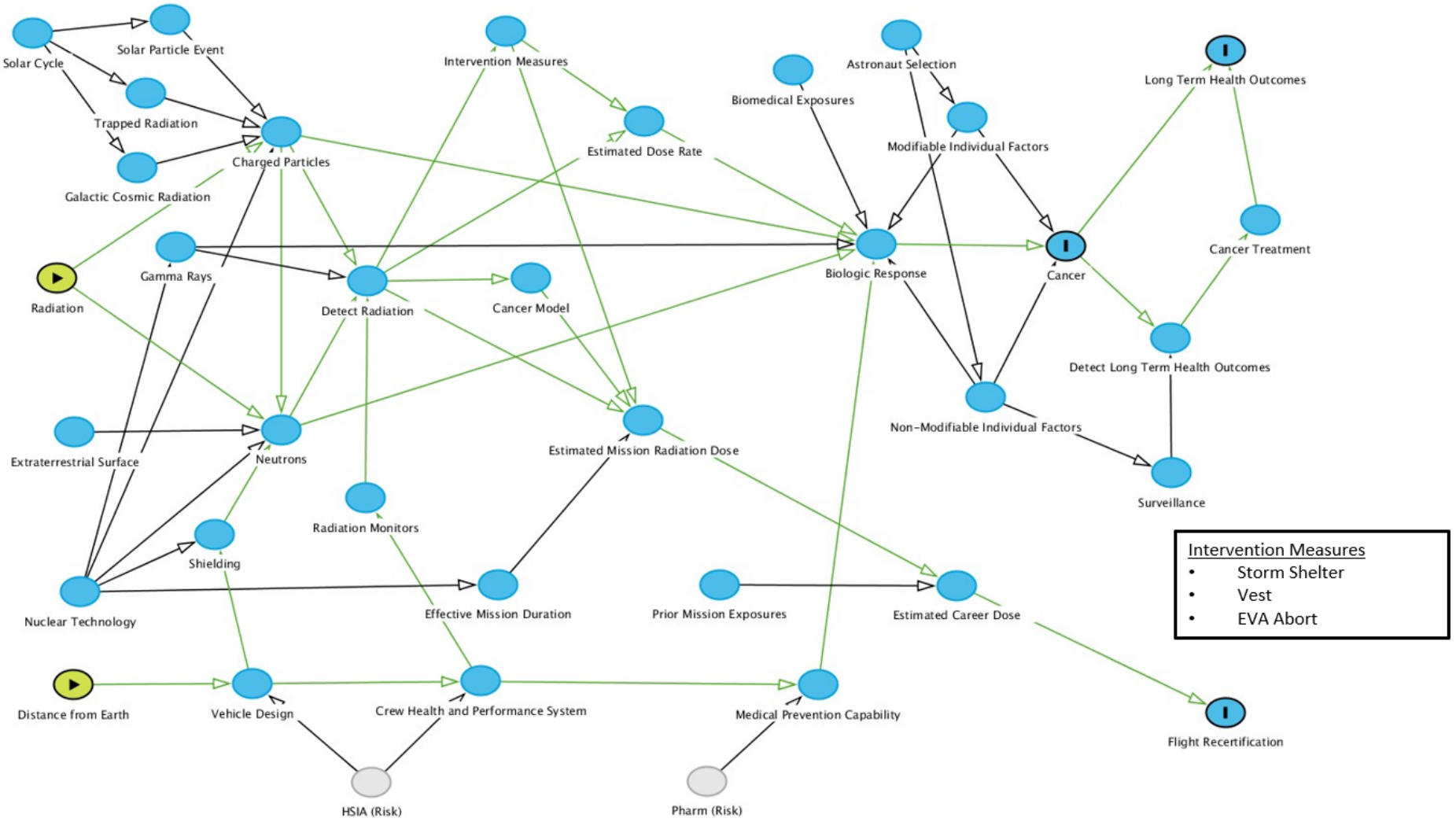
The Pharm Risk centers around **Pharmaceutical Effectiveness**. There are three basic things that contribute to this. 1. **In-Mission Shelf Life**, 2. **Physiologic Changes**, and **Antimicrobial Resistance**. Hazards affecting this risk include **Distance from Earth, Hostile Close Environment, Radiation and Altered Gravity.**

- **In-Mission Shelf** Life is defined from the time that medication is packed to whenever the medication is used or jettisoned. This is dependent on **Environmental Conditions** in the vehicle and **Pharmaceutical Storage Conditions** - i.e., refrigeration, packaging, etc. The **Manufacturer Shelf Life** refers to the labeled shelf life the medication would have without spaceflight exposure. **Effective Mission Duration** refers to how long the medications are exposed to the spaceflight environment.
- **Physiologic Changes** are the changes that the human body experiences that affect how a pharmaceutical functions within the body. Fundamentally this is broken into **absorption**, **distribution**, **elimination**, and **metabolism** of medications. **Metabolism** is affected by many factors including enzyme expression and **pharmacogenomics**. All lead to variations in **Pharmacokinetics** (the concentration of the active ingredient in the body over time) and **Pharmacodynamics** (how the target tissues use the medication). **Individual Factors** (age, sex, etc.), **Hydration**, and **Fluid Shifts** affect these physiologic changes.
- **Antimicrobial resistance,** including antibiotics, antivirals and antifungals**,** can affect the effectiveness of some pharmaceuticals.
- **Pharmaceutical Effectiveness** is upstream **of Medical Prevention Capability**, **Medical Diagnostic Capability**, and **Medical Treatment Capability**.
- **Medical Prevention Capability** in this case includes any medications used to prevent the effects of other risks. Examples include Potassium Citrate for Renal Stone Prevention, Bisphosphonates

for Bone protection, etc. There are 11 risks shown that have known potential pharmaceutical preventive cases.

- **Medical Diagnostic Capability** includes any medications used to assist in diagnosis. For example, proparacaine used to enable intraocular pressure measurements for the Risk of Spaceflight Associated Neuro-ocular Syndrome (SANS) risk. Note that in this example proparacaine **In-Mission Shelf Life** is strongly affected by refrigeration (**Storage Conditions**).
- **Medical Treatment Capability** includes any medications used to treat medical conditions. This includes medications for symptoms including pain, nausea, fever, etc. as well as definitive treatments such as antibiotics for infections. Multiple risks include treatment needs including **Cardiovascular (Risk), EVA (Risk), Decompression Sickness (Risk), and Electric Shock (Risk)*.** Most of the risks shown in the **Preventive Medication Capability** pathway include a need for treatment as well i.e., pain control for renal stones, etc.
- **Medical Prevention Capability** and **Medical Treatment Capability** can affect the severity of **Side Effects** which then can affect **Individual Readiness, Crew Capability and Task Performance**, all which could lead to Loss of Mission Objectives or **Loss of Mission.**
- Additional paths included:
  - **Pharmaceutical Toxicity** can occur from two sources: 1) degradation products may be toxic; 2) dosing errors and other factors can lead to under-or over-dosing of a given medication. **In-mission Shelf Life** can reduce the amount of active pharmaceutical ingredients present or lead to degradation products that may cause **Pharmaceutical Toxicity.** Over-dosing of medication can lead to life-threatening toxicities including suppression of breathing in the case of opioid use or damage to organs such as liver failure in acetaminophen overdose.
  - **Medication compatibility –** This includes both the compatibility of medications of the vehicle environment (**Vehicle Design**) and the suit **(Suit Design).** It also includes the capability of the provision of a medication while wearing the suit. This affects what medications can be administered to the crew in suited operations.
  - Vehicle systems and suits that can be damaged by a medication therapy - I.e., topical medications that cause **Suit Damage.** We do not know what components of medications create problems for the suit and the atmosphere in the suit but continue to be asked by engineering for that information.
  - **Suit Design** that doesn't allow for proper **Medical Treatment Capability -** E.g., Orion 144-hour suit contingency allows for a small port in the helmet to administer a small number of oral medications. Not all medications fit.
  - **Resupply and Resource Availability – Distance from Earth** can affect the ability to **Resupply** in some DRMs can lead to a risk of inadequate medications. If **Pharmaceutical Effectiveness** is lessened through either degradation or PK/PD issues, crew may use more medications than originally planned and potentially run out sooner.
  - **Surveillance** enables us to **Detect Long Term Health Outcomes** and better characterize the risk as we gather more evidence.

Risk of Radiation Carcinogenesis (Radiation Carcinogenesis Risk)



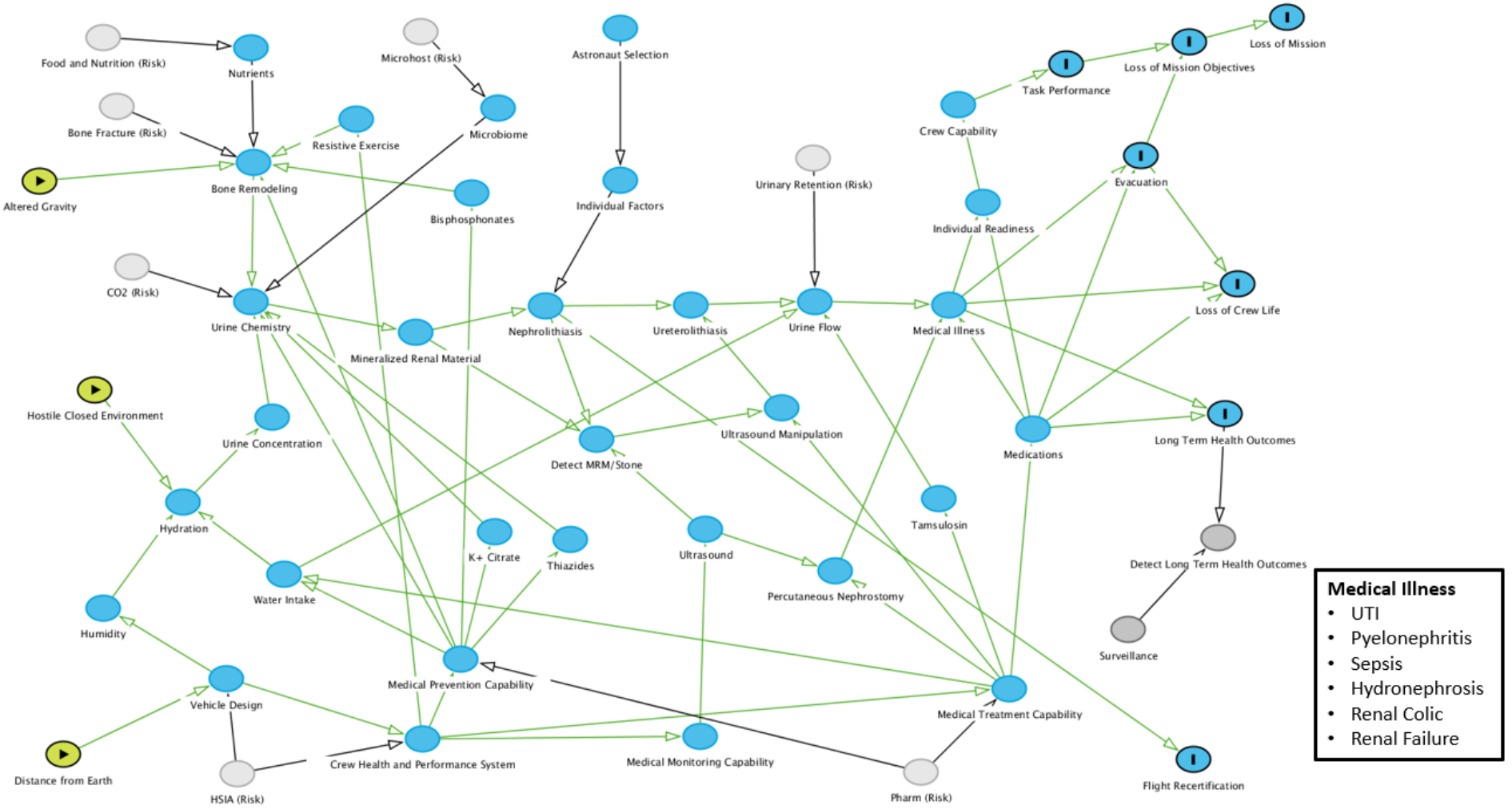
Radiation Carcinogenesis Risk DAG Narrative

- Exposure to space **Radiation** increases the likelihood that an individual will develop cancer due to interaction of **Charged Particles** and **Neutrons** with the human body. The ionizations that occur within the body lead to a **Biologic Response** that occurs on the cellular and molecular level which modifies the likelihood that an astronaut will develop **Cancer** post-mission and post-career.
  - The flux of **Charged Particles** that astronauts may receive is affected by the **Trapped Radiation**, **Galactic Cosmic Radiation** (GCR), and **Solar Particle Events** that may happen during a mission. These in turn are affected by the **Solar Cycle**.
  - The flux of **Neutrons** is affected by **Charged Particle** interactions with vehicle **Shielding** or **Extraterrestrial Surfaces** such as the Moon or Mars.
  - **Nuclear Technology**, if used in a mission for propulsion or power generation, can lead to additional **Charged Particle** exposure, **Gamma Ray** exposure, and additional **Neutron** exposure for the astronauts.
  - Other **Biomedical Exposures** such as CT scans for research or medical purposes can also affect **Biologic Response** and likelihood of developing **Cancer**.
- Besides spaceflight radiation exposures, there are other factors that modify an individual's susceptibility to developing cancer that must be considered. **Astronaut Selection** processes modify the **Individual Factors** present in the crew.
  - **Non-Modifiable Individual Factors** such as age, sex, genetic predispositions, and pre-existing medical conditions.
  - **Modifiable Individual Factors** such as smoking habits, exercise and dietary habits, alcohol habits, etc.
  - Any of these factors can modify the likelihood that **Cancer** will occur for a given astronaut post-career.
- **Surveillance** enables us to detect Cancer (**Detect Long Term Health Outcomes**) which can inform **Cancer Treatment.** Both the occurrence of **Cancer** and **Cancer Treatments** can affect **Long Term Health Outcomes** such as subsequent illnesses, premature death, and quality of life issues.
- **Distance from Earth** impacts the **Vehicle Design** through and volume allocations for **Shielding** and the **Crew Health and Performance System.** Inclusion of these are affected by the **HSIA (Risk).**
- The Crew Health and Performance System provides allocations for:
  - **Medical Prevention Capability** which may provide medications or supplements designed to reduce overall space radiation carcinogenesis risk by modifying the biologic response to radiation. These would be affected by the **Pharm (Risk)** issues like all other medications.
  - **Radiation Monitors** on the spacecraft enable the detection of changes in **Charged Particle** or Neutron flux (**Detect Radiation**) that may be associated with **Solar Particle Events**, changes in **Galactic Cosmic Rays**, and **Trapped Radiation** due to the **Solar Cycle**.
    - Monitoring can drive **Intervention Measures** in mission such as reconfiguring mass for a storm shelter, donning additional radiation protection, or early termination of EVAs.

- Monitoring also enables **Estimated Dose Rate** and **Estimated Mission Dose** as well as informing the **Cancer Model** regarding crew exposures. The **Estimated Mission Dose** can be affected by **Effective Mission Duration** which in turn can be modified by **Nuclear Technologies**.

Estimated Mission Radiation Dose is combined with **Prior Mission Exposures** to assess an **Estimated Career Dose** for each astronaut. This information is used in conjunction with agency standards to inform **Flight Recertification** for each astronaut.

Risk of Renal Stone Formation (Renal Stone Risk)



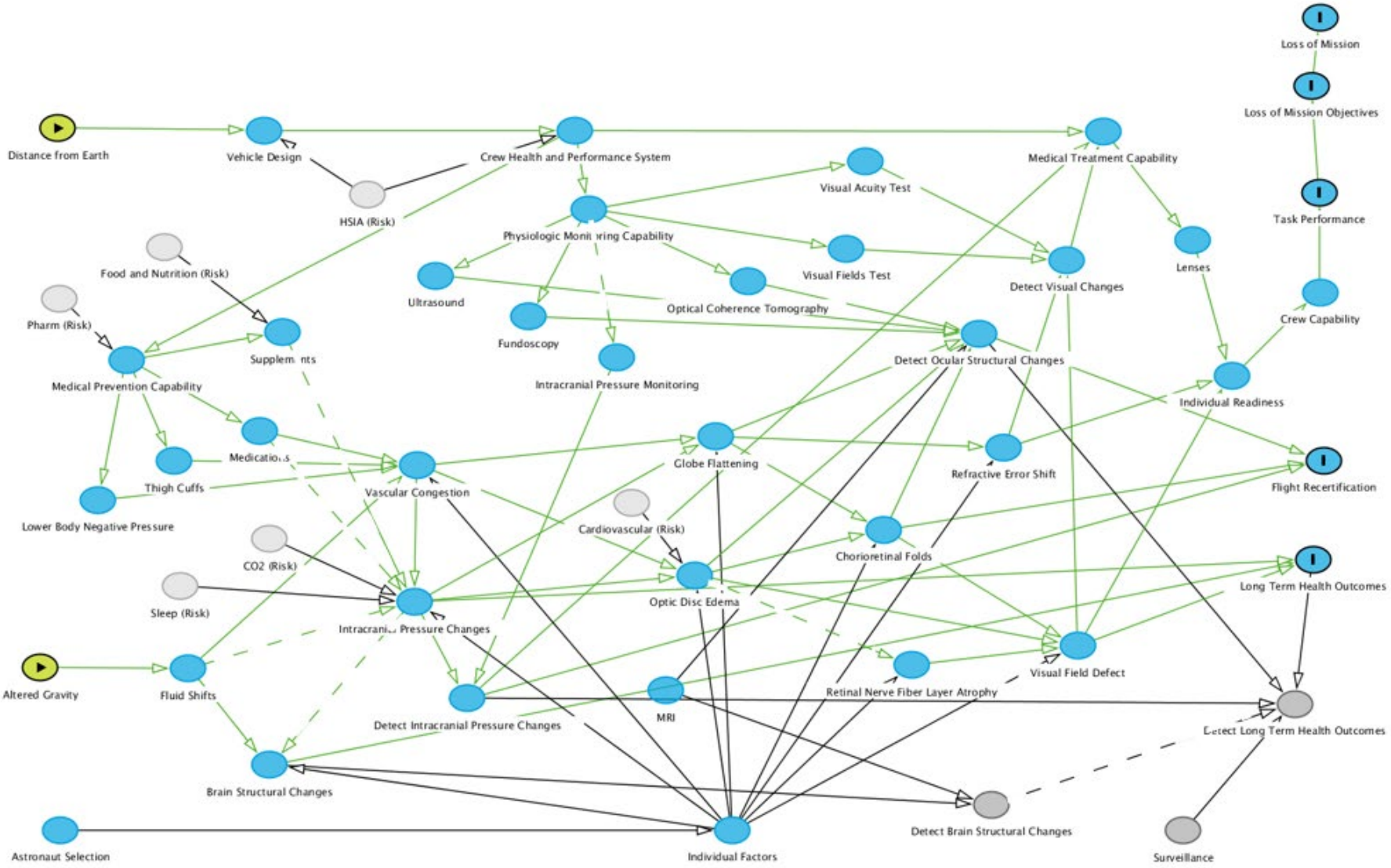
Renal Stone Risk DAG Narrative

The Risk of Renal Stone Formation (urolithiasis) in spaceflight is predicated on the Hazards influencing **Urine Chemistry. Altered Gravity** may cause increased calcium in the blood and urine due to **Bone Remodeling**, while the **Hostile Closed Environment** may alter the **Hydration Status**.

- The central story of the Renal Stone Risk focuses on the pathway from **Urine Chemistry** to **Medical Illness**. The steps included are:
  - **Urine Chemistry** is affected by a variety of factors including the **Microbiome**. The calcium, potassium, citrate, oxalate and other chemical concentrations in the urine determine the probability that **Mineralized Renal Material** will precipitate out of the urine and adhere to the wall of the nephron or calyx.
  - The growth of this **Mineralized Renal Material** in part determines the likelihood that it will break off and become a kidney stone also called **Nephrolithiasis**. When this occurs, the stone exists in the kidney but does not cause pain or infection.
  - There is some probability that the stone in the kidney will progress and enter the ureter. This is called **Ureterolithiasis** and at this point the stone can cause pain and other symptoms. This includes affecting **Urine Flow** which can predispose to several types of **Medical Illness** including **Hydronephrosis**, **UTI**, **Pyelonephritis**, and possibly **Sepsis** if untreated.
  - All of these things can affect **Crew Capability** because the pain, nausea, and infections can cause functional incapacitation for some time, typically less than 14 days unless the stone fails to pass. With failure to pass and progression to other **Medical Illnesses**, there is a chance that **Evacuation** or **Loss of Crew Life** could occur. Effects on **Individual Readiness**, **Crew Capability** or **Evacuation** can lead to problems with **Task Performance** that can lead to **Loss of Mission Objectives** or **Loss of Mission** if severe.
- There are several contributing factors that can modify the likelihood of each of the above steps occurring. Those include:
  - **Urine Chemistry** is affected by:
    - Excess calcium in the blood that can occur as a result of **Bone Remodeling** which is affected by the **Bone Fracture (Risk).**
    - Changes in Urine Concentration that are affected by Hydration Status
    - And the **CO2 (Risk)** that affects the acid-base balance in the body.
  - **Nephrolithiasis** is affected by **Individual Factors** such as genetic predispositions as well as by **Astronaut Selection** as those individuals with a high risk of renal stones would not be selected into the Astronaut Corps.
  - Urine Flow is also affected by the Urinary Retention (Risk).
- To counteract the progress of this process, multiple **Crew Health and Performance System** Capabilities must be considered in **Vehicle Design.** These are affected by the **HSIA (Risk).**
- **Medical Prevention Capabilities** can affect several steps in this process:
  - **Water Intake** requirements for crew affect the **Hydration Status** and has been shown to be effective at preventing stone formation.

  - **Potassium Citrate** and **Thiazide** medications directly affect the **Urine Chemistry** and can help prevent stone formation.
  - **Exercise** and **Bisphosphonate** medications directly affect **Bone Remodeling** including the calcium released into the bloodstream.
  - **Nutrients** affect **Urine Chemistry** through the intake of various substances such as oxalate, calcium, magnesium, etc. and must be considered in the **Food and Nutrition (Risk).**
  - Medical Monitoring Capabilities:
    - **Ultrasound Diagnosis** is a key monitoring capability for several reasons. It allows diagnosis and monitoring of **Mineralized Renal Material** and **Nephrolithiasis** before they become significant clinical issues. **Ultrasound** may also detect stones within the ureter.
- It also enables several treatment options discussed below:
  - Medical Treatment Capabilities:
    - Recent progress has been made in focused ultrasound applications that enable non-invasive **Ultrasound Manipulation** of stones in the kidney before they enter the Ureter. It also may enable **Ultrasound Manipulation** of stones in the Ureter including the capability to remove some stones from the proximal or distal Ureter and decreasing the time that crew are symptomatic.
    - In the case of **Hydronephrosis** or **Pyelonephritis**, **Ultrasound** can be used to guide insertion of a **Percutaneous Nephrostomy** Tube that can alleviate symptoms and help stabilize an otherwise sick astronaut.
    - **Tamsulosin** is a medication that relaxes the smooth muscle in the Ureter and can help allow **Ureterolithiasis** to pass faster.
    - **Medications** can include pain medications like NSAIDs and Opioids as well as anti-emetic medications such as Ondansetron that can control the symptoms of the **Medical Illnesses** caused by renal stones. This can also include antibiotics in the cases of **UTI** and **Pyelonephritis**. Effectiveness of all medications is in part affected by the **Pharm (Risk).**
- Failure to diagnose and treat renal stones can lead to **Long Term Health Outcomes** including chronic kidney disease and other issues. **Surveillance** post-mission and post career enables us to **Detect Long Term Health Outcomes** and better characterize the long term risk.

Risk of Spaceflight Associated Neuro-ocular Syndrome (SANS Risk)

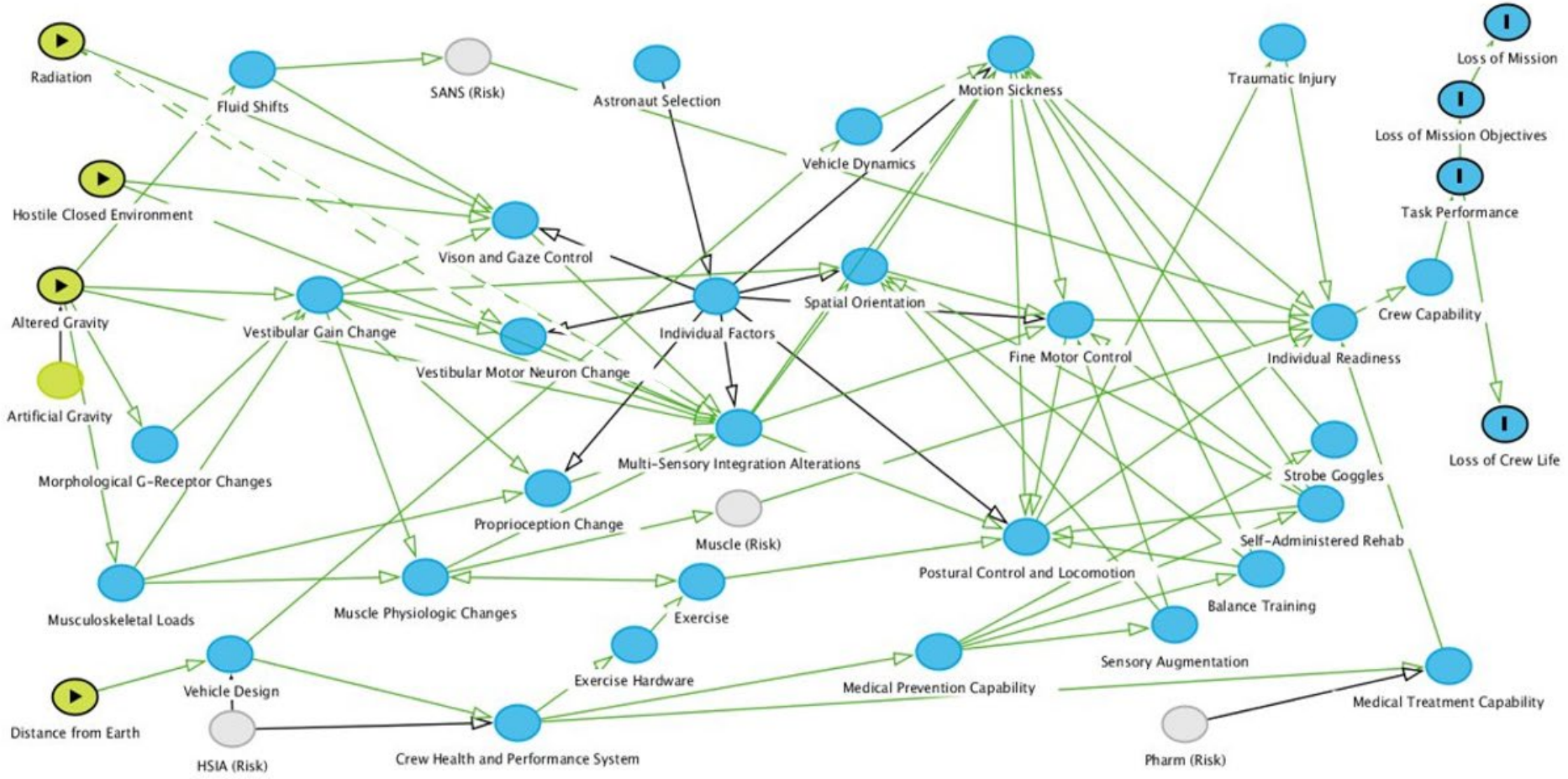


SANS Risk DAG Narrative

- **Altered Gravity** removes (0 g) or reduces (partial g) the hydrostatic pressure gradient, causing a cephalad **Fluid Shifts** within the arterial and venous systems and within the cerebrospinal fluid column. **Individual Factors** such as age, sex, genetic predispositions, pre-existing medical conditions and more influence variability in biologic response to the spaceflight environment. This can affect multiple nodes discussed below.
- These cause physiologic changes including **Venous Congestion** and possibly **Intracranial Pressure Changes** in the brain. **CO2 (Risk)** and **Sleep (Risk)** may have a causal connection to Intracranial Pressure Changes as CO2 is known to cause vasodilation of cerebral arterioles, and impaired sleep may reduce lymphatic/glymphatic clearance from the brain and eye. Invasive measures of **Intracranial Pressure Changes** have not been obtained in-flight.
- These physiologic changes are hypothesized to underlie the structural changes in the eye including **Optic Disc Edema**, **Globe Flattening**, and **Chorioretinal Folding.** Terrestrially, **Optic Disc Edema** can lead to **Retinal Nerve Fiber Layer Atrophy** but this has not been observed in the astronaut population.
- In-mission, these structural changes lead to functional changes in the eye including **Refractive Error Shifts,** and reversible **Visual Field Defects** have been detected postflight. These in turn affect **Individual Readiness** for mission tasks that can progressively affect **Crew Capability** and **Task Performance** overall.
- **Brain Structural Changes** are hypothesized to result from the cephalad fluid shift, but potential acute effects and/or **Long Term Health Outcomes** are unknown.
- To characterize the risk, **Surveillance** is required to **Detect Long Term Health Outcomes** that may present as cognitive or visual decrements post-flight or post-career.
- To assess and counteract the SANS issues in flight, the **Vehicle Design** must include a **Crew Health and Performance System** that provides mass and volume allocations for several countermeasure pathways. Inclusion of these pathways are affected by the **HSIA (Risk).**
- Medical Prevention Capabilities include:
  - **Astronaut Selection** affects and limits the **Individual Factors** present in the crewmembers.
  - **Lower Body Negative Pressure** is under consideration as a preventive countermeasure for many effects of **Fluid Shifts**.
  - Veno-occlusive Thigh Cuffs may reduce Fluid Shifts and may improve Venous Congestion and Intracranial Pressure Changes.
  - **Supplements** such as B vitamins are hypothesized to affect homocysteine pathways and improve microvascular function and reduce edema. These are related to the **Food and Nutrition (Risk).**
  - **Medications** have been considered to prevent **Intracranial Pressure Changes** and these are affected by the **Pharm (Risk).**
- Monitoring Capabilities include:
  - **Optical Coherence Tomography** is used pre-, post-, and in-flight to assess the retina, choroid, and optic nerve head.
  - In-flight **Fundoscopy** to assess gross structural changes in the optic nerve head and retina.

  - Pre- and post-flight **MRI** to track structural changes in the eye and brain.
  - Pre-, post-, and in-flight Ultrasound to assess structural changes within and posterior to the eye.
  - Testing for **Visual Acuity** and **Visual Fields** assess the functional state of the eye. These allow us to **Detect Visual Changes** and guide **Medical Treatment Capability** in-mission.
  - In-Flight direct **Intracranial Pressure Monitoring** is of interest but has not been performed to date. It is speculated that this information could enable us to **Detect Intracranial Pressure Changes** and that information could be used to guide **Medical Treatment Capabilities** in the future.
- Medical Treatment Capabilities:
  - **Corrective Lenses** are the current treatment modality in-mission for visual changes that may affect **Individual Readiness.** This requires the ability to provide corrective lenses with the appropriate corrective power.
  - There is currently no proven inflight pharmaceutical treatment available for SANS.
- **Flight Recertification** has been affected when ocular structure changes (e.g., severe **SANS findings**) and **Intracranial Pressure Changes** have been **detected** post flight.

Risk of Altered Sensorimotor/Vestibular Function Impacting Critical Mission Tasks (Sensorimotor Risk)

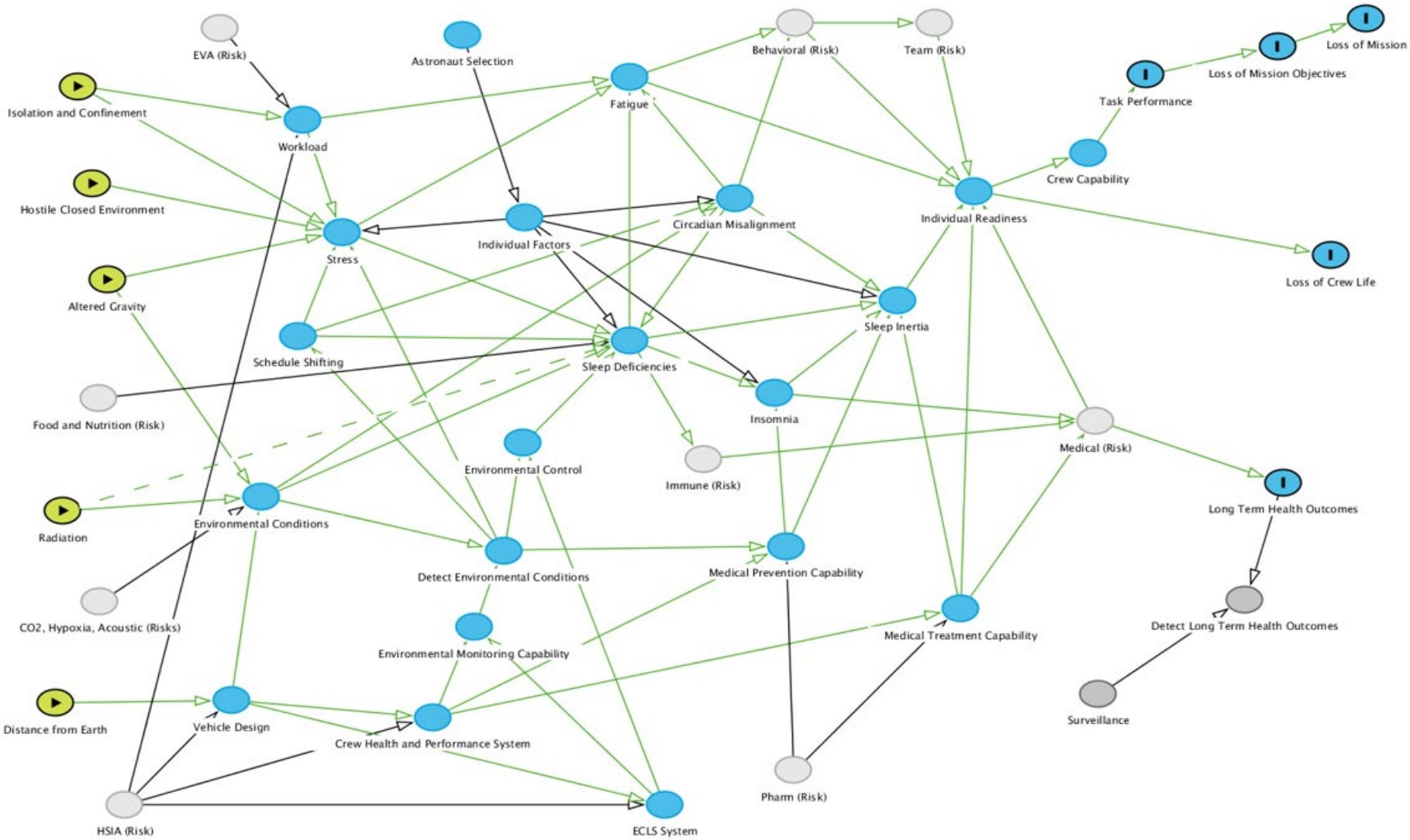


Sensorimotor Risk DAG Narrative

- The Sensorimotor Risk is primarily derived from **Altered Gravity** environmental changes but also has effects from **Radiation** and **Hostile Closed Environment**.
- Time spent in an **Altered Gravity** environment causes physical changes to the body including:
  - **Fluid Shifts** – fluid shifts from the lower body towards the upper body.
  - **Musculoskeletal Loads** – end-organ changes (e.g., otoconia size, changes in neural synapses) to physical unloading.
  - **Morphological G-Receptor Changes** – cellular responses to physical unloading.
- These changes lead to physiologic changes that affect:
  - **Vision and Gaze Control** - vision is the ability to see and gaze control is the ability to orient the eyes, and maintain fixation, on a desired visual target. **Radiation** can induce cataracts that affect vision.
  - **Vestibular Gain Changes -** the relationship between accelerations, including gravitational and vestibular responses.
  - **Vestibular Motor Neuron Changes** - vestibular neurons adapt to reduced or increased firing rates and become more or less sensitive. **Radiation** and the **Hostile Closed Environment** are suspected to affect motor neurons.
  - **Proprioception** - a global term that encapsulates multiple internal sensors that monitor the relationship between one body segment and another.
  - **Muscle Physiologic Changes** - reduced loading on muscle, tendons, and ligaments that cause both structural and functional changes in strength.
- All of these physiologic changes send signals that must be interpreted by the brain and here is represented by **Multi-Sensory Integration Alterations**. **Radiation** and the **Hostile Closed Environment** effects on the central nervous system is suspected to affect this central processing.
- The central nervous system must integrate information from all of these systems. **Multi-Sensory Integration Alterations** lead to functional impairments such as:
  - **Motion Sickness** occurs when vestibular and ocular signals from the brain are conflicting.
  - **Fine Motor Control** limits the ability to perform tasks that require delicate control.
  - **Postural Control and Locomotion** refer to the balance and ability to walk that are required to perform physical tasks in a gravity environment.
- The severity of these functional impairments directly impacts **Individual Readiness** and **Crew Capability** and specific tasks including:
  - Manual Control of Vehicles which depends on Fine Motor Control and perception.
  - EVA (Risk) through the increased likelihood of falls or injury.
  - Crew Egress (Risk) through the increased likelihood of falls or injury.
- These affect **Individual Readiness**, **Crew Capability** and through them **Task Performance** and other Mission Level.

- **Distance from Earth** affects the mass, power, volume, and bandwidth allocations for **Vehicle Design** the **Crew Health and Performance System** in particular. These include:
  - Exercise including Exercise Hardware which affects Postural Control and Locomotion.
  - Medical Prevention Capabilities such as the following are still experimental and include:
    - Strobe Goggles.
    - Self-Administered Rehab.
    - Sensory Augmentation.
    - Balance Training.
- **Medical Treatment Capabilities** can include medications such as Phenergan, etc. that are susceptible to stability issues included in the **Pharm (Risk).**
- **Artificial Gravity** as a countermeasure holds the potential to significantly reduce the Sensorimotor Risk but is high cost to implement.

Risk of Performance Decrements and Adverse Health Outcomes Resulting from Sleep Loss, Circadian Desynchronization, and Work Overload (Sleep Risk)



Sleep Risk DAG Narrative

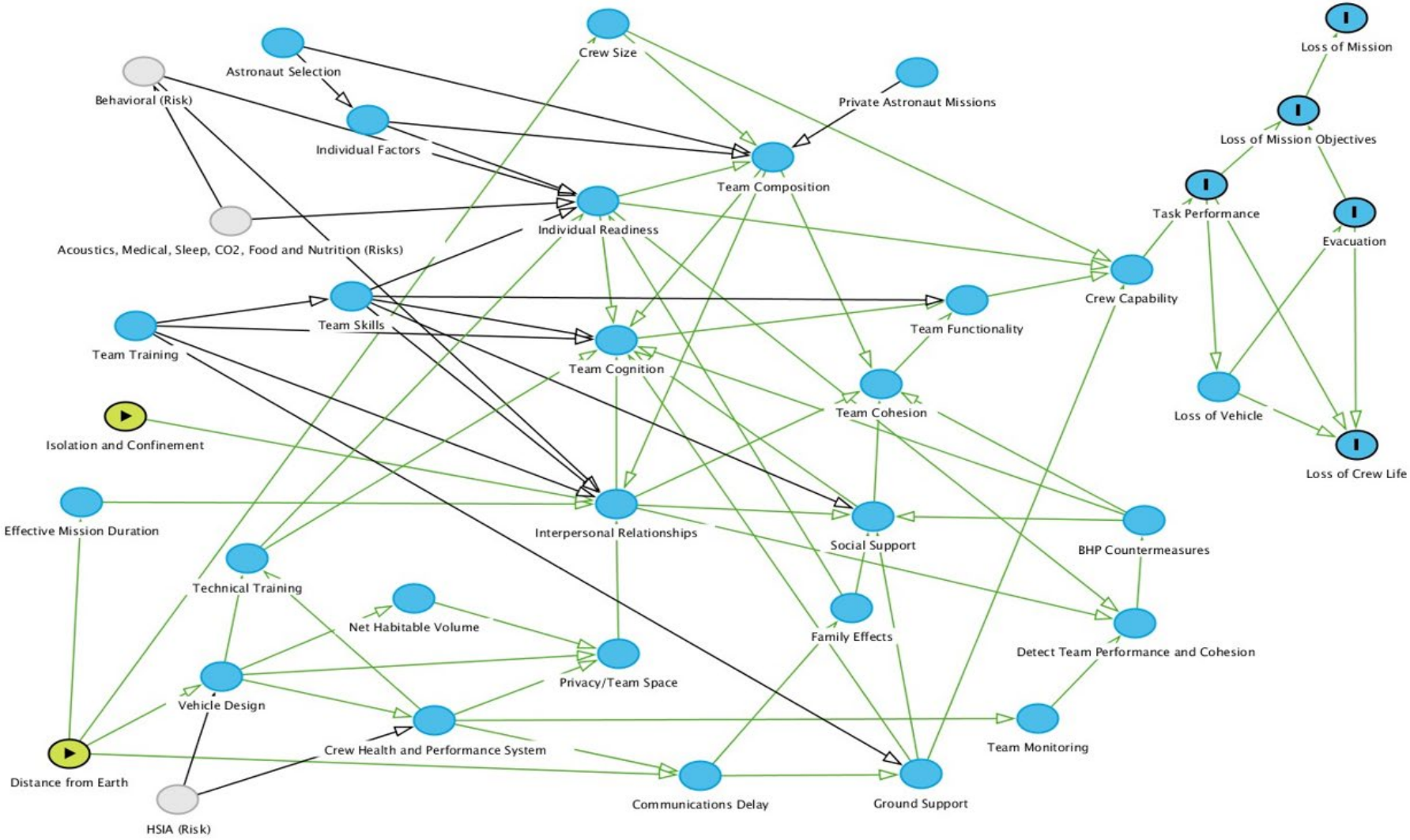
The Sleep Risk is driven mainly by the hazards of **Isolation and Confinement**, **Hostile Closed Environment**, and **Altered Gravity** each of which impacts the **Stress** of the crewmember.

The Sleep Risk focuses around two key nodes:

- **Sleep Deficiencies** occur for a variety of reasons in human spaceflight including:
  - **Schedule Shifting** including slam shifting that has been a common occurrence given arrivals and departures of vehicles from different parts of the world, etc.
  - The **Workload** that an astronaut undertakes, including the strenuous demands of any EVAs represented by the **EVA (risk)**.
  - **Stress** encountered in the mission environment for example as relates to alarms and emergencies.
  - **Environmental Conditions** that are present in the sleep quarters including temperature, humidity, noise, privacy, etc.
  - **Food and Nutrition (Risk)** represents the connection between the food that astronauts are given and can include effects of specific substances like caffeine and insulin and meal-timing relative to sleep timing.
- Circadian Misalignment is dependent on:
  - **Environmental Conditions** specifically including lighting as the intensity, wavelength, and timing of lighting exposure drives circadian entrainment.
  - **Schedule Shifting** including slam shifting that creates an inappropriate series of lighting cues as well.
  - There is also a dependence on **Behavioral (Risk)** and **Team (Risk)** not shown here due to the acyclic requirement.
- When these occur, they can lead to other issues including:
  - **Fatigue** which as a category can include mental fatigue, physical fatigue, sleepiness/drowsiness etc. These all can affect **Crew Capability** by impacting readiness for **Task Performance**.
  - **Sleep Inertia** is amplified when astronauts are chronically sleep deprived, wakes at an adverse circadian phase or from deep sleep or when crew take hypnotic medications. This can affect **Individual Readiness** and **Crew Capability** including the timing to response to alarms for example.
  - **Insomnia** is when sporadic sleep deficiencies become persistent and meet the definition of a clinical medical condition. This is an inability to get adequate sleep when provided adequate opportunity. This is part of the **Medical (Risk)** and leads to further medical issues requiring treatment.
- **Environmental Conditions** are defined by the Vehicle Design and the ELCS System design and are dependent on Standards/Requirements and HSI Processes that are part of the HSIA (Risk). This is specifically true for private sleep quarters IF they are designed into the systems.
  - **Radiation**, including **Solar Particle Events**, can cause **Environmental Conditions** to change.

  - **Environmental Monitoring** enables **Detect Environmental Changes** can cause **Schedule Shifting** when responding (i.e., reconfiguring mass to mitigate radiation exposures) and Stress among the crew in the case of **Solar Particle Events**.
  - There is weak evidence that suggests that Radiation may cause Sleep Deficiencies.
- The **Crew Health and Performance System** includes several potential countermeasures for sleep issues:
  - **Environmental Monitoring** which provides the ability to **Detect Environmental Conditions** relevant to sleep. And, when designed into the **ECLS System**, the ability for the crew to exercise **Environmental Control** over the relevant parameters that disrupt sleep in the sleeping quarters.
  - **Medical Prevention Capability** includes Hypnotic and other medications that may be used in anticipation of **Sleep Deficiencies** that could occur for example in the case of expected Slam Shifting.
  - In cases where sleep issues are not expected or growing, **Medical Treatment Capabilities** may be brought to bear to minimize the consequences of the **Sleep Disturbances** or **Insomnia**.
- Sleep issues can lead to other **Medical (Risk**) issues as well as **Long Term Health Outcomes** including diabetes, hypertension, etc. that should be monitoring in post-flight and post-career crew through **Surveillance** in order to **Detect Long Term Health Outcomes** and better inform the magnitude of the long term health risks associated with Sleep.

Risk of Performance and Behavioral Health Decrements Due to Inadequate Cooperation, Coordination, Communication, and Psychosocial Adaptation within a Team (Team Risk)



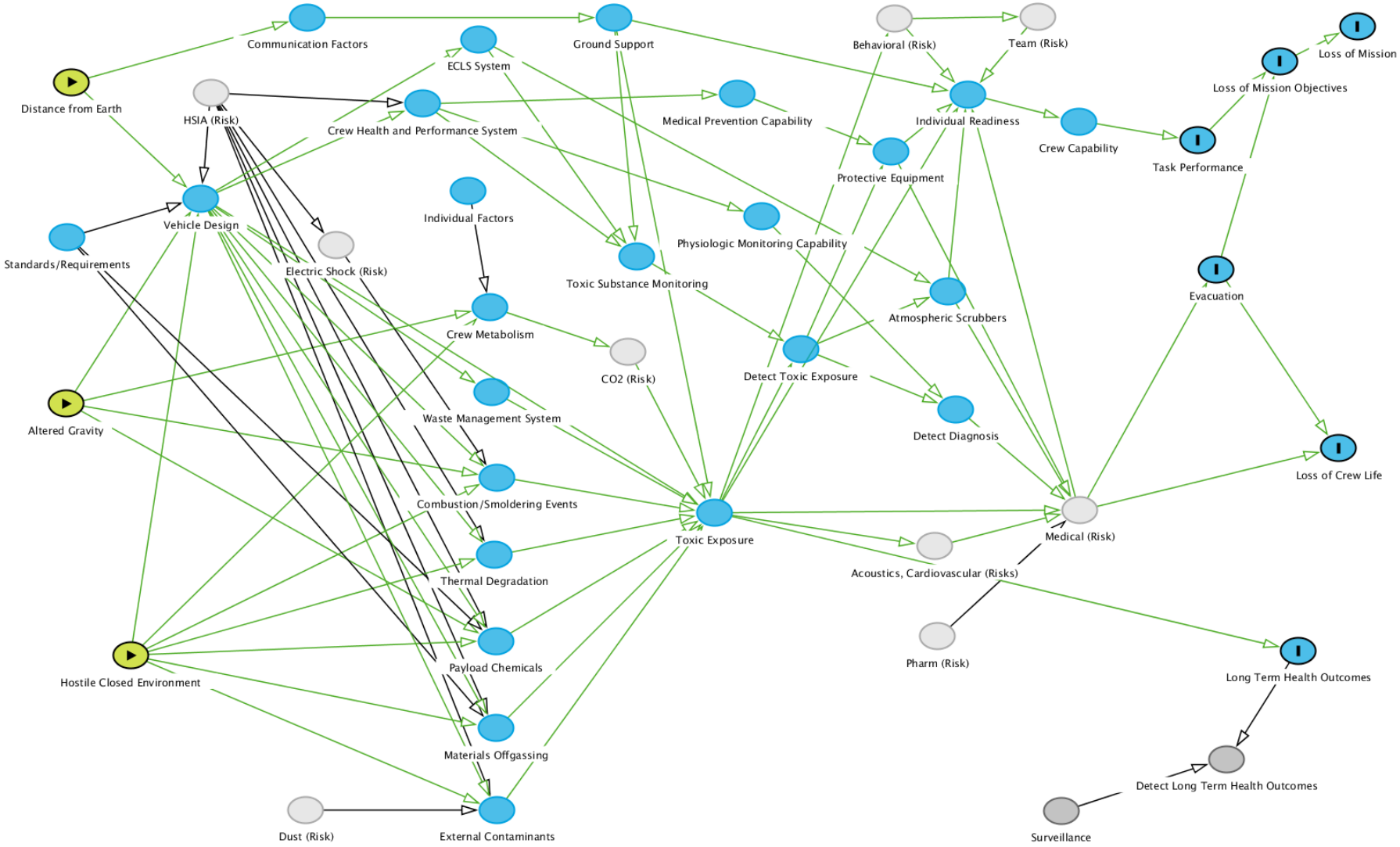
Team Risk DAG Narrative

- **Isolation and Confinement** affects **Interpersonal Relationships** directly and through monotony, boredom, and other possible Behavioral affects that are represented in the **Behavioral (Risk).**
- **Distance from Earth** affects the mass and volume allocations that limit **Vehicle Design** decisions. It also affects **Communications Delays**, influences **Effective Mission Duration**, and affects **Crew Size**.
- The central issue in the Team Risk is that **Team Cohesion**, **Team Skills**, and **Team Cognition** come together to influence **Team Functionality**, and ultimately, **Crew Capability**. **Ground Support**, which will be heavily impacted by communication delays, is an important part of the spaceflight multi-team system. The Team Risk operates downstream of many other Risks, and at a higher level than the individual, but is heavily influenced by the individuals and individual-level Risks in the system.
  - **Duration** is related to distance, but not always, and it has implications for the (likely decremented) team functioning over time.
  - **Crew Size** is another potential stressor that is more loosely tied to the 5 Hazards, but has implications for the knowledge, skills and abilities, relationships, and simply # of person-hours, hands available onboard.
- **Team Functionality** is the degree of coordination, cooperation, communication, and psychosocial adaptation that enables a team to successfully complete tasks and live and work as a team. It is affected by:
  - **Team Cognition** is shared understanding among team members that is related to roles and responsibilities, team mission objectives and norms, and familiarity with team members' knowledge, skills and abilities. **Team Cognition** is supported by many factors related to **Team Composition** and **Interpersonal Relationships,** the team **Training** together, engaging in **Team Skills** and **Social Support**, **Countermeasures** (e.g., debriefs)**,** and **Individual Readiness and Factors** (i.e., individual cognition). **Ground Support** is an important part of **Team Cognition** across the multi-team system.
  - **Team Skills** consist of information sharing, backup behaviors, leadership/followership, team care, and providing social support, among others. **Team Skills** are developed through training and supported by **Countermeasures** such debriefs and psychological support tools and experts. **Team Skills** support **Individual Readiness** to function on a team, offer social support, create and maintain shared **Team Cognition**.
  - **Team Cohesion** is tendency for a group to operate in a unified fashion while working towards a goal or to satisfy the emotional needs of its members. It is affected by **Interpersonal Relationships** that develop through shared values and complementary personalities (**Team Composition**) and **Social Support** during shared experiences.
- **Crew Capability** is the readiness of the entire crew to perform required tasks including the functional capacity as well as knowledge, skills and abilities, at both an individual and team level. Inadequate **Task Performance** during critical team tasks (e.g., EVAs for repairs or surface ops) can lead to **Loss of Vehicle** or **Loss of Mission Objectives** or **Loss of Crew Life**. This is affected by:
  - **Team Functionality** as represented above.

- **Crew Size** effects the pool of available knowledge/skills/abilities and person-hours onboard, as well as **Interpersonal Relationships** via **Team Composition.**
- **Individual Readiness** is affected by several other risks, and it affects the crew capability in a similar fashion to crew size.
- **Communication Delays** also negatively influence the real-time **Crew Capability**, particularly in time pressure situations (e.g., emergency response), by restricting timely troubleshooting by and coordination with **Ground Support**.

- **Countermeasures** and other factors influence the level of **Team Cohesion**, **Team Skills**, and **Team Cognition.** These include:
  - **Training** performed before and during a mission. This includes both technical *and* team skills training /behavioral health training. **Technical training** is dependent on **Vehicle Design** and the design of Vehicle Systems and the **Crew Health and Performance System** and can affect the **Individual Readiness** and shared understanding (**Team Cognition**) of these vehicle systems. **Team Training** affects each **Individual's Readiness** to work and live as a team, affect **Interpersonal Relationships** as they train together, and affect shared understanding (**Team Cognition**) of team norms.
  - **Astronaut Selection** creates a pool of well-qualified, highly skilled, team-oriented individuals (**Individual Factors**). A physically and psychological fit individual (**Acoustics, Medical, Sleep, CO2, Food and Nutrition (Risks), Behavioral (Risk))**, combined with **Team Skills** enhanced through **Team Training**, results in **Individual Readiness**.
  - **Team Composition** is influenced by a given DRM's **Distance from Earth** and **Crew Size**, and by the mission objectives, and the **Individual's Readiness** to meet those objectives. **Team Composition** is an ongoing consideration as different tasks occur throughout the mission, and it does not end when the crew is assigned.
    - The risk introduced by **Private Astronaut Missions** and space tourists is an unknown and may severely disruptive the entire system. Private Astronaut Missions (PAMs) will not have the same level of strategic Selection, Composition, Training, or Countermeasure support as the professional astronauts and will affect **Team Composition**.
  - The HSIA (Risk) influences Vehicle Design and systems (Crew Health and Performance System, Environmental Control), affecting the Net Habitable Volume and the availability of Privacy/Team Space. Both Privacy and shared Team Space (e.g., a dining/worktable) influences Interpersonal Relationships.
  - **Interpersonal Relationships** are affected by the mix of individuals on the mission **(Team Composition, Behavioral Risk**), the **Team Training** experienced together the **Team Skills** they use to support the relationships. **Interpersonal Relationships** particularly during longer **Effective Mission Durations** are a strong predictor of **Team Cohesion**, and how the team provides work and non-work supportive behaviors to coordinate and cooperate **(Social Support, Team Cognition**.
  - **Communication Delays** restrict the degree of **Social Support** provided by **Family Effects**, **Ground Support**, and psychological support **(BHP Countermeasures)** from experts on Earth. **Team Monitoring** allows experts, team members, or autonomous systems to prompt the team to engage in team-supportive countermeasures (e.g., debriefs), but these may be restricted due to **Communication Delays**.

Risk of Toxic Exposure (Toxic Exposure Risk)



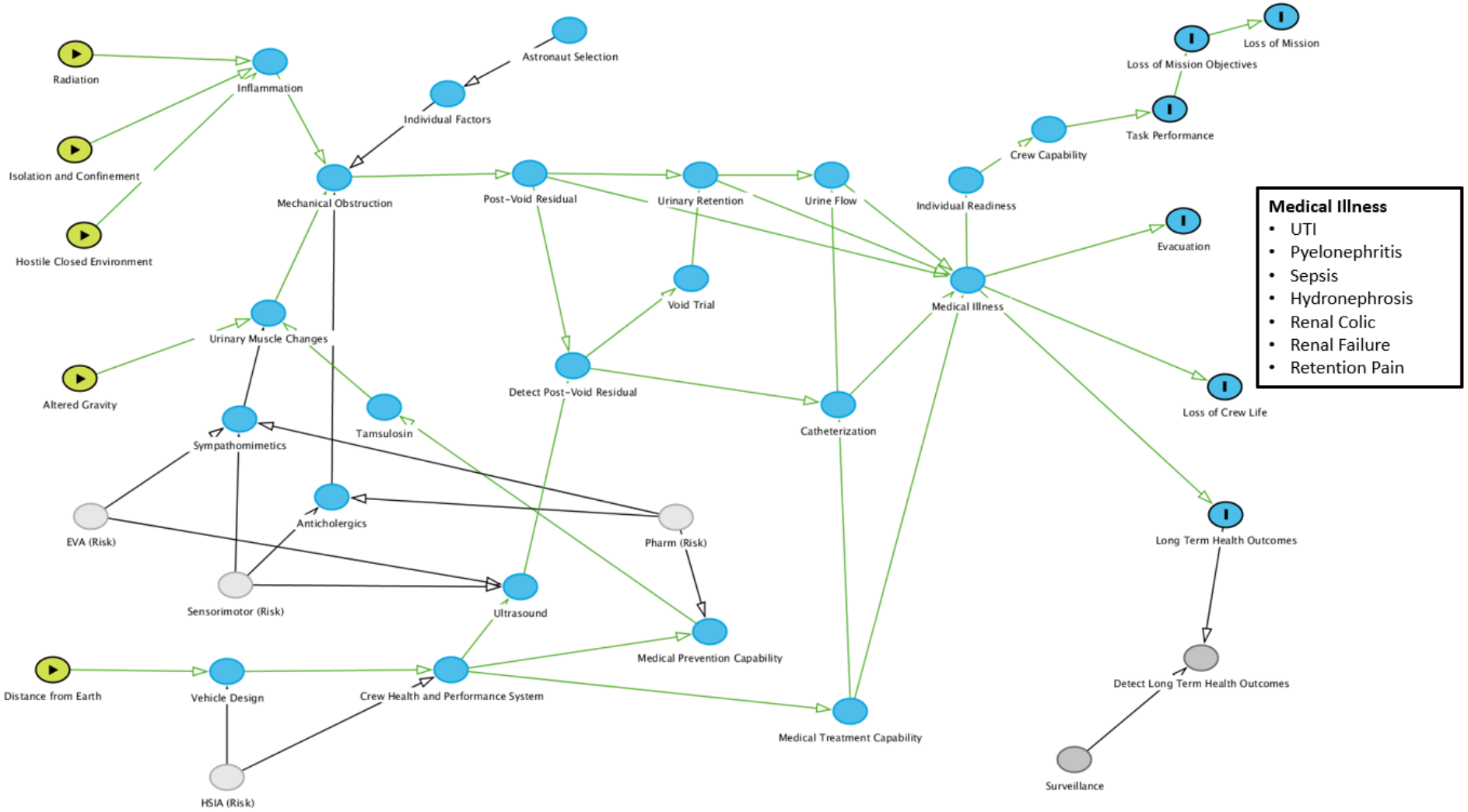
Toxic Exposure Risk DAG Narrative

- Numerous sources of toxic materials onboard spacecraft are impacted by the Hazards:
  - **Altered Gravity** results in increased exposure risk to floating particles and liquids, reduced dispersion of gases in areas that aren't well ventilated, and greater difficulty in capturing and cleaning a release.
  - A **Hostile Closed Environment** limits removal capabilities and increases exposure likelihood (small volume for gases and volatiles to fill).
- **Toxic Exposure** is dependent on the release of toxic substances into the interior of the spacecraft or spacesuit that can affect the health and performance of the astronauts. This can be caused by:
  - **Crew Metabolism** includes the CO2 (Risk) exhaled by the crew which in some cases can reach toxic levels. Biovariability is determined by **Individual Factors**.
  - **Waste Management System** includes the above as well as chemicals used for neutralizing/cleaning and waste from bodily functions.
  - **Combustion/Smoldering Events** have happened in prior spaceflight and can result in release of Carbon Monoxide, weak acids, and other toxic substances. This is in part dependent on the **Electric Shock (Risk)**.
  - **Thermal Degradation** is the result of heated materials such as plastics that are not combusting but are releasing toxic vapors into the local atmosphere.
  - **Payload Chemicals** refers to chemicals that may be brough on-board by a visiting spacecraft or payload that is not always present in the vehicle systems.
  - **Materials Off-Gassing** occurs for plastics, rubbers, and other substances that are not thermally dependent.
  - **External Contaminants** such as lunar or Martian **Dust (Risk)** may be brought into the vehicle or habitat.
- All of these except **Crew Metabolism** are dependent on Vehicle Design and the HSIA (Risk).
- If a **Toxic Exposure** occurs, there are several pathways to affect **Individual Readiness** and **Crew Capability** including:
  - Some toxins have cardiovascular toxicities – **Cardiovascular (Risk) -** that can lead to dysrhythmias and myocardial tissue damage.
  - Some toxins are **Ototoxins** and can affect the **Acoustics (Risk).**
  - Several toxins can cause **Environmental Injuries** such as CO poisoning or Ammonia inhalation that can occur from coolant release and other **Medical (Risk)** issues that can lead to consequences such as **Evacuation**, **Loss of Crew Life** or **Long Term Health Outcomes**.
  - These can also lead to **Behavioral (Risk)** issues including altered mental status, effects on **Cognitive Function**, and **Psychological Status** that can affect the **Team (Risk).**
- If a **Toxic Exposure** occurs, then the ability of the crew to mitigate the problem depends on what has been designed into the **Vehicle Design** and the **Crew Health and Performance System**, and **ECLS System**.
- Toxic Substance Monitoring enables Detect Toxic Exposure which can drive countermeasure use such as using Atmospheric Scrubbers or donning Protective Equipment. Protective Equipment is

part of the Medical Prevention Capabilities designed into the Crew Health and Performance System.

- **Physiologic Monitoring Capability** can include physical and laboratory biomarkers that can identify the physiologic response of an affected astronaut and help **Detect Diagnosis** to tailor medical care which is part of the **Medical (Risk)**.
- Effectiveness of medical interventions is in part dependent on the **Pharm (Risk)** for **Pharmaceutical Effectiveness**.
- Historically the detection of system issues that can lead to **Release of Toxic Substances** has in large part depended on **Ground Support** from **Mission Control**. This is available in LEO, but **Communication Factors** must be considered in DRMs that have more **Distance from Earth**. Increased autonomy needs for crews may drive an increased monitoring capability to reduce the risk of toxic exposures.
- Some toxic exposures can lead to **Long Term Health Outcomes** such as cardiovascular, pulmonary, renal, and other medical conditions. **Surveillance** such as occupational health surveillance post-flight and post career is critical to **Detect Long Term Health Outcomes** and better characterize the magnitude of the Long Term Health risks.

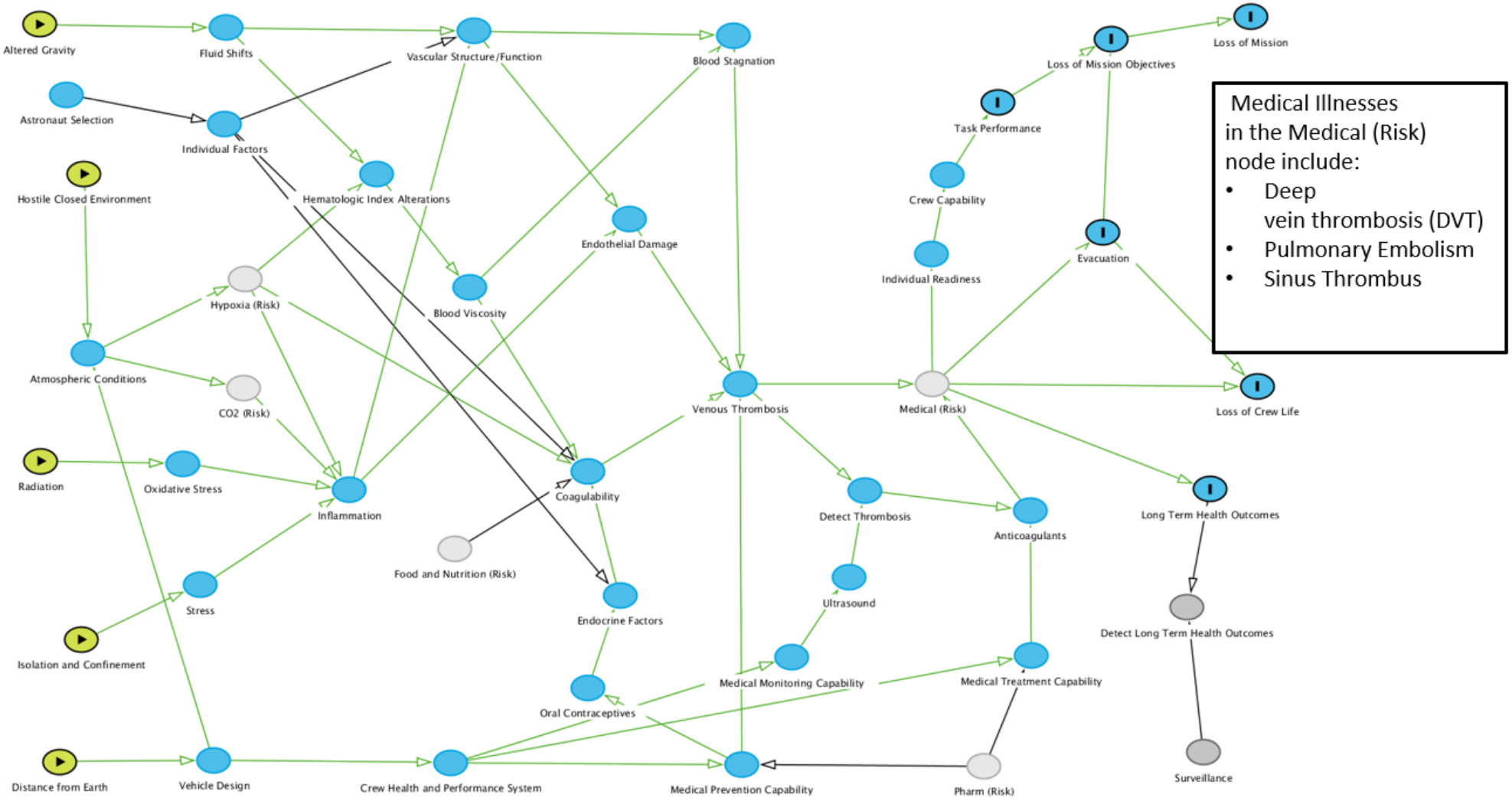
Risk of Urinary Retention (Urinary Retention Risk)



Urinary Retention Risk DAG Narrative

- The central focus of the Urinary Retention DAG begins with the **Urinary Retention** node which is the point at which the retention of urine in an astronaut reaches a clinically significant level. **Inflammation** can result from the hazards of **Radiation, Hostile Closed Environment, and Isolation and Confinement**. Prior to that, astronauts may retain urine that they are not aware of and this is called **Post-Void Residual**. Retention may be intentional in some situations. When retained urine begins to affect **Urine Flow**, this can lead to several Medical Illnesses that can affect **Individual Readiness** and **Crew Capability** including:
  - Infectious processes like **Urinary Tract Infections**, **Pyelonephritis** (kidney infection) and potentially **Sepsis** if untreated, can result from **Urinary Retention**.
  - Renal Colic, Retention Pain, and Hydronephrosis can result from **Urinary Retention** or **Urine Flow** disruption.
- All of these, if untreated, can potentially lead to **Renal Failure** which has implications for **Evacuation**, **Loss of Crew Life** and **Long Term Health Outcomes**.
- Retention of urine can be cause by **Mechanical Obstruction** at the level of the urinary bladder or prostate (in men). Retention may also be intentional in some situations (e.g. not wanting to use MAG). Retention is affected by **Individual Factors** like age, sex, and genetic predispositions and can be caused by:
  - **Urinary Muscle Changes** that occur in **Altered Gravity** environments or due to Side Effects of certain medication classes including **Sympathomimetics** and **Anticholinergics** used for **EVA (Risk)** mitigation, **Sensorimotor (Risk)** mitigation, Space Motion Sickness, and congestion.
  - **Inflammation** in the bladder or prostate
- Countermeasures must be designed into the mass and volume allocations for the **Vehicle Design** and **Crew Health and Performance System** to effect risk mitigation. These are affected by the **HSIA (Risk)** and include:
  - **Ultrasound Monitoring** is used to **Detect Post-Void Residual** when increased, and if severe can inform the use of countermeasures such as a **Void Trial**.
  - Medical Prevention Capability such as Tamsulosin can help to relax Urinary Muscle Changes.
  - **Medical Treatment Capability** such as **Catheterization** may be needed to relieve **Urinary Retention** and prevent the development of other **Medical Illnesses**. Other medical treatments may be needed if **Medical Illness** progresses (i.e. **UTI** -> **Pyelonephritis** -> **Sepsis**).
- Effectiveness of the Medical Prevention Capability and the Medical Treatment Capability is dependent on the Pharm (Risk).
- **Long Term Health Outcomes** may occur and **Surveillance** is needed post-flight and post-mission to help **Detect Long Term Health Outcomes** and characterize the magnitude of the Long Term Health risk contribution.

Concern of Venous Thromboembolism (VTE Concern)



VTE Concern DAG Narrative

- **Venous Thromboembolism** development centers around Virchow's Triad which leads to thrombosis.
- **Blood Stagnation** – the flow of blood is altered in spaceflight.
- **Blood Coagulability** - changes in the coagulation factors of blood during spaceflight.
- **Endothelial Damage** – damage to wall of blood vessels that exposes underlying tissue.
- **Astronaut Selection** affects and limits the **Individual Factors** present in the crewmembers. **Individual Factors** such as genetics, age, sex, smoking habits, etc. Can all affect likelihood of changes in Virchow's Triad.
- Specific possible causal paths include:
  - **Fluid Shifts** that occur in spaceflight can lead to distension and alteration of **Vascular Structure/Function** which in turn can cause **Blood Stagnation** leading to **Venous Thrombosis**.
  - **Hematologic Index Alterations** such as changing hematocrit in response to hypoxia and atmospheric conditions can lead to **Blood Viscosity** changes which affect **Coagulability** and the likelihood of **Venous Thrombosis**.
  - Oxidative Stress and/or Psychological Stress can lead to Inflammation which can lead to Endothelial Damage by altering of Vascular Structure/Function.
- Medical conditions of concern include **DVT, Pulmonary Embolism or Sinus Thrombus,** all of which can lead to changes in **Individual Readiness** and **Crew Capability** affecting **Task Performance,** likelihood of **Evacuation** for medical reasons and in severe cases can contribute to **Loss of Crew Life.**
- Countermeasures against VTE must be included in the **Crew Health and Performance System** and accommodated in **Vehicle Design**.
- **Medical Prevention Capability** including the use of **Oral Contraceptives,** which are used to mitigate abnormal uterine bleeding during flight but can also increase the risk thrombosis.
  - **Medical Treatment Capability** includes **Anticoagulants** and other medications and supportive care.
  - The effectiveness of medications are modified by the **Pharm (Risk)** as medications used are subject to stability and PK/PD issues.
  - **Medical Monitoring Capability,** such as ultrasound, is needed to detect a thrombus .

Long Term Health Outcomes that may occur as a result of VTE must be included in Surveillance post flight and post-career in order to effectively Detect Long Term Health Outcomes and characterize the magnitude of this risk in the Long Term Health domain.

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Appendix A - DAGtionary

To avoid the paradigm, where different teams of experts use different terminology to refer to the same concept, a dictionary of common terms, the DAGtionary, was developed. The DAGtionary enforces common terminology for node names across the Human System Risk Board direct acyclic graphs (DAGs). These nodes provide points of connection between the DAGs. The DAGtionary was approved by the HSRB and will be configuration managed along with the DAGs themselves.

When definitions already existed in NASA STD 3001 this document attempted to utilize those terms. However, discrepancies may exist and in those cases each document's definitions are exclusive to each respective document.

Appendix A – Directed Acyclic Graph Dictionary

Nodes	Definitions	Additional Notes
Absorption	One of the four pharmacokinetic parameters that describe how a drug is dissociating from its dosage form, dissolving in body fluids, and diffusing across biological membranes.	
Acoustics (Risk)	Risk of Hearing Loss and Performance Decrements Due to Acoustics Issues in Space; also referred to as the Hearing Loss Risk.	Risk Statement: Given changes in environmental (e.g., noise) and physiological conditions in space flight, there is the possibility that the auditory system will experience temporary or permanent reductions in hearing sensitivity or that crew performance will be impacted
Aerobic Fitness	The ability to perform dynamic exercise that involves large muscle groups at a moderate to high intensity for prolonged periods.	$\dot{V}O_2$max is the gold standard measurement index of aerobic capacity.
Aerobic (Risk)	Risk of Reduced Physical Performance Capabilities Due to Reduced Aerobic Capacity.	Risk Statement: Given that exposure to a microgravity environment causes cardiovascular fitness (maximal aerobic capacity) to decline, there is a possibility that mission task performance would be impaired, or tasks could not be performed.
Air Contamination	Harmful or poisonous substances affecting air quality within the vehicle or habitat in-mission.	
Airlock Design	An airtight room with two entrances that provides an isolated volume for transfer between a pressurized vehicle and the vacuum of space.	
Altered Gravity	Gravity environment that is less than Earth-normal (1g)	Human System Risk Hazard - Exposure to a gravity environment that is less than Earth-normal begins a process of adaptation; some of these adaptations create issues for human bodies that developed to function in a 0g (gravity) environment.
Ambient CO_2 Level	Concentration of carbon dioxide (CO_2) in occupied spaces with air exchange; the distributed cabin CO_2 level.	The regulatory definition of ambient air is - that portion of the atmosphere, external to buildings, to which the general public has access.
Anomalous Events	Occurrences that are inconsistent with or deviating from what is usual, normal, or expected.	
Anthropometry	The science of measuring the human body and its parts and functional capabilities. Includes lengths, circumferences, body mass, etc. (NASA-STD-3001)	Anthropometry is used to understand human physical variation and to recommend appropriate accommodations for vehicle/crew interfaces. An individual's anthropometry may

Appendix A – Directed Acyclic Graph Dictionary

Nodes	Definitions	Additional Notes
		predispose them to certain injuries.
Anticholinergics	Competitive antagonists of the neurotransmitter acetylcholine at central and peripheral receptor sites within the cholinergic system.	Anticholinergics can cause physiologic effects on circulation, respiration, alertness, urination, and vision; they are used to treat many conditions (e.g., cholinergic toxicity, urinary incontinence, respiratory disorders, cardiovascular disease, and alertness disorders).
Anticoagulants	A group of chemical substances, including drugs known as blood thinners that increase the time it takes for blood to clot.	Anticoagulants are used to treat blood clots, or in conditions where the risk of blood clots is increased (e.g., stroke or heart attacks).
Antimicrobial Resistance	The ability of a microorganism (bacteria, virus, fungi, parasite) to resist the effects of antimicrobial drug treatment.	Antimicrobial Resistance occurs when bacteria, viruses, fungi, and parasites change over time and no longer respond to medicines making infections harder to treat and increasing the risk of disease spread, severe illness and death.
Arc Flash/Sparking	Arc flash is a type of electrical explosion or discharge that results from a connection through air to ground or another voltage phase in an electrical system. · Arc - a high temperature luminous electrical discharge across a gap · Spark - a small incandescent particle created by some arcs	Injuries from arc flash/sparking can include external burns (i.e., severe burns to the skin), internal burns and intoxication from inhaling hot gasses and vaporized metal, hearing damage, eye damage and blindness from the ultraviolet light of the flash as well as many other devastating injuries.
Arterial Gas Embolism	A blockage of blood supply caused by air bubbles in a blood vessel or the heart.	Causes of an arterial gas embolism may include trauma, surgery, and decompression sickness. Symptoms can include breathing difficulty, chest pain, and confusion. Treatments include hospital care, oxygen, removing air from the heart, and a high-pressure chamber.
Artificial Gravity	The creation of an inertial force that mimics the effects of a gravitational force, usually by rotation.	
Aspiration	Inhalation of material not usually in the respiratory system.	Aspiration of vomitus, blood, or mucus may occur when a person is unconscious.
Astronaut	An individual selected and trained to travel into space and to monitor, operate, and control parts of, or the whole space system to complete mission objectives.	An astronaut may or may not be assigned to a mission.
Astronaut Selection	The narrowing down of the pool of individual applicants to the most suitable for spaceflight.	Astronaut selection involves assessing qualifications and experiences, physical and medical condition/history, as well as

Appendix A – Directed Acyclic Graph Dictionary

Nodes	Definitions	Additional Notes
		psychiatric health and job-relevant psychological competencies (e.g., decision-making skills, leadership skills, interpersonal skills) using multiple methods such as interviews, psychological tests, and individual and team-based behavioral evaluations, to finalize selection of applicants that will be employed by NASA as astronaut candidates. Not to be confused with Crew Assignment which is the narrowing down of the pool of trained Astronauts for specific missions.
Atmospheric Conditions	The composition of the invisible gaseous substances within the vehicle/habitat (e.g., nitrogen, oxygen, argon, carbon dioxide) as well as the pressure, temperature, humidity, etc.	
Atmospheric Dust Level	The quantity of particulate matter in the air.	
Atmospheric Mixing	The process of maintaining the correct balance of oxygen, nitrogen, water vapor, and carbon dioxide (CO_2) in an enclosed environment.	
Atmospheric Scrubbers	Life support equipment that removes metabolic, off-gassing, and other contaminants from breathable air.	
Autonomous Systems	The combination of elements that function together to produce the capability to meet a need that under specified conditions, functions without intervention by the crew.	The elements of autonomous systems include all hardware, software, equipment, facilities, personnel, processes, and procedures needed for this purpose.
Balance Training	Training designed to improve upright balance by strengthening postural muscles and/or improving the use of visual/vestibular/somatosensory information for appropriate postural adjustments.	
Barotrauma	Injuries caused by changes in pressure.	Barotrauma injuries can occur during airplane flights or scuba diving; barotrauma of the ear is common; barotrauma of the lung may be fatal.
Behavioral (Risk)	Risk of Adverse Cognitive or Behavioral Conditions and Psychiatric Disorders.	Risk Statement: Given that crews of future exploration missions will be exposed to extended durations of isolation and confinement, greater distances from Earth, as well as increased exposures to radiation and altered gravity, there is a possibility that these singular or combined hazards could lead to (a)

Appendix A – Directed Acyclic Graph Dictionary

Nodes	Definitions	Additional Notes
		adverse cognitive or behavioral conditions affecting crew health and performance during the mission; (b) development of psychiatric disorders if adverse behavioral health conditions are undetected or inadequately mitigated; and (c) long term health consequences, including late-emerging cognitive and behavioral changes.
BHP Countermeasures	Behavioral health and performance (BHP) actions, procedures, equipment, standards, or requirements.	These countermeasures prevent or mitigate decrements to astronaut behavioral or cognitive health and performance.
BHP Family Services	Behavioral health and performance (BHP) support including counseling for astronauts and their families; launch and landing support; and in-mission psychological support.	Examples include regular care packages and private family conferences between astronauts and their families to facilitate real-time one-on-one communication before, during, and after a long-duration missions.
BHP Intervention Capability	Behavioral health and performance (BHP) countermeasures used *in mission.*	Examples include private psychological conferences and pharmaceutical treatment.
BHP Monitoring Capability	Behavioral health and performance (BHP) ability to watch, observe, and track astronaut behavioral health, cognitive and emotional performance to implement interventions as needed.	
BHP Prevention Capability	Behavioral health and performance (BHP) support to prevent decline of astronaut behavioral health and cognitive performance; used in all mission phases.	
Biologic Response	Reaction of an organism to a change in its environment.	
Biomedical Exposures	Pre-flight research and medical tests utilizing ionizing radiation.	Exposures can include medical imaging such as CT scans, X-Rays, etc.
Bisphosphonates	A group of medicines that slows down or prevent bone loss, preserving bone strength.	
Blood Stagnation	A decrease in blood flow velocity or net movement of blood through a vessel.	Blood stagnation usually results from changes in pressure or obstruction to flow.
Blood Viscosity	A measure of the resistance to blood flow.	The viscosity is measured by the internal friction modified by the relative amounts of its constituents.
Body Posture	The position the body or body segments such as extremities relative to each other and to accelerations or forces experienced within a vehicle or suit.	

Appendix A – Directed Acyclic Graph Dictionary

Nodes	Definitions	Additional Notes
Bone Density	Mineral content within a projected image of bone (area) or a spatial volume of bone.	
Bone Formation	Process by which osteoblasts produce new mineralized bone tissue.	
Bone Fracture	Partial or complete break in a bone.	
Bone Fracture (Risk)	Risk of Bone Fracture due to Space flight-induced Changes to Bone.	Risk Statement: Given the skeletal changes that occur during space flight, there is a possibility that the bones of crewmembers during and after space flight are not as strong as they were before space flight and a fracture may occur postflight for activities otherwise unlikely to induce fracture prior to space flight.
Bone Remodeling	Highly regulated process by which old or damaged bone tissue is removed and replaced with new bone material.	Alterations to the bone remodeling process during space flight may weaken bones or impair fracture healing.
Bone Resorption	Process by which osteoclasts break down the tissue in bones and release calcium from bone tissue to the blood.	
Bone Structure	Spatial distribution of bone tissue (minerals and collagen matrix) in a 3D volume of whole bone.	
Brain Structural Changes	Anatomical alterations to the brain.	Changes due to spaceflight are usually considered to be upward shift of the brain within the calvarium, increased ventricle size, etc.
Breathing Masks	Emergency equipment providing protection from hypoxia through exclusion of harmful dusts, fumes, vapors or gases and provision of oxygen or clean air.	
Burn Treatment Capability	Medical management and care of a burn.	One example is the ability to provide relief of symptoms and prevent infection.
Burns	Tissue injury resulting from excessive exposure to thermal, chemical, electrical, or radioactive agents.	
Cabin Visibility	Ability to see within the habitable volume.	
Cancer	A large group of almost 100 diseases. Its two main characteristics are uncontrolled growth of the cells in the human body and the potential ability of these cells to migrate from the original site and spread to distant	

Nodes	Definitions	Additional Notes
	sites.	
Cancer Model	A health-effects model intended to provide estimates of cancer risk and uncertainties for defined space radiation exposure scenarios.	
Cancer Treatment	Use of surgery, radiation therapy, medications, and/or other therapies to cure a cancer, shrink a tumor, or reduce tumor burden.	
Capability	Having attributes (such as physical or cognitive) required for performance. (NASA-STD-3001)	
Cardiac Structure/Function	The anatomy and physiology of the heart and coronary vessels.	
Cardiovascular (Risk)	Risk of Cardiovascular Adaptations Contributing to Adverse Mission Performance and Health Outcomes.	Risk Statement: Given that exposure to the space flight environment can contribute to cardiovascular deconditioning, dysfunction, and remodeling, there is a possibility that crews will experience impaired performance and negative cardiovascular health outcomes during and after space flight and planetary operations.
Cartilage Defect	A focal area of damaged cartilage at an articular surface (the surface where bones meet).	
Catheterization	Introduction of a catheter, a tubular, flexible instrument, passed into the body for withdrawal of fluids from (or introduction of fluids into) a blood vessel a body cavity.	Examples include insertion of a catheter into the urethra to drain the urinary bladder or percutaneous tubes that can drain areas in the abdomen.
Central Nervous System Changes	Alterations in Central Nervous System function that may be temporary or persistent.	CNS changes may be a result of a singular or synergistic combination of space flight hazards, such as alterations to brain or cerebral spinal fluid volume or distribution, cerebral blood flow, cellular function, etc.
Charged Particles	An atomic particle that has an electric charge, either positive or negative.	Examples of charged particles include protons, electrons, and ions.
Charged Surface	Surface with non-zero electric charge which exhibits electrostatic attraction or repulsion in the presence of other matter with charge.	
Chondrocyte Metabolism	Chondrocyte metabolism is normally oxidative phosphorylation. If the microenvironment around the	Chondrocyte metabolism is thought to be part of the process responsible for osteoarthritis (OA) and a potential target of

Nodes	Definitions	Additional Notes
	cartilage changes (usually inflammatory changes), then it results in a shift in the chondrocyte metabolism to glycolysis.	pharmacologic countermeasures for OA.
Chorioretinal Folds	Undulations of the choroid, Bruch's membrane (BM), retinal pigment epithelium (RPE), and the overlying retina. Can be subdivided into choroidal folds, retinal folds, and peripapillary wrinkles.	
Circadian Misalignment	Desynchronization between the timing of the master circadian pacemaker in the suprachiasmatic nucleus (SCN) of the hypothalamus and sleep wake timing or desynchronization between the SCN and peripheral oscillators, such as those in the gut, liver, and reproductive organs.	Circadian rhythm is synchronized to the environmental sleep-wake schedule via light exposure and can adapt to different sleep-wake schedules (e.g., jet lag) with sufficient light exposure and as long as such schedules are within the range of entrainment (~23.5-25 h). Timing, intensity, wavelength, duration, and pattern of light exposure determine how quickly the circadian rhythm will shift to a new schedule. Misalignment can be caused by inappropriately timed or insufficiently comprised lighting and large schedule shifts. Can cause sleep deficiency and associated exacerbation of cognitive impairment.
Cleaning	Physical removal of dust, microbes, marks, or other impurities, from the habitat/suit by washing, wiping, or disinfecting.	
Clinically Significant Immune Dysregulation	Refers to altered immune cellular function, inflammation, etc., reached a level which creates demonstrable / measurable / prognostic indication for impending disease.	
CO_2 Physiologic Changes	Measurable variances in cellular, tissue, organ, or body function that are caused by CO_2 concentrations.	CO_2 Physiologic Changes refers to specific changes caused by CO_2 and does not delineate specific biomarkers at this level. These changes may be cumulative with physiologic changes in other risks due to other causes.
CO_2 Production	Generation and release of CO_2.	CO2 production can be caused by humans or other spacecraft sources (SPHERES, etc.).
CO_2 Removal	Elimination of CO_2.	CO_2 removal is primarily via environmental control and life support systems in the context of spacecraft.
CO_2 (Risk)	Risk of Nominal Acute and Chronic Ambient Carbon	Risk Statement: Given that average cabin CO_2 levels in

Appendix A – Directed Acyclic Graph Dictionary

Nodes	Definitions	Additional Notes
	Dioxide Exposure in Crewed Vehicles.	spacecraft are maintained above ambient terrestrial levels with routine occurrence of short-term spikes and that the correlation between the cabin average and actual crew exposures remains unknown, there is a possibility that short-term and long-term CO_2 exposures will adversely impact crew health and performance.
Coagulability	A measure of the capability to form a blood clot, modified by specific factors and biochemical pathways.	
Cochlear Changes	Permanent or temporary alterations to the structure or function of the inner ear (cochlea), usually for the worse.	Cochlear changes may be gradual or sudden and affected by internal (disease, genetics, etc.) or external (noise, ototoxins, pressure changes, etc.) factors.
Cognitive Function	Any mental process that involves symbolic operations. Cognitive function encompasses awareness and capacity for judgment.	Cognitive function includes the mental processes of perception, learning, memory, comprehension, judgment, and reasoning. (NASA-STD-3001)
Combustion/Smoldering Events	Burning gasses or vapors that are undergoing combustion.	The events lead to production of byproducts including carbon monoxide, carbon dioxide, nitrogen oxides, particulate matter (smoke), and volatiles specific to combusted materials.
Communication Factors	Circumstances that effect the communication systems which include information provided to and from the crew by way of voice, text, video, and/or telemetry (NASA-STD-3001); this includes constraints on communication between a crew and ground support personnel.	Examples of communication factors are bandwidth, stability/consistency of link, and delay due to distance from Earth.
Communications Delay	Time delay between when a communication is sent to when the communication is received.	
Compartment Isolation	Use of a small room/airlock to modify the environment in preparation for upcoming tasks.	An example of compartment isolation is isolating the airlock and dropping the pressure to avoid impacts on resources for the whole stack plus the impact on science to depress the entire cabin.
Connective Tissue Changes	Changes to the tissue (bone, cartilage, fat, blood, or lymphatic) that supports, protects, and gives structure to other tissues and organs in the body.	Changes during a mission may predispose a crewmember to MSK injury.
Crew	Two or more astronauts assigned to a mission that have been trained to monitor, operate, and control parts of,	

Nodes	Definitions	Additional Notes
	or the whole space system. (NASA-STD-3001)	
Crew Assignment	The selection of individual astronaut crewmembers to a specific mission.	
Crew Capability	Represents the ability/readiness of the entire crew to perform a task. Includes functional capacity and knowledge, skills, and abilities.	
Crew Composition	See Team Composition.	
Crew Egress (Risk)	Risk to Vehicle Crew Egress Capability as Applied to Earth and Extraterrestrial Landings.	Risk Statement: Given that there are new spacecraft that will transport crews to the Moon and Mars surface and return them to Earth, that these spacecraft have diverse landing modalities and will function in different landing environments, and that the crew may be deconditioned on landing, there is a possibility that astronauts will not be able to independently egress the vehicles, may not be able to perform post-landing tasks in a timely manner, and may be unable to perform surface EVAs post-landing, including those required for emergencies.
Crew Health and Performance System	Vehicle system that provides health and performance support to crew.	
Crew Metabolism	Total amount of the biochemical reactions involved in maintaining the living condition of the cells of the crew.	
Crew Size	The total number of astronauts on a mission team that have been trained to monitor, operate, and control parts of, or the whole space system in the vehicle/habitat.	
Crew Vehicle Integration	What vehicle and systems are fielded, how complex and maintainable they are, and how information on system state is provided back to crew and ground support.	
Data Accessibility	The degree to which crew can access and meaningfully use data gathered by spacecraft systems and medical systems.	
Data Architecture	The models, policies, rules, and standards that govern which data is collected and how it is stored, arranged, integrated, and used in data systems.	

Appendix A – Directed Acyclic Graph Dictionary

Nodes	Definitions	Additional Notes
DCS (Risk)	Risk of Decompression Sickness (DCS).	Risk Statement: Given that tissue inert gas partial pressure is often greater than ambient pressure during phases of a mission (primarily EVA), there is a possibility of decompression sickness.
DCS Type I	Decompression Sickness Type I - A sickness induced by too rapid a decrease in atmospheric pressure sufficient to cause bubbles to form from gases (normally nitrogen [N2]) dissolved in blood and other body tissues. (NASA-STD-3001)	DCS Type I tends to be mild and affects primarily the joints, skin, and lymphatic vessels.
DCS Type II	Decompression Sickness Type II - A sickness induced by too rapid a decrease in atmospheric pressure sufficient to cause bubbles to form from gases (normally nitrogen [N2]) dissolved in blood and other body tissues. (NASA-STD-3001)	DCS Type II may be life-threatening, often affects vital organ systems, including the brain and spinal cord, the respiratory system, and the circulatory system.
Denitrogenation	Reduction of nitrogen from blood and body tissues by breathing gases devoid of nitrogen.	In aerospace medicine, the removal of nitrogen from the body of a person preparing to fly in an environment in which the barometric pressure will be much lower than at sea level.
Depressurization	Reducing the pressure of air or gas within a suit, chamber, or vehicle.	
Detect Atmospheric Changes	Ability to identify, measure and report the presence or existence of changes in features of the envelope of gases including pressure, temperature, and humidity in the vehicle/habitat/suit.	Once detection of a change occurs, then treatment/intervention can be brought to bear.
Detect Atmospheric Dust	Ability to identify, measure and report airborne dust within the habitat to assess concentration.	
Detect BHP Changes	Ability to identify, measure and report changes in the behavioral and cognitive state of astronauts in the vehicle/habitat/suit.	
Detect Bone Density Changes	Ability to identify, measure and report changes in bone mineral distribution in a 2D image (g/cm^2) or 3D volume (g/cm^3) of bone tissue over time.	
Detect Bone Structure Changes	Ability to identify, measure and report changes (beyond measurement error) in 3D distribution of bone tissue over time with serial measurements of whole, cortical, and trabecular bones.	

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Nodes	Definitions	Additional Notes
Detect Brain Structural Changes	Ability to identify, measure and report brain structural changes.	Detection is usually accomplished with Magnetic Resonance Imaging.
Detect CO_2 Level	Ability to identify, measure and report the presence and amount of carbon dioxide.	
Detect Contamination	Ability to identify, measure and report harmful, unwholesome, or undesirable, substances in the air, water, food, pharmaceuticals, or surfaces.	
Detect CV Events	Ability to identify, measure and report cardiovascular (CV) events in-mission.	Cardiovascular events include ischemia, myocardial infarction, dysrhythmia, venous thromboembolism, etc.
Detect DCS	Ability to identify, measure and report if there is supersaturation of inert gas in the bloodstream and tissues.	Decompression Sickness (DCS) is a sickness induced by too rapid a decrease in atmospheric pressure sufficient to cause bubbles to form from gases (normally nitrogen [N2]) dissolved in blood and other body tissues. (NASA-STD-3001)
Detect Diagnosis	Ability to correctly detect and identify the cause of any medical issues during a space flight mission.	Correct diagnosis enables appropriate treatment of medical conditions that occur in-mission. Misdiagnosis can cause additional harm and waste of resources when attempting to treat.
Detect Dysrhythmia	Ability to identify, measure and report any abnormal heart rhythm.	
Detect Environmental Conditions	Ability to identify, measure and report the state of the surroundings	Environmental conditions can include air, water, contamination, acceleration, acoustics, vibration, radiation, temperature, atmosphere, pressure, humidity, ppO_2, and $ppCO_2$.
Detect EVA Readiness	Ability to identify, measure and report the preparedness of equipment and crew to conduct an extravehicular activity (EVA).	
Detect Events	Ability to identify, measure and report a notable divergence from what is nominal and/or expected for vehicle, habitat, spacesuit or human systems.	
Detect Hearing Changes	Ability to identify and measure changes in auditory performance, may use audiometric surveillance or crewmember report.	Objective changes in auditory threshold are detected and quantified by comparing current audiometric results with a pre-flight baseline. Changes of a given magnitude in specific frequency regions are clinically significant and may require further action.
Detect Immune Changes	Ability to identify, measure and report the progression	Subclinical Immune Dysregulation precedes Persistent

Nodes	Definitions	Additional Notes
	of Immune Dysregulation from Persistent Subclinical Immune Dysregulation to Clinically Significant Immune Dysregulation to Medical Illness.	Subclinical Immune Dysregulation and refers to changes in cellular proliferation and function that does not have a known clinical issue.
Detect Intracranial Pressure Changes	Ability to identify, measure and report changes in intracranial pressure.	Detection is usually performed via post-flight lumbar puncture.
Detect Long Term Health Outcomes	Ability to identify, measure and report if any health outcomes have occurred post-space flight or post-career as a result of their occupational exposures (and resultant immune dysregulation) during space flight or training.	
Detect MRM/Stone	Ability to identify, measure and report mineralized (MRM) renal material or stones in the urinary tract.	
Detect Noise Levels	Ability to identify, measure and report ambient noise levels through personal dosimetry and/or static measurement using a sound level meter.	Such measurements help determine if noise levels are hazardous or may impact crew performance or rest. Noise is defined as sound in the auditory range (15 Hz to 20,000 Hz) that is hazardous, undesired, and/or inappropriate to the intended use of the space.
Detect Ocular Structural Changes	Ability to identify, measure and report ocular structural changes.	Detection can be accomplished using tools such as optical coherence tomography, ultrasound, fundoscopy, etc.
Detect Physiologic Changes	Ability to identify, measure and report the cellular, molecular, physiologic, pathologic, and functional changes that occur in individual astronauts during a space flight mission.	
Detect Post-Void Residual	Ability to identify, measure and report on the amount of urine in the bladder following urination.	
Detect Pressure Changes	Ability to identify, measure and report the presence of fluctuations in atmospheric pressure.	
Detect Radiation	Ability to identify, measure and report the level of ionizing radiation.	
Detect Team Performance and Cohesion	Ability to identify, measure and report the changes in crew performance and cohesion over time using monitoring tools.	
Detect Thrombosis	Ability to identify, measure and report the presence of a clot within a blood vessel.	

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Nodes	Definitions	Additional Notes
Detect Toxic Exposure	Ability to identify, measure and report specific toxic compounds of potential concern.	
Detect Visual Changes	Ability to identify, measure and report visual performance decrements.	Detection can be accomplished using methods such as visual acuity (Snellen chart), visual field testing, etc.
Diagnose Events	Ability to identify the cause of an anomalous event thereby enabling appropriate maintenance and repair for vehicle, habitat, spacesuit or human systems.	
Diagnose Rhabdomyolysis	Identification of the destruction or degeneration of muscle tissue and the accompanied release of breakdown products into the bloodstream.	Rhabdomyolysis is usually from traumatic injury, excessive exertion, or stroke.
Diagnostic Capability	The sensors, data, tools, expertise, etc. that are available to identify any specific medical condition occurring in-mission	Correct diagnosis enables appropriate treatment decisions. Diagnosis is dependent on all tools and expertise being available.
Distance from Earth	Numerical measurement of how far apart objects (vehicle or habitat) are from the Earth	Human System Risk Hazard - Impacts real-time communications, consumables resupply, time to evacuation, and available mass and volume that can limit inclusion of countermeasures.
Distribution	One of four pharmacokinetic parameters that describes the transport process of a drug which deliver it to body areas away from the absorption site.	
Dust Monitor	A device utilized to provide data on exposure levels of celestial dust within the habitat.	
Dust Removal	Elimination of dust from the airborne region of the habitat.	
Dust (Risk)	Risk of Adverse Health & Performance Effects of Celestial Dust Exposure.	Risk Statement: Given the unique properties of lunar and other celestial bodies' dust, there is a possibility that exposure could lead to serious health effects (e.g., respiratory, cardiopulmonary, ocular, or dermal harm) or to crew performance impacts during celestial body missions.
Dust Source	Event or trigger that introduces dust to the habitat.	
Dust Suspension	The process of dust within a habitable volume rising into the breathing zone.	Dust may be suspended when brought into the habitable volume on the suit, tools, or sampling equipment before it has time to settle or be removed by ECLS. It can also occur when settled dust in partial gravity becomes resuspended in micro gravity.

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Nodes	Definitions	Additional Notes
DXA	Dual-energy X-ray absorptiometry (DXA), an x-ray-based test that measures bone mineral in a 2D projected image of bone tissue.	
Dynamic Loads (Risk)	Risk of Injury from Dynamic Loads.	Risk Statement: Given the range of anticipated dynamic loads transferred to the crew via the vehicle, there is a possibility of loss of crew or crew injury during dynamic phases of flight.
Dysrhythmia	Abnormality in a physiological rhythm, especially in the activity of the heart.	
Dysrhythmia Monitor	Ability to observe and keep a continuous record of an abnormality in a physiological rhythm, especially in the activity of the heart.	
Dysrhythmia Treatment	Medical management and care of an abnormal cardiac rhythm with medication or procedure during a space flight mission.	
Ebullism	Formation of bubbles in the bodily fluids because of an extreme or rapid reduction in the surrounding pressure.	
ECLS System	Environmental Control and Life Support (ECLS) Systems designed to distribute air and remove contaminants. The elements include all hardware, software, equipment, facilities, personnel, processes, and procedures needed for this purpose.	
Effective Exposure Duration	Length of time of exposure to a hazard or other node.	
Effective Gravity Level	The period encompassing the exposure of crew to altered gravity during the design mission duration from launch to terrestrial landing.	
Effective Mission Duration	The total time the crew is away from the surface of Earth, measured from launch of the Earth launch vehicle to landing or splashdown of the Earth return spacecraft. (NASA-STD-3001)	
Electric Shock (Risk)	Risk to Crew Health Due to Electrical Shock.	Risk Statement: Given that all human space flight mission vehicles and suits have electrical systems, there is a possibility of electrical shock from both direct contact and from plasma.
Electrical Muscle Effects	The response of muscle tissue to electrical current.	Muscle Effects include tetany and inadvertent contraction of the

Nodes	Definitions	Additional Notes
		muscle that can cause difficulty or errors during operations.
Electrical Hardware	Tools, machinery, and other durable equipment that functionally rely on electric energy to drive their core parts.	
Electrical Shock	Describes when human-electrical contact occurs inside the spacecraft and may occur without sparking.	
Electrical System Design	Plan or specification for electrical systems, groups of connected electrical components, to carry out some operation.	
Elimination	Describes the process by which a pharmacologic substance is pulled or removed from the body.	Elimination processes can include renal function, hepatic function and minor pathways.
Endocrine Factors	Locally produced or circulating levels of hormones in response to a stimulus or stimuli and the sensitivity or ability of the target tissues to respond.	Hormones may be secreted by the endocrine system or introduced through exogenous sources such as medications. The interaction between the hormone and its receptor triggers a cascade of biochemical reactions in the target cell that eventually modify the cell's function or activity.
Endothelial Damage	Damage or disruption to the inner lining (endothelium) of a blood vessel.	Damage can contribute to dysfunction and disease.
Energy (Calories)	Quantitative property that must be transferred to a body or physical system to perform work on the body, or to heat it. The dietary Calorie (i.e. kilocalorie) is an energy unit used to describe the energy content of food and is defined as the amount of heat needed to raise the temperature of 1 kilogram of water by one degree Celsius.	
Environmental Conditions	Nominal or off-nominal conditions within the vehicle.	Environmental conditions include air, water, contamination, acceleration, acoustics, vibration, radiation, temperature, atmosphere, pressure, humidity, ppO_2, $ppCO_2$, etc.
Environmental Control	Ability to regulate the surroundings or conditions in which the crew lives and operates.	Environmental control includes accommodating increased O_2 consumption, additional output of heat, CO_2, perspiration droplets, odor, and particulates like skin, hair, or lint from clothing or other materials, vibration, lighting, noise, and temperature.
Environmental Injury	Any non-traumatic bodily damage that is the direct	

Nodes	Definitions	Additional Notes
	result of a known external exposure.	
Environmental Monitoring Capability	Ability to test, log, and review the parameters that describe the environment in which the crew lives and operates to ensure they do not exceed specified limits.	
Environmental Risks	Risks with potentially harmful factors originating from external conditions or surroundings.	HSRB environmental Risks include Toxic Exposure, SANS, DCS, Hypoxia, CO_2, Dust, Sensorimotor, Hearing Loss, Electrical Shock and Non-Ionizing Radiation.
Estimated Career Dose	The amount of radiation dose estimated to be received by an astronaut over the course of their career.	
Estimated Dose Rate	Estimated dose of ionizing radiation absorbed or delivered per unit of time.	
Estimated Mission Radiation Dose	Estimated amount of radiation dose for a particular design reference mission category (length of a mission, distance from Earth, etc.).	
Extravehicular Activity	Operations performed by suited crew outside the pressurized environment of a flight vehicle or habitat (during space flight or on a destination surface). Includes contingency operations performed inside unpressurized vehicles or habitats. (NASA-STD-3001)	
EVA Decision Support	Ability of the system (human or computer) to support determinations, judgments, and courses of action before and during an extravehicular activity to reduce cognitive workload.	
EVA Duration	Length of time an extravehicular activity lasts, can be planned or actual.	
EVA Frequency	Number of extravehicular activities conducted in a given period, and how often are they occurring (tempo).	
EVA Operations	Activities performed by suited crew outside the pressurized environment of a flight vehicle or habitat (during space flight or on a destination surface).	EVA Operations include contingency operations performed inside unpressurized vehicles or habitats.
EVA (Risk)	Risk of Injury and Compromised Performance Due to EVA Operations.	Risk Statement: Given the high-performance physiological and functional demands of operating in a self-contained EVA or

Nodes	Definitions	Additional Notes
		training suit in various gravity fields and system environments, there is a possibility that crew injury and compromised physiological and functional performance may occur.
EVA Task Timeline	Planning duration and quantity of tasks to ensure activities to be performed during an extravehicular activity are feasible and appropriate	The EVA task timeline may be affected by solar particle events.
Evacuation	Leaving the vehicle or habitat due to an injury or illness.	Changing return times to Earth for different Design Reference Missions (DRMs) affects the resources required for successful evacuation. In Mars DRMs, evacuation is not available due to orbital mechanics.
Exercise	Any bodily activity that enhances or maintains physical fitness and overall health and wellness.	Exercise is used to maintain or minimize loss of crew cardiovascular fitness and of muscle mass and crew cardiovascular fitness, to maintain muscle mass and strength/endurance, for recovery from strenuous tasks and confined postures, to rehabilitate minor muscle injuries, and to maintain bone mass. Exercise also has behavioral health benefits.
Exercise Hardware	Equipment or systems designed to perform aerobic and resistive training stimuli needed to maintain health and performance that enables successful mission task performance.	
Exercise Prescription	Planned, structured, repetitive, and purposeful activities that involve progressive modifications over time for frequency, intensity, time, and volume.	
External Contaminants	Harmful or poisonous substances on the outside of a spacecraft that may enter the habitable volume via suit contamination during EVA or docking of visiting vehicles.	
Extraterrestrial Surface	Celestial bodies existing or occurring outside the earth or its atmosphere.	Examples of an extraterrestrial surface include moon, planetary, asteroid, etc. (NASA-STD-3001)
Eye Injury	Injury (environmental or traumatic) that occurs to the eyeball, eyelids, or orbital area.	
Fall Height	Distance to the landing surface from the crewmember's	

Nodes	Definitions	Additional Notes
	workstation or operating region.	
Family Effects	Perceived connectedness with family, stress associated with family relationships or with family situations that are influencing family members' well-being.	
Family/World Events	Acute and chronic stressors of life outside of operational duties and events.	Examples include family health conditions, family or marital discord, birth of a child, death of a loved one, and major world events such as natural disasters or terrorist attacks.
Fatigue	Weariness, exhaustion, or decreased attention. May result in decreased ability to perform mental or physical tasks.	Fatigue is usually related to labor, exertion, or stress. May result from lack of sleep, circadian shifts, mood decrements, boredom, or disease. May cause decreased ability to perform mental or physical tasks. (NASA-STD-3001)
Fine Motor Control	The coordination and dexterity of muscles, bones, and nerves required to produce precise movements.	
Flight Recertification	Evaluation of a crewmember's physical or mental health after a mission to assist in determination of ability to return to flight.	Risk Impact Category which applies when throughout the career of an astronaut.
Fluid Shifts	A physiologic response to altered gravity or acceleration that creates a shift of bodily fluids (e.g., blood, cerebrospinal fluid) from one region to another.	
Food Acceptability	A subjective measurement evaluating the hedonics associated with food.	Food acceptability is influenced by factors related to the individual, the food, and the environment. These factors include sensory properties of the food (i.e., taste, smell, and texture), variety available, contextual implications, individual's culture, food preferences, previous exposures and subsequent expectations, and physiological status (i.e., hunger, thirst, and health status). If food is not acceptable it will not be consumed in sufficient quantities to receive adequate energy and nutrients.
Food and Nutrition (Risk)	Risk of Performance Decrement and Crew Illness Due to Inadequate Food and Nutrition.	Risk Statement: Given that there is a constrained space flight environment with a limited-source food supply and altered nutrient requirements, there is a possibility of inadequate nutritional delivery resulting in performance decrement, crew illness, and long-term health effects.
Food Contamination	Refers to foods that have been corrupted by a physical,	Contaminated food could lead to infections.

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	biological, or chemical substance that renders the food unfit or unsafe for consumption.	
Food Preparation	Making food ready for consumption including thawing, cooking, heating, cooling, cutting, assembling, and portioning.	In space flight, food preparation is generally limited to the addition of water and heat to ready-to-eat shelf stable food to an acceptable temperature for consumption (not cooking).
Food Production	The process of converting raw materials into edible food fit for human consumption including cultivating, crop management, harvesting, cleaning, fermenting, slicing, processing, packaging, etc.	
Food Safety	Food safety encompasses the conditions and practices observed to preserve the safety and quality of food to prevent food contamination and food-borne illness.	Food safety includes proper and sanitary food handling, preparation, and storage.
Food Storage	Food storage can be divided into three types, dry, refrigerated, and frozen.	Factors which may impact food shelf life and type of food storage considered include humidity, pressure, atmosphere, and radiation. Foods stored in dry storage are those which do not require a climate-controlled environment (i.e., canned goods). Refrigerated foods are those that need to be kept cool at all times (i.e., meats, cheese, and eggs). The refrigerator temperature should be at or below 4 degrees Celsius. Freezing foods requires keeping them below -18 degrees Celsius. Freeze-thaw cycles can damage food structures due to ice crystal growth.
Food System	The interconnected network of activities and resources involved in providing nutrients for human nourishment and sustaining life.	A food system includes the production, aggregation, processing, packaging, distribution, consumption, and disposal of food. In space flight to date, the food system can be defined as all foods, beverages, vitamins, supplements, and associated packaging and utensils, as well as support for preparation such as water dispensers and food warmers.
Food Variety	Foods with diverse characteristics including foods from the entire range of food groups (vegetables, fruits, grains, meat, fish, and dairy products).	Variety also refers to the number of different foods within each food group.
Fundoscopy	The act of examining the fundus of the eye.	Fundoscopy is nominally performed via a retinal camera and/or optical coherence tomography (OCT) device during space flight.
Galactic Cosmic Radiation	Ionizing radiation composed of highly energetic protons	These particles represent the “background” radiation in space

Nodes	Definitions	Additional Notes
	and heavy charged particles that originate outside the solar system traveling at near relativistic speeds.	and are the primary contributors to radiation exposure during spaceflight.
Gamma Rays	Also known as gamma radiation, is a penetrating form of electromagnetic radiation arising from the radioactive decay of atomic nuclei. It consists of the shortest wavelength electromagnetic waves, typically shorter than those of x-rays.	
Globe Flattening	Structural deformation (flattening) of the posterior side of the eyeball, typically centered at the insertion point of the optic nerve into the globe.	
Ground Support	Operations and tasks performed by ground personnel utilizing space flight systems, hardware, and equipment including during launches and after landings.	Ground support includes mission control support as well as any physical, psychological, and behavioral health support.
Hardware/System Failure	An event or interaction that results in the vehicle system not functioning nominally or safely, with the potential for downstream consequences.	
Hearing Countermeasures	A means to offset undesirable physical effects to hearing hazards.	Hearing countermeasures include engineering controls or use of hearing protection.
Helmet/Protective Visors	Coverings, films, or filters designed into spacesuit visors that may provide protection from environmental factors.	Visors may provide protection from sources such as sunlight, thermal, etc.
Hematologic Index Alterations	Changes in the absolute or relative proportions of the blood constituents.	
Hostile Closed Environment	A sealed habitable volume and environmental system that does not rely on matter exchange with any part outside the system.	Human System Risk Hazard - The habitable volume and environmental systems required to enable life and work in any space vehicle or habitat can expose astronauts to different atmospheric, water, or microbial challenges as well as acceleration environments that can lead to injury.
HSI Processes	Human System Integration (HSI) - An interdisciplinary and comprehensive management and engineering methodology that focuses on the integration of humans and cyber-physical systems during systems design and development or acquisition, to enable overall systems resilience.	

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HSIA (Risk)	Risk of Adverse Outcomes Due to Inadequate Human Systems Integration Architecture.	Risk Statement: Given need for increasing crew independence and greater operational complexity in future exploration missions, there is a possibility of adverse outcomes associated with deficiencies in Human Systems Integration, specifically that crew are unable to adequately respond to unanticipated critical malfunctions and/or perform safety critical procedures.
Human Error	Either an action that is not intended or desired by the person or a failure on the part of the person to perform a prescribed action within specified limits of accuracy, sequence, or time that does not produce the expected result and has led or has the potential to lead to an unwanted consequence.	
Human-Electrical Contact	The contact between a human and anything electrical that can cause an electrical shock to the human.	
Human System Risk Hazard	Set space flight Hazards (Altered Gravity, Distance from Earth, Hostile Closed Environment, Isolation and Confinement and Radiation) that are defined in the Human System Risk Management Plan.	
Humidity	A measure of the amount of moisture in the air.	
Hydration	The action of providing liquid to bodily tissues to compensate for fluid lost from the body.	
Hygiene	Hygiene in space includes the everyday tasks of washing hair, brushing teeth, shaving, and going to the bathroom. It also includes washing and changing of clothes, as well as wiping down exercise equipment after use and covering up cuts and skin breaks while in space.	Hygiene can be important in controlling bacteria and other microorganisms.
Hypoxia	Low oxygen at the tissue level; in context of the Hypoxia risk, denotes severe hypoxia.	Hypoxia could potentially occur as a result of suit failure, toxic exposures, or depressurization from vehicle failure all of which could lead to loss of crew life.
Hypoxia (Risk)	Risk of Reduced Crew Health and Performance Due to Hypoxia.	Risk Statement: Given that future human exploration missions require robust, flexible Extravehicular Activity (EVA) architecture protocols that include the use of a reduced pressure cabin atmosphere enabling staged denitrogenation, there is a

Nodes	Definitions	Additional Notes
		possibility that this atmosphere could result in compromised health and performance to the crewmember due to exposure to mild hypobaric hypoxia.
Immune (Risk)	Risk of Adverse Health Event Due To Altered Immune Response;	Risk Statement: Given that exposure to orbital space flight results in persistent dysregulation of the immune system, which leads to reactivation of latent herpes-viruses and likely to an increased clinical incidence, including rashes and hypersensitivity reactions, there is a possibility that crewmembers will be susceptible to certain diseases during exploration class missions.
Impedance Factors	Factors that oppose an electrical circuits current impeding the flow of the charge.	Impedance factors includes insulation of clothing and/or shoes as well as amount of sweat on the body.
Incapacitation/Crew Rescue	Injuries sustained by a crewmember during an extravehicular activity that prevent the affected crewmember from continuing independent operations, and which would require support from other suited crew to avert mission level outcomes.	
Individual Factors	The influence that each crewmember will have on biologic variability (e.g., physical, physiological, or behavioral) affecting risk. This node as a category is broken out into two types: Modifiable (lifestyle choices, smoking status, exercise habits, etc.) Non-modifiable (age, sex, genetic predispositions, etc.).	
Individual Readiness	The level to which a crewmember is prepared mentally and physically to perform necessary tasks.	
Infection	Invasion and multiplication of microorganisms in body tissues.	
Inflammation	The local response of living tissues to injury from any agent which could be microbial, immunological, physical, or chemical. There are two main types of inflammation: Acute - early reaction to injury or infection, short duration.	Chronic inflammation can be triggered by oxidative stress, persistent subclinical immune dysregulation and clinically significant immune dysregulation which may contribute to medical illness, particularly chronic illness and may or may not be accompanied by pain and fatigue.

Nodes	Definitions	Additional Notes
	Chronic – occurs after a delay, longer duration.	
Inflight Hearing Exams	Audiometric testing that evaluates the structure, function, and changes of the auditory system.	Testing may include, but is not limited to, air and bone conduction audiometry and tympanometry.
Ingestion Toxicity	Systemic damage or injury to the body resulting from swallowing of a harmful substance in space flight.	
In-Mission Shelf Life	The period from when a medication is packaged for a mission to the time of it's stated beyond use or expiration date.	
Insomnia	Dissatisfaction with sleep quantity or quality, associated with one (or more) of the following symptoms: Difficulty initiating sleep or maintaining sleep, characterized by frequent awakenings or problems returning to sleep after awakenings.	
Interpersonal Relationships	Emotional, psychosocial relationships between two individuals.	
Intervention Decision	The selection of action(s) taken in response to an anomalous event to correct the causes and/or mitigate the consequences.	
Intervention Measures	Decisions made or actions taken to mitigate specific health and performance risks.	Interventions could include reconfiguring mass for a storm shelter, donning additional radiation protection, or early termination of EVAs in the case of a solar particle event.
Intervention Source Control	Control measures at the site of origin, such as debridement, drainage and/or excision, used to control ongoing infection.	
Intracochlear Pressure	An increase in the static pressure of cochlear fluids.	Pressure may be increased due to whole-body fluid shifts from microgravity. The increase in cochlear fluids can mimic disease processes and degrade hearing ability.
Intracranial Pressure Changes	Changes from an individual's nominal baseline intracranial pressure.	Intracranial pressure changes may occur as a result of altered gravity or accelerations.
Intracranial Pressure Monitoring	The act of measuring pressure exerted by fluids such as cerebrospinal fluid (CSF) inside the skull and on the brain tissue.	
Intravascular Volume	Volume of blood in the vascular space (i.e., arteries, arterioles, capillaries, venules, and veins).	

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Isolation and Confinement	Physical and mental separation from general population.	Human System Risk Hazard - Increasing time in isolation increases the risk of psychological, physical, and mental health issues for crew.
K+ Citrate	Potassium citrate, a medication which modifies urine chemistry (making urine less acidic).	Potassium citrate may be used to reduce the risk of renal stone formation.
Lab Blood Monitoring	Lab blood monitoring enables the capability to detect immune changes during space flight that are either subclinical or become clinically significant.	When detected, these can enable further interventions or deployment of countermeasures including such actions as evaluations by the crew medical officer or prevention/treatment prescriptions to reduce or avoid further negative consequences (also, potential saliva monitoring).
Landing Profile	Duration, direction, and magnitude of acceleration that a crewmember experiences during landing on a terrestrial or extraterrestrial surface, arriving on solid ground or in water.	
Landing Site Environment	The state of the surroundings where a vehicle will land. Includes climate and accessibility by ground support.	For example, landing environments may include landing location, temperature, humidity, weather, sea state, gravity, etc.
Laser	Device that emits a coherent beam of light typically falling within the ultraviolet, visible, or infrared range of the electromagnetic spectrum.	
Lenses	Optical devices that neutralize the refractive error of the eye, thereby focusing images onto the retina.	The optical devices are usually glasses or contact lenses.
Long Term Health	Risk Impact Category indicating the lifetime impact of space flight on physical and mental health and performance of astronaut's post flight including post-career.	The LTH category consists of the Health Outcomes impact subcategory which includes medical conditions resulting from career exposures to the space flight environment, and the Quality-of-Life impact subcategory which identifies decrements in the ability of a post-flight astronaut to perform daily living activities as a result of career exposure to the space flight environment.
Long Term Health Clinical Decisions	Any clinical decisions occurring post-flight or post career that are based on prior space flight exposure data and/or clinical testing data.	
Long Term Health Outcomes	Medical conditions that impact the ability of a post-flight astronaut to perform daily living activities as a	

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Nodes	Definitions	Additional Notes
	result of career exposure to the space flight environment.	
Long Term Health Quality	Impacts to quality of life of a post-flight astronaut to perform daily living activities as a result of career exposure to the space flight environment.	
Loss of Crew	Loss of (the whole) crew during the mission.	Usually reserved for catastrophic events like Challenger, Columbia, Apollo 1 but can describe an entire crew being permanently incapacitated.
Loss of Crew Life	Loss of (a single) crewmember life during the mission.	For example - if Fred Haise had died of sepsis during Apollo 03 and he was the only one who died.
Loss of EVA Content	Loss of one or more planned objective during extravehicular activities during a mission.	
Loss of EVA(s)	Inability to conduct planned or contingency extravehicular activities during a mission.	
Loss of Mission	Evacuation/abort prior to mission objectives being accomplished.	Indicates anything that can lead to loss of a mission
Loss of Mission Objectives	Some mission objectives are lost, and other mission objectives can still be achieved.	Single crewmember disability can lead to decreased functionality of that crewmember; this may impact if the rest of the team can accomplish other mission objectives.
Loss of Vehicle	The vehicle is rendered unusable during a mission, requiring evacuation of crew.	
Lower Body Negative Pressure	A device/chamber covering the lower body that is sealed at the waist which through decompression intended to cause fluid shifts to the lower body.	
Lung Injury	Any damage to the upper or lower airways	Potential sources of injuries include but are not limited to edema, inflammation, and fibrosis resulting from celestial dust exposure.
Maintainability	A measure of the ease and rapidity with which a system or equipment can be preserved against failure or restored to operational status.	Maintenance includes servicing, repair, modification, modernization, overhaul, inspection, condition determination, corrosion control, and initial provisioning of support items. (NASA-STD-3001)
Manufacturer Shelf Life	A period that a drug manufacturer guarantees product quality, from date of manufacture until the labeled expiration date.	

Nodes	Definitions	Additional Notes
Materials Offgassing	Volatile compounds that are produced and released into the air over time and as a function of temperature from soft goods like plastics.	
Measurable Hearing Shift	A change in auditory thresholds that is greater than normal test re-test variability.	A high frequency shift is present when the mean thresholds at 2000, 3000, and 4000 Hz have changed by 10 dB or more when compared to the pre-flight baseline. A low frequency shift is present when the mean thresholds at 250 and 500 Hz have changed by 10 dB or more when compared to the pre-flight baseline.
Mechanical Obstruction	A partial or total blockage of the bladder out flow tract caused by an object.	One example of a mechanical obstruction is a tumor compressing the urethra.
Mechanical Systems	Sub-components including pumps, seals/gaskets, valves, and mechanical parts that contribute to the Environmental Control and Life Support Systems for vehicles and suits.	These sub-components of the ECLS are designed to distribute air and remove contaminants (ventilation, carbon dioxide removal assembly (CDRA), thermal amine swing bed (TAS), etc.).
Medical Diagnostic Capability	The in-mission capability to correctly detect and identify the cause of medical issues in space flight.	This capability can include training, experience, laboratory, imaging, and other medical diagnostic support tools.
Medical Illness	Any illness that is not specifically caused by traumatic injury or environmental injury.	Examples of medical illness include dermatitis, infections, atypical allergies/hypersensitivities, cancer, and autoimmune diseases.
Medical Monitoring Capability	Capability to assess, log, and track aspects of crew health relevant to medical diagnosis and progression of disease, that is designed into the Crew Health and Performance System.	Monitoring capability can include physiologic, laboratory, imaging, symptomatic, or other methods.
Medical Prevention Capability	Availability and efficacy of countermeasures to prevent undesired medical conditions in the crew during a mission.	Prevention capability can include an array of countermeasures for preventing potential risks in space to crewmember and mission, including clinical/physician and family conferences, pharmaceutical products to 'reset' immunity, resistive exercise, and supplemental nutrition, as well as stress-relieving breathing or guided meditation exercises or behavioral training to reduce negative mental outcomes.
Medical Treatment Capability	The ability to address health conditions using onboard therapeutics, crewmembers, and ground-based resources.	Treatment capability includes all of the medications, consumables, hardware, software, equipment, facilities, personnel, processes, and procedures needed to design into the

Nodes	Definitions	Additional Notes
		Crew Health and Performance System in a mission.
Medical (Risk)	Risk of Adverse Health Outcomes and Decrements in Performance Due to Medical Conditions that occur in Mission, as well as Long Term Health Outcomes Due to Mission Exposures.	Risk Statement: Given that medical conditions will occur during human space flight missions, there is a possibility of adverse health outcomes & decrements in performance during these missions and for long term health.
Medication Compatibility	A medication's harmonious coexistence with its storage environment, administration (e.g., delivery and simultaneous administration with other medications) that promotes safe and effective use without the incidence of negative physiological consequences or chemical interactions; Specific to suit - The ability of a medication to be used safely in the suit without negatively impacting the suit environment or components.	
Medications	A pharmaceutical or other substance used for medical diagnosis, prevention, or treatment.	
Metabolism	How a drug is biotransformed (broken down) in the body [i.e., hepatic function, hepatic enzymes, other organs (e.g., Lungs, kidney, gastrointestinal, skin)];	This is one of the four pharmacokinetic parameters that describes the conversion of the administered drug into another substance (either an active or inactive metabolite).
Microbial Resistance Factors	Description of the main drivers of antimicrobial resistance in space flight.	Evidence that the virulence of certain microbes changes in response to space flight, increasing risk of infections or indirectly leading to infections through changes in microbiome status.
Microbial Virulence Factors	Evidence that the virulence of certain microbes changes in response to space flight environment.	Changes may lead to an increased risk of infections especially during deep space missions.
Microbiome	All microbiota that live in or on our human body (including all tissue, fluids, and the various organs they can normally inhabit such as the GI tract, conjunctiva, moth/nose, vagina, and the skin).	May also refer to interactions between the crew microbiome with other crewmembers, or the microbiome of the vehicle or environment.
Microhost (Risk)	Risk of Adverse Health Effects Due to Host-Microorganism Interactions.	Risk Statement: Given that evidence collected during space flight indicates alterations in microbial virulence and astronaut immune function, there is a possibility that infectious disease will have increased prevalence and/or will be more severe during space flight missions.

Appendix A – Directed Acyclic Graph Dictionary

Nodes	Definitions	Additional Notes
Mild Hypoxia	Oxygen is not available in sufficient amounts at the tissue level.	Mild hypoxia can lead to issues with cognitive function, acute mountain sickness fatigue and decreased endurance capacity.
Mineralized Renal Material	Nascent areas of renal calcification detected by ultrasound; five characteristics help define MRM: shadowing, Doppler twinkle, frequency dispersion, size, and anatomic location.	
Mission	A major activity required to accomplish an Agency goal or to effectively pursue a scientific, technological, or engineering opportunity directly related to an Agency goal. (NASA-STD-3001)	Mission needs are independent of any particular system or technological solution.
Mission Architecture Complexity	A measure of the number, diversity, and intricacy of mission systems and operations (e.g., surface versus orbital), and their interactions, both pre-mission and during mission operations.	
Mission Level Outcomes	Set outcomes defined in the HSRB Risk Management Plan.	Task Performance, Evacuation, Loss of mission objectives, Loss of Crew Life, Loss of Crew, Loss of Mission, Flight Recertification, Long Term Health Outcomes, and Long-Term Health Quality.
Mitigation Options	All possible actions that could be taken in response to the anomalous event to reduce the risk of adverse outcomes.	
Modifiable Individual Factors	Factors that influence the biologic variability among individual crewmembers that affect risk.	Modifiable factors include lifestyle choices, smoking status, exercise habits, etc. These can be further decomposed depending on risk needs.
Monitoring Capability	The ability periodically or continuously observe, record, and systematically review the status of vehicle, habitat, spacesuit or human systems.	Monitoring capability includes checking for quality or fidelity; testing to determine if a signal comes within limits; watching and observing for a specific signal or purpose; keeping track of, regulating, or controlling. (NASA-STD-3001)
Morphological G-Receptor Changes	Changes to the end organ, including neuronal sensitivity changes, otoconial mass changes, cilia changes, etc.	
Motion Sickness	Vestibular disturbance leading to nausea and/or vomiting.	
Motivation	Internal, subjective experience of drive, desire, or willingness to exert effort or resources toward a task or	

Nodes	Definitions	Additional Notes
	goal.	
MRI	Magnetic Resonance Imaging (MRI), a diagnostic test that measures the response of atomic nuclei in body tissue (hydrogen nuclei of water) to radio waves in a strong magnetic field.	This does not expose the subject being scanned to radiation. The scanner is large enough for the whole body but is used to target specific areas of interest.
Multi-Sensory Integration Alterations	Changes to the internal weighting of the individual's information-gathering abilities to see, hear, touch, smell, and taste (sensory signals) that are integrated by the central nervous system to produce the perception of the physical environment and one's relation to it.	Perception includes temperature, pain, kinesthesia, and equilibrium.
Muscle Performance	The ability of the muscle to produce force. Muscular fitness is composed of the functional parameters of strength, endurance, and power.	Loss of muscle performance on a mission may impair task completion or predispose a crewmember to musculoskeletal injury.
Muscle Physiologic Changes	Adaptations in muscle including muscle size, strength, metabolism, and hormonal and neural interactions, in response to the loading environment (e.g., altered gravity, exercise/work) that affect performance.	
Muscle (Risk)	Risk of Impaired Performance Due to Reduced Muscle Size, Strength, and Endurance.	Risk Statement: Given that exposure to a microgravity or partial gravity environment causes muscle size, strength, and endurance to decline, there is a possibility that mission task performance would be impaired or tasks could not be performed.
Musculoskeletal Injury	Any injury (environmental or traumatic) that occurs to the muscles, bones, tendons, ligaments, or other parts of the musculoskeletal system.	
Musculoskeletal Loads	Forces that are applied to/experienced by the body including forces on the tissues, fluids, or materials of the body.	Loads can originate from the external environment (gravity or acceleration) or may result from voluntary or involuntary actions of the individual (exercise/work).
Nephrolithiasis	Presence of stones in the urine collection area of the kidney.	Nephrolithiasis occurs due to a decrease in urine volume or excess of stone-forming substances in the urine.
Net Habitable Volume	The functional volume left available on a spacecraft after accounting for the loss of volume caused by deployed equipment, stowage, trash, and any other items that decrease the functional volume. (NASA-STD-	

Nodes	Definitions	Additional Notes
	3001)	
Neuro/Ocular Injury	Any injury (environmental or traumatic) that occurs to the eye or brain.	
Neutrons	A subatomic particle which has a neutral charge; a type of ionizing radiation.	High energy neutrons originating from GCR or created as secondary radiation are extremely efficient at ionization and more likely to cause cell damage than protons.
Noise Exposure	The level, spectrum, and duration of noise experienced by a human. Noise is defined as sound in the auditory range (15 Hz to 20,000 Hz) that is hazardous, undesired, and/or inappropriate to the intended use of the space. (NASA-STD-3001)	Noise exposure data can be used to determine expected impacts on human performance (e.g., alarm detection, face to-face communication, etc.), hazards to hearing, and disruptions to sleep.
Non-Ionizing Radiation (Risk)	Risk of Adverse Health Outcomes and Performance Decrements resulting from Non-Ionizing Radiation during Space flight.	Risk Statement: Given the potential for exposure to sunlight and ground-based lasers during space flight missions, there is a possibility that crewmembers could develop solar retinopathy, cataracts, conjunctivitis, photokeratitis, hemorrhagic retinal lesions and/or erythema which may result in permanent damage and/or may impact mission performance.
Non-Modifiable Individual Factors	Factors that influence the biologic variability among individual crewmembers that affect risk. Non-modifiable factors include age, sex, genetic predispositions, pre-existing medical conditions, etc. These can be further decomposed depending on risk needs.	
Nuclear Technology	Technology that involves nuclear reactions of atomic nuclei.	The use of these technologies for space flight may change the radiation carcinogenesis risk to an astronaut.
Nutrient Deficiencies	Nutrient deficiencies occur when the body is not getting enough nutrients to support normal physiological system function.	Deficiencies include vitamins, minerals, fluid, and energy, and can be due to inadequate dietary intake or impaired digestion, absorption, transport, metabolism of nutrients, genetics, environmental factors, and can occur with some drug-nutrient interactions.
Nutrient Toxicities	Nutrient toxicities occur when nutrients are in excess of needs at such a high concentration that is harmful to the body.	Nutrient toxicities generally occur due to excessive consumption.
Nutrients	Nutrients are substances that provide the body with	Carbohydrates, protein, fat, and water are macronutrients,

Nodes	Definitions	Additional Notes
	the nourishment essential for growth and maintenance of life.	required by the body in large quantities to sustain life. Micronutrients (including vitamins, minerals, and phytochemicals) are needed in smaller amounts for proper functioning of body systems.
On-Board Expertise	The collective knowledge, skills, and abilities of the integrated human-system team on the vehicle, especially pertaining to vehicle systems and complex operations.	
Operations Design	Planning and execution of an activity, mission, or maneuver. (NASA-STD-3001)	
Optic Disc Edema	Swelling of the retinal nerve fibers as they pass through the optic nerve head (aka optic disc) and exit the eye.	
Optical Coherence Tomography	Non-invasive ophthalmic imaging technology that provides high-resolution, cross-sectional views of ocular anatomy (e.g., retina, cornea), as well as images that mimic color retinal photography.	
Oral Contraceptives	A group of hormone containing substances (estrogen and progestin) that are used in menstrual management and pregnancy prevention.	
Organ Perfusion	Under or over perfusion of organs, possibly contributing to ischemia or organ damage.	
Orthostatic Intolerance	Unable or impaired ability to stand (gravity vector in z-axis).	Orthostatic intolerance usually occurs due to hypotension or motion sickness.
Orthostatic Intolerance Countermeasures	A means to offset undesirable effects of orthostatic intolerance.	These can be performed during the missions (e.g., exercise) or applied prior to or during re-exposure to gravity (e.g., fluid loading, lower body compression garments) and may be used during recovery from space flight.
Osteoarthritis	A degenerative disease that occurs when the protective cartilage that cushions the ends of the bones wears down over time often resulting in chronic joint pain.	
Other Risks	Nodes in a directed acyclic graph which only identify a connection at the risk level and do not carry information about what specific connections exist in detail.	

Nodes	Definitions	Additional Notes
Ototoxins	A group of chemicals (medications) that can cause chemical damage to auditory or vestibular systems negatively impacting hearing or balance functions.	
Oxidative Stress	Imbalance between the production of free radical activity and antioxidant activity.	Long term exposure to these types of stressors may contribute towards many diseases, particularly chronic or immune-related ones.
Payload Chemicals	Chemicals that are used in experimental payloads.	
Percutaneous Nephrostomy	The placement of a catheter through the skin into the kidney to drain urine.	
Persistent Subclinical Immune Dysregulation	Changes in cellular proliferation and function that does not have a known clinical issue directly following it; chronic "off nominal" immune status due to stress, environment, or other mission factors.	Changes may include altered Leukocyte Distribution and Function, Latent Viral Reactivation, Altered Cytokine, Inflammation Balance.
Pharm (Risk)	Risk of Ineffective or Toxic Medications During Long-Duration Exploration Space flight.	Risk Statement: Given that there is no current method to sufficiently characterize medication use, drug quality and performance, clinical outcomes, and the impact of a hostile space environment on pharmaceutical stability and potency during long-duration exploration missions, there is a possibility that provision of a safe and effective drug treatment will be significantly limited, impacting crew health and performance.
Pharmaceutical Contamination	Harmful or poisonous substances that can be introduced into pharmaceuticals when repackaged.	Repackaged pharmaceuticals are susceptible to contamination and may increase risk for infection among crew.
Pharmaceutical Effectiveness	The extent to which a drug achieves its intended (labeled) effect under standard clinical conditions.	
Pharmaceutical Storage Conditions	Acceptable environmental conditions (temperature, humidity) for storage of medications set forth by the United States Pharmacopeia (USP).	Usually controlled room storage, cool storage and refrigerator storage and based on manufacturer stability of where a medication is maintained until use.
Pharmaceutical Toxicity	The expression of a poisonous or harmful effect a drug can produce.	
Pharmacodynamics	How drugs act on the body to produce a desired effect.	The onset, intensity and duration of therapeutic response elicited by a medication (PD) depends on the rates of absorption, distribution, metabolism, and elimination (PK).
Pharmacogenomics	How genes affect drug response in an individual.	
Pharmacokinetics	What happens to a medication from the time it enters,	

Nodes	Definitions	Additional Notes
	and all traces exit the body, as described by four processes (pharmacokinetic parameters: absorption, distribution, metabolism, and excretion).	
Physical Status	Subset of Individual Factors - Refers to the condition of the crewmember at any given time during a mission. Can be affected by injuries, activity level, diet, nutrition, sleep cycle, and workload.	Examples of physical status include immediate physical state of a crewmember identified prior to embarking on a specific mission task like EVA.
Physiologic Monitoring Capability	Capability to assess, log, and track aspects of crew health that provide insight into physiologic response to stimuli that is designed into the Crew Health and Performance Systems.	Physiologic monitoring capability can include exercise monitoring, sleep monitoring, etc.
Planned EVA Content	Predetermined tasks expected to be completed during an extravehicular activity.	
Plasma Induced Shock	Can occur during EVA Operations. Radiation impacts on the spacecraft can result in charged surfaces and if there is suit-vehicle/habitat contact then a shock may occur.	
Post-Landing Task Performance	Ability to carry out post landing tasks in a manner that avoids crew injury.	Tasks may include vehicle safing, as well as tasks resulting from off-nominal landings.
Postural Control and Locomotion	Ability to maintain balance during static postures (lying, sitting, standing) and dynamic movements (walking, tandem walking, jumping).	
Post-Void Residual	The amount of urine left in the bladder after urination.	
Preflight Hearing Status	The audiometric thresholds obtained prior to flight that quantify auditory performance.	These data are often used as a baseline for comparison to in-flight and post-flight audiometric thresholds.
Pre-Mission Food Storage Time	The length of time food has been refrigerated or packaged before a mission. This can range from weeks to years.	
Pressure Suits	Suits with pressure significantly lower than the ambient cabin pressure of a spacecraft.	This makes crewmembers subject to decompression sickness.
Pre-syncope/Syncope	Under perfusion or decreased oxygenation of the brain leading to symptoms including faintness, dizziness, nausea, weakness, and tunnel vision.	
Preventive Source Control	Measures taken to reduce, eliminate or prevent	Examples of source control include monitoring for sources of

Nodes	Definitions	Additional Notes
	microbial spread.	microbial spread, changing of filters (air, water etc.), wiping down of surfaces with antimicrobial agents, eliminating sources of emissions by sealing off or assuring proper off-gassing (prior to launch).
Previous Injury	Damage or trauma to the body that occurred at any time in the past.	This can include pre-mission injuries such as training injuries that limit range of motion or strength.
Prior Mission Exposures	Space flight exposures obtained during a previous mission for a particular astronaut.	
Privacy/Team Space	Privacy: Having an acceptable level of control over the extent of sharing oneself (physically, behaviorally, or intellectually) with others. (NASA-STD-3001)/ Team Space: shared space that facilitates social interactions and teamwork.	This includes limiting other people's access to you and limiting your perceived presence of other people; may involve touch, sight, sound, and smell. Acceptable level is dependent upon an individual's background and training.
Private Astronaut Missions	Space flight missions not managed by NASA or other government space agencies but instead by private organizations.	
Probiotics	Live microorganisms (e.g., beneficial bacteria and/or yeast) which are consumed to promote health benefits, particularly in the digestive system by restoring the balance between the various types of microorganisms found.	
Procedure Design	The plan of action including steps, conditions, and constraints used to complete a specific mission goal.	
Proprioception Change	Alterations in the internal sense of body movement and location.	
Protective Equipment	A set of components used to mitigate or control effects of hazards prior to occurrence.	Physical equipment such as gloves, foot, and eye protection, hearing protection devices (earplugs, muffs), hard hats, respirators, and full body suits can provide a physical barrier from exposure to chemical releases and other harmful substances.
Protective Glasses	Specialized glasses providing eye protection from environmental exposures including foreign object debris, sunlight, laser, and some particle/chemical releases.	

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Nodes	Definitions	Additional Notes
Protective Windows and Filters	Scratch panes, shades, or filters designed into spacecraft windows systems that provide protection from sunlight and laser exposures.	
Psychological Status	Refers to the mood and psychological state of the individual and/or crew at any given time during a mission.	These factors can directly affect Individual Readiness, Crew Capability by decreasing an individual's readiness for Task Performance if crew are distracted, preoccupied, dysregulated, unmotivated, or uncooperative.
QCT	Quantitative Computed Tomography (QCT), an x-ray based diagnostic test that measures bone mineral in a 3D volume of bone tissue.	This exposes the subject being scanned to radiation. The scanner is large enough for the whole body, but it is used to target specific areas of interest. The hip and lumbar spine are the most common skeletal sites for clinical evaluation with QCT.
Radiation	Human System Risk Hazard - Any combination of electromagnetic radiation or particles that deposits enough kinetic energy to create ionization events when interacting with matter.	Ionizing radiation energy absorption damages biological systems that may lead to clinical illness or contribute to human health and performance decrements.
Radiation Carcinogenesis (Risk)	Risk of Radiation Carcinogenesis.	Risk Statement: Given crew is exposed to radiation from the space environment, there is the possibility for increased cancer morbidity or mortality.
Radiation Monitors	Device that allows for the determination of the amount of radiation within a spacecraft or for a particular person.	
Recycling	The action or process of converting waste into reusable material.	
Refractive Error Shift	Change in the overall optical power of the eye which may require the use of lenses to properly focus images onto the retina.	
Renal Stone (Risk)	Risk of Renal Stone Formation.	Risk Statement: Given changes in urinary biochemistry during space flight, there is a possibility that symptomatic renal stones will form, which could cause renal colic (pain), nausea, vomiting, hematuria, infection, hydronephrosis.
Resistive Exercise	Dynamic exercises involving concentric (shortening) and eccentric (lengthening) muscle actions that recruit a muscle in isolation or multiple muscle groups.	
Resource Availability	Availability of necessary items needed for prevention,	

Nodes	Definitions	Additional Notes
	detection, and treatment of anomalies in the human and the vehicle.	
Resupply	The ability to restock consumables (i.e., medications, medical supplies, food, water, spare parts, etc.).	
Retinal Nerve Fiber Layer Atrophy	Permanent loss of the axons that transmit neural signals from the retina to the brain, a process which ultimately provides the perception of vision.	
Rhabdomyolysis	The destruction or degeneration of muscle tissue (as from traumatic injury, excessive exertion, or stroke) accompanied by the release of breakdown products into the bloodstream.	
Rhabdomyolysis Treatment	Medical management and care for the destruction or degeneration of muscle tissue (as from traumatic injury, excessive exertion, or stroke).	
SANS (Risk)	Risk of Space flight Associated Neuro-ocular Syndrome.	Risk Statement: Given that ocular and brain structural changes develop during space flight, there is a possibility that these changes could lead to short-term or long-term vision alterations, cognitive effects, or other deleterious health effects.
Schedule Shifting	Shifting sleep-wake timing to accommodate mission events.	Schedule shifting may involve small shifts in sleep timing or large shifts. Small and large schedule shifts can lead to circadian misalignment, sleep loss, and subsequent cognitive impairment.
Scheduling	Arranging, controlling, and optimizing work and workloads to facilitate crew timeline of activities.	
Seals/Gaskets	Potentially vulnerable portions of a suit system from a dust perspective.	
Self-Administered Rehab	A set of exercises that are designed to incrementally increase in difficulty and challenge the sensorimotor system.	These will presumably result in a faster readaptation.
Sensorimotor (Risk)	Risk of Altered Sensorimotor/Vestibular Function Impacting Critical Mission Tasks.	Risk Statement: Given that altered gravity leads to changes in sensorimotor/vestibular function that manifest in motion sickness, spatial disorientation, decrements in postural control and locomotion, and manual and fine motor control deficits, there is a possibility that crew will experience performance decrements in manual/vehicle control, extravehicular activities,

Nodes	Definitions	Additional Notes
		and egress during and following these transitions.
Sensory Augmentation	External tools such as vibrotactile feedback, an external horizon, galvanic vestibular stimulation, or others that help enhance the accuracy/sensitivity of the individual's information-gathering abilities.	Sensory abilities include the abilities to see, hear, touch, smell, and taste. Includes temperature, pain, kinesthesia, and equilibrium. (NASA-STD-3001)
Sepsis	A potentially life-threatening medical condition that occurs when the body's response to an infection damages its own tissues.	
Shielding	A barrier between a source of radiation and a potential target (e.g., the astronaut); shielding can be solid, liquid or gas which absorbs the energy of the radiation.	
Side Effects	Unwanted or undesirable effects related to a drug. Also known as adverse effects.	
Skeletal Fragility	A condition of bone that renders its biomechanical capacity so low that bone will fracture with minimal or no loading.	
Skin Injury	Any injury (environmental or traumatic) that occurs to the body's outermost organ, often affecting the epidermis and dermis layers.	
Skin Irritation	Redness, abrasion, or damage of the skin related to mechanical contact with celestial dust.	
Sleep Deficiencies	Obtaining sleep of insufficient quantity or quality.	Insufficient quantity of sleep leads to chronic sleep deprivation and subsequent performance impairment. Insufficient quality of sleep may occur when sleep is disrupted due to environmental factors or schedule shifting (i.e., sleeping in a circadian misaligned state). Insufficient sleep quality may involve disrupted or fragmented sleep or altered sleep architecture (e.g., reduced quantity of REM/NREM sleep, atypical sleep cycle stages). Sleep deficiency leads to cognitive impairment.
Sleep Inertia	Sleep inertia is a transitional state between sleep and wake (i.e., grogginess experienced upon waking), accompanied by cognitive impairment and desire to return to sleep.	The severity of sleep inertia depends on the stage of sleep from which one has awoken, the circadian phase at which one wakes, and prior sleep history. The cognitive impairment experienced in conjunction with sleep inertia can be as severe as 24 hours of sleep loss. Sleep inertia symptoms are worst immediately upon

Nodes	Definitions	Additional Notes
		waking. Recovery from sleep inertia can last for up to two hours.
Sleep (Risk)	Risk of Performance Decrements and Adverse Health Outcomes Resulting from Sleep Loss, Circadian Desynchronization, and Work Overload.	Risk Statement: Given that astronauts experience sleep loss, circadian desynchronization, and work overload, there is a possibility that performance decrements and adverse health outcomes will occur.
Social Dynamics	The social interaction dynamics within the crew and between the crew and ground support teams.	Social dynamics include group living competencies, culture, language, and personality, among other factors.
Social Support	Collective structure (perceived or real) for help or aid from a mixture of relationships such as friends, family, colleagues, acquaintances, and the public; perceived social support is when individuals believe they have support available.	
Solar Cycle	An approximately 11-year cycle experienced by the Sun.	During the solar cycle, the Sun's stormy behavior builds to a maximum, and its magnetic field reverses. Then, the Sun settles back down to a minimum before another cycle begins
Solar Particle Event	Phenomenon which occurs when particles from the Sun are accelerated and transiently alter the local radiation environment.	
Spatial Orientation	The accuracy of perceived body position with respect to a gravity-inertial vector and/or external surroundings (e.g., spacecraft).	
Staged Denitrogenation	Gradual or phased reduction of nitrogen in lungs and body tissues by breathing gases devoid of nitrogen.	
Standards/Requirements	NASA documents (in HSRB DAGs, usually refers to the NASA STD 3001 Vol 1 and Vol 2) that contain common and repeated use of rules, conditions, guidelines, or characteristics for products or related processes and production methods and related management system practices. Requirements are usually much more detailed "children" of these Standards and are negotiated with the Space flight Programs and HMTA at the onset of the Program.	Standards for the HSIA Risk include NASA documents (e.g., NASA STD 3001 Vol 1 and Vol 2) that contain the desired functionality, features, or other attributes of systems being developed or acquired without stating a method for achieving it.
Startle Reaction	An unconscious defensive response to sudden or	

Nodes	Definitions	Additional Notes
	threatening stimuli such as a loud noise, sharp movement, or shock.	
Starvation	Starvation is a severe deficiency in caloric energy intake, below the level necessary to sustain life.	Starvation results in suffering or death caused by extreme hunger and undernourishment.
Stress	Measurable physiological response which may be characterized as emotional or physical tension, to environmental factors. It is mediated by various 'stress hormones' which the body produces to respond to such stressors.	Stress may be acute (EVA) or chronic (prolonged isolation), resulting in differing effects on physiology. Stress can result in negative physiological responses, such as immune suppression, negative cardiovascular events or outcomes, sleep disturbances and ultimately, decreased task performance and cognition.
Stress Relieving VR	Virtual reality (VR) systems and/or programming that mitigates stress.	
Strobe Goggles	Goggles that flash between a transparent and opaque view with the goal of helping people who are undergoing vestibular readaptation to maintain gaze without suffering from retinal slip, or an object slipping over your retina instead of stabilizing there.	
Sudden Sensorineural Loss	An unexplained, rapid loss of hearing (in the inner ear) that occurs all at once or over a few days. One or both ears may be affected.	
Suit Damage	Harm or injury to the flight or EVA suit.	For example, an actor (topical medication) causes an impairment or negatively impacts the usefulness of the suit.
Suit Design	The form and function of the spacesuit to support the operational mission goals and performance environment.	
Suit Failure	Compromised function of the suit system possibly due to the unanticipated malfunction of a component, unexpected interaction of subsystems, unintended behavior, or external environmental effect.	
Suit Habitability	Capability of an EVA suit to provide a micro-environment for crew that must provide all the life support, nutrition, hydration, waste, and consumables management function of an actual space vehicle, while allowing crewmembers to perform mission tasks.	EVA spacesuits are designed to be used for durations of less than a day due to potential human and suit system constraints. This includes all suited phases (e.g., prebreathe, leak checks, airlock depress, repress).
Suit-Vehicle/Habitat Contact	Suit, vehicle, and/or habitat exposure to charged	

Nodes	Definitions	Additional Notes
	surfaces.	
Sunlight	Solar radiation, includes ultraviolet, visible, infrared, and near-infrared ranges of the electromagnetic spectrum.	
Supplements	Consumable products that contain a dietary ingredient such as vitamins, minerals, amino acids, herbs or botanicals;	Supplements are designed to enhance nutrient composition of diet which may be lower than needed (such as Vitamin D or B complex) or to improve a condition which has been associated with loss or lowered levels of a nutrient (such as chondroitin sulfate and glucosamine for arthritis). Certain nutritional supplements are included in the proposed immune countermeasures suite.
Surface Contamination	Harmful or poisonous substances affecting surface quality within the vehicle, suit, or habitat in-mission.	Microbes on surfaces are found regularly on ISS, cleaning procedures can decrease impact on crew.
Surface Dust Level	The quantity of particulate matter on the surfaces within the within the vehicle, suit, or habitat in-mission.	
Surveillance	Monitoring and diagnostic services available to active and retired astronauts to facilitate early detection of health conditions that may be associated with exposures incurred during space flight or space flight training.	
Sympathomimetics	A group of chemical substances (stimulant compounds) that elicit an effect on the sympathetic nervous system.	
System Complexity	A measure of the number, diversity, and intricacy of vehicle systems and their interactions.	
System Knowledge Resources	The information that describes and fully specifies the system, including analyses, drawings, and requirements.	Crew performance for maintenance and repair if spacesuit, vehicle, and habitat issues is dependent on ready access to information and manuals needed.
System Telemetry	Vehicle/system state information received from distal sensors.	
Tamsulosin	A medication (alpha-1 blocker) used to treat BPH. Off label use treatment for kidney stone expulsion.	
Task	A specific type, piece, or amount of work; a subset of an activity or job that is called out in a procedure. (NASA-STD-3001)	

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Nodes	Definitions	Additional Notes
Task Performance	Likelihood of successful performance of a task based on factors such as response time, efficiency, or accuracy.	
Team	A collection of individuals who are assigned to support and achieve a particular mission. This can encompass both the spaceflight crew and ground support for a particular mission.	
Team Cognition	Shared understanding among team members that is related to roles and responsibilities; team norms; familiarity with team members' knowledge, skills, and abilities; and engaging in team decision-making and problem-solving.	
Team Cohesion	Tendency for a group to operate in a unified fashion while working towards a goal or to satisfy the emotional needs of its members.	
Team Composition	The mix of individuals on a team that evolves to meet mission demands pre-mission through post mission phases. This includes those the ground support, intelligent systems, and sub-teams; composition factors for mission performance include personality traits, values, culture, demographics, knowledge, skills, and abilities.	
Team Functionality	The degree of coordination, cooperation, communication, and psychosocial adaptation that enables a team to successfully complete tasks and live and work as a team.	
Team Monitoring	Observing changes in team task performance, team processes, and interpersonal dynamics through surveys and unobtrusive tools such as semantic analysis.	
Team (Risk)	Risk of Performance and Behavioral Health Decrements Due to Inadequate Cooperation, Coordination, Communication, and Psychosocial Adaptation within a Team.	Risk Statement: Given that the conditions of space missions may lead to inadequate functioning within a team (inadequate cooperation, coordination, communication and/or psychosocial adaptation), which includes flight crew and ground support, there is a possibility that performance and behavioral health decrements will occur.

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Nodes	Definitions	Additional Notes
Team Skills	Skills that enable team functioning and performance.	Team skills include information sharing, backup behaviors, leadership/followership, team care, and providing social support, among others.
Team Training	Training focused on team skills for living and working together in space.	
Technical Training	Training focused on technical skills needed to perform tasks in space.	
Temperature	The degree or intensity of heat present in a substance or object; an environmental factor which may contribute to several Risks.	
Thermal Degradation	Chemicals produced when a material is exposed to elevated temperatures	For example, Teflon releases PFIB at very high temps.
Thermal Environment	Cabin temperature and humidity environment during and post landing.	
Thiazides	A class of drugs that act directly on the kidneys to promote diuresis and increase urine flow.	Thiazides are primarily used in the treatment of hypertension. It is also used to reduce kidney stone recurrence.
Thigh Cuffs	Cuffs placed around the upper thigh which can be tightened or inflated to occlude venous (i.e., sequestering blood in the lower body) and arterial blood flow (i.e., blood flow restriction).	
Time Critical Procedure Execution	Accomplishing the steps in a procedure that must be completed within a specific period to prevent unwanted consequences and/or achieve the desired outcome.	
Tool Design	The form and function of a hardware/software device, implement, or method to accomplish a particular outcome in a specific operating environment.	
Tox (Risk)	Risk of Toxic Exposure.	Risk Statement: Given that the numerous sources of toxic chemicals onboard spacecraft cannot be eliminated, there is a risk of toxic exposure that will impact crew performance and lead to Loss of Mission Objectives (LOMO), Loss of Mission (LOM), Loss of Crew (LOC), or Long-Term Health (LTH) Conditions.
Toxic Exposure	Contact with agents or substances in the interior of the	

Nodes	Definitions	Additional Notes
	spacecraft or spacesuit that can affect the health and performance of the astronauts.	
Toxic Substance Monitoring	Monitoring for specific toxic compounds of potential concern.	
Training	The act of undertaking a course of instruction in skills, knowledge or fitness that relate to specific competencies needed for space flight missions.	Training has specific goals of improving an individual or team's capability, capacity, and performance.
Trapped Radiation	Charged particles trapped by Earth's magnetic field.	
Traumatic Injury	Any injury that occurs as a result of as a result of penetrating or blunt forces or thermal loads.	
Treatment Decision	Determination of need to manage and provide care for crew with medications or procedures during a space flight mission.	
Ultrasound	An imaging modality to examine the internal organs using very high frequency sound waves.	
Ultrasound Manipulation	Treatment modality to aid in movement of a renal stone either before it enters the ureter or moving it out of the ureter thus decreasing time of symptoms.	Ultrasound Manipulation is also known as propulsive ultrasound or ultrasound propulsion.
Ureterolithiasis	Stones in the ureter.	
Urinary Muscle Changes	Alterations in muscle function due to altered gravity environment, side effects of medications, etc.	
Urinary Retention	A condition in which all the urine from the bladder cannot be emptied.	
Urinary Retention (Risk)	Risk of Urinary Retention.	Risk Statement: Given that the space flight environment alters the gravity vector involved in terrestrial micturition and causes physiological changes that may require use of predisposing medications, and that mission operational schedules may limit access to voiding, there is a possibility of health and performance impact during space flight by significant discomfort from urinary retention and associated urinary tract infection.
Urine Chemistry	The levels of stone-promoting substances (Ca, oxalate, uric acid, pH) in the urine and its pH.	
Urine Concentration	The state of saturation of urine relative to water content.	

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Nodes	Definitions	Additional Notes
Urine Flow	The ability for urine to flow normally through the urinary tract.	
Vascular Congestion	Increased blood volume in a vessel as a result of changes in pressure and/or obstruction.	
Vascular Structure/Function	Anatomy and physiological function of the arteries, arterioles, venules, veins, and capillaries.	
Vehicle Design	Determining and developing the form and function of space vehicles toward the operational mission goals and performance environment.	Vehicle design includes restraints and occupant protection measures.
Vehicle Dynamics	Angular and linear accelerations of a vehicle.	
Vehicle Failure	Compromised function of the vehicle system.	Vehicle failure could possibly occur due to the unanticipated malfunction of a component, unexpected interaction of subsystems, unintended behavior, or external environmental effect.
Vehicle Systems	The set of systems, subsystems, and components (e.g., thermal control system, pump module, flow control valve) that make up a whole vehicle. Also, may refer to vehicle systems across multiple vehicles (Orion, Gateway, HLS).	
Venous Thrombosis	The development of a blood clot in a vein.	
Vestibular Gain Change	The relationship between accelerations, including gravitational, and vestibular responses.	
Vestibular Motor Neuron Change	Vestibular neurons adapt to reduced or increased firing rates and become more, or less, sensitive.	
Vibration Isolation System	Passive or active mechanical interface between the exercise device and the vehicle to isolate the exercise system and eliminate/attenuate exercise reaction loads transmitted to the vehicle.	
Vison and Gaze Control	Vision is the ability to see and gaze control is the ability to orient the eyes, and maintain fixation, on a desired visual target.	
Visual Acuity Test	A primary vision test which measures the visual system's ability to discern targets (e.g., letters) at a given distance (e.g., 20 feet) from the patient.	Visual Acuity is defined by the smallest letters that can be identified under standard viewing conditions. An average acuity for young adults is about -

Nodes	Definitions	Additional Notes
		0.1 logMAR but declines with age. (NASA-STD-3001) age.
Visual Field Defect	Dysfunction in central or peripheral vision.	
Visual Fields Test	Ophthalmic diagnostic test which detects defects in central and peripheral vision.	
Void Trial	Measure of the ability of the bladder to empty.	
Vomit	Disgorging the contents of the stomach through the mouth.	
VTE (Concern)	Concern of Venous Thromboembolism (VTE).	Risk Statement: Given there has been an asymptomatic in-flight venous thrombosis of unknown origin aboard the International Space Station (ISS), there is a potential risk for a crewmember to encounter the terrestrial consequences of venous thromboses and treatment adverse events which include pain, post-thrombotic syndrome, pulmonary embolism, death, recurrence, and bleeding (treatment-related risk).
Waste Management System	The combination of elements that function together to produce the capability to facilitate the clean, efficient, and reliable collection and management of human waste (urine, feces, vomitus, and menses).	Waste Management Systems include systems for food waste, body waste, personal hygiene, and exercise. Elements of the systems include all hardware, software, equipment, facilities, personnel, processes, and procedures.
Water Contamination	Harmful or poisonous substances affecting water quality within the vehicle or habitat in-mission.	Regular monitoring and use of disinfectants (iodine and silver as examples) helps limit infections in crew.
Water Intake	Water intake encompasses the total fluid intake consumed from foods, plain drinking water, and other beverages.	
Workload	Level of demand placed on a crewmember's physical, cognitive, and/or temporal resources in a unit of time.	Physical workload refers to the number of individual physical activities that are conducted simultaneously or in close succession. Similarly, mental, or cognitive workload refers to the number of mental operations or activities that are conducted simultaneously or in close succession. (NASA-STD-3001) Such demands tax time/schedules, physical abilities, and cognitive abilities of the crew which are finite resources.

Appendix A – Directed Acyclic Graph Dictionary

Appendix B – DAG Nodes to Risks Mapping

The following is a tabular representation of each node in the Human System Risk DAGs and all of the Risks using that particular node. The node names appear on the left side and the Risk names appear at the top. Each blue box intersection represents a node appearing in that DAG. Some nodes are common across many Risks like “Altered Gravity”, others appear in only one Risk like “Blood Viscosity”.

Appendix B – DAG Nodes to Risks Mapping

Node	Acoustics Risk	Behavioral Risk	Bone Fracture Risk	Cardiovascular Risk	CO2 Risk	Crew Egress Risk	DCS Risk	Dust Risk	Dynamic Loads Risk	Electrical Shock Risk	EVA Risk	Food and Nutrition Risk	HSIA Risk	Hypoxia Risk	Immune Risk	Medical Conditions Risk	Microhost Risk	Muscle and Aerobic Risks	Non-Ionizing Radiation Risk	Pharm Risk	Radiation Carcinogenesis	Renal Stone Risk	SANS Risk	Sensorimotor Risk	Sleep Risk	Team Risk	Toxic Exposure Risk	Urinary Retention Risk	VTE Concern
Absorption																				■									
Acoustics (Risk)																									■	■	■		
Aerobic (Risk)			■	■		■						■				■													
Aerobic Fitness																		■											
Air Contamination																	■												
Airlock Design							■																						
Altered Gravity	■		■	■	■	■	■		■		■	■		■	■	■	■	■		■		■	■	■	■		■	■	■
Ambient CO2 Level					■													■											
Anomalous Events													■																
Anthropometry									■																				
Anticholergics																												■	
Anticoagulants																													■
Antimicrobial Resistance																				■									
Arc Flash/Sparking										■																			
Arterial Gas Embolism							■																						
Artificial Gravity																								■					
Aspiration						■																							
Astronaut Selection	■	■	■	■			■		■		■	■			■	■	■	■			■	■	■	■	■	■		■	■
Atmospheric Conditions							■							■	■														■
Atmospheric Dust Level								■																					
Atmospheric Mixing					■																						■		
Atmospheric Scrubbers																										■			
Autonomous Systems													■																
Balance Training																								■					
Barotrauma	■																												
Behavioral (Risk)					■							■			■	■	■			■					■	■	■		
BHP Countermeasures																										■			
BHP Family Services		■																											
BHP Intervention Capability		■																											
BHP Monitoring Capability		■																											
BHP Prevention Capability		■																											

Appendix B – DAG Nodes to Risks Mapping

Node	Acoustics Risk	Behavioral Risk	Bone Fracture Risk	Cardiovascular Risk	CO2 Risk	Crew Egress Risk	DCS Risk	Dust Risk	Dynamic Loads Risk	Electrical Shock Risk	EVA Risk	Food and Nutrition Risk	HSIA Risk	Hypoxia Risk	Immune Risk	Medical Conditions Risk	Microhost Risk	Muscle and Aerobic Risks	Non-Ionizing Radiation Risk	Pharm Risk	Radiation Carcinogenesis	Renal Stone Risk	SANS Risk	Sensorimotor Risk	Sleep Risk	Team Risk	Toxic Exposure Risk	Urinary Retention Risk	VTE Concern
Biologic Response																					■								
Biomedical Exposures																					■								
Bisphosphonates																						■							
Blood Stagnation																													■
Blood Viscosity																													■
Body Posture									■																				
Bone Density			■																										
Bone Formation			■																										
Bone Fracture			■																										
Bone Fracture (Risk)					■	■						■								■		■							
Bone Remodeling									■													■							
Bone Resorption			■																										
Bone Structure			■																										
Brain Structural Changes																							■						
Breathing Masks										■				■															
Burn Treatment Capability										■																			
Burns										■																			
Cabin Visibility								■																					
Cancer																					■								
Cancer Model																					■								
Cancer Treatment																					■								
Cardiac Structure/Function				■																									
Cardiovascular (Risk)						■		■				■						■		■			■				■		
Cartilage Defect			■																										
Catheterization																												■	
Central Nervous System Changes		■							■																				
Charged Particles																					■								
Charged Surface										■																			
Chondrocyte Metabolism			■																										
Chorioretinal Folds																							■						
Circadian Misalignment															■										■				
Cleaning								■																					
Clinically Significant Immune Dysregulation															■														

Appendix B – DAG Nodes to Risks Mapping

Node	Acoustics Risk	Behavioral Risk	Bone Fracture Risk	Cardiovascular Risk	CO2 Risk	Crew Egress Risk	DCS Risk	Dust Risk	Dynamic Loads Risk	Electrical Shock Risk	EVA Risk	Food and Nutrition Risk	HSIA Risk	Hypoxia Risk	Immune Risk	Medical Conditions Risk	Microhost Risk	Muscle and Aerobic Risks	Non-Ionizing Radiation Risk	Pharm Risk	Radiation Carcinogenesis	Renal Stone Risk	SANS Risk	Sensorimotor Risk	Sleep Risk	Team Risk	Toxic Exposure Risk	Urinary Retention Risk	VTE Concern
CO2 (Risk)															■							■	■		■	■	■		■
CO2 Physiologic Changes					■																								
CO2 Production					■																								
CO2 Removal					■																								
Coagulability																													■
Cochlear Changes	■																												
Cognitive Function		■									■			■															
Combustion/Smoldering Events																										■			
Communication Factors		■											■			■										■	■		
Communications Delay																										■			
Compartment Isolation														■															
Connective Tissue Changes									■																				
Crew Capability	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■		■	■	■	■	■	■	■	■
Crew Composition		■																											
Crew Egress (Risk)																■													
Crew Health and Performance System	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Crew Metabolism																											■		
Crew Size					■								■													■			
Crew Vehicle Integration						■				■			■																
Data Accessibility													■			■													
Data Architecture													■			■													
DCS (Risk)			■			■					■			■						■									
DCS Type I							■																						
DCS Type II							■																						
Denitrogenation							■																						
Depressurization							■							■															
Detect Atmospheric Changes														■															
Detect Atmospheric Dust								■																					
Detect BHP Changes		■																											
Detect Bone Density Changes			■																										
Detect Bone Structure Changes			■																										

Appendix B – DAG Nodes to Risks Mapping

Node	Acoustics Risk	Behavioral Risk	Bone Fracture Risk	Cardiovascular Risk	CO2 Risk	Crew Egress Risk	DCS Risk	Dust Risk	Dynamic Loads Risk	Electrical Shock Risk	EVA Risk	Food and Nutrition Risk	HSIA Risk	Hypoxia Risk	Immune Risk	Medical Conditions Risk	Microhost Risk	Muscle and Aerobic Risks	Non-Ionizing Radiation Risk	Pharm Risk	Radiation Carcinogenesis	Renal Stone Risk	SANS Risk	Sensorimotor Risk	Sleep Risk	Team Risk	Toxic Exposure Risk	Urinary Retention Risk	VTE Concern
Detect Brain Structural Changes																							■						
Detect CO2 Level					■																								
Detect Contamination																	■												
Detect CV Events				■																									
Detect DCS							■																						
Detect Diagnosis																■											■		
Detect Dysrhythmia										■																			
Detect Environmental Conditions																■									■				
Detect EVA Readiness											■																		
Detect Events													■																
Detect Hearing Changes	■																												
Detect Immune Changes															■														
Detect Intracranial Pressure Changes																							■						
Detect Long Term Health Outcomes	■	■	■	■		■	■	■	■	■	■	■			■	■	■		■	■	■	■	■		■		■	■	■
Detect MRM/Stone																						■							
Detect Noise Levels	■																												
Detect Ocular Structural Changes																							■						
Detect Physiologic Changes																■													
Detect Post-Void Residual																												■	
Detect Pressure Changes	■																												
Detect Radiation																					■								
Detect Team Performance and Cohesion																										■			
Detect Thrombosis																													■
Detect Toxic Exposure																											■		
Detect Visual Changes																							■						
Diagnose Events													■																
Diagnose Rhabdomyolysis										■																			
Diagnostic Capability													■																
Distance from Earth	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Distribution																				■									
Dust (Risk)															■												■		

Appendix B – DAG Nodes to Risks Mapping

Node	Acoustics Risk	Behavioral Risk	Bone Fracture Risk	Cardiovascular Risk	CO2 Risk	Crew Egress Risk	DCS Risk	Dust Risk	Dynamic Loads Risk	Electrical Shock Risk	EVA Risk	Food and Nutrition Risk	HSIA Risk	Hypoxia Risk	Immune Risk	Medical Conditions Risk	Microhost Risk	Muscle and Aerobic Risks	Non-Ionizing Radiation Risk	Pharm Risk	Radiation Carcinogenesis	Renal Stone Risk	SANS Risk	Sensorimotor Risk	Sleep Risk	Team Risk	Toxic Exposure Risk	Urinary Retention Risk	VTE Concern
Dust Monitor								■																					
Dust Removal								■																					
Dust Source								■																					
Dust Suspension								■																					
DXA			■																										
Dynamic Loads (Risk)			■			■					■																		
Dysrhythmia										■																			
Dysrhythmia Monitor										■																			
Dysrhythmia Treatment										■																			
Ebullism							■																						
ECLS System					■			■										■							■		■		
Effective Exposure Duration	■				■	■								■															
Effective Gravity Level						■												■											
Effective Mission Duration												■	■					■		■	■					■			
Electric Shock (Risk)																				■							■		
Electrical Hardware										■																			
Electrical Muscle Effects										■																			
Electrical Shock										■																			
Electrical System Design										■																			
Elimination																				■									
Endocrine Factors			■	■														■											■
Endothelial Damage																													■
Energy (Calories)												■																	
Environmental Conditions	■			■												■									■				
Environmental Control	■				■																				■				
Environmental Injury						■					■					■													
Environmental Monitoring Capability	■				■									■		■	■								■				
Environmental Risks																■					■								
Estimated Career Dose																					■								
Estimated Dose Rate																					■								
Estimated Mission Radiation Dose																					■								
EVA (Risk)																■				■					■			■	

Appendix B – DAG Nodes to Risks Mapping

Node	Acoustics Risk	Behavioral Risk	Bone Fracture Risk	Cardiovascular Risk	CO2 Risk	Crew Egress Risk	DCS Risk	Dust Risk	Dynamic Loads Risk	Electrical Shock Risk	EVA Risk	Food and Nutrition Risk	HSIA Risk	Hypoxia Risk	Immune Risk	Medical Conditions Risk	Microhost Risk	Muscle and Aerobic Risks	Non-Ionizing Radiation Risk	Pharm Risk	Radiation Carcinogenesis	Renal Stone Risk	SANS Risk	Sensorimotor Risk	Sleep Risk	Team Risk	Toxic Exposure Risk	Urinary Retention Risk	VTE Concern
EVA Decision Support											■																		
EVA Duration											■																		
EVA Frequency											■																		
EVA Operations							■	■		■				■															
EVA Task Timeline											■																		
Evacuation		■	■	■	■	■		■	■	■		■	■		■	■	■			■		■				■	■	■	■
Exercise		■		■	■										■					■				■					
Exercise Hardware																		■						■					
Exercise Prescription																		■											
External Contaminants																											■		
Extraterrestrial Surface																					■								
Eye Injury								■											■										
Fall Height						■					■																		
Family Effects																										■			
Family/World Events		■																											
Fatigue											■							■							■				
Fine Motor Control																								■					
Flight Recertification			■	■		■		■	■						■	■			■		■	■	■						
Fluid Shifts	■			■																■			■	■					■
Food Acceptability												■																	
Food and Nutrition (Risk)			■	■	■										■		■	■		■		■	■		■	■			■
Food Contamination																	■												
Food Preparation												■																	
Food Production												■																	
Food Safety												■																	
Food Storage												■																	
Food System												■																	
Food Variety												■																	
Fundoscopy																							■						
Galactic Cosmic Radiation																					■								
Gamma Rays																					■								
Globe Flattening																							■						
Ground Support		■				■							■			■										■	■		
Hardware/System Failure										■																			

Appendix B – DAG Nodes to Risks Mapping

Node	Acoustics Risk	Behavioral Risk	Bone Fracture Risk	Cardiovascular Risk	CO2 Risk	Crew Egress Risk	DCS Risk	Dust Risk	Dynamic Loads Risk	Electrical Shock Risk	EVA Risk	Food and Nutrition Risk	HSIA Risk	Hypoxia Risk	Immune Risk	Medical Conditions Risk	Microhost Risk	Muscle and Aerobic Risks	Non-Ionizing Radiation Risk	Pharm Risk	Radiation Carcinogenesis	Renal Stone Risk	SANS Risk	Sensorimotor Risk	Sleep Risk	Team Risk	Toxic Exposure Risk	Urinary Retention Risk	VTE Concern
Hearing Countermeasures	■																												
Helmet/Protective Visors																			■										
Hematologic Index Alterations																													■
Hostile Closed Environment	■			■	■	■	■	■	■	■	■	■		■	■	■	■			■		■		■	■		■	■	■
HSI Processes													■																
HSIA (Risk)	■	■	■	■	■	■	■	■		■	■	■		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	
Human Error										■																			
Human-Electrical Contact										■																			
Humidity																		■				■							
Hydration												■								■		■							
Hygiene																	■												
Hypoxia														■															
Hypoxia (Risk)					■	■									■										■				■
Immune (Risk)				■				■				■		■			■			■					■				
Impedance Factors										■																			
Incapacitation/ Crew Rescue											■																		
Individual Factors	■	■	■	■	■		■		■		■	■		■	■	■	■	■		■		■	■	■	■	■	■	■	■
Individual Readiness	■	■	■	■	■	■	■	■	■	■	■	■		■	■	■	■	■	■	■		■	■	■	■	■	■	■	■
Infection																	■												
Inflammation		■		■											■													■	■
Inflight Hearing Exams	■																												
Ingestion Toxicity								■																					
In-Mission Shelf Life																			■	■									
Insomnia																									■				
Interpersonal Relationships																										■			
Intervention Decision													■																
Intervention Measures																					■								
Intervention Source Control																	■												
Intracochlear Pressure	■																												
Intracranial Pressure Changes																							■						

Appendix B – DAG Nodes to Risks Mapping

Node	Acoustics Risk	Behavioral Risk	Bone Fracture Risk	Cardiovascular Risk	CO2 Risk	Crew Egress Risk	DCS Risk	Dust Risk	Dynamic Loads Risk	Electrical Shock Risk	EVA Risk	Food and Nutrition Risk	HSIA Risk	Hypoxia Risk	Immune Risk	Medical Conditions Risk	Microhost Risk	Muscle and Aerobic Risks	Non-Ionizing Radiation Risk	Pharm Risk	Radiation Carcinogenesis	Renal Stone Risk	SANS Risk	Sensorimotor Risk	Sleep Risk	Team Risk	Toxic Exposure Risk	Urinary Retention Risk	VTE Concern
Intracranial Pressure Monitoring																							■						
Intravascular Volume				■																									
Isolation and Confinement		■									■				■	■	■	■							■	■		■	■
K+ Citrate																						■							
Lab Blood Monitoring															■														
Landing Profile						■																							
Landing Site Environment						■																							
Laser																			■										
Lenses																							■						
Long Term Health Clinical Decisions			■																										
Long Term Health Outcomes	■	■	■	■		■	■	■	■	■	■	■			■	■	■		■	■	■	■	■		■		■	■	■
Loss of Crew Life		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■		■		■		■	■	■	■	■	■
Loss of EVA Content											■																		
Loss of EVA(s)							■																						
Loss of Mission		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■		■	■	■	■	■	■	■	■
Loss of Mission Objectives	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■		■	■	■	■	■	■	■	■
Loss of Vehicle													■	■												■			
Lower Body Negative Pressure																							■						
Lung Injury								■																					
Maintainability													■																
Manufacturer Shelf Life																				■									
Materials Offgassing																											■		
Measurable Hearing Shift	■																												
Mechanical Obstruction																												■	
Mechanical Systems					■																								
Medical (Risk)	■				■			■				■		■						■					■	■	■		■
Medical Diagnostic Capability							■			■						■				■									
Medical Illness				■											■	■						■						■	
Medical Monitoring Capability				■																		■							■
Medical Prevention Capability				■		■		■							■	■	■		■	■	■	■	■	■	■		■	■	■

Appendix B – DAG Nodes to Risks Mapping

Node	Acoustics Risk	Behavioral Risk	Bone Fracture Risk	Cardiovascular Risk	CO2 Risk	Crew Egress Risk	DCS Risk	Dust Risk	Dynamic Loads Risk	Electrical Shock Risk	EVA Risk	Food and Nutrition Risk	HSIA Risk	Hypoxia Risk	Immune Risk	Medical Conditions Risk	Microhost Risk	Muscle and Aerobic Risks	Non-Ionizing Radiation Risk	Pharm Risk	Radiation Carcinogenesis	Renal Stone Risk	SANS Risk	Sensorimotor Risk	Sleep Risk	Team Risk	Toxic Exposure Risk	Urinary Retention Risk	VTE Concern
Medical Treatment Capability			■	■		■	■	■	■	■	■				■	■	■		■	■		■	■	■	■			■	■
Medication Compatibility																				■									
Medications																						■	■						
Metabolism																				■									
Microbial Resistance Factors																	■												
Microbial Virulence Factors															■		■												
Microbiome															■		■					■							
Microhost (Risk)												■			■					■		■							
Mild Hypoxia														■															
Mineralized Renal Material																						■							
Mission Architecture Complexity													■																
Mitigation Options													■																
Modifiable Individual Factors																					■								
Monitoring Capability													■																
Morphological G-Receptor Changes																								■					
Motion Sickness						■																		■					
Motivation																		■											
MRI			■																				■						
Multi-Sensory Integration Alterations																								■					
Muscle (Risk)			■			■						■				■								■					
Muscle Performance									■									■											
Muscle Physiologic Changes																		■						■					
Musculoskeletal Injury									■																				
Musculoskeletal Loads			■															■						■					
Nephrolithiasis																						■							
Net Habitable Volume					■																					■			
Neuro/Ocular Injury									■																				
Neutrons																					■								
Noise Exposure	■																												

Appendix B – DAG Nodes to Risks Mapping

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Non-Modifiable Individual Factors																					■								
Nuclear Technology																					■								
Nutrient Deficiencies												■																	
Nutrient Toxicities												■																	
Nutrients												■			■							■							
On-Board Expertise													■			■													
Operations Design						■																	■						
Optic Disc Edema																							■						
Optical Coherence Tomography																							■						
Oral Contraceptives																													■
Organ Perfusion				■		■																							
Orthostatic Intolerance				■																									
Orthostatic Intolerance Countermeasures				■																									
Osteoarthritis			■																										
Other Risks		■											■			■													
Ototoxins	■																												
Oxidative Stress		■		■											■														■
Payload Chemicals																										■			
Percutaneous Nephrostomy																						■							
Persistent Subclinical Immune Dysregulation															■														
Pharm (Risk)	■		■	■	■			■				■			■	■	■	■			■	■	■	■	■		■	■	■
Pharmaceutical Contamination																	■												
Pharmaceutical Effectiveness																				■									
Pharmaceutical Storage Conditions																				■									
Pharmaceutical Toxicity																				■									
Pharmacodynamics																				■									
Pharmacogenomics																				■									
Pharmacokinetics																				2									
Physical Status											■																		

Appendix B – DAG Nodes to Risks Mapping

Node	Acoustics Risk	Behavioral Risk	Bone Fracture Risk	Cardiovascular Risk	CO2 Risk	Crew Egress Risk	DCS Risk	Dust Risk	Dynamic Loads Risk	Electrical Shock Risk	EVA Risk	Food and Nutrition Risk	HSIA Risk	Hypoxia Risk	Immune Risk	Medical Conditions Risk	Microhost Risk	Muscle and Aerobic Risks	Non-Ionizing Radiation Risk	Pharm Risk	Radiation Carcinogenesis	Renal Stone Risk	SANS Risk	Sensorimotor Risk	Sleep Risk	Team Risk	Toxic Exposure Risk	Urinary Retention Risk	VTE Concern
Physiologic Monitoring Capability										■	■					■							■				■		
Planned EVA Content											■																		
Plasma Induced Shock										■																			
Post-Landing Task Performance						■																							
Postural Control and Locomotion																								■					
Post-Void Residual																												■	
Preflight Hearing Status	■																												
Pressure Suits														■															
Pre-syncope/Syncope				■																									
Preventive Source Control																	■												
Previous Injury											■																		
Prior Mission Exposures																					■								
Privacy/Team Space																										■			
Private Astronaut Missions																										■			
Probiotics															■														
Procedure Design						■					■		■																
Proprioception Change																								■					
Protective Equipment																											■		
Protective Glasses																			■										
Protective Windows and Filters																			■										
Psychological Status		■																											
QCT			■																										
Radiation		■	■	■						■	■	■			■	■			■	■	■			■	■			■	■
Radiation Carcinogenesis (Risk)												■								■									
Radiation Monitors																					■								
Recycling												■																	
Refractive Error Shift																							■						
Renal Stone (Risk)					■							■								■									
Resistive Exercise			■															■				■							
Resource Availability													■			■				■									
Resupply												■	■			■				■									

Appendix B – DAG Nodes to Risks Mapping

Node	Acoustics Risk	Behavioral Risk	Bone Fracture Risk	Cardiovascular Risk	CO2 Risk	Crew Egress Risk	DCS Risk	Dust Risk	Dynamic Loads Risk	Electrical Shock Risk	EVA Risk	Food and Nutrition Risk	HSIA Risk	Hypoxia Risk	Immune Risk	Medical Conditions Risk	Microhost Risk	Muscle and Aerobic Risks	Non-Ionizing Radiation Risk	Pharm Risk	Radiation Carcinogenesis	Renal Stone Risk	SANS Risk	Sensorimotor Risk	Sleep Risk	Team Risk	Toxic Exposure Risk	Urinary Retention Risk	VTE Concern
Retinal Nerve Fiber Layer Atrophy																							■						
Rhabdomyolysis										■																			
Rhabdomyolysis Treatment										■																			
SANS (Risk)					■				■					■						■				■					
Schedule Shifting																									■				
Scheduling																		■											
Seals/Gaskets								■																					
Self-Administered Rehab																								■					
Sensorimotor (Risk)			■			■			■									■										■	
Sensory Augmentation																								■					
Sepsis																	■												
Shielding																					■								
Side Effects																				■									
Skeletal Fragility			■																										
Skin Injury																			■										
Skin Irritation								■																					
Sleep (Risk)				■	■							■		■	■			■		■						■			
Sleep Deficiencies																									■				
Sleep Inertia																									■				
Social Dynamics		■																											
Social Support																										■			
Solar Cycle																					■								
Solar Particle Event																					■								
Spatial Orientation																								■					
Staged Denitrogenation														■															
Standards/Requirements		■											■														■		
Startle Reaction										■																			
Starvation												■																	
Stress															■										■				■
Stress Relieving VR															■														
Strobe Goggles																								■					
Sudden Sensorineural Loss	■																												
Suit Damage																				■									

Appendix B – DAG Nodes to Risks Mapping

Node	Acoustics Risk	Behavioral Risk	Bone Fracture Risk	Cardiovascular Risk	CO2 Risk	Crew Egress Risk	DCS Risk	Dust Risk	Dynamic Loads Risk	Electrical Shock Risk	EVA Risk	Food and Nutrition Risk	HSIA Risk	Hypoxia Risk	Immune Risk	Medical Conditions Risk	Microhost Risk	Muscle and Aerobic Risks	Non-Ionizing Radiation Risk	Pharm Risk	Radiation Carcinogenesis	Renal Stone Risk	SANS Risk	Sensorimotor Risk	Sleep Risk	Team Risk	Toxic Exposure Risk	Urinary Retention Risk	VTE Concern
Suit Design	■		■	■	■	■	■	■	■	■			■	■		■			■	■									
Suit Failure							■				■			■															
Suit Habitability											■																		
Suit-Vehicle/Habitat Contact										■																			
Sunlight																			1										
Supplements															■								■						
Surface Contamination								■									■												
Surface Dust Level								■																					
Surveillance	■	■	■	■		■	■	■	■	■	■	■			■	■	■		■	■	■	■	■		■		■	■	■
Sympathomimetics																												■	
System Complexity													■																
System Knowledge Resources													■																
System Telemetry													■																
Tamsulosin																						■							
Task Performance	■	■	■	■	■		■	■	■	■	■	■	■	■	■	■	■	■	■	■		■	■	■	■	■	■	■	■
Team (Risk)		■			■	■						■			■	■	■								■		■		
Team Cognition																										■			
Team Cohesion																										■			
Team Composition																										■			
Team Functionality																										■			
Team Monitoring																										■			
Team Skills																										■			
Team Training																										■			
Technical Training																										■			
Temperature																		■											
Thermal Degradation																											■		
Thermal Environment						■																							
Thiazides																						■							
Thigh Cuffs																							■						
Time Critical Procedure Execution													■																
Tool Design											■																		
Tox (Risk)	■			■																									

Appendix B – DAG Nodes to Risks Mapping

Node	Acoustics Risk	Behavioral Risk	Bone Fracture Risk	Cardiovascular Risk	CO2 Risk	Crew Egress Risk	DCS Risk	Dust Risk	Dynamic Loads Risk	Electrical Shock Risk	EVA Risk	Food and Nutrition Risk	HSIA Risk	Hypoxia Risk	Immune Risk	Medical Conditions Risk	Microhost Risk	Muscle and Aerobic Risks	Non-Ionizing Radiation Risk	Pharm Risk	Radiation Carcinogenesis	Renal Stone Risk	SANS Risk	Sensorimotor Risk	Sleep Risk	Team Risk	Toxic Exposure Risk	Urinary Retention Risk	VTE Concern
Toxic Exposure														■													■		
Toxic Substance Monitoring																											■		
Training		■									■		■			■													
Trapped Radiation																					■								
Traumatic Injury						■					■					■								■					
Treatment Decision																■													
Ultrasound			■																			■	■					■	■
Ultrasound Manipulation																						■							
Ureterolithiasis																						■							
Urinary Muscle Changes																											■		
Urinary Retention																											■		
Urinary Retention (Risk)																				■		■							
Urine Chemistry																						■							
Urine Concentration																						■							
Urine Flow																						■					■		
Vascular Congestion																							■						
Vascular Structure/Function				■					■																				■
Vehicle Design	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Vehicle Dynamics									■															■					
Vehicle Failure							■							■															
Vehicle Systems													■																
Venous Thrombosis																													■
Vestibular Gain Change																								■					
Vestibular Motor Neuron Change																								■					
Vibration Isolation System																		■											
Vison and Gaze Control																								■					
Visual Acuity Test																							■						
Visual Field Defect																							■						
Visual Fields Test																							■						
Void Trial																											■		
Vomit						■																							
VTE (Concern)												■								■									

Appendix B – DAG Nodes to Risks Mapping

Node	Acoustics Risk	Behavioral Risk	Bone Fracture Risk	Cardiovascular Risk	CO2 Risk	Crew Egress Risk	DCS Risk	Dust Risk	Dynamic Loads Risk	Electrical Shock Risk	EVA Risk	Food and Nutrition Risk	HSIA Risk	Hypoxia Risk	Immune Risk	Medical Conditions Risk	Microhost Risk	Muscle and Aerobic Risks	Non-Ionizing Radiation Risk	Pharm Risk	Radiation Carcinogenesis	Renal Stone Risk	SANS Risk	Sensorimotor Risk	Sleep Risk	Team Risk	Toxic Exposure Risk	Urinary Retention Risk	VTE Concern
Waste Management System																											■		
Water Contamination																	■												
Water Intake																						■							
Workload		■					■				■														■				

Appendix C – Risk Formatting Instructions
DAG Formatting from DAGitty 3.0

The Human System Risk DAGs were created using DAGitty 3.0 (3) a publicly available browser-based environment for creating, editing, and analyzing causal diagrams. DAGitty is available under the terms of the GNU general public license. Text formatting files for each Risk (as of May 2022) are included here. Note that a limitation of the DAGitty program is that it does not capture the complete information held in the official versions of the DAG. The program is unable to provide capture information such as the dotted lines seen in some of the DAGs in this document. These dotted lines signify causal connections that are weakly hypothetical at this point when evaluated based on evidence in the literature or within NASA's available data. The DAGitty files below should be thought of as representing the basic skeleton of the DAG. NASA is both investigating currently available software and developing internal software to enable DAG creation and visualization with the appropriate amount of information captured. These will be released to the public when available.

Appendix C – Risk Formatting Instructions

Acoustics Risk

dag {
"Altered Gravity" [exposure,pos="-1.554,-0.472"]
"Astronaut Selection" [pos="-1.509,-0.473"]
"Cochlear Changes" [pos="-1.528,-0.465"]
"Crew Capability" [pos="-1.504,-0.466"]
"Crew Health and Performance System" [pos="-1.539,-0.443"]
"Detect Hearing Changes" [pos="-1.517,-0.448"]
"Detect Long Term Health Outcomes" [pos="-1.504,-0.448"]
"Detect Noise Levels" [pos="-1.523,-0.454"]
"Detect Pressure Changes" [pos="-1.535,-0.450"]
"Distance from Earth" [exposure,pos="-1.554,-0.452"]
"Effective Exposure Duration" [pos="-1.539,-0.472"]
"Environmental Conditions" [pos="-1.543,-0.452"]
"Environmental Control" [pos="-1.532,-0.454"]
"Environmental Monitoring Capability" [pos="-1.537,-0.446"]
"Fluid Shifts" [pos="-1.548,-0.470"]
"HSIA (Risk)" [latent,pos="-1.552,-0.441"]
"Hearing Countermeasures" [pos="-1.509,-0.453"]
"Hostile Closed Environment" [exposure,pos="-1.553,-0.458"]
"Individual Factors" [pos="-1.517,-0.470"]
"Individual Readiness" [pos="-1.505,-0.462"]
"Inflight Hearing Exams" [pos="-1.520,-0.444"]
"Intracochlear Pressure" [pos="-1.541,-0.467"]
"Long Term Health Outcomes" [outcome,pos="-1.502,-0.455"]
"Loss of Mission Objectives" [outcome,pos="-1.502,-0.474"]
"Measurable Hearing Shift" [pos="-1.517,-0.459"]
"Medical (Risk)" [latent,pos="-1.509,-0.459"]
"Noise Exposure" [pos="-1.545,-0.457"]
"Pharm (Risk)" [latent,pos="-1.550,-0.461"]
"Preflight Hearing Status" [pos="-1.527,-0.448"]
"Sudden Sensorineural Loss" [pos="-1.522,-0.468"]
"Suit Design" [pos="-1.545,-0.447"]
"Task Performance" [outcome,pos="-1.503,-0.469"]
"Tox (Risk)" [latent,pos="-1.549,-0.465"]
"Vehicle Design" [pos="-1.552,-0.447"]
Barotrauma [pos="-1.528,-0.458"]
Ototoxins [pos="-1.539,-0.462"]
Surveillance [pos="-1.508,-0.443"]
"Altered Gravity" -> "Fluid Shifts"
"Astronaut Selection" -> "Individual Factors"
"Cochlear Changes" -> "Measurable Hearing Shift"
"Crew Capability" -> "Task Performance"
"Crew Health and Performance System" -> "Environmental Monitoring Capability"
"Crew Health and Performance System" -> "Hearing Countermeasures"
"Crew Health and Performance System" -> "Inflight Hearing Exams"
"Detect Hearing Changes" -> "Hearing Countermeasures"
"Detect Noise Levels" -> "Hearing Countermeasures"
"Detect Pressure Changes" -> "Environmental Control"
"Distance from Earth" -> "Vehicle Design"
"Effective Exposure Duration" -> "Cochlear Changes"
"Environmental Conditions" -> "Detect Pressure Changes"
"Environmental Conditions" -> Barotrauma
"Environmental Control" -> Barotrauma
"Environmental Monitoring Capability" -> "Detect Noise Levels"
"Environmental Monitoring Capability" -> "Detect Pressure Changes"
"Fluid Shifts" -> "Intracochlear Pressure"
"HSIA (Risk)" -> "Crew Health and Performance System"
"HSIA (Risk)" -> "Suit Design"
"HSIA (Risk)" -> "Vehicle Design"
"Hearing Countermeasures" -> "Individual Readiness"
"Hostile Closed Environment" -> "Noise Exposure"
"Individual Factors" -> "Measurable Hearing Shift"
"Individual Factors" -> "Sudden Sensorineural Loss"
"Individual Readiness" -> "Crew Capability"
"Inflight Hearing Exams" -> "Detect Hearing Changes"
"Intracochlear Pressure" -> "Cochlear Changes"
"Long Term Health Outcomes" -> "Detect Long Term Health Outcomes"
"Measurable Hearing Shift" -> "Detect Hearing Changes"
"Measurable Hearing Shift" -> "Individual Readiness"
"Measurable Hearing Shift" -> "Long Term Health Outcomes"
"Measurable Hearing Shift" -> "Medical (Risk)"
"Medical (Risk)" -> "Individual Readiness"

Appendix C – Risk Formatting Instructions

"Medical (Risk)" -> "Long Term Health Outcomes"
"Noise Exposure" -> "Cochlear Changes"
"Noise Exposure" -> "Detect Noise Levels"
"Noise Exposure" -> "Task Performance"
"Pharm (Risk)" -> Ototoxins
"Preflight Hearing Status" -> "Detect Hearing Changes"
"Sudden Sensorineural Loss" -> "Cochlear Changes"
"Suit Design" -> "Environmental Conditions"
"Task Performance" -> "Loss of Mission Objectives"
"Tox (Risk)" -> Ototoxins
"Vehicle Design" -> "Crew Health and Performance System"
"Vehicle Design" -> "Environmental Conditions"
"Vehicle Design" -> "Noise Exposure"
Barotrauma -> "Cochlear Changes"
Barotrauma -> "Measurable Hearing Shift"
Ototoxins -> "Cochlear Changes"
Surveillance -> "Detect Long Term Health Outcomes"
}

Appendix C – Risk Formatting Instructions

Behavioral Risk Narrative

```
dag {
bb="-0.5,-0.5,0.5,0.5"
"Astronaut Selection" [pos="-0.239,0.215"]
"BHP Family Services" [pos="-0.036,-0.353"]
"BHP Intervention Capability" [pos="0.284,0.399"]
"BHP Monitoring Capability" [pos="0.151,0.259"]
"BHP Prevention Capability" [pos="0.049,0.173"]
"Central Nervous System Changes" [pos="-0.042,-0.109"]
"Cognitive Function" [pos="0.118,0.015"]
"Communication Factors" [pos="-0.224,0.418"]
"Crew Capability" [pos="0.295,-0.216"]
"Crew Composition" [pos="-0.253,-0.450"]
"Crew Health and Performance System" [pos="-0.076,0.296"]
"Detect BHP Changes" [pos="0.198,0.128"]
"Detect Long Term Health Outcomes" [pos="0.392,0.217"]
"Distance from Earth" [exposure,pos="-0.435,0.334"]
"Family/World Events" [pos="0.108,-0.434"]
"Ground Support" [pos="0.010,0.413"]
"HSIA (Risk)" [latent,pos="-0.354,0.416"]
"Individual Factors" [pos="-0.068,0.123"]
"Individual Readiness" [pos="0.226,-0.169"]
"Isolation and Confinement" [exposure,pos="-0.414,-0.239"]
"Long Term Health Outcomes" [outcome,pos="0.389,0.100"]
"Loss of Crew Life" [outcome,pos="0.429,-0.055"]
"Loss of Mission Objectives" [outcome,pos="0.366,-0.431"]
"Loss of Mission" [outcome,pos="0.450,-0.460"]
"Other Risks" [latent,pos="-0.273,-0.117"]
"Oxidative Stress" [pos="-0.339,0.119"]
"Psychological Status" [pos="0.109,-0.271"]
"Social Dynamics" [pos="-0.090,-0.453"]
"Standards/Requirements" [pos="-0.396,0.217"]
"Task Performance" [outcome,pos="0.337,-0.302"]
"Team (Risk)" [latent,pos="0.220,-0.367"]
"Vehicle Design" [pos="-0.225,0.329"]
Evacuation [outcome,pos="0.428,-0.275"]
Exercise [pos="-0.205,-0.023"]
Inflammation [pos="-0.239,0.116"]
Radiation [exposure,pos="-0.450,0.119"]
Surveillance [pos="0.413,0.380"]
Training [pos="-0.369,-0.104"]
Workload [pos="-0.174,-0.302"]
"Astronaut Selection" -> "Individual Factors"
"BHP Family Services" -> "Psychological Status"
"BHP Intervention Capability" -> "Individual Readiness"
"BHP Monitoring Capability" -> "Detect BHP Changes"
"BHP Prevention Capability" -> "Cognitive Function"
"BHP Prevention Capability" -> "Psychological Status"
"Central Nervous System Changes" -> "Cognitive Function"
"Central Nervous System Changes" -> "Long Term Health Outcomes"
"Central Nervous System Changes" -> "Psychological Status"
"Cognitive Function" -> "Detect BHP Changes"
"Cognitive Function" -> "Individual Readiness"
"Cognitive Function" -> "Team (Risk)"
"Communication Factors" -> "Ground Support"
"Crew Capability" -> "Task Performance"
"Crew Composition" -> "Social Dynamics"
"Crew Health and Performance System" -> "BHP Intervention Capability"
"Crew Health and Performance System" -> "BHP Monitoring Capability"
"Crew Health and Performance System" -> "BHP Prevention Capability"
"Crew Health and Performance System" -> Exercise
"Detect BHP Changes" -> "BHP Intervention Capability"
"Distance from Earth" -> "Communication Factors"
"Distance from Earth" -> "Vehicle Design"
"Family/World Events" -> "Psychological Status"
"Ground Support" -> "BHP Family Services"
"Ground Support" -> "BHP Intervention Capability"
"Ground Support" -> "BHP Monitoring Capability"
"Ground Support" -> "BHP Prevention Capability"
"HSIA (Risk)" -> "Standards/Requirements"
"HSIA (Risk)" -> "Vehicle Design"
"Individual Factors" -> "Central Nervous System Changes"
"Individual Factors" -> "Cognitive Function"
"Individual Factors" -> "Psychological Status"
"Individual Readiness" -> "Crew Capability"
"Isolation and Confinement" -> "Central Nervous System Changes"
```

"Isolation and Confinement" -> "Psychological Status"
"Long Term Health Outcomes" -> "Detect Long Term Health Outcomes"
"Loss of Mission Objectives" -> "Loss of Mission"
"Other Risks" -> "Central Nervous System Changes"
"Other Risks" -> "Cognitive Function"
"Other Risks" -> "Psychological Status"
"Oxidative Stress" -> Inflammation
"Psychological Status" -> "Detect BHP Changes"
"Psychological Status" -> "Individual Readiness"
"Psychological Status" -> "Long Term Health Outcomes"
"Psychological Status" -> "Team (Risk)"
"Social Dynamics" -> "Psychological Status"
"Standards/Requirements" -> "Astronaut Selection"
"Standards/Requirements" -> "Vehicle Design"
"Task Performance" -> "Loss of Crew Life"
"Task Performance" -> "Loss of Mission Objectives"
"Task Performance" -> Evacuation
"Team (Risk)" -> "Individual Readiness"
"Vehicle Design" -> "Crew Health and Performance System"
Evacuation -> "Loss of Mission Objectives"
Exercise -> "Cognitive Function"
Exercise -> "Psychological Status"
Inflammation -> "Central Nervous System Changes"
Radiation -> "Oxidative Stress"
Surveillance -> "Detect Long Term Health Outcomes"
Training -> "Individual Factors"
Training -> "Social Dynamics"
Workload -> "Cognitive Function"
Workload -> "Psychological Status"
}

Appendix C – Risk Formatting Instructions

Bone Fracture Risk

```
dag {
bb="0,0,1,1"
"Altered Gravity" [exposure,pos="0.054,0.304"]
"Astronaut Selection" [pos="0.052,0.743"]
"Bone Density" [pos="0.371,0.551"]
"Bone Formation" [pos="0.219,0.690"]
"Bone Fracture" [pos="0.679,0.368"]
"Bone Resorption" [pos="0.221,0.517"]
"Bone Structure" [pos="0.366,0.740"]
"Cartilage Defect" [pos="0.368,0.898"]
"Chondrocyte Metabolism" [pos="0.185,0.895"]
"Crew Capability" [pos="0.761,0.214"]
"Crew Health and Performance System"
[pos="0.449,0.044"]
"DCS (Risk)" [latent,pos="0.699,0.875"]
"Detect Bone Density Changes"
[pos="0.558,0.480"]
"Detect Bone Structure Changes"
[pos="0.535,0.752"]
"Detect Long Term Health Outcomes"
[pos="0.881,0.837"]
"Distance from Earth"
[exposure,pos="0.054,0.159"]
"Dynamic Loads (Risk)" [latent,pos="0.465,0.116"]
"Endocrine Factors" [pos="0.050,0.532"]
"Flight Recertification"
[outcome,pos="0.918,0.553"]
"Food and Nutrition (Risk)"
[latent,pos="0.158,0.387"]
"HSIA (Risk)" [latent,pos="0.124,0.039"]
"Individual Factors" [pos="0.108,0.646"]
"Individual Readiness" [pos="0.722,0.298"]
"Long Term Health Clinical Decisions"
[pos="0.729,0.754"]
"Long Term Health Outcomes"
[outcome,pos="0.901,0.672"]
"Loss of Crew Life" [outcome,pos="0.919,0.446"]
"Loss of Mission Objectives"
[outcome,pos="0.827,0.057"]
"Loss of Mission" [outcome,pos="0.944,0.055"]
"Medical Treatment Capability"
[pos="0.676,0.041"]
"Muscle (Risk)" [latent,pos="0.398,0.294"]
"Musculoskeletal Loads" [pos="0.338,0.409"]
"Pharm (Risk)" [latent,pos="0.142,0.791"]
"Resistive Exercise" [pos="0.222,0.301"]
"Sensorimotor, Aerobic (Risks)"
[latent,pos="0.425,0.205"]
"Skeletal Fragility" [pos="0.730,0.563"]
"Suit Design" [pos="0.221,0.166"]
"Task Performance" [outcome,pos="0.775,0.151"]
"Vehicle Design" [pos="0.276,0.038"]
DXA [pos="0.469,0.425"]
Evacuation [outcome,pos="0.840,0.364"]
MRI [pos="0.464,0.827"]
Osteoarthritis [pos="0.617,0.896"]
QCT [pos="0.470,0.602"]
Radiation [exposure,pos="0.050,0.889"]
Surveillance [pos="0.759,0.932"]
Ultrasound [pos="0.653,0.183"]
"Altered Gravity" -> "Chondrocyte Metabolism"
"Altered Gravity" -> "Musculoskeletal Loads"
"Astronaut Selection" -> "Individual Factors"
"Bone Density" -> "Detect Bone Density Changes"
"Bone Density" -> "Skeletal Fragility"
"Bone Formation" -> "Bone Density"
"Bone Formation" -> "Bone Structure"
"Bone Fracture" -> "Individual Readiness"
"Bone Fracture" -> "Long Term Health Outcomes"
"Bone Fracture" -> Evacuation
"Bone Fracture" -> Osteoarthritis
"Bone Resorption" -> "Bone Density"
"Bone Resorption" -> "Bone Structure"
"Bone Structure" -> "Detect Bone Structure
Changes"
"Bone Structure" -> "Long Term Health
Outcomes"
"Bone Structure" -> "Skeletal Fragility"
"Cartilage Defect" -> Osteoarthritis
"Chondrocyte Metabolism" -> "Cartilage Defect"
"Crew Capability" -> "Task Performance"
"Crew Health and Performance System" ->
"Medical Treatment Capability"
"Crew Health and Performance System" ->
"Resistive Exercise"
"Crew Health and Performance System" ->
Ultrasound
"DCS (Risk)" -> "Long Term Health Outcomes"
"Detect Bone Density Changes" -> "Detect Long
Term Health Outcomes"
"Detect Bone Density Changes" -> "Flight
Recertification"
"Detect Bone Density Changes" -> "Long Term
Health Clinical Decisions"
"Detect Bone Structure Changes" -> "Detect Long
Term Health Outcomes"
"Detect Bone Structure Changes" -> "Long Term
Health Clinical Decisions"
"Distance from Earth" -> "Vehicle Design"
"Dynamic Loads (Risk)" -> "Bone Fracture"
```

"Endocrine Factors" -> "Bone Formation"
"Endocrine Factors" -> "Bone Resorption"
"Food and Nutrition (Risk)" -> "Bone Resorption"
"HSIA (Risk)" -> "Suit Design"
"HSIA (Risk)" -> "Vehicle Design"
"Individual Factors" -> "Bone Formation"
"Individual Factors" -> "Bone Resorption"
"Individual Readiness" -> "Crew Capability"
"Long Term Health Clinical Decisions" -> "Long Term Health Outcomes"
"Long Term Health Outcomes" -> "Detect Long Term Health Outcomes"
"Loss of Mission Objectives" -> "Loss of Mission"
"Medical Treatment Capability" -> "Individual Readiness"
"Muscle (Risk)" -> "Bone Fracture"
"Muscle (Risk)" -> "Musculoskeletal Loads"
"Musculoskeletal Loads" -> "Bone Formation"
"Musculoskeletal Loads" -> "Bone Fracture"
"Musculoskeletal Loads" -> "Bone Resorption"
"Pharm (Risk)" -> "Bone Formation"
"Pharm (Risk)" -> "Bone Resorption"
"Resistive Exercise" -> "Muscle (Risk)"
"Resistive Exercise" -> "Musculoskeletal Loads"
"Sensorimotor, Aerobic (Risks)" -> "Bone Fracture"
"Skeletal Fragility" -> "Bone Fracture"
"Skeletal Fragility" -> "Long Term Health Outcomes"
"Suit Design" -> "Bone Fracture"
"Suit Design" -> "Dynamic Loads (Risk)"
"Task Performance" -> "Loss of Crew Life"
"Task Performance" -> "Loss of Mission Objectives"
"Vehicle Design" -> "Bone Fracture"
"Vehicle Design" -> "Crew Health and Performance System"
"Vehicle Design" -> "Dynamic Loads (Risk)"
DXA -> "Detect Bone Density Changes"
Evacuation -> "Loss of Crew Life"
Evacuation -> "Loss of Mission Objectives"
MRI -> "Detect Bone Structure Changes"
Osteoarthritis -> "Individual Readiness"
Osteoarthritis -> "Long Term Health Outcomes"
QCT -> "Detect Bone Density Changes"
QCT -> "Detect Bone Structure Changes"
Radiation -> "Bone Resorption"
Radiation -> "Chondrocyte Metabolism"
Surveillance -> "Detect Long Term Health Outcomes"
Ultrasound -> "Detect Bone Structure Changes"
}

Appendix C – Risk Formatting Instructions

Cardiovascular Risk

dag {
"Aerobic (Risk)" [latent,pos="-1.237,-3.915"]
"Altered Gravity" [exposure,pos="-1.242,-1.448"]
"Astronaut Selection" [pos="-1.242,-2.613"]
"Cardiac Structure/Function" [pos="-1.239,-2.226"]
"Crew Capability" [pos="-1.236,-3.025"]
"Crew Health and Performance System" [pos="-1.240,-3.728"]
"Detect CV Events" [pos="-1.238,-2.468"]
"Detect Long Term Health Outcomes" [pos="-1.236,-0.384"]
"Distance from Earth" [exposure,pos="-1.242,-4.223"]
"Endocrine Factors" [pos="-1.241,-1.952"]
"Environmental Conditions" [pos="-1.238,-0.082"]
"Flight Recertification" [outcome,pos="-1.235,-1.394"]
"Fluid Shifts" [pos="-1.241,-1.621"]
"Food and Nutrition, Immune, Sleep (Risks)" [latent,pos="-1.241,-0.594"]
"HSIA (Risk)" [latent,pos="-1.242,-3.207"]
"Hostile Closed Environment" [exposure,pos="-1.242,-0.026"]
"Individual Factors" [pos="-1.241,-2.441"]
"Individual Readiness" [pos="-1.237,-3.520"]
"Intravascular Volume" [pos="-1.240,-2.090"]
"Long Term Health Outcomes" [outcome,pos="-1.235,-0.944"]
"Loss of Crew Life" [outcome,pos="-1.235,-1.803"]
"Loss of Mission Objectives" [outcome,pos="-1.236,-3.619"]
"Loss of Mission" [outcome,pos="-1.235,-4.213"]
"Medical Illness" [pos="-1.238,-1.739"]
"Medical Monitoring Capability" [pos="-1.239,-3.566"]
"Medical Prevention Capability" [pos="-1.239,-3.123"]
"Medical Treatment Capability" [pos="-1.238,-3.936"]
"Organ Perfusion" [pos="-1.237,-1.739"]
"Orthostatic Intolerance Countermeasures" [pos="-1.240,-2.889"]
"Orthostatic Intolerance" [pos="-1.238,-0.708"]
"Oxidative Stress" [pos="-1.240,-1.196"]
"Pharm (Risk)" [latent,pos="-1.239,-4.059"]
"Pre-syncope/Syncope" [pos="-1.237,-2.478"]
"Suit Design" [pos="-1.241,-2.813"]
"Task Performance" [outcome,pos="-1.236,-2.673"]
"Tox (Risk)" [latent,pos="-1.238,-1.314"]
"Vascular Structure/Function" [pos="-1.239,-1.234"]
"Vehicle Design" [pos="-1.241,-3.910"]
Evacuation [outcome,pos="-1.236,-2.144"]
Exercise [pos="-1.241,-3.161"]
Inflammation [pos="-1.240,-0.559"]
Radiation [exposure,pos="-1.242,-0.969"]
Surveillance [pos="-1.237,0.102"]
"Aerobic (Risk)" -> "Individual Readiness"
"Altered Gravity" -> "Endocrine Factors"
"Altered Gravity" -> "Fluid Shifts"
"Altered Gravity" -> "Oxidative Stress"
"Altered Gravity" -> Inflammation
"Astronaut Selection" -> "Individual Factors"
"Cardiac Structure/Function" -> "Aerobic (Risk)"
"Cardiac Structure/Function" -> "Medical Illness"
"Cardiac Structure/Function" -> "Orthostatic Intolerance"
"Crew Capability" -> "Task Performance"
"Crew Health and Performance System" -> "Medical Monitoring Capability"
"Crew Health and Performance System" -> "Medical Prevention Capability"
"Crew Health and Performance System" -> "Medical Treatment Capability"
"Crew Health and Performance System" -> Exercise
"Detect CV Events" -> "Medical Treatment Capability"
"Distance from Earth" -> "Vehicle Design"
"Endocrine Factors" -> "Fluid Shifts"
"Endocrine Factors" -> "Orthostatic Intolerance"
"Environmental Conditions" -> "Orthostatic Intolerance"
"Fluid Shifts" -> "Cardiac Structure/Function"
"Fluid Shifts" -> "Intravascular Volume"
"Fluid Shifts" -> "Oxidative Stress"
"Fluid Shifts" -> "Vascular Structure/Function"
"Fluid Shifts" -> Inflammation
"Food and Nutrition, Immune, Sleep (Risks)" -> "Oxidative Stress"
"Food and Nutrition, Immune, Sleep (Risks)" -> Inflammation
"HSIA (Risk)" -> "Crew Health and Performance System"
"HSIA (Risk)" -> "Suit Design"

"HSIA (Risk)" -> "Vehicle Design"
"Hostile Closed Environment" -> "Orthostatic Intolerance"
"Individual Factors" -> "Cardiac Structure/Function"
"Individual Factors" -> "Endocrine Factors"
"Individual Factors" -> "Fluid Shifts"
"Individual Factors" -> "Oxidative Stress"
"Individual Factors" -> "Vascular Structure/Function"
"Individual Factors" -> Inflammation
"Individual Readiness" -> "Crew Capability"
"Intravascular Volume" -> "Cardiac Structure/Function"
"Intravascular Volume" -> "Orthostatic Intolerance"
"Intravascular Volume" -> "Vascular Structure/Function"
"Long Term Health Outcomes" -> "Detect Long Term Health Outcomes"
"Loss of Mission Objectives" -> "Loss of Mission"
"Medical Illness" -> "Detect CV Events"
"Medical Illness" -> "Flight Recertification"
"Medical Illness" -> "Long Term Health Outcomes"
"Medical Illness" -> "Organ Perfusion"
"Medical Monitoring Capability" -> "Detect CV Events"
"Medical Prevention Capability" -> "Intravascular Volume"
"Medical Prevention Capability" -> "Medical Illness"
"Medical Prevention Capability" -> "Orthostatic Intolerance Countermeasures"
"Medical Treatment Capability" -> "Organ Perfusion"
"Organ Perfusion" -> "Loss of Crew Life"
"Organ Perfusion" -> "Pre-syncope/Syncope"
"Organ Perfusion" -> Evacuation
"Orthostatic Intolerance Countermeasures" -> "Orthostatic Intolerance"
"Orthostatic Intolerance" -> "Organ Perfusion"
"Oxidative Stress" -> "Cardiac Structure/Function"
"Oxidative Stress" -> "Vascular Structure/Function"
"Oxidative Stress" -> Inflammation
"Pharm (Risk)" -> "Medical Prevention Capability"
"Pharm (Risk)" -> "Medical Treatment Capability"
"Pre-syncope/Syncope" -> "Individual Readiness"
"Suit Design" -> "Orthostatic Intolerance Countermeasures"
"Task Performance" -> "Loss of Mission Objectives"
"Tox (Risk)" -> "Medical Illness"
"Vascular Structure/Function" -> "Aerobic (Risk)"
"Vascular Structure/Function" -> "Medical Illness"
"Vascular Structure/Function" -> "Orthostatic Intolerance"
"Vehicle Design" -> "Crew Health and Performance System"
"Vehicle Design" -> "Orthostatic Intolerance Countermeasures"
Evacuation -> "Loss of Crew Life"
Evacuation -> "Loss of Mission Objectives"
Exercise -> "Cardiac Structure/Function"
Exercise -> "Intravascular Volume"
Exercise -> "Oxidative Stress"
Exercise -> "Vascular Structure/Function"
Exercise -> Inflammation
Inflammation -> "Cardiac Structure/Function"
Inflammation -> "Vascular Structure/Function"
Radiation -> "Oxidative Stress"
Radiation -> Inflammation
Surveillance -> "Detect Long Term Health Outcomes"
}

Appendix C – Risk Formatting Instructions

CO2 Risk

```
dag {
"Altered Gravity" [exposure,pos="-1.658,-1.415"]
"Ambient CO2 Level" [pos="-1.329,-1.093"]
"Atmospheric Mixing" [pos="-1.526,-1.073"]
"Behavioral (Risk)" [latent,pos="-1.088,-1.390"]
"Bone Fracture (Risk)" [latent,pos="-1.012,-0.910"]
"CO2 Physiologic Changes" [pos="-1.128,-1.166"]
"CO2 Production" [pos="-1.518,-1.217"]
"CO2 Removal" [pos="-1.495,-0.999"]
"Crew Capability" [pos="-0.845,-1.303"]
"Crew Health and Performance System" [pos="-1.426,-0.859"]
"Crew Size" [pos="-1.543,-1.326"]
"Detect CO2 Level" [pos="-1.174,-0.937"]
"Distance from Earth" [exposure,pos="-1.683,-0.928"]
"ECLS System" [pos="-1.426,-0.779"]
"Effective Exposure Duration" [pos="-1.275,-1.299"]
"Environmental Control" [pos="-1.160,-1.063"]
"Environmental Monitoring Capability" [pos="-1.180,-0.775"]
"Food and Nutrition (Risk)" [latent,pos="-1.649,-1.216"]
"HSIA (Risk)" [latent,pos="-1.696,-0.764"]
"Hostile Closed Environment" [exposure,pos="-1.641,-1.126"]
"Hypoxia (Risk)" [latent,pos="-1.327,-1.190"]
"Individual Factors" [pos="-1.270,-1.390"]
"Individual Readiness" [pos="-0.933,-1.235"]
"Loss of Crew Life" [outcome,pos="-0.633,-0.955"]
"Loss of Mission Objectives" [outcome,pos="-0.686,-1.438"]
"Loss of Mission" [outcome,pos="-0.628,-1.497"]
"Mechanical Systems" [pos="-1.649,-0.998"]
"Medical (Risk)" [latent,pos="-0.835,-0.919"]
"Net Habitable Volume" [pos="-1.374,-0.961"]
"Pharm (Risk)" [latent,pos="-1.669,-1.292"]
"Renal Stone (Risk)" [latent,pos="-1.013,-0.992"]
"SANS (Risk)" [latent,pos="-1.014,-0.830"]
"Sleep (Risk)" [latent,pos="-1.084,-1.283"]
"Suit Design" [pos="-1.570,-0.766"]
"Task Performance" [outcome,pos="-0.761,-1.367"]
"Team (Risk)" [latent,pos="-0.932,-1.392"]
"Vehicle Design" [pos="-1.677,-0.843"]
Evacuation [outcome,pos="-0.714,-1.155"]
Exercise [pos="-1.472,-1.135"]
"Altered Gravity" -> "Atmospheric Mixing"
"Altered Gravity" -> "CO2 Physiologic Changes"
"Ambient CO2 Level" -> "CO2 Physiologic Changes"
"Ambient CO2 Level" -> "Detect CO2 Level"
"Ambient CO2 Level" -> "Hypoxia (Risk)"
"Atmospheric Mixing" -> "Ambient CO2 Level"
"Behavioral (Risk)" -> "Individual Readiness"
"Behavioral (Risk)" -> "Team (Risk)"
"Bone Fracture (Risk)" -> "Medical (Risk)"
"CO2 Physiologic Changes" -> "Behavioral (Risk)"
"CO2 Physiologic Changes" -> "Bone Fracture (Risk)"
"CO2 Physiologic Changes" -> "Individual Readiness"
"CO2 Physiologic Changes" -> "Loss of Crew Life"
"CO2 Physiologic Changes" -> "Medical (Risk)"
"CO2 Physiologic Changes" -> "Renal Stone (Risk)"
"CO2 Physiologic Changes" -> "SANS (Risk)"
"CO2 Physiologic Changes" -> "Sleep (Risk)"
"CO2 Physiologic Changes" -> Evacuation
"CO2 Production" -> "Ambient CO2 Level"
"CO2 Removal" -> "Ambient CO2 Level"
"Crew Capability" -> "Task Performance"
"Crew Health and Performance System" -> "Detect CO2 Level"
"Crew Health and Performance System" -> Exercise
"Crew Size" -> "CO2 Production"
"Detect CO2 Level" -> "Environmental Control"
"Distance from Earth" -> "Vehicle Design"
"ECLS System" -> "Environmental Control"
"ECLS System" -> "Environmental Monitoring Capability"
"ECLS System" -> "Mechanical Systems"
"Effective Exposure Duration" -> "CO2 Physiologic Changes"
"Environmental Control" -> "CO2 Physiologic Changes"
"Environmental Monitoring Capability" -> "Crew Health and Performance System"
"Environmental Monitoring Capability" -> "Detect CO2 Level"
"Food and Nutrition (Risk)" -> "CO2 Production"
"HSIA (Risk)" -> "Net Habitable Volume"
"HSIA (Risk)" -> "Suit Design"
"HSIA (Risk)" -> "Vehicle Design"
"Hostile Closed Environment" -> "CO2 Production"
"Hostile Closed Environment" -> "CO2 Removal"
```

"Hypoxia (Risk)" -> "CO2 Physiologic Changes"
"Individual Factors" -> "Behavioral (Risk)"
"Individual Factors" -> "CO2 Physiologic Changes"
"Individual Factors" -> "CO2 Production"
"Individual Readiness" -> "Crew Capability"
"Loss of Mission Objectives" -> "Loss of Mission"
"Mechanical Systems" -> "Atmospheric Mixing"
"Mechanical Systems" -> "CO2 Removal"
"Medical (Risk)" -> "Behavioral (Risk)"
"Medical (Risk)" -> "Individual Readiness"
"Medical (Risk)" -> "Loss of Crew Life"
"Medical (Risk)" -> Evacuation
"Net Habitable Volume" -> "Ambient CO2 Level"
"Pharm (Risk)" -> "CO2 Production"
"Renal Stone (Risk)" -> "Medical (Risk)"
"SANS (Risk)" -> "Medical (Risk)"
"Sleep (Risk)" -> "Behavioral (Risk)"
"Sleep (Risk)" -> "Individual Readiness"
"Suit Design" -> "Mechanical Systems"
"Task Performance" -> "Loss of Mission Objectives"
"Team (Risk)" -> "Crew Capability"
"Vehicle Design" -> "Crew Health and Performance System"
"Vehicle Design" -> "ECLS System"
"Vehicle Design" -> "Net Habitable Volume"
Evacuation -> "Loss of Crew Life"
Evacuation -> "Loss of Mission Objectives"
Exercise -> "CO2 Production"
}

Appendix C – Risk Formatting Instructions

Crew Egress Risk

```
dag {
"Aerobic (Risk)" [latent,pos="-0.691,-1.683"]
"Altered Gravity" [exposure,pos="-1.768,-2.448"]
"Bone Fracture (Risk)" [latent,pos="-0.672,-0.267"]
"Cardiovascular (Risk)" [latent,pos="-0.684,-1.218"]
"Crew Capability" [pos="0.167,-1.917"]
"Crew Health and Performance System" [pos="-0.286,1.146"]
"Crew Vehicle Integration" [pos="-1.137,0.880"]
"Detect Long Term Health Outcomes" [pos="0.976,1.320"]
"Distance from Earth" [exposure,pos="-1.763,-0.081"]
"Dynamic Loads (Risk)" [latent,pos="-0.628,0.335"]
"Effective Exposure Duration" [pos="-1.437,-1.386"]
"Effective Gravity Level" [pos="-1.368,-1.889"]
"Environmental Injury" [pos="0.137,-0.341"]
"Fall Height" [pos="-1.245,0.041"]
"Flight Recertification" [outcome,pos="1.080,0.132"]
"Ground Support" [pos="0.603,1.175"]
"HSIA (Risk)" [latent,pos="-1.647,1.660"]
"Hostile Closed Environment" [exposure,pos="-1.726,-1.336"]
"Hypoxia, DCS (Risks)" [latent,pos="-0.591,0.880"]
"Individual Readiness" [pos="-0.114,-1.706"]
"Landing Profile" [pos="-1.230,0.481"]
"Landing Site Environment" [pos="-1.494,-0.400"]
"Long Term Health Outcomes" [outcome,pos="1.042,0.677"]
"Loss of Crew Life" [outcome,pos="1.127,-0.525"]
"Loss of Mission Objectives" [outcome,pos="0.927,-2.324"]
"Loss of Mission" [outcome,pos="1.121,-2.674"]
"Medical Prevention Capability" [pos="-0.150,0.742"]
"Medical Treatment Capability" [pos="0.374,0.519"]
"Motion Sickness" [pos="-0.272,-0.426"]
"Muscle (Risk)" [latent,pos="-0.635,-2.199"]
"Operations Design" [pos="0.148,1.517"]
"Organ Perfusion" [pos="-0.199,-1.142"]
"Post-Landing Task Performance" [pos="0.585,-2.028"]
"Procedure Design" [pos="0.399,1.353"]
"Sensorimotor (Risk)" [latent,pos="-0.684,-0.756"]
"Suit Design" [pos="-0.933,1.724"]
"Team (Risk)" [latent,pos="-0.110,-2.396"]
"Thermal Environment" [pos="-1.147,-0.910"]
"Traumatic Injury" [pos="0.008,0.210"]
"Vehicle Design" [pos="-1.717,1.172"]
Aspiration [pos="0.235,-0.945"]
Evacuation [pos="0.932,-1.021"]
Surveillance [pos="0.693,1.779"]
Vomit [pos="0.003,-0.709"]
"Aerobic (Risk)" -> "Individual Readiness"
"Altered Gravity" -> "Effective Gravity Level"
"Bone Fracture (Risk)" -> "Traumatic Injury"
"Cardiovascular (Risk)" -> "Aerobic (Risk)"
"Cardiovascular (Risk)" -> "Individual Readiness"
"Cardiovascular (Risk)" -> "Organ Perfusion"
"Crew Capability" -> "Post-Landing Task Performance"
"Crew Health and Performance System" -> "Medical Prevention Capability"
"Crew Health and Performance System" -> "Medical Treatment Capability"
"Crew Vehicle Integration" -> "Post-Landing Task Performance"
"Distance from Earth" -> "Effective Exposure Duration"
"Distance from Earth" -> "Suit Design"
"Distance from Earth" -> "Vehicle Design"
"Dynamic Loads (Risk)" -> "Bone Fracture (Risk)"
"Dynamic Loads (Risk)" -> "Traumatic Injury"
"Effective Exposure Duration" -> "Effective Gravity Level"
"Effective Gravity Level" -> "Aerobic (Risk)"
"Effective Gravity Level" -> "Bone Fracture (Risk)"
"Effective Gravity Level" -> "Cardiovascular (Risk)"
"Effective Gravity Level" -> "Muscle (Risk)"
"Effective Gravity Level" -> "Sensorimotor (Risk)"
"Environmental Injury" -> "Individual Readiness"
"Fall Height" -> "Bone Fracture (Risk)"
"Fall Height" -> "Traumatic Injury"
"Ground Support" -> "Medical Treatment Capability"
"Ground Support" -> "Post-Landing Task Performance"
"HSIA (Risk)" -> "Crew Vehicle Integration"
"HSIA (Risk)" -> "Operations Design"
"HSIA (Risk)" -> "Procedure Design"
"HSIA (Risk)" -> "Suit Design"
"HSIA (Risk)" -> "Vehicle Design"
```

"Hostile Closed Environment" -> "Dynamic Loads (Risk)"
"Hostile Closed Environment" -> "Landing Profile"
"Hostile Closed Environment" -> "Landing Site Environment"
"Hypoxia, DCS (Risks)" -> "Environmental Injury"
"Individual Readiness" -> "Crew Capability"
"Individual Readiness" -> Evacuation
"Landing Profile" -> "Dynamic Loads (Risk)"
"Landing Site Environment" -> "Ground Support"
"Landing Site Environment" -> "Sensorimotor (Risk)"
"Landing Site Environment" -> "Thermal Environment"
"Long Term Health Outcomes" -> "Detect Long Term Health Outcomes"
"Loss of Mission Objectives" -> "Loss of Mission"
"Medical Prevention Capability" -> "Motion Sickness"
"Medical Prevention Capability" -> "Organ Perfusion"
"Medical Treatment Capability" -> "Flight Recertification"
"Medical Treatment Capability" -> "Individual Readiness"
"Medical Treatment Capability" -> "Long Term Health Outcomes"
"Medical Treatment Capability" -> "Loss of Crew Life"
"Motion Sickness" -> Vomit
"Muscle (Risk)" -> "Individual Readiness"
"Muscle (Risk)" -> "Traumatic Injury"
"Operations Design" -> "Post-Landing Task Performance"
"Organ Perfusion" -> Vomit
"Post-Landing Task Performance" -> "Loss of Mission Objectives"
"Procedure Design" -> "Post-Landing Task Performance"
"Sensorimotor (Risk)" -> "Individual Readiness"
"Sensorimotor (Risk)" -> "Motion Sickness"
"Sensorimotor (Risk)" -> "Traumatic Injury"
"Suit Design" -> "Bone Fracture (Risk)"
"Suit Design" -> "Crew Vehicle Integration"
"Suit Design" -> "Dynamic Loads (Risk)"
"Suit Design" -> "Hypoxia, DCS (Risks)"
"Suit Design" -> "Thermal Environment"
"Team (Risk)" -> "Crew Capability"
"Thermal Environment" -> "Cardiovascular (Risk)"
"Traumatic Injury" -> "Flight Recertification"
"Traumatic Injury" -> "Individual Readiness"
"Traumatic Injury" -> "Long Term Health Outcomes"
"Traumatic Injury" -> "Loss of Crew Life"
"Traumatic Injury" -> Evacuation
"Vehicle Design" -> "Crew Health and Performance System"
"Vehicle Design" -> "Crew Vehicle Integration"
"Vehicle Design" -> "Dynamic Loads (Risk)"
"Vehicle Design" -> "Fall Height"
"Vehicle Design" -> "Hypoxia, DCS (Risks)"
"Vehicle Design" -> "Landing Profile"
"Vehicle Design" -> "Landing Site Environment"
"Vehicle Design" -> "Thermal Environment"
Aspiration -> "Individual Readiness"
Aspiration -> "Loss of Crew Life"
Aspiration -> Evacuation
Evacuation -> "Loss of Crew Life"
Evacuation -> "Loss of Mission Objectives"
Surveillance -> "Detect Long Term Health Outcomes"
Vomit -> "Individual Readiness"
Vomit -> Aspiration
}

Appendix C – Risk Formatting Instructions

DCS Risk

```
dag {
"Airlock Design" [pos="-0.092,-1.722"]
"Altered Gravity" [exposure,pos="-0.091,-3.232"]
"Arterial Gas Embolism" [pos="0.014,-2.759"]
"Astronaut Selection" [pos="-0.020,-5.338"]
"Atmospheric Conditions" [pos="-0.073,-4.977"]
"Crew Capability" [pos="0.010,-4.600"]
"Crew Health and Performance System" [pos="-0.064,1.500"]
"DCS Type I" [pos="-0.022,-1.736"]
"DCS Type II" [pos="-0.007,-1.745"]
"Detect DCS" [pos="-0.022,-0.734"]
"Detect Long Term Health Outcomes" [pos="0.042,0.221"]
"Distance from Earth" [exposure,pos="-0.095,0.079"]
"EVA Operations" [pos="-0.065,-2.342"]
"HSIA (Risk)" [latent,pos="-0.094,1.508"]
"Hostile Closed Environment" [exposure,pos="-0.088,-4.596"]
"Individual Factors" [pos="-0.020,-3.983"]
"Individual Readiness" [pos="-0.006,-4.784"]
"Long Term Health Outcomes" [outcome,pos="0.046,-0.900"]
"Loss of Crew Life" [outcome,pos="0.047,-2.465"]
"Loss of EVA(s)" [outcome,pos="0.019,-0.369"]
"Loss of Mission Objectives" [outcome,pos="0.045,-4.023"]
"Loss of Mission" [outcome,pos="0.050,-4.935"]
"Medical Diagnostic Capability" [pos="-0.034,-0.146"]
"Medical Treatment Capability" [pos="0.004,1.493"]
"Suit Design" [pos="-0.067,-0.329"]
"Suit Failure" [pos="-0.043,-2.846"]
"Task Performance" [outcome,pos="0.026,-4.466"]
"Vehicle Design" [pos="-0.082,-0.582"]
"Vehicle Failure" [pos="-0.065,-3.737"]
Denitrogenation [pos="-0.047,-3.761"]
Depressurization [pos="-0.033,-4.963"]
Ebullism [pos="0.029,-3.487"]
Surveillance [pos="0.037,1.368"]
Workload [pos="-0.044,-1.963"]
"Airlock Design" -> "EVA Operations"
"Altered Gravity" -> "EVA Operations"
"Altered Gravity" -> Denitrogenation
"Arterial Gas Embolism" -> "Individual Readiness"
"Arterial Gas Embolism" -> "Long Term Health Outcomes"
"Arterial Gas Embolism" -> "Loss of Crew Life"
"Arterial Gas Embolism" -> "Loss of EVA(s)"
"Astronaut Selection" -> "Individual Factors"
"Atmospheric Conditions" -> Denitrogenation
"Atmospheric Conditions" -> Depressurization
"Crew Capability" -> "Task Performance"
"Crew Health and Performance System" -> "Medical Diagnostic Capability"
"Crew Health and Performance System" -> "Medical Treatment Capability"
"DCS Type I" -> "DCS Type II"
"DCS Type I" -> "Detect DCS"
"DCS Type I" -> "Individual Readiness"
"DCS Type I" -> "Loss of EVA(s)"
"DCS Type II" -> "Individual Readiness"
"DCS Type II" -> "Long Term Health Outcomes"
"DCS Type II" -> "Loss of Crew Life"
"DCS Type II" -> "Loss of EVA(s)"
"Detect DCS" -> "Medical Treatment Capability"
"Detect Long Term Health Outcomes" <-> "Long Term Health Outcomes"
"Distance from Earth" -> "Vehicle Design"
"EVA Operations" -> "Suit Failure"
"EVA Operations" -> Workload
"HSIA (Risk)" -> "Crew Health and Performance System"
"HSIA (Risk)" -> "Suit Design"
"HSIA (Risk)" -> "Vehicle Design"
"Hostile Closed Environment" -> "Atmospheric Conditions"
"Hostile Closed Environment" -> "EVA Operations"
"Individual Factors" -> "DCS Type I"
"Individual Factors" -> "DCS Type II"
"Individual Readiness" -> "Crew Capability"
"Individual Readiness" -> "Loss of EVA(s)"
"Loss of EVA(s)" -> "Loss of Mission Objectives"
"Loss of Mission Objectives" -> "Loss of Mission"
"Medical Diagnostic Capability" -> "Detect DCS"
"Medical Treatment Capability" -> "DCS Type II"
"Medical Treatment Capability" -> "Individual Readiness"
"Medical Treatment Capability" -> "Long Term Health Outcomes"
"Medical Treatment Capability" -> "Loss of Crew Life"
"Medical Treatment Capability" -> "Loss of EVA(s)"
"Suit Design" -> "Atmospheric Conditions"
"Suit Design" -> "Medical Treatment Capability"
"Suit Design" -> "Suit Failure"
"Suit Design" -> Denitrogenation
```

"Suit Failure" -> Depressurization
"Task Performance" -> "Loss of Mission Objectives"
"Vehicle Design" -> "Airlock Design"
"Vehicle Design" -> "Atmospheric Conditions"
"Vehicle Design" -> "Crew Health and Performance System"
"Vehicle Design" -> "Vehicle Failure"
"Vehicle Failure" -> "Atmospheric Conditions"
"Vehicle Failure" -> Depressurization
Denitrogenation -> "DCS Type I"
Denitrogenation -> "EVA Operations"
Depressurization -> "Arterial Gas Embolism"
Depressurization -> "DCS Type I"
Depressurization -> "DCS Type II"
Depressurization -> Ebullism
Ebullism -> "Loss of Crew Life"
Ebullism -> "Loss of EVA(s)"
Surveillance -> "Detect Long Term Health Outcomes"
Workload -> "DCS Type I"
}

Appendix C – Risk Formatting Instructions

Dust Risk

```
dag {
bb="-0.5,-0.5,0.5,0.5"
"Altered Gravity" [exposure,pos="-0.413,-0.450"]
"Atmospheric Dust Level" [pos="-0.160,-0.215"]
"Cabin Visibility" [pos="0.071,-0.474"]
"Cardiovascular (Risk)" [latent,pos="0.055,-0.361"]
"Crew Capability" [pos="0.303,-0.313"]
"Crew Health and Performance System" [pos="-0.158,0.398"]
"Detect Atmospheric Dust" [pos="-0.156,0.146"]
"Detect Long Term Health Outcomes" [pos="0.404,0.310"]
"Distance from Earth" [exposure,pos="-0.438,0.290"]
"Dust Monitor" [pos="-0.228,0.255"]
"Dust Removal" [pos="-0.261,-0.041"]
"Dust Source" [pos="-0.279,-0.352"]
"Dust Suspension" [pos="-0.139,-0.454"]
"ECLS System" [pos="-0.279,0.117"]
"EVA Operations" [pos="-0.344,-0.277"]
"Eye Injury" [pos="0.051,-0.189"]
"Flight Recertification" [outcome,pos="0.441,0.009"]
"HSIA (Risk)" [latent,pos="-0.401,0.416"]
"Hostile Closed Environment" [exposure,pos="-0.413,-0.157"]
"Immune (Risk)" [latent,pos="0.053,-0.277"]
"Individual Readiness" [pos="0.241,-0.278"]
"Ingestion Toxicity" [pos="0.056,0.078"]
"Long Term Health Outcomes" [outcome,pos="0.415,0.186"]
"Loss of Crew Life" [outcome,pos="0.440,-0.113"]
"Loss of Mission Objectives" [outcome,pos="0.391,-0.423"]
"Loss of Mission" [outcome,pos="0.452,-0.452"]
"Lung Injury" [pos="0.052,-0.102"]
"Medical (Risk)" [latent,pos="0.188,-0.146"]
"Medical Prevention Capability" [pos="0.202,0.140"]
"Medical Treatment Capability" [pos="0.244,0.348"]
"Pharm (Risk)" [latent,pos="0.106,0.416"]
"Seals/Gaskets" [pos="-0.365,-0.002"]
"Skin Irritation" [pos="0.053,-0.011"]
"Suit Design" [pos="-0.395,0.178"]
"Surface Dust Level" [pos="-0.098,-0.041"]
"Task Performance" [outcome,pos="0.372,-0.338"]
"Vehicle Design" [pos="-0.311,0.366"]
Cleaning [pos="-0.079,0.265"]
Evacuation [outcome,pos="0.322,-0.197"]
Surveillance [pos="0.385,0.430"]
"Altered Gravity" -> "Dust Suspension"
"Atmospheric Dust Level" -> "Cabin Visibility"
"Atmospheric Dust Level" -> "Cardiovascular (Risk)"
"Atmospheric Dust Level" -> "Detect Atmospheric Dust"
"Atmospheric Dust Level" -> "Dust Suspension"
"Atmospheric Dust Level" -> "Eye Injury"
"Atmospheric Dust Level" -> "Immune (Risk)"
"Atmospheric Dust Level" -> "Ingestion Toxicity"
"Atmospheric Dust Level" -> "Lung Injury"
"Atmospheric Dust Level" -> "Skin Irritation"
"Atmospheric Dust Level" -> "Surface Dust Level"
"Cabin Visibility" -> "Task Performance"
"Cardiovascular (Risk)" -> "Medical (Risk)"
"Crew Capability" -> "Task Performance"
"Crew Health and Performance System" -> "Medical Prevention Capability"
"Crew Health and Performance System" -> "Medical Treatment Capability"
"Detect Atmospheric Dust" -> "Detect Long Term Health Outcomes"
"Detect Atmospheric Dust" -> "Dust Removal"
"Detect Atmospheric Dust" -> "Medical Prevention Capability"
"Detect Atmospheric Dust" -> Cleaning
"Distance from Earth" -> "Suit Design"
"Distance from Earth" -> "Vehicle Design"
"Dust Monitor" -> "Detect Atmospheric Dust"
"Dust Removal" -> "Atmospheric Dust Level"
"Dust Source" -> "Atmospheric Dust Level"
"Dust Suspension" -> "Cabin Visibility"
"ECLS System" -> "Dust Removal"
"EVA Operations" -> "Atmospheric Dust Level"
"Eye Injury" -> "Medical (Risk)"
"HSIA (Risk)" -> "Suit Design"
"HSIA (Risk)" -> "Vehicle Design"
"Hostile Closed Environment" -> "Atmospheric Dust Level"
"Immune (Risk)" -> "Flight Recertification"
"Immune (Risk)" -> "Medical (Risk)"
"Individual Readiness" -> "Crew Capability"
"Ingestion Toxicity" -> "Medical (Risk)"
"Long Term Health Outcomes" -> "Detect Long Term Health Outcomes"
```

Appendix C – Risk Formatting Instructions

"Loss of Mission Objectives" -> "Loss of Mission"
"Lung Injury" -> "Medical (Risk)"
"Medical (Risk)" -> "Individual Readiness"
"Medical (Risk)" -> "Long Term Health Outcomes"
"Medical (Risk)" -> "Loss of Crew Life"
"Medical (Risk)" -> Evacuation
"Medical Prevention Capability" -> "Eye Injury"
"Medical Prevention Capability" -> "Ingestion Toxicity"
"Medical Prevention Capability" -> "Lung Injury"
"Medical Prevention Capability" -> "Skin Irritation"
"Medical Treatment Capability" -> "Individual Readiness"
"Medical Treatment Capability" -> "Long Term Health Outcomes"
"Medical Treatment Capability" -> "Medical (Risk)"
"Medical Treatment Capability" -> Evacuation
"Pharm (Risk)" -> "Medical Prevention Capability"
"Pharm (Risk)" -> "Medical Treatment Capability"
"Seals/Gaskets" -> "Atmospheric Dust Level"
"Skin Irritation" -> "Medical (Risk)"
"Suit Design" -> "Seals/Gaskets"
"Surface Dust Level" -> "Immune (Risk)"
"Surface Dust Level" -> "Ingestion Toxicity"
"Surface Dust Level" -> "Skin Irritation"
"Task Performance" -> "Loss of Mission Objectives"
"Vehicle Design" -> "Crew Health and Performance System"
"Vehicle Design" -> "Dust Monitor"
"Vehicle Design" -> "ECLS System"
"Vehicle Design" -> "Seals/Gaskets"
"Vehicle Design" -> Cleaning
Cleaning -> "Surface Dust Level"
Evacuation -> "Loss of Crew Life"
Surveillance -> "Detect Long Term Health Outcomes"
}

Appendix C – Risk Formatting Instructions

Dynamic Loads Risk

```
dag {
bb="0,0,1,1"
"Altered Gravity" [exposure,pos="0.070,0.118"]
"Astronaut Selection" [pos="0.052,0.416"]
"Body Posture" [pos="0.456,0.768"]
"Bone Remodeling" [pos="0.300,0.572"]
"Central Nervous System Changes"
[pos="0.309,0.029"]
"Connective Tissue Changes" [pos="0.307,0.329"]
"Crew Capability" [pos="0.712,0.172"]
"Crew Health and Performance System"
[pos="0.439,0.893"]
"Detect Long Term Health Outcomes"
[pos="0.866,0.856"]
"Distance from Earth"
[exposure,pos="0.084,0.853"]
"Flight Recertification"
[outcome,pos="0.925,0.636"]
"Hostile Closed Environment"
[exposure,pos="0.090,0.666"]
"Individual Factors" [pos="0.163,0.415"]
"Individual Readiness" [pos="0.635,0.230"]
"Long Term Health Outcomes"
[outcome,pos="0.909,0.744"]
"Loss of Crew Life" [outcome,pos="0.936,0.479"]
"Loss of Mission Objectives"
[outcome,pos="0.885,0.071"]
"Loss of Mission" [outcome,pos="0.948,0.026"]
"Medical Treatment Capability"
[pos="0.636,0.893"]
"Muscle Performance" [pos="0.307,0.243"]
"Musculoskeletal Injury" [pos="0.534,0.505"]
"Neuro/Ocular Injury" [pos="0.532,0.355"]
"SANS (Risk)" [latent,pos="0.503,0.099"]
"Sensorimotor (Risk)" [latent,pos="0.571,0.767"]
"Suit Design" [pos="0.298,0.920"]
"Task Performance" [outcome,pos="0.786,0.122"]
"Vascular Structure/Function"
[pos="0.307,0.145"]
"Vehicle Design" [pos="0.298,0.805"]
"Vehicle Dynamics" [pos="0.297,0.687"]
Anthropometry [pos="0.306,0.423"]
Evacuation [outcome,pos="0.823,0.371"]
Surveillance [pos="0.758,0.914"]
"Altered Gravity" -> "Bone Remodeling"
"Altered Gravity" -> "Central Nervous System
Changes"
"Altered Gravity" -> "Connective Tissue Changes"
"Altered Gravity" -> "Muscle Performance"
"Altered Gravity" -> "Vascular Structure/Function"
"Altered Gravity" -> Anthropometry
"Astronaut Selection" -> "Individual Factors"
"Body Posture" -> "Musculoskeletal Injury"
"Body Posture" -> "Neuro/Ocular Injury"
"Bone Remodeling" -> "Musculoskeletal Injury"
"Central Nervous System Changes" ->
"Neuro/Ocular Injury"
"Connective Tissue Changes" -> "Musculoskeletal
Injury"
"Crew Capability" -> "Task Performance"
"Crew Health and Performance System" ->
"Medical Treatment Capability"
"Distance from Earth" -> "Suit Design"
"Distance from Earth" -> "Vehicle Design"
"Hostile Closed Environment" -> "Vehicle
Dynamics"
"Individual Factors" -> "Bone Remodeling"
"Individual Factors" -> "Connective Tissue
Changes"
"Individual Factors" -> "Muscle Performance"
"Individual Factors" -> "Musculoskeletal Injury"
"Individual Factors" -> Anthropometry
"Individual Readiness" -> "Crew Capability"
"Long Term Health Outcomes" -> "Detect Long
Term Health Outcomes"
"Loss of Mission Objectives" -> "Loss of Mission"
"Medical Treatment Capability" -> "Individual
Readiness"
"Medical Treatment Capability" -> "Loss of Crew
Life"
"Medical Treatment Capability" -> Evacuation
"Muscle Performance" -> "Musculoskeletal Injury"
"Musculoskeletal Injury" -> "Flight Recertification"
"Musculoskeletal Injury" -> "Individual Readiness"
"Musculoskeletal Injury" -> "Long Term Health
Outcomes"
"Musculoskeletal Injury" -> "Loss of Crew Life"
"Musculoskeletal Injury" -> Evacuation
"Neuro/Ocular Injury" -> "Flight Recertification"
"Neuro/Ocular Injury" -> "Individual Readiness"
"Neuro/Ocular Injury" -> "Long Term Health
Outcomes"
"Neuro/Ocular Injury" -> Evacuation
"SANS (Risk)" -> "Neuro/Ocular Injury"
"Sensorimotor (Risk)" -> "Body Posture"
"Suit Design" -> "Body Posture"
"Suit Design" -> "Musculoskeletal Injury"
"Task Performance" -> "Loss of Mission
Objectives"
```

"Vascular Structure/Function" -> "Neuro/Ocular Injury"
"Vehicle Design" -> "Body Posture"
"Vehicle Design" -> "Crew Health and Performance System"
"Vehicle Design" -> "Musculoskeletal Injury"
"Vehicle Design" -> "Vehicle Dynamics"
"Vehicle Dynamics" -> "Body Posture"
"Vehicle Dynamics" -> "Musculoskeletal Injury"
"Vehicle Dynamics" -> "Neuro/Ocular Injury"
Anthropometry -> "Musculoskeletal Injury"
Evacuation -> "Loss of Crew Life"
Evacuation -> "Loss of Mission Objectives"
Surveillance -> "Detect Long Term Health Outcomes"
}

Appendix C – Risk Formatting Instructions

Electric Shock Risk

dag {
"Arc Flash/Sparking" [pos="-1.336,-1.005"]
"Burn Treatment Capability" [pos="-1.219,-0.950"]
"Charged Surface" [pos="-1.394,-0.956"]
"Crew Capability" [pos="-1.160,-0.991"]
"Crew Health and Performance System" [pos="-1.405,-0.937"]
"Crew Vehicle Integration" [pos="-1.482,-0.973"]
"Detect Dysrhythmia" [pos="-1.291,-0.960"]
"Detect Long Term Health Outcomes" [pos="-1.139,-0.938"]
"Diagnose Rhabdomyolysis" [pos="-1.282,-0.946"]
"Distance from Earth" [exposure,pos="-1.490,-0.933"]
"Dysrhythmia Monitor" [pos="-1.319,-0.952"]
"Dysrhythmia Treatment" [pos="-1.238,-0.959"]
"EVA Operations" [pos="-1.385,-0.968"]
"Electrical Hardware" [pos="-1.442,-0.980"]
"Electrical Muscle Effects" [pos="-1.252,-0.995"]
"Electrical Shock" [pos="-1.334,-0.988"]
"Electrical System Design" [pos="-1.482,-0.999"]
"HSIA (Risk)" [latent,pos="-1.488,-0.951"]
"Hardware/System Failure" [pos="-1.427,-0.991"]
"Hostile Closed Environment" [exposure,pos="-1.481,-1.008"]
"Human Error" [pos="-1.422,-1.005"]
"Human-Electrical Contact" [pos="-1.380,-0.997"]
"Impedance Factors" [pos="-1.373,-0.984"]
"Individual Readiness" [pos="-1.203,-0.991"]
"Long Term Health Outcomes" [outcome,pos="-1.138,-0.951"]
"Loss of Crew Life" [outcome,pos="-1.133,-0.963"]
"Loss of Mission Objectives" [outcome,pos="-1.141,-1.009"]
"Loss of Mission" [outcome,pos="-1.129,-1.015"]
"Medical Diagnostic Capability" [pos="-1.332,-0.932"]
"Medical Treatment Capability" [pos="-1.251,-0.935"]
"Physiologic Monitoring Capability" [pos="-1.360,-0.948"]
"Plasma Induced Shock" [pos="-1.334,-0.977"]
"Rhabdomyolysis Treatment" [pos="-1.202,-0.942"]
"Startle Reaction" [pos="-1.250,-1.005"]
"Suit Design" [pos="-1.431,-0.968"]
"Suit-Vehicle/Habitat Contact" [pos="-1.336,-0.967"]
"Task Performance" [outcome,pos="-1.151,-1.001"]
"Vehicle Design" [pos="-1.462,-0.943"]
Burns [pos="-1.254,-0.985"]
Dysrhythmia [pos="-1.276,-0.978"]
Evacuation [outcome,pos="-1.136,-0.978"]
Radiation [exposure,pos="-1.497,-0.963"]
Rhabdomyolysis [pos="-1.253,-0.970"]
Surveillance [pos="-1.168,-0.931"]
"Arc Flash/Sparking" -> "Startle Reaction"
"Arc Flash/Sparking" -> Dysrhythmia
"Burn Treatment Capability" -> "Individual Readiness"
"Burn Treatment Capability" -> "Long Term Health Outcomes"
"Burn Treatment Capability" -> "Loss of Crew Life"
"Burn Treatment Capability" -> Evacuation
"Charged Surface" -> "Suit-Vehicle/Habitat Contact"
"Crew Capability" -> "Task Performance"
"Crew Health and Performance System" -> "Medical Diagnostic Capability"
"Crew Health and Performance System" -> "Medical Treatment Capability"
"Crew Health and Performance System" -> "Physiologic Monitoring Capability"
"Crew Vehicle Integration" -> "Human Error"
"Detect Dysrhythmia" -> "Dysrhythmia Treatment"
"Diagnose Rhabdomyolysis" -> "Rhabdomyolysis Treatment"
"Distance from Earth" -> "Vehicle Design"
"Dysrhythmia Monitor" -> "Detect Dysrhythmia"
"Dysrhythmia Treatment" -> "Individual Readiness"
"Dysrhythmia Treatment" -> "Loss of Crew Life"
"Dysrhythmia Treatment" -> Evacuation
"EVA Operations" -> "Suit-Vehicle/Habitat Contact"
"Electrical Hardware" -> "Electrical System Design"
"Electrical Muscle Effects" -> "Individual Readiness"
"Electrical Shock" -> "Electrical Muscle Effects"
"Electrical Shock" -> "Startle Reaction"
"Electrical Shock" -> Burns
"Electrical Shock" -> Dysrhythmia
"Electrical Shock" -> Rhabdomyolysis
"Electrical System Design" -> "Hardware/System Failure"
"Electrical System Design" -> "Human Error"
"HSIA (Risk)" -> "Suit Design"

"HSIA (Risk)" -> "Vehicle Design"
"Hardware/System Failure" -> "Human-Electrical Contact"
"Hostile Closed Environment" -> "Electrical System Design"
"Human Error" -> "Arc Flash/Sparking"
"Human Error" -> "Human-Electrical Contact"
"Human-Electrical Contact" -> "Electrical Shock"
"Impedance Factors" -> "Electrical Shock"
"Impedance Factors" -> "Plasma Induced Shock"
"Individual Readiness" -> "Crew Capability"
"Long Term Health Outcomes" -> "Detect Long Term Health Outcomes"
"Loss of Mission Objectives" -> "Loss of Mission"
"Medical Diagnostic Capability" -> "Diagnose Rhabdomyolysis"
"Medical Treatment Capability" -> "Burn Treatment Capability"
"Medical Treatment Capability" -> "Dysrhythmia Treatment"
"Medical Treatment Capability" -> "Rhabdomyolysis Treatment"
"Physiologic Monitoring Capability" -> "Dysrhythmia Monitor"
"Plasma Induced Shock" -> "Startle Reaction"
"Rhabdomyolysis Treatment" -> "Individual Readiness"
"Rhabdomyolysis Treatment" -> "Long Term Health Outcomes"
"Rhabdomyolysis Treatment" -> "Loss of Crew Life"
"Rhabdomyolysis Treatment" -> Evacuation
"Startle Reaction" -> "Individual Readiness"
"Suit Design" -> "EVA Operations"
"Suit-Vehicle/Habitat Contact" -> "Plasma Induced Shock"
"Task Performance" -> "Loss of Mission Objectives"
"Vehicle Design" -> "Charged Surface"
"Vehicle Design" -> "Crew Health and Performance System"
"Vehicle Design" -> "Crew Vehicle Integration"
"Vehicle Design" -> "Electrical Hardware"
"Vehicle Design" -> "Electrical System Design"
Burns -> "Individual Readiness"
Burns -> "Long Term Health Outcomes"
Burns -> "Loss of Crew Life"
Burns -> Evacuation
Dysrhythmia -> "Detect Dysrhythmia"
Dysrhythmia -> "Individual Readiness"
Dysrhythmia -> "Loss of Crew Life"
Dysrhythmia -> Evacuation
Evacuation -> "Loss of Crew Life"
Evacuation -> "Loss of Mission Objectives"
Radiation -> "Charged Surface"
Rhabdomyolysis -> "Diagnose Rhabdomyolysis"
Rhabdomyolysis -> "Individual Readiness"
Rhabdomyolysis -> "Long Term Health Outcomes"
Rhabdomyolysis -> "Loss of Crew Life"
Rhabdomyolysis -> Evacuation
Surveillance -> "Detect Long Term Health Outcomes"
}

Appendix C – Risk Formatting Instructions

EVA Risk

dag {
bb="0,0,1,1"
"Altered Gravity" [exposure,pos="0.063,0.666"]
"Astronaut Selection" [pos="0.057,0.508"]
"Cognitive Function" [pos="0.529,0.224"]
"Crew Capability" [pos="0.694,0.223"]
"Crew Health and Performance System" [pos="0.448,0.046"]
"DCS (Risk)" [latent,pos="0.653,0.663"]
"Detect EVA Readiness" [pos="0.448,0.484"]
"Detect Long Term Health Outcomes" [pos="0.900,0.769"]
"Distance from Earth" [exposure,pos="0.062,0.047"]
"Dynamic Loads (Risk)" [latent,pos="0.189,0.844"]
"EVA Decision Support" [pos="0.285,0.143"]
"EVA Duration" [pos="0.285,0.325"]
"EVA Frequency" [pos="0.284,0.396"]
"EVA Task Timeline" [pos="0.169,0.146"]
"Environmental Injury" [pos="0.675,0.398"]
"Fall Height" [pos="0.617,0.867"]
"HSIA (Risk)" [latent,pos="0.542,0.544"]
"Hostile Closed Environment" [exposure,pos="0.079,0.931"]
"Incapacitation/ Crew Rescue" [pos="0.901,0.393"]
"Individual Factors" [pos="0.179,0.648"]
"Individual Readiness" [pos="0.623,0.158"]
"Isolation and Confinement" [exposure,pos="0.077,0.216"]
"Long Term Health Outcomes" [outcome,pos="0.909,0.670"]
"Loss of Crew Life" [outcome,pos="0.898,0.578"]
"Loss of EVA Content" [pos="0.902,0.227"]
"Loss of Mission Objectives" [outcome,pos="0.900,0.132"]
"Loss of Mission" [outcome,pos="0.901,0.037"]
"Medical Treatment Capability" [pos="0.674,0.048"]
"Physical Status" [pos="0.284,0.563"]
"Physiologic Monitoring Capability" [pos="0.448,0.143"]
"Planned EVA Content" [pos="0.170,0.398"]
"Previous Injury" [pos="0.284,0.733"]
"Procedure Design" [pos="0.704,0.907"]
"Suit Design" [pos="0.462,0.686"]
"Suit Failure" [pos="0.545,0.673"]
"Suit Habitability" [pos="0.371,0.929"]
"Task Performance" [pos="0.792,0.224"]
"Tool Design" [pos="0.779,0.873"]
"Traumatic Injury" [pos="0.740,0.544"]
"Vehicle Design" [pos="0.286,0.048"]
Fatigue [pos="0.528,0.316"]
Radiation [exposure,pos="0.063,0.343"]
Surveillance [pos="0.898,0.887"]
Training [pos="0.411,0.590"]
Workload [pos="0.374,0.399"]
"Altered Gravity" -> "Physical Status"
"Altered Gravity" -> "Planned EVA Content"
"Altered Gravity" -> "Suit Habitability"
"Altered Gravity" -> Workload
"Astronaut Selection" -> "Individual Factors"
"Cognitive Function" -> "Individual Readiness"
"Cognitive Function" -> "Traumatic Injury"
"Crew Capability" -> "Task Performance"
"Crew Health and Performance System" -> "Medical Treatment Capability"
"Crew Health and Performance System" -> "Physiologic Monitoring Capability"
"DCS (Risk)" -> "Environmental Injury"
"Detect EVA Readiness" -> "Loss of EVA Content"
"Detect Long Term Health Outcomes" -> "Long Term Health Outcomes"
"Distance from Earth" -> "EVA Decision Support" [pos="0.151,0.087"]
"Distance from Earth" -> "Vehicle Design"
"Dynamic Loads (Risk)" -> "Previous Injury"
"EVA Decision Support" -> "Cognitive Function"
"EVA Decision Support" -> Workload
"EVA Duration" -> "Cognitive Function"
"EVA Duration" -> Workload
"EVA Frequency" -> "Cognitive Function"
"EVA Frequency" -> Workload
"EVA Task Timeline" -> "EVA Decision Support"
"EVA Task Timeline" -> "EVA Duration"
"Environmental Injury" -> "Incapacitation/ Crew Rescue"
"Environmental Injury" -> "Individual Readiness"
"Environmental Injury" -> "Loss of EVA Content"
"Fall Height" -> "Traumatic Injury"
"HSIA (Risk)" -> "Fall Height"
"HSIA (Risk)" -> "Procedure Design"
"HSIA (Risk)" -> "Suit Design"
"HSIA (Risk)" -> "Tool Design"
"HSIA (Risk)" -> "Vehicle Design"
"HSIA (Risk)" -> Training
"Hostile Closed Environment" -> "Physical Status"
"Hostile Closed Environment" -> "Planned EVA Content"
"Hostile Closed Environment" -> "Suit Habitability"

"Incapacitation/ Crew Rescue" -> "Loss of Crew Life"
"Incapacitation/ Crew Rescue" -> "Loss of EVA Content"
"Individual Factors" -> "Previous Injury"
"Individual Readiness" -> "Crew Capability"
"Isolation and Confinement" -> "Cognitive Function"
"Loss of EVA Content" -> "Loss of Mission Objectives"
"Loss of Mission Objectives" -> "Loss of Mission"
"Medical Treatment Capability" -> "Individual Readiness"
"Physical Status" -> "Detect EVA Readiness"
"Physical Status" -> "Individual Readiness"
"Physical Status" -> Workload
"Physiologic Monitoring Capability" -> "Detect EVA Readiness"
"Physiologic Monitoring Capability" -> "EVA Decision Support"
"Planned EVA Content" -> "EVA Decision Support"
"Planned EVA Content" -> "EVA Duration"
"Planned EVA Content" -> "EVA Frequency"
"Planned EVA Content" -> "EVA Task Timeline"
"Previous Injury" -> "Physical Status"
"Previous Injury" -> Workload
"Procedure Design" -> "Task Performance"
"Procedure Design" -> "Traumatic Injury"
"Suit Design" -> "Suit Failure"
"Suit Design" -> "Suit Habitability"
"Suit Failure" -> "Environmental Injury"
"Suit Failure" -> "Individual Readiness"
"Suit Failure" -> "Traumatic Injury"
"Suit Habitability" -> "Suit Failure"
"Suit Habitability" -> Workload
"Task Performance" -> "Loss of EVA Content"
"Tool Design" -> "Task Performance"
"Tool Design" -> "Traumatic Injury"
"Traumatic Injury" -> "Incapacitation/ Crew Rescue"
"Traumatic Injury" -> "Individual Readiness"
"Traumatic Injury" -> "Long Term Health Outcomes"
"Traumatic Injury" -> "Loss of EVA Content"
"Vehicle Design" -> "Crew Health and Performance System"
Fatigue -> "Cognitive Function"
Fatigue -> "Individual Readiness"
Fatigue -> "Traumatic Injury"
Radiation -> "Cognitive Function"
Surveillance -> "Detect Long Term Health Outcomes"
Training -> "Individual Readiness"
Training -> "Previous Injury"
Workload -> "Environmental Injury"
Workload -> Fatigue
}

Appendix C – Risk Formatting Instructions

Food and Nutrition Risk

```
dag {
bb="-0.5,-0.5,0.5,0.5"
"Altered Gravity" [exposure,pos="-0.439,0.153"]
"Astronaut Selection" [pos="-0.344,-0.409"]
"Behavioral (Risk)" [latent,pos="0.090,-0.438"]
"Cardiovascular (Risk)" [latent,pos="0.083,0.141"]
"Crew Capability" [pos="0.244,-0.324"]
"Crew Health and Performance System" [pos="-0.353,-0.283"]
"Detect Long Term Health Outcomes" [pos="0.385,0.194"]
"Distance from Earth" [exposure,pos="-0.440,-0.436"]
"Effective Mission Duration" [pos="-0.166,-0.443"]
"Energy (Calories)" [pos="-0.055,-0.019"]
"Food Acceptability" [pos="-0.171,-0.169"]
"Food Preparation" [pos="-0.264,-0.147"]
"Food Production" [pos="-0.304,0.025"]
"Food Safety" [pos="-0.179,0.236"]
"Food Storage" [pos="-0.311,0.322"]
"Food System" [pos="-0.355,-0.120"]
"Food Variety" [pos="-0.171,0.061"]
"HSIA (Risk)" [latent,pos="-0.442,-0.113"]
"Hostile Closed Environment" [exposure,pos="-0.424,0.402"]
"Immune (Risk)" [latent,pos="0.085,0.023"]
"Individual Factors" [pos="-0.274,-0.317"]
"Individual Readiness" [pos="0.189,-0.253"]
"Long Term Health Outcomes" [outcome,pos="0.386,0.033"]
"Loss of Crew Life" [outcome,pos="0.416,-0.109"]
"Loss of Mission Objectives" [outcome,pos="0.342,-0.450"]
"Loss of Mission" [outcome,pos="0.436,-0.479"]
"Medical (Risk)" [latent,pos="0.197,-0.142"]
"Microhost, Renal Stone, Bone Fracture (Risks), VTE (Concern)" [latent,pos="0.076,-0.100"]
"Muscle, Aerobic (Risk)" [latent,pos="0.089,-0.317"]
"Nutrient Deficiencies" [pos="0.202,0.289"]
"Nutrient Toxicities" [pos="0.158,0.185"]
"Pharm (Risk)" [latent,pos="0.037,0.379"]
"Radiation Carcinogenesis (Risk)" [latent,pos="0.211,0.384"]
"Sleep (Risk)" [latent,pos="0.087,-0.199"]
"Task Performance" [outcome,pos="0.294,-0.383"]
"Team (Risk)" [latent,pos="0.207,-0.438"]
"Vehicle Design" [pos="-0.439,-0.318"]
Evacuation [outcome,pos="0.292,-0.144"]
Hydration [pos="-0.040,-0.431"]
Nutrients [pos="-0.054,0.243"]
Radiation [exposure,pos="-0.430,0.272"]
Recycling [pos="-0.168,-0.346"]
Resupply [pos="-0.280,-0.442"]
Starvation [pos="0.252,-0.034"]
Surveillance [pos="0.386,0.337"]
"Altered Gravity" -> "Food System"
"Astronaut Selection" -> "Individual Factors"
"Behavioral (Risk)" -> "Individual Readiness"
"Behavioral (Risk)" -> "Team (Risk)"
"Cardiovascular (Risk)" -> "Medical (Risk)"
"Crew Capability" -> "Task Performance"
"Crew Health and Performance System" -> "Food System"
"Detect Long Term Health Outcomes" <-> "Long Term Health Outcomes"
"Distance from Earth" -> "Vehicle Design"
"Distance from Earth" -> Resupply
"Effective Mission Duration" -> "Food System"
"Effective Mission Duration" -> Resupply
"Energy (Calories)" -> "Behavioral (Risk)"
"Energy (Calories)" -> "Immune (Risk)"
"Energy (Calories)" -> "Microhost, Renal Stone, Bone Fracture (Risks), VTE (Concern)"
"Energy (Calories)" -> "Muscle, Aerobic (Risk)"
"Energy (Calories)" -> "Sleep (Risk)"
"Energy (Calories)" -> Starvation
"Food Acceptability" -> "Behavioral (Risk)"
"Food Acceptability" -> "Energy (Calories)"
"Food Acceptability" -> Hydration
"Food Acceptability" -> Nutrients
"Food Preparation" -> "Food Acceptability"
"Food Preparation" -> "Food Safety"
"Food Preparation" -> "Food Variety"
"Food Preparation" -> Hydration
"Food Production" -> "Energy (Calories)"
"Food Production" -> "Food Acceptability"
"Food Production" -> "Food Safety"
"Food Production" -> "Food Storage"
"Food Production" -> "Food Variety"
"Food Production" -> Nutrients
"Food Safety" -> "Energy (Calories)"
"Food Safety" -> "Medical (Risk)"
"Food Safety" -> Hydration
"Food Safety" -> Nutrients
"Food Storage" -> "Energy (Calories)"
"Food Storage" -> "Food Acceptability"
"Food Storage" -> "Food Safety"
"Food Storage" -> "Food Variety"
```

Appendix C – Risk Formatting Instructions

"Food Storage" -> Hydration
"Food Storage" -> Nutrients
"Food System" -> "Food Preparation"
"Food System" -> "Food Production"
"Food System" -> "Food Storage"
"Food System" -> Recycling
"Food Variety" -> "Behavioral (Risk)"
"Food Variety" -> "Energy (Calories)"
"Food Variety" -> "Food Acceptability"
"Food Variety" -> Nutrients
"HSIA (Risk)" -> "Crew Health and Performance System"
"HSIA (Risk)" -> "Food System"
"HSIA (Risk)" -> "Vehicle Design"
"Hostile Closed Environment" -> "Food Storage"
"Immune (Risk)" -> "Medical (Risk)"
"Individual Factors" -> "Food Acceptability"
"Individual Readiness" -> "Crew Capability"
"Individual Readiness" -> "Loss of Crew Life"
"Loss of Mission Objectives" -> "Loss of Mission"
"Medical (Risk)" -> "Individual Readiness"
"Medical (Risk)" -> Evacuation
"Microhost, Renal Stone, Bone Fracture (Risks), VTE (Concern)" -> "Medical (Risk)"
"Muscle, Aerobic (Risk)" -> "Individual Readiness"
"Muscle, Aerobic (Risk)" -> "Medical (Risk)"
"Nutrient Deficiencies" -> "Long Term Health Outcomes"
"Nutrient Deficiencies" -> "Medical (Risk)"
"Nutrient Toxicities" -> "Long Term Health Outcomes"
"Nutrient Toxicities" -> "Medical (Risk)"
"Pharm (Risk)" -> "Nutrient Deficiencies"
"Pharm (Risk)" -> "Nutrient Toxicities"
"Pharm (Risk)" -> Nutrients
"Radiation Carcinogenesis (Risk)" -> "Long Term Health Outcomes"
"Sleep (Risk)" -> "Individual Readiness"
"Sleep (Risk)" -> "Medical (Risk)"
"Task Performance" -> "Loss of Mission Objectives"
"Team (Risk)" -> "Crew Capability"
"Vehicle Design" -> "Crew Health and Performance System"
Evacuation -> "Loss of Crew Life"
Evacuation -> "Loss of Mission Objectives"
Hydration -> "Behavioral (Risk)"
Hydration -> "Microhost, Renal Stone, Bone Fracture (Risks), VTE (Concern)"
Hydration -> "Sleep (Risk)"
Nutrients -> "Behavioral (Risk)"
Nutrients -> "Cardiovascular (Risk)"
Nutrients -> "Immune (Risk)"
Nutrients -> "Microhost, Renal Stone, Bone Fracture (Risks), VTE (Concern)"
Nutrients -> "Muscle, Aerobic (Risk)"
Nutrients -> "Nutrient Deficiencies"
Nutrients -> "Nutrient Toxicities"
Nutrients -> "Radiation Carcinogenesis (Risk)"
Nutrients -> "Sleep (Risk)"
Radiation -> "Food Storage"
Recycling -> Hydration
Resupply -> "Food System"
Starvation -> "Individual Readiness"
Starvation -> "Loss of Crew Life"
Surveillance -> "Detect Long Term Health Outcomes"
}

Appendix C – Risk Formatting Instructions

HSIA Risk

```
dag {
bb="-0.5,-0.5,0.5,0.5"
"Anomalous Events" [pos="-0.213,-0.042"]
"Autonomous Systems" [pos="-0.320,0.203"]
"Communication Factors" [pos="-0.422,-0.379"]
"Crew Capability" [pos="-0.005,-0.294"]
"Crew Health and Performance System" [pos="-0.330,-0.001"]
"Crew Size" [pos="-0.036,-0.457"]
"Crew Vehicle Integration" [pos="-0.290,0.323"]
"Data Accessibility" [pos="0.159,0.198"]
"Data Architecture" [pos="0.161,0.297"]
"Detect Events" [pos="-0.065,-0.047"]
"Diagnose Events" [pos="0.086,-0.042"]
"Diagnostic Capability" [pos="0.080,0.083"]
"Distance from Earth" [exposure,pos="-0.446,-0.041"]
"Effective Mission Duration" [pos="-0.328,-0.182"]
"Ground Support" [pos="-0.292,-0.380"]
"HSI Processes" [pos="-0.291,0.411"]
"Intervention Decision" [pos="0.249,-0.041"]
"Loss of Crew Life" [outcome,pos="0.427,0.037"]
"Loss of Mission Objectives" [outcome,pos="0.349,-0.430"]
"Loss of Mission" [outcome,pos="0.442,-0.470"]
"Loss of Vehicle" [pos="0.354,-0.050"]
"Mission Architecture Complexity" [pos="-0.326,-0.291"]
"Mitigation Options" [pos="0.247,0.068"]
"Monitoring Capability" [pos="-0.107,0.073"]
"On-Board Expertise" [pos="-0.163,-0.455"]
"Other Risks" [latent,pos="0.049,-0.458"]
"Procedure Design" [pos="0.011,0.236"]
"Resource Availability" [pos="0.305,0.162"]
"Standards/Requirements" [pos="-0.421,0.405"]
"Suit Design" [pos="-0.157,0.409"]
"System Complexity" [pos="-0.212,0.156"]
"System Knowledge Resources" [pos="0.239,0.419"]
"System Telemetry" [pos="0.079,0.416"]
"Task Performance" [outcome,pos="0.300,-0.328"]
"Time Critical Procedure Execution" [pos="-0.103,-0.156"]
"Vehicle Design" [pos="-0.423,0.259"]
"Vehicle Systems" [pos="-0.111,0.333"]
Evacuation [outcome,pos="0.396,-0.249"]
Maintainability [pos="-0.109,0.239"]
Resupply [pos="-0.404,0.111"]
Training [pos="-0.180,-0.251"]
"Anomalous Events" -> "Detect Events"
"Autonomous Systems" -> "Anomalous Events"
"Autonomous Systems" -> "Crew Health and Performance System"
"Autonomous Systems" -> "System Complexity"
"Communication Factors" -> "Ground Support"
"Crew Capability" -> "Detect Events"
"Crew Capability" -> "Diagnose Events"
"Crew Capability" -> "Intervention Decision"
"Crew Capability" -> "Task Performance"
"Crew Capability" -> "Time Critical Procedure Execution"
"Crew Health and Performance System" -> "Crew Capability"
"Crew Health and Performance System" -> Training
"Crew Size" -> "Crew Capability"
"Crew Size" -> "On-Board Expertise"
"Crew Vehicle Integration" -> "Anomalous Events"
"Crew Vehicle Integration" -> "Autonomous Systems"
"Crew Vehicle Integration" -> "System Complexity"
"Data Accessibility" -> "Diagnostic Capability"
"Data Accessibility" -> "Monitoring Capability"
"Data Architecture" -> "Data Accessibility"
"Detect Events" -> "Diagnose Events"
"Diagnose Events" -> "Intervention Decision"
"Diagnostic Capability" -> "Diagnose Events"
"Distance from Earth" -> "Communication Factors"
"Distance from Earth" -> "Vehicle Design"
"Distance from Earth" -> Resupply
"Effective Mission Duration" -> "Anomalous Events"
"Ground Support" -> "Crew Capability"
"Ground Support" -> "Detect Events"
"Ground Support" -> "Diagnose Events"
"Ground Support" -> "Intervention Decision"
"HSI Processes" -> "Crew Vehicle Integration"
"HSI Processes" -> "Suit Design"
"HSI Processes" -> "Vehicle Design"
"Intervention Decision" -> "Loss of Vehicle"
"Intervention Decision" -> "Task Performance"
"Intervention Decision" -> Evacuation
"Loss of Mission Objectives" -> "Loss of Mission"
"Loss of Vehicle" -> "Loss of Crew Life"
"Mission Architecture Complexity" -> "Anomalous Events"
"Mitigation Options" -> "Intervention Decision"
```

"Monitoring Capability" -> "Crew Health and Performance System"
"Monitoring Capability" -> "Detect Events"
"Monitoring Capability" -> "Diagnostic Capability"
"On-Board Expertise" -> "Crew Capability"
"On-Board Expertise" -> "Diagnostic Capability"
"On-Board Expertise" -> "Monitoring Capability"
"Other Risks" -> "Crew Capability"
"Procedure Design" -> "Task Performance"
"Resource Availability" -> "Mitigation Options"
"Resource Availability" -> "Task Performance"
"Standards/Requirements" -> "HSI Processes"
"Suit Design" -> "Anomalous Events"
"Suit Design" -> "System Telemetry"
"System Complexity" -> "Anomalous Events"
"System Complexity" -> "Diagnostic Capability"
"System Complexity" -> Maintainability
"System Knowledge Resources" -> "Data Architecture"
"System Telemetry" -> "Data Architecture"
"Task Performance" -> "Loss of Mission Objectives"
"Task Performance" -> "Loss of Vehicle"
"Time Critical Procedure Execution" -> "Anomalous Events"
"Vehicle Design" -> "Anomalous Events"
"Vehicle Design" -> "Autonomous Systems"
"Vehicle Design" -> "Crew Health and Performance System"
"Vehicle Design" -> "Crew Vehicle Integration"
"Vehicle Design" -> "Vehicle Systems"
"Vehicle Design" -> Maintainability
"Vehicle Systems" -> "System Knowledge Resources"
"Vehicle Systems" -> "System Telemetry"
"Vehicle Systems" -> Maintainability
Evacuation -> "Loss of Crew Life"
Evacuation -> "Loss of Mission Objectives"
Maintainability -> "Monitoring Capability"
Maintainability -> "Procedure Design"
Maintainability -> "Task Performance"
Resupply -> "Resource Availability"
Training -> "Crew Capability"
}

Appendix C – Risk Formatting Instructions

Hypoxia Risk

dag {
"Altered Gravity" [exposure,pos="-0.817,-1.515"]
"Atmospheric Conditions" [pos="-0.725,-1.910"]
"Breathing Masks" [pos="-0.310,-0.692"]
"Cognitive Function" [pos="-0.361,-0.979"]
"Compartment Isolation" [pos="-0.192,0.108"]
"Crew Capability" [pos="-0.180,-2.805"]
"Crew Health and Performance System" [pos="-0.476,0.917"]
"DCS, Immune, SANS, Sleep (Risks)" [latent,pos="-0.615,0.587"]
"Detect Atmospheric Changes" [pos="-0.451,0.038"]
"Distance from Earth" [exposure,pos="-0.803,0.115"]
"EVA Operations" [pos="-0.724,-2.635"]
"Effective Exposure Duration" [pos="-0.517,-1.542"]
"Environmental Monitoring Capability" [pos="-0.377,0.449"]
"HSIA (Risk)" [latent,pos="-0.820,0.912"]
"Hostile Closed Environment" [exposure,pos="-0.788,-3.105"]
"Individual Factors" [pos="-0.344,-1.777"]
"Individual Readiness" [pos="-0.279,-2.780"]
"Loss of Crew Life" [outcome,pos="-0.055,-0.536"]
"Loss of Mission Objectives" [outcome,pos="-0.034,-2.385"]
"Loss of Mission" [outcome,pos="-0.017,-3.055"]
"Loss of Vehicle" [pos="-0.016,-1.225"]
"Medical (Risk)" [latent,pos="-0.079,0.923"]
"Mild Hypoxia" [pos="-0.517,-0.974"]
"Pressure Suits" [pos="-0.254,-0.292"]
"Staged Denitrogenation" [pos="-0.782,-0.974"]
"Suit Design" [pos="-0.759,-0.018"]
"Suit Failure" [pos="-0.615,-2.120"]
"Task Performance" [outcome,pos="-0.087,-2.805"]
"Toxic Exposure" [pos="-0.432,-2.559"]
"Vehicle Design" [pos="-0.718,0.874"]
"Vehicle Failure" [pos="-0.503,-2.979"]
Depressurization [pos="-0.343,-2.979"]
Hypoxia [pos="-0.135,-0.877"]
"Altered Gravity" -> "EVA Operations"
"Altered Gravity" -> "Staged Denitrogenation"
"Atmospheric Conditions" -> "DCS, Immune, SANS, Sleep (Risks)"
"Atmospheric Conditions" -> "Detect Atmospheric Changes"
"Atmospheric Conditions" -> "Mild Hypoxia"
"Atmospheric Conditions" -> "Staged Denitrogenation"
"Breathing Masks" -> "Individual Readiness"
"Cognitive Function" -> "Individual Readiness"
"Compartment Isolation" -> "Individual Readiness"
"Crew Capability" -> "Task Performance"
"Crew Health and Performance System" -> "Environmental Monitoring Capability"
"Crew Health and Performance System" -> "Medical (Risk)"
"DCS, Immune, SANS, Sleep (Risks)" -> "Cognitive Function"
"DCS, Immune, SANS, Sleep (Risks)" -> "Medical (Risk)"
"Detect Atmospheric Changes" -> "Breathing Masks"
"Detect Atmospheric Changes" -> "Compartment Isolation"
"Detect Atmospheric Changes" -> "Pressure Suits"
"Distance from Earth" -> "Vehicle Design"
"EVA Operations" -> "Suit Failure"
"Effective Exposure Duration" -> "Mild Hypoxia"
"Environmental Monitoring Capability" -> "Detect Atmospheric Changes"
"HSIA (Risk)" -> "Suit Design"
"HSIA (Risk)" -> "Vehicle Design"
"Hostile Closed Environment" -> "Atmospheric Conditions"
"Hostile Closed Environment" -> "Vehicle Failure"
"Individual Factors" -> "Cognitive Function"
"Individual Readiness" -> "Crew Capability"
"Loss of Mission Objectives" -> "Loss of Mission"
"Loss of Vehicle" -> "Loss of Crew Life"
"Loss of Vehicle" -> "Loss of Mission Objectives"
"Medical (Risk)" -> "Loss of Crew Life"
"Mild Hypoxia" -> "Cognitive Function"
"Mild Hypoxia" -> "DCS, Immune, SANS, Sleep (Risks)"
"Mild Hypoxia" -> "Medical (Risk)"
"Pressure Suits" -> "Individual Readiness"
"Staged Denitrogenation" -> "Mild Hypoxia"
"Suit Design" -> "Staged Denitrogenation"
"Suit Design" -> "Suit Failure"
"Suit Failure" -> "Mild Hypoxia"
"Suit Failure" -> Hypoxia
"Task Performance" -> "Loss of Crew Life"
"Task Performance" -> "Loss of Mission Objectives"
"Task Performance" -> "Loss of Vehicle"

"Toxic Exposure" -> "Detect Atmospheric Changes"
"Toxic Exposure" -> Hypoxia
"Vehicle Design" -> "Atmospheric Conditions"
"Vehicle Design" -> "Crew Health and Performance System"
"Vehicle Design" -> "Vehicle Failure"
"Vehicle Failure" -> "Toxic Exposure"
"Vehicle Failure" -> Depressurization
Depressurization -> "Detect Atmospheric Changes"
Depressurization -> Hypoxia
Hypoxia -> "Individual Readiness"
Hypoxia -> "Loss of Crew Life"
Hypoxia -> "Medical (Risk)"
}

Appendix C – Risk Formatting Instructions

Immune Risk

dag {
bb="0,0,1,1"
"Altered Gravity" [exposure,pos="0.204,0.047"]
"Astronaut Selection" [pos="0.415,0.024"]
"Atmospheric Conditions" [pos="0.236,0.477"]
"Behavioral (Risk)" [latent,pos="0.631,0.131"]
"Circadian Misalignment" [pos="0.267,0.566"]
"Clinically Significant Immune Dysregulation" [pos="0.556,0.453"]
"Crew Capability" [pos="0.740,0.195"]
"Crew Health and Performance System" [pos="0.413,0.889"]
"Detect Immune Changes" [pos="0.522,0.577"]
"Detect Long Term Health Outcomes" [pos="0.890,0.861"]
"Distance from Earth" [exposure,pos="0.058,0.718"]
"Dust (Risk)" [latent,pos="0.076,0.479"]
"Flight Recertification" [outcome,pos="0.923,0.489"]
"Food and Nutrition (Risk)" [latent,pos="0.102,0.151"]
"HSIA (Risk)" [latent,pos="0.065,0.895"]
"Hostile Closed Environment" [exposure,pos="0.071,0.381"]
"Hypoxia, CO2 (Risks)" [latent,pos="0.086,0.255"]
"Individual Factors" [pos="0.417,0.191"]
"Individual Readiness" [pos="0.713,0.284"]
"Isolation and Confinement" [exposure,pos="0.073,0.578"]
"Lab Blood Monitoring" [pos="0.570,0.727"]
"Long Term Health Outcomes" [outcome,pos="0.917,0.597"]
"Loss of Crew Life" [outcome,pos="0.930,0.358"]
"Loss of Mission Objectives" [outcome,pos="0.822,0.041"]
"Loss of Mission" [outcome,pos="0.944,0.042"]
"Medical Illness" [pos="0.644,0.397"]
"Medical Prevention Capability" [pos="0.698,0.573"]
"Medical Treatment Capability" [pos="0.752,0.728"]
"Microbial Virulence Factors" [pos="0.494,0.082"]
"Microhost (Risk)" [latent,pos="0.352,0.106"]
"Oxidative Stress" [pos="0.232,0.166"]
"Persistent Subclinical Immune Dysregulation" [pos="0.417,0.329"]
"Pharm (Risk)" [latent,pos="0.588,0.887"]
"Sleep (Risk)" [latent,pos="0.150,0.673"]
"Stress Relieving VR" [pos="0.279,0.770"]
"Task Performance" [outcome,pos="0.780,0.116"]
"Team (Risk)" [latent,pos="0.695,0.050"]
"Vehicle Design" [pos="0.153,0.797"]
Evacuation [outcome,pos="0.832,0.284"]
Exercise [pos="0.417,0.520"]
Inflammation [pos="0.545,0.290"]
Microbiome [pos="0.269,0.359"]
Nutrients [pos="0.168,0.288"]
Probiotics [pos="0.355,0.524"]
Radiation [exposure,pos="0.055,0.073"]
Stress [pos="0.281,0.667"]
Supplements [pos="0.355,0.690"]
Surveillance [pos="0.731,0.880"]
"Altered Gravity" -> "Microbial Virulence Factors"
"Altered Gravity" -> "Persistent Subclinical Immune Dysregulation"
"Astronaut Selection" -> "Individual Factors"
"Atmospheric Conditions" -> "Persistent Subclinical Immune Dysregulation"
"Behavioral (Risk)" -> "Individual Readiness"
"Behavioral (Risk)" -> "Team (Risk)"
"Circadian Misalignment" -> "Persistent Subclinical Immune Dysregulation"
"Clinically Significant Immune Dysregulation" -> "Detect Immune Changes"
"Clinically Significant Immune Dysregulation" -> "Medical Illness"
"Clinically Significant Immune Dysregulation" -> Inflammation
"Crew Capability" -> "Task Performance"
"Crew Health and Performance System" -> "Lab Blood Monitoring"
"Crew Health and Performance System" -> "Medical Prevention Capability"
"Crew Health and Performance System" -> "Medical Treatment Capability"
"Crew Health and Performance System" -> "Stress Relieving VR"
"Crew Health and Performance System" -> Exercise
"Crew Health and Performance System" -> Probiotics
"Crew Health and Performance System" -> Supplements
"Detect Immune Changes" -> "Medical Prevention Capability"
"Detect Immune Changes" -> "Medical Treatment Capability"
"Distance from Earth" -> "Circadian Misalignment"
"Distance from Earth" -> "Vehicle Design"

Appendix C – Risk Formatting Instructions

"Distance from Earth" -> Nutrients
"Dust (Risk)" -> "Atmospheric Conditions"
"Food and Nutrition (Risk)" -> Nutrients
"HSIA (Risk)" -> "Crew Health and Performance System"
"HSIA (Risk)" -> "Vehicle Design"
"Hostile Closed Environment" -> "Atmospheric Conditions"
"Hostile Closed Environment" -> "Circadian Misalignment"
"Hostile Closed Environment" -> "Microbial Virulence Factors"
"Hostile Closed Environment" -> Microbiome
"Hostile Closed Environment" -> Nutrients
"Hostile Closed Environment" -> Stress
"Hypoxia, CO2 (Risks)" -> "Atmospheric Conditions"
"Hypoxia, CO2 (Risks)" -> "Oxidative Stress"
"Individual Factors" -> "Clinically Significant Immune Dysregulation"
"Individual Factors" -> "Persistent Subclinical Immune Dysregulation"
"Individual Readiness" -> "Crew Capability"
"Isolation and Confinement" -> Microbiome
"Isolation and Confinement" -> Stress
"Lab Blood Monitoring" -> "Detect Immune Changes"
"Long Term Health Outcomes" -> "Detect Long Term Health Outcomes"
"Loss of Mission Objectives" -> "Loss of Mission"
"Medical Illness" -> "Behavioral (Risk)"
"Medical Illness" -> "Flight Recertification"
"Medical Illness" -> "Individual Readiness"
"Medical Illness" -> "Long Term Health Outcomes"
"Medical Illness" -> "Loss of Crew Life"
"Medical Illness" -> Evacuation
"Medical Prevention Capability" -> "Medical Illness"
"Medical Treatment Capability" -> "Individual Readiness"
"Medical Treatment Capability" -> "Loss of Crew Life"
"Medical Treatment Capability" -> Evacuation
"Microbial Virulence Factors" -> "Medical Illness"
"Microhost (Risk)" -> "Microbial Virulence Factors"
"Microhost (Risk)" -> Microbiome
"Oxidative Stress" -> "Persistent Subclinical Immune Dysregulation"
"Oxidative Stress" -> Inflammation
"Persistent Subclinical Immune Dysregulation" -> "Clinically Significant Immune Dysregulation"
"Persistent Subclinical Immune Dysregulation" -> "Detect Immune Changes"
"Persistent Subclinical Immune Dysregulation" -> Inflammation
"Pharm (Risk)" -> "Medical Prevention Capability"
"Pharm (Risk)" -> "Medical Treatment Capability"
"Pharm (Risk)" -> Probiotics
"Pharm (Risk)" -> Supplements
"Sleep (Risk)" -> "Circadian Misalignment"
"Sleep (Risk)" -> Stress
"Stress Relieving VR" -> Stress
"Task Performance" -> "Loss of Mission Objectives"
"Team (Risk)" -> "Crew Capability"
"Vehicle Design" -> "Crew Health and Performance System"
Evacuation -> "Loss of Crew Life"
Evacuation -> "Loss of Mission Objectives"
Exercise -> "Persistent Subclinical Immune Dysregulation"
Inflammation -> "Medical Illness"
Microbiome -> "Oxidative Stress"
Microbiome -> "Persistent Subclinical Immune Dysregulation"
Nutrients -> "Oxidative Stress"
Nutrients -> "Persistent Subclinical Immune Dysregulation"
Probiotics -> Nutrients
Radiation -> "Oxidative Stress"
Stress -> "Persistent Subclinical Immune Dysregulation"
Supplements -> Nutrients
Surveillance -> "Detect Long Term Health Outcomes"
}

Appendix C – Risk Formatting Instructions

Medical Risk

```
dag {
bb="-0.5,-0.5,0.5,0.5"
"Altered Gravity" [exposure,pos="-0.447,-0.142"]
"Astronaut Selection" [pos="-0.440,-0.041"]
"Behavioral, Team, Crew Egress, Aerobic, Muscle (Risks)" [latent,pos="0.158,-0.475"]
"Communication Factors" [pos="-0.265,0.337"]
"Crew Capability" [pos="0.224,-0.331"]
"Crew Health and Performance System" [pos="-0.254,0.236"]
"Data Accessibility" [pos="0.060,-0.144"]
"Data Architecture" [pos="-0.078,0.268"]
"Detect Diagnosis" [pos="0.128,-0.221"]
"Detect Environmental Conditions" [pos="-0.007,-0.336"]
"Detect Long Term Health Outcomes" [pos="0.293,0.331"]
"Detect Physiologic Changes" [pos="0.009,-0.059"]
"Distance from Earth" [exposure,pos="-0.428,0.183"]
"EVA (Risk)" [latent,pos="-0.276,-0.285"]
"Environmental Conditions" [pos="-0.315,-0.470"]
"Environmental Injury" [pos="-0.136,-0.295"]
"Environmental Monitoring Capability" [pos="-0.074,-0.441"]
"Environmental Risks" [latent,pos="-0.233,-0.371"]
"Flight Recertification" [outcome,pos="0.437,0.189"]
"Ground Support" [pos="0.046,0.347"]
"HSIA (Risk)" [latent,pos="-0.443,0.359"]
"Hostile Closed Environment" [exposure,pos="-0.418,-0.305"]
"Individual Factors" [pos="-0.312,-0.042"]
"Individual Readiness" [pos="0.162,-0.289"]
"Isolation and Confinement" [exposure,pos="-0.422,0.077"]
"Long Term Health Outcomes" [outcome,pos="0.423,0.400"]
"Loss of Crew Life" [outcome,pos="0.434,-0.062"]
"Loss of Mission Objectives" [outcome,pos="0.384,-0.426"]
"Loss of Mission" [outcome,pos="0.445,-0.468"]
"Medical Diagnostic Capability" [pos="0.098,0.025"]
"Medical Illness" [pos="-0.143,-0.033"]
"Medical Prevention Capability" [pos="-0.157,0.128"]
"Medical Treatment Capability" [pos="0.314,-0.143"]
"On-Board Expertise" [pos="0.315,0.026"]
"Other Risks" [latent,pos="-0.316,-0.188"]
"Pharm (Risk)" [latent,pos="0.135,0.227"]
"Physiologic Monitoring Capability" [pos="-0.053,0.063"]
"Resource Availability" [pos="0.107,0.410"]
"Suit Design" [pos="-0.217,0.065"]
"Task Performance" [pos="0.294,-0.379"]
"Traumatic Injury" [pos="-0.124,-0.171"]
"Treatment Decision" [pos="0.208,-0.170"]
"Vehicle Design" [pos="-0.300,0.075"]
Evacuation [pos="0.406,-0.202"]
Radiation [exposure,pos="-0.450,-0.453"]
Resupply [pos="-0.334,0.405"]
Surveillance [pos="0.213,0.411"]
Training [pos="0.156,0.102"]
"Altered Gravity" -> "Environmental Conditions"
"Altered Gravity" -> "Traumatic Injury"
"Astronaut Selection" -> "Individual Factors"
"Behavioral, Team, Crew Egress, Aerobic, Muscle (Risks)" -> "Individual Readiness"
"Communication Factors" -> "Ground Support"
"Crew Capability" -> "Task Performance"
"Crew Health and Performance System" -> "Data Architecture"
"Crew Health and Performance System" -> "Medical Diagnostic Capability"
"Crew Health and Performance System" -> "Medical Prevention Capability"
"Crew Health and Performance System" -> "Medical Treatment Capability"
"Crew Health and Performance System" -> Training
"Data Accessibility" -> "Medical Diagnostic Capability"
"Data Architecture" -> "Environmental Monitoring Capability"
"Data Architecture" -> "Ground Support"
"Data Architecture" -> "Physiologic Monitoring Capability"
"Data Architecture" -> Training
"Detect Diagnosis" -> "Treatment Decision"
"Detect Environmental Conditions" -> "Data Accessibility"
"Detect Environmental Conditions" -> "Detect Long Term Health Outcomes"
"Detect Environmental Conditions" -> "Long Term Health Outcomes"
```

"Detect Physiologic Changes" -> "Data Accessibility"
"Distance from Earth" -> "Communication Factors"
"Distance from Earth" -> "Vehicle Design"
"Distance from Earth" -> Resupply
"EVA (Risk)" -> "Traumatic Injury"
"Environmental Conditions" -> "Detect Environmental Conditions"
"Environmental Conditions" -> "Environmental Risks"
"Environmental Injury" -> "Behavioral, Team, Crew Egress, Aerobic, Muscle (Risks)"
"Environmental Injury" -> "Flight Recertification"
"Environmental Injury" -> "Individual Readiness"
"Environmental Injury" -> "Long Term Health Outcomes"
"Environmental Injury" -> "Loss of Crew Life"
"Environmental Injury" -> Evacuation
"Environmental Monitoring Capability" -> "Detect Environmental Conditions"
"Environmental Risks" -> "Environmental Injury"
"Ground Support" -> "Medical Diagnostic Capability"
"Ground Support" -> "Treatment Decision"
"Ground Support" -> Training
"HSIA (Risk)" -> "Crew Health and Performance System"
"HSIA (Risk)" -> "Suit Design"
"HSIA (Risk)" -> "Vehicle Design"
"Hostile Closed Environment" -> "Environmental Conditions"
"Hostile Closed Environment" -> "Traumatic Injury"
"Individual Factors" -> "Environmental Injury"
"Individual Factors" -> "Medical Illness"
"Individual Readiness" -> "Crew Capability"
"Isolation and Confinement" -> "Medical Illness"
"Long Term Health Outcomes" -> "Detect Long Term Health Outcomes"
"Loss of Mission Objectives" -> "Loss of Mission"
"Medical Diagnostic Capability" -> "Detect Diagnosis"
"Medical Illness" -> "Behavioral, Team, Crew Egress, Aerobic, Muscle (Risks)"
"Medical Illness" -> "Flight Recertification"
"Medical Illness" -> "Individual Readiness"
"Medical Illness" -> "Long Term Health Outcomes"
"Medical Illness" -> "Loss of Crew Life"
"Medical Illness" -> Evacuation
"Medical Prevention Capability" -> "Medical Illness"
"Medical Treatment Capability" -> "Behavioral, Team, Crew Egress, Aerobic, Muscle (Risks)"
"Medical Treatment Capability" -> "Flight Recertification"
"Medical Treatment Capability" -> "Individual Readiness"
"Medical Treatment Capability" -> "Long Term Health Outcomes"
"Medical Treatment Capability" -> "Loss of Crew Life"
"Medical Treatment Capability" -> "Treatment Decision"
"Medical Treatment Capability" -> Evacuation
"On-Board Expertise" -> "Medical Diagnostic Capability"
"On-Board Expertise" -> "Medical Treatment Capability"
"Other Risks" -> "Environmental Injury"
"Other Risks" -> "Medical Illness"
"Other Risks" -> "Traumatic Injury"
"Pharm (Risk)" -> "Medical Prevention Capability"
"Pharm (Risk)" -> "Medical Treatment Capability"
"Physiologic Monitoring Capability" -> "Detect Physiologic Changes"
"Resource Availability" -> "Medical Treatment Capability"
"Resource Availability" -> "Pharm (Risk)"
"Suit Design" -> "Environmental Injury"
"Suit Design" -> "Traumatic Injury"
"Task Performance" -> "Loss of Mission Objectives"
"Traumatic Injury" -> "Behavioral, Team, Crew Egress, Aerobic, Muscle (Risks)"
"Traumatic Injury" -> "Detect Diagnosis"
"Traumatic Injury" -> "Detect Physiologic Changes"
"Traumatic Injury" -> "Flight Recertification"
"Traumatic Injury" -> "Individual Readiness"
"Traumatic Injury" -> "Long Term Health Outcomes"
"Traumatic Injury" -> "Loss of Crew Life"
"Traumatic Injury" -> "Medical Treatment Capability"
"Traumatic Injury" -> Evacuation
"Treatment Decision" -> "Individual Readiness"
"Vehicle Design" -> "Crew Health and Performance System"
"Vehicle Design" -> "Traumatic Injury"
Evacuation -> "Loss of Crew Life"

Evacuation -> "Loss of Mission Objectives"
Radiation -> "Environmental Conditions"
Resupply -> "Resource Availability"
Surveillance -> "Detect Long Term Health Outcomes"
Training -> "Medical Diagnostic Capability"
Training -> "Medical Treatment Capability"
}

Appendix C – Risk Formatting Instructions

Microhost Risk

```
dag {
bb="0,0,1,1"
"Air Contamination" [pos="0.292,0.513"]
"Altered Gravity" [exposure,pos="0.096,0.234"]
"Astronaut Selection" [pos="0.470,0.038"]
"Behavioral (Risk)" [latent,pos="0.648,0.152"]
"Crew Capability" [pos="0.772,0.204"]
"Crew Health and Performance System"
[pos="0.450,0.910"]
"Detect Contamination" [pos="0.628,0.598"]
"Detect Long Term Health Outcomes"
[pos="0.833,0.902"]
"Distance from Earth"
[exposure,pos="0.077,0.682"]
"Environmental Monitoring Capability"
[pos="0.624,0.702"]
"Food Contamination" [pos="0.295,0.693"]
"Food and Nutrition (Risk)"
[latent,pos="0.171,0.640"]
"HSIA (Risk)" [latent,pos="0.229,0.913"]
"Hostile Closed Environment"
[exposure,pos="0.092,0.484"]
"Immune (Risk)" [latent,pos="0.479,0.224"]
"Individual Factors" [pos="0.470,0.135"]
"Individual Readiness" [pos="0.698,0.263"]
"Intervention Source Control" [pos="0.629,0.497"]
"Isolation and Confinement"
[exposure,pos="0.097,0.105"]
"Long Term Health Outcomes"
[outcome,pos="0.915,0.713"]
"Loss of Crew Life" [outcome,pos="0.919,0.445"]
"Loss of Mission Objectives"
[outcome,pos="0.865,0.060"]
"Loss of Mission" [outcome,pos="0.943,0.025"]
"Medical Prevention Capability"
[pos="0.459,0.815"]
"Medical Treatment Capability"
[pos="0.743,0.796"]
"Microbial Resistance Factors"
[pos="0.327,0.121"]
"Microbial Virulence Factors" [pos="0.289,0.334"]
"Pharm (Risk)" [latent,pos="0.197,0.748"]
"Pharmaceutical Contamination"
[pos="0.299,0.783"]
"Preventive Source Control" [pos="0.438,0.708"]
"Surface Contamination" [pos="0.289,0.424"]
"Task Performance" [outcome,pos="0.807,0.142"]
"Team (Risk)" [latent,pos="0.722,0.096"]
"Vehicle Design" [pos="0.130,0.817"]
"Water Contamination" [pos="0.292,0.602"]
Evacuation [outcome,pos="0.835,0.330"]
Hygiene [pos="0.492,0.643"]
Infection [pos="0.629,0.389"]
Microbiome [pos="0.400,0.255"]
Sepsis [pos="0.748,0.389"]
Surveillance [pos="0.691,0.906"]
"Air Contamination" -> "Detect Contamination"
"Air Contamination" -> Infection
"Altered Gravity" -> "Microbial Virulence Factors"
"Astronaut Selection" -> "Individual Factors"
"Behavioral (Risk)" -> "Individual Readiness"
"Behavioral (Risk)" -> "Team (Risk)"
"Crew Capability" -> "Task Performance"
"Crew Health and Performance System" ->
"Environmental Monitoring Capability"
"Crew Health and Performance System" ->
"Intervention Source Control"
"Crew Health and Performance System" ->
"Medical Prevention Capability"
"Crew Health and Performance System" ->
"Medical Treatment Capability"
"Detect Contamination" -> "Intervention Source
Control"
"Distance from Earth" -> "Vehicle Design"
"Environmental Monitoring Capability" -> "Detect
Contamination"
"Food Contamination" -> Infection
"Food and Nutrition (Risk)" -> "Food
Contamination"
"HSIA (Risk)" -> "Crew Health and Performance
System"
"HSIA (Risk)" -> "Vehicle Design"
"Hostile Closed Environment" -> "Air
Contamination"
"Hostile Closed Environment" -> "Food
Contamination"
"Hostile Closed Environment" -> "Microbial
Virulence Factors"
"Hostile Closed Environment" -> "Pharmaceutical
Contamination"
"Hostile Closed Environment" -> "Surface
Contamination"
"Hostile Closed Environment" -> "Water
Contamination"
"Immune (Risk)" -> Infection
"Individual Factors" -> Infection
"Individual Factors" -> Microbiome
"Individual Readiness" -> "Crew Capability"
"Intervention Source Control" -> Infection
"Isolation and Confinement" -> Microbiome
```

"Long Term Health Outcomes" -> "Detect Long Term Health Outcomes"
"Loss of Mission Objectives" -> "Loss of Mission"
"Medical Prevention Capability" -> "Preventive Source Control"
"Medical Prevention Capability" -> Hygiene
"Medical Treatment Capability" -> "Individual Readiness"
"Medical Treatment Capability" -> "Long Term Health Outcomes"
"Medical Treatment Capability" -> "Loss of Crew Life"
"Medical Treatment Capability" -> Evacuation
"Medical Treatment Capability" -> Sepsis
"Microbial Resistance Factors" -> Microbiome
"Microbial Virulence Factors" -> Infection
"Microbial Virulence Factors" -> Microbiome
"Pharm (Risk)" -> "Pharmaceutical Contamination"
"Pharmaceutical Contamination" -> Infection
"Preventive Source Control" -> "Air Contamination"
"Preventive Source Control" -> "Food Contamination"
"Preventive Source Control" -> "Surface Contamination"
"Preventive Source Control" -> "Water Contamination"
"Surface Contamination" -> "Detect Contamination"
"Surface Contamination" -> Infection
"Task Performance" -> "Loss of Mission Objectives"
"Team (Risk)" -> "Crew Capability"
"Vehicle Design" -> "Crew Health and Performance System"
"Water Contamination" -> "Detect Contamination"
"Water Contamination" -> Infection
Evacuation -> "Loss of Crew Life"
Evacuation -> "Loss of Mission Objectives"
Hygiene -> Infection
Infection -> "Behavioral (Risk)"
Infection -> "Individual Readiness"
Infection -> "Long Term Health Outcomes"
Infection -> Sepsis
Microbiome -> "Immune (Risk)"
Microbiome -> Infection
Sepsis -> "Individual Readiness"
Sepsis -> "Long Term Health Outcomes"
Sepsis -> "Loss of Crew Life"
Sepsis -> Evacuation
Surveillance -> "Detect Long Term Health Outcomes"
}

Appendix C – Risk Formatting Instructions

Muscle and Aerobic Risks

```
dag {
"Aerobic Exercise" [pos="-1.294,-1.238"]
"Aerobic Fitness" [pos="-0.971,-1.286"]
"Altered Gravity" [exposure,pos="-1.668,-1.069"]
"Ambient CO2 Level" [pos="-1.492,-1.434"]
"Astronaut Selection" [pos="-1.085,-0.785"]
"Cardiovascular (Risk)" [latent,pos="-1.114,-1.243"]
"Crew Capability" [pos="-0.841,-1.297"]
"Crew Health and Performance System" [pos="-1.093,-1.591"]
"Distance from Earth" [exposure,pos="-1.669,-1.586"]
"ECLS System" [pos="-1.678,-1.350"]
"Effective Gravity Level" [pos="-1.593,-1.010"]
"Effective Mission Duration" [pos="-1.603,-1.132"]
"Endocrine Factors" [pos="-1.283,-0.811"]
"Exercise Hardware" [pos="-1.174,-1.421"]
"Exercise Prescription" [pos="-1.342,-1.360"]
"Food and Nutrition (Risk)" [latent,pos="-1.489,-1.183"]
"HSIA (Risk)" [latent,pos="-1.576,-1.683"]
"Individual Factors" [pos="-1.162,-0.861"]
"Individual Readiness" [pos="-0.875,-1.121"]
"Isolation and Confinement" [exposure,pos="-1.656,-0.874"]
"Loss of Crew Life" [outcome,pos="-0.676,-1.204"]
"Loss of Mission Objectives" [outcome,pos="-0.707,-1.515"]
"Loss of Mission" [outcome,pos="-0.668,-1.650"]
"Muscle Performance" [pos="-0.965,-0.980"]
"Muscle Physiologic Changes" [pos="-1.120,-1.015"]
"Musculoskeletal Loads" [pos="-1.372,-0.907"]
"Pharm (Risk)" [latent,pos="-1.014,-0.882"]
"Resistive Exercise" [pos="-1.267,-1.022"]
"Sensorimotor (Risk)" [latent,pos="-0.904,-0.876"]
"Sleep (Risk)" [latent,pos="-1.564,-0.773"]
"Task Performance" [outcome,pos="-0.773,-1.414"]
"Vehicle Design" [pos="-1.500,-1.583"]
"Vibration Isolation System" [pos="-1.300,-1.539"]
Fatigue [pos="-1.462,-0.773"]
Humidity [pos="-1.528,-1.350"]
Motivation [pos="-1.413,-1.036"]
Scheduling [pos="-1.425,-1.517"]
Temperature [pos="-1.547,-1.259"]
"Aerobic Exercise" -> "Cardiovascular (Risk)"
"Aerobic Exercise" -> "Endocrine Factors"
"Aerobic Exercise" -> "Muscle Physiologic Changes"
"Aerobic Fitness" -> "Individual Readiness"
"Altered Gravity" -> "Effective Gravity Level"
"Ambient CO2 Level" -> "Exercise Prescription"
"Astronaut Selection" -> "Individual Factors"
"Cardiovascular (Risk)" -> "Aerobic Fitness"
"Crew Capability" -> "Task Performance"
"Crew Health and Performance System" -> "Exercise Hardware"
"Distance from Earth" -> "Effective Mission Duration"
"Distance from Earth" -> "Vehicle Design"
"ECLS System" -> "Ambient CO2 Level"
"ECLS System" -> Humidity
"ECLS System" -> Temperature
"Effective Gravity Level" -> "Musculoskeletal Loads"
"Effective Mission Duration" -> "Muscle Physiologic Changes"
"Effective Mission Duration" -> Motivation
"Endocrine Factors" -> "Muscle Physiologic Changes"
"Exercise Hardware" -> "Aerobic Exercise"
"Exercise Hardware" -> "Exercise Prescription"
"Exercise Hardware" -> "Resistive Exercise"
"Exercise Hardware" -> "Vibration Isolation System"
"Exercise Prescription" -> "Aerobic Exercise"
"Exercise Prescription" -> "Resistive Exercise"
"Exercise Prescription" -> Motivation
"Food and Nutrition (Risk)" -> "Aerobic Exercise"
"Food and Nutrition (Risk)" -> "Muscle Physiologic Changes"
"Food and Nutrition (Risk)" -> "Resistive Exercise"
"Food and Nutrition (Risk)" -> Fatigue
"HSIA (Risk)" -> "Crew Health and Performance System"
"HSIA (Risk)" -> "ECLS System"
"HSIA (Risk)" -> "Vehicle Design"
"HSIA (Risk)" -> "Vibration Isolation System"
"HSIA (Risk)" -> Motivation
"Individual Factors" -> "Endocrine Factors"
"Individual Factors" -> "Muscle Physiologic Changes"
"Individual Factors" -> Motivation
"Individual Readiness" -> "Crew Capability"
"Isolation and Confinement" -> "Endocrine Factors"
"Isolation and Confinement" -> Motivation
```

Appendix C – Risk Formatting Instructions

"Loss of Mission Objectives" -> "Loss of Mission"
"Muscle Performance" -> "Individual Readiness"
"Muscle Physiologic Changes" -> "Aerobic Fitness"
"Muscle Physiologic Changes" -> "Cardiovascular (Risk)"
"Muscle Physiologic Changes" -> "Muscle Performance"
"Musculoskeletal Loads" -> "Muscle Physiologic Changes"
"Pharm (Risk)" -> "Muscle Physiologic Changes"
"Resistive Exercise" -> "Cardiovascular (Risk)"
"Resistive Exercise" -> "Endocrine Factors"
"Resistive Exercise" -> "Muscle Physiologic Changes"
"Sensorimotor (Risk)" -> "Muscle Performance"
"Sleep (Risk)" -> Fatigue
"Task Performance" -> "Loss of Crew Life"
"Task Performance" -> "Loss of Mission Objectives"
"Vehicle Design" -> "Crew Health and Performance System"
"Vehicle Design" -> "ECLS System"
"Vehicle Design" -> "Vibration Isolation System"
"Vibration Isolation System" -> "Exercise Prescription"
Fatigue -> "Endocrine Factors"
Fatigue -> Motivation
Humidity -> "Exercise Prescription"
Motivation -> "Aerobic Exercise"
Motivation -> "Resistive Exercise"
Scheduling -> "Exercise Prescription"
Temperature -> "Exercise Prescription"
}

Appendix C – Risk Formatting Instructions

Non-Ionizing Radiation Risk

```
dag {
bb="-0.5,-0.5,0.5,0.5"
"Crew Capability" [pos="0.110,-0.365"]
"Crew Health and Performance System" [pos="-0.061,0.335"]
"Detect Long Term Health Outcomes" [pos="0.356,0.406"]
"Distance from Earth" [exposure,pos="-0.436,0.285"]
"Eye Injury" [pos="-0.147,-0.340"]
"Flight Recertification" [outcome,pos="0.410,0.130"]
"HSIA (Risk)" [latent,pos="-0.256,0.398"]
"Helmet/Protective Visors" [pos="-0.227,0.080"]
"Individual Readiness" [pos="0.012,-0.332"]
"Long Term Health Outcomes" [outcome,pos="0.411,0.274"]
"Loss of Mission Objectives" [outcome,pos="0.330,-0.427"]
"Loss of Mission" [outcome,pos="0.449,-0.465"]
"Medical Prevention Capability" [pos="0.008,0.195"]
"Medical Treatment Capability" [pos="0.193,0.252"]
"Protective Glasses" [pos="-0.026,-0.002"]
"Protective Windows and Filters" [pos="-0.350,-0.026"]
"Skin Injury" [pos="-0.146,-0.175"]
"Suit Design" [pos="-0.226,0.226"]
"Task Performance" [outcome,pos="0.202,-0.389"]
"Vehicle Design" [pos="-0.310,0.285"]
Laser [pos="-0.353,-0.340"]
Radiation [exposure,pos="-0.438,-0.270"]
Sunlight [pos="-0.353,-0.174"]
Surveillance [pos="0.212,0.411"]
"Crew Capability" -> "Task Performance"
"Crew Health and Performance System" -> "Medical Prevention Capability"
"Crew Health and Performance System" -> "Medical Treatment Capability"
"Distance from Earth" -> "Vehicle Design"
"Eye Injury" -> "Flight Recertification"
"Eye Injury" -> "Individual Readiness"
"Eye Injury" -> "Long Term Health Outcomes"
"HSIA (Risk)" -> "Crew Health and Performance System"
"HSIA (Risk)" -> "Suit Design"
"HSIA (Risk)" -> "Vehicle Design"
"Helmet/Protective Visors" -> "Eye Injury"
"Helmet/Protective Visors" -> "Skin Injury"
"Individual Readiness" -> "Crew Capability"
"Long Term Health Outcomes" -> "Detect Long Term Health Outcomes"
"Loss of Mission Objectives" -> "Loss of Mission"
"Medical Prevention Capability" -> "Protective Glasses"
"Medical Treatment Capability" -> "Individual Readiness"
"Protective Glasses" -> "Eye Injury"
"Protective Windows and Filters" -> "Eye Injury"
"Protective Windows and Filters" -> "Skin Injury"
"Skin Injury" -> "Individual Readiness"
"Skin Injury" -> "Long Term Health Outcomes"
"Suit Design" -> "Helmet/Protective Visors"
"Task Performance" -> "Loss of Mission Objectives"
"Vehicle Design" -> "Crew Health and Performance System"
"Vehicle Design" -> "Protective Windows and Filters"
Laser -> "Eye Injury"
Laser -> "Skin Injury"
Radiation -> Laser
Radiation -> Sunlight
Sunlight -> "Eye Injury"
Sunlight -> "Skin Injury"
Surveillance -> "Detect Long Term Health Outcomes"
}
```

Appendix C – Risk Formatting Instructions

Pharm Risk

dag {
"Altered Gravity" [exposure,pos="-1.648,-0.760"]
"Antimicrobial Resistance" [pos="-1.347,-0.871"]
"Behavioral (Risk)" [latent,pos="-1.130,-1.660"]
"Bone Fracture (Risk)" [latent,pos="-1.135,-1.154"]
"Cardiovascular (Risk)" [latent,pos="-0.948,-0.970"]
"Crew Capability" [pos="-0.840,-1.599"]
"Crew Health and Performance System" [pos="-1.444,-1.596"]
"DCS (Risk)" [latent,pos="-0.900,-1.070"]
"Detect Long Term Health Outcomes" [pos="-0.728,-0.812"]
"Distance from Earth" [exposure,pos="-1.646,-1.900"]
"EVA (Risk)" [latent,pos="-0.831,-1.128"]
"Effective Mission Duration" [pos="-1.630,-1.359"]
"Electric Shock (Risk)" [latent,pos="-0.846,-1.017"]
"Fluid Shifts" [pos="-1.573,-0.842"]
"Food and Nutrition (Risk)" [latent,pos="-1.041,-0.846"]
"HSIA (Risk)" [latent,pos="-1.484,-1.783"]
"Hostile Closed Environment" [exposure,pos="-1.624,-1.212"]
"Immune (Risk)" [latent,pos="-1.135,-1.055"]
"In-Mission Shelf Life" [pos="-1.486,-1.129"]
"Individual Factors" [pos="-1.407,-0.757"]
"Individual Readiness" [pos="-0.868,-1.452"]
"Long Term Health Outcomes" [outcome,pos="-0.716,-0.995"]
"Loss of Crew Life" [outcome,pos="-0.700,-1.265"]
"Loss of Mission Objectives" [outcome,pos="-0.753,-1.838"]
"Loss of Mission" [outcome,pos="-0.708,-1.936"]
"Manufacturer Shelf Life" [pos="-1.536,-1.479"]
"Medical (Risk)" [latent,pos="-0.893,-1.290"]
"Medical Diagnostic Capability" [pos="-1.308,-0.760"]
"Medical Prevention Capability" [pos="-1.298,-0.986"]
"Medical Treatment Capability" [pos="-1.116,-1.802"]
"Medication Compatibility" [pos="-1.301,-1.685"]
"Microhost (Risk)" [latent,pos="-1.137,-0.950"]
"Pharmaceutical Effectiveness" [pos="-1.344,-1.197"]
"Pharmaceutical Storage Conditions" [pos="-1.444,-1.376"]
"Pharmaceutical Toxicity" [pos="-1.306,-1.441"]
"Radiation Carcinogenesis (Risk)" [latent,pos="-1.015,-0.719"]
"Renal Stone (Risk)" [latent,pos="-1.132,-1.352"]
"Resource Availability" [pos="-1.401,-1.893"]
"SANS (Risk)" [latent,pos="-1.179,-0.715"]
"Side Effects" [pos="-0.992,-1.743"]
"Sleep (Risk)" [latent,pos="-1.130,-1.558"]
"Suit Damage" [pos="-1.037,-1.874"]
"Suit Design" [pos="-1.268,-1.860"]
"Task Performance" [outcome,pos="-0.814,-1.732"]
"Urinary Retention (Risk)" [latent,pos="-1.135,-1.250"]
"VTE (Concern)" [latent,pos="-1.133,-1.456"]
"Vehicle Design" [pos="-1.566,-1.683"]
Absorption [pos="-1.511,-1.027"]
Distribution [pos="-1.489,-0.871"]
Elimination [pos="-1.504,-0.963"]
Evacuation [outcome,pos="-0.736,-1.513"]
Exercise [pos="-1.538,-0.741"]
Hydration [pos="-1.588,-1.004"]
Metabolism [pos="-1.468,-0.798"]
Pharmacodynamics [pos="-1.391,-1.067"]
Pharmacogenomics [pos="-1.400,-0.939"]
Pharmacokinetics [pos="-1.452,-1.024"]
Radiation [exposure,pos="-1.667,-1.072"]
Resupply [pos="-1.524,-1.889"]
Surveillance [pos="-0.860,-0.715"]
"Altered Gravity" -> "Fluid Shifts"
"Antimicrobial Resistance" -> "Pharmaceutical Effectiveness"
"Behavioral (Risk)" -> "Medical (Risk)"
"Bone Fracture (Risk)" -> "Medical (Risk)"
"Cardiovascular (Risk)" -> "Medical (Risk)"
"Crew Capability" -> "Task Performance"
"Crew Health and Performance System" -> "Medication Compatibility"
"Crew Health and Performance System" -> "Pharmaceutical Storage Conditions"
"Crew Health and Performance System" -> "Suit Design"
"DCS (Risk)" -> "Medical (Risk)"
"Distance from Earth" -> "Effective Mission Duration"
"Distance from Earth" -> "Vehicle Design"
"Distance from Earth" -> Resupply
"EVA (Risk)" -> "Medical (Risk)"
"Effective Mission Duration" -> "In-Mission Shelf Life"
"Effective Mission Duration" -> Absorption

"Electric Shock (Risk)" -> "Medical (Risk)"
"Fluid Shifts" -> Absorption
"Fluid Shifts" -> Distribution
"Fluid Shifts" -> Elimination
"Fluid Shifts" -> Metabolism
"Food and Nutrition (Risk)" -> "Medical (Risk)"
"HSIA (Risk)" -> "Crew Health and Performance System"
"HSIA (Risk)" -> "Medication Compatibility"
"HSIA (Risk)" -> "Suit Design"
"HSIA (Risk)" -> "Vehicle Design"
"Hostile Closed Environment" -> "Pharmaceutical Storage Conditions"
"Immune (Risk)" -> "Medical (Risk)"
"In-Mission Shelf Life" -> "Pharmaceutical Effectiveness"
"In-Mission Shelf Life" -> "Pharmaceutical Toxicity"
"Individual Factors" -> Absorption
"Individual Factors" -> Distribution
"Individual Factors" -> Elimination
"Individual Factors" -> Metabolism
"Individual Factors" -> Pharmacogenomics
"Individual Readiness" -> "Crew Capability"
"Long Term Health Outcomes" -> "Detect Long Term Health Outcomes"
"Loss of Mission Objectives" -> "Loss of Mission"
"Manufacturer Shelf Life" -> "In-Mission Shelf Life"
"Manufacturer Shelf Life" -> "Pharmaceutical Storage Conditions"
"Medical (Risk)" -> "Individual Readiness"
"Medical (Risk)" -> "Long Term Health Outcomes"
"Medical (Risk)" -> "Loss of Crew Life"
"Medical (Risk)" -> Evacuation
"Medical Diagnostic Capability" -> "SANS (Risk)"
"Medical Prevention Capability" -> "Behavioral (Risk)"
"Medical Prevention Capability" -> "Bone Fracture (Risk)"
"Medical Prevention Capability" -> "Food and Nutrition (Risk)"
"Medical Prevention Capability" -> "Immune (Risk)"
"Medical Prevention Capability" -> "Microhost (Risk)"
"Medical Prevention Capability" -> "Radiation Carcinogenesis (Risk)"
"Medical Prevention Capability" -> "Renal Stone (Risk)"
"Medical Prevention Capability" -> "SANS (Risk)"
"Medical Prevention Capability" -> "Side Effects"
"Medical Prevention Capability" -> "Sleep (Risk)"
"Medical Prevention Capability" -> "Urinary Retention (Risk)"
"Medical Prevention Capability" -> "VTE (Concern)"
"Medical Treatment Capability" -> "Food and Nutrition (Risk)"
"Medical Treatment Capability" -> "Medical (Risk)"
"Medical Treatment Capability" -> "Side Effects"
"Medication Compatibility" -> "Medical Treatment Capability"
"Medication Compatibility" -> "Suit Design"
"Microhost (Risk)" -> "Medical (Risk)"
"Pharmaceutical Effectiveness" -> "Medical Diagnostic Capability"
"Pharmaceutical Effectiveness" -> "Medical Prevention Capability"
"Pharmaceutical Effectiveness" -> "Medical Treatment Capability"
"Pharmaceutical Effectiveness" -> "Pharmaceutical Toxicity"
"Pharmaceutical Storage Conditions" -> "In-Mission Shelf Life"
"Pharmaceutical Toxicity" -> "Medical (Risk)"
"Radiation Carcinogenesis (Risk)" -> "Long Term Health Outcomes"
"Renal Stone (Risk)" -> "Medical (Risk)"
"Resource Availability" -> "Crew Health and Performance System"
"SANS (Risk)" -> "Medical (Risk)"
"Side Effects" -> "Individual Readiness"
"Side Effects" -> "Medical (Risk)"
"Sleep (Risk)" -> "Medical (Risk)"
"Suit Damage" -> "Loss of Mission Objectives"
"Suit Design" -> "Medical Treatment Capability"
"Suit Design" -> "Suit Damage"
"Task Performance" -> "Loss of Mission Objectives"
"Urinary Retention (Risk)" -> "Medical (Risk)"
"VTE (Concern)" -> "Medical (Risk)"
"Vehicle Design" -> "Crew Health and Performance System"
Absorption -> "Pharmaceutical Effectiveness"
Absorption -> Pharmacokinetics
Distribution -> Pharmacokinetics
Elimination -> Pharmacokinetics
Evacuation -> "Loss of Crew Life"
Evacuation -> "Loss of Mission Objectives"
Exercise -> Metabolism
Hydration -> Absorption

Hydration -> Distribution
Metabolism -> Pharmacokinetics
Pharmacodynamics -> "Pharmaceutical Effectiveness"
Pharmacogenomics -> Metabolism
Pharmacogenomics -> Pharmacodynamics
Pharmacokinetics -> Pharmacodynamics
Radiation -> "In-Mission Shelf Life"
Resupply -> "Resource Availability"
Surveillance -> "Detect Long Term Health Outcomes"
}

Appendix C – Risk Formatting Instructions

Carcinogenesis Risk

```
dag {
bb="-0.5,-0.5,0.5,0.5"
"Astronaut Selection" [pos="0.179,-0.433"]
"Biologic Response" [pos="0.161,-0.201"]
"Biomedical Exposures" [pos="0.101,-0.394"]
"Cancer Model" [pos="-0.088,-0.163"]
"Cancer Treatment" [pos="0.438,-0.228"]
"Charged Particles" [pos="-0.268,-0.325"]
"Crew Health and Performance System" [pos="-0.124,0.284"]
"Detect Long Term Health Outcomes" [pos="0.373,-0.097"]
"Detect Radiation" [pos="-0.206,-0.160"]
"Distance from Earth" [exposure,pos="-0.418,0.288"]
"Effective Mission Duration" [pos="-0.112,0.177"]
"Estimated Career Dose" [pos="0.219,0.178"]
"Estimated Dose Rate" [pos="-0.006,-0.337"]
"Estimated Mission Radiation Dose" [pos="-0.007,-0.005"]
"Extraterrestrial Surface" [pos="-0.417,0.008"]
"Flight Recertification" [outcome,pos="0.413,0.319"]
"Galactic Cosmic Radiation" [pos="-0.372,-0.286"]
"Gamma Rays" [pos="-0.344,-0.198"]
"HSIA (Risk)" [latent,pos="-0.203,0.396"]
"Intervention Measures" [pos="-0.106,-0.437"]
"Long Term Health Outcomes" [outcome,pos="0.413,-0.416"]
"Medical Prevention Capability" [pos="0.119,0.288"]
"Modifiable Individual Factors" [pos="0.227,-0.342"]
"Non-Modifiable Individual Factors" [pos="0.240,-0.031"]
"Nuclear Technology" [pos="-0.413,0.185"]
"Pharm (Risk)" [latent,pos="0.039,0.395"]
"Prior Mission Exposures" [pos="0.048,0.177"]
"Radiation Monitors" [pos="-0.207,0.081"]
"Solar Cycle" [pos="-0.447,-0.435"]
"Solar Particle Event" [pos="-0.348,-0.450"]
"Trapped Radiation" [pos="-0.366,-0.368"]
"Vehicle Design" [pos="-0.289,0.287"]
Cancer [outcome,pos="0.298,-0.199"]
Neutrons [pos="-0.268,0.005"]
Radiation [exposure,pos="-0.430,-0.163"]
Shielding [pos="-0.316,0.121"]
Surveillance [pos="0.374,0.053"]
"Astronaut Selection" -> "Modifiable Individual Factors"
"Astronaut Selection" -> "Non-Modifiable Individual Factors"
"Biologic Response" -> Cancer
"Biomedical Exposures" -> "Biologic Response"
"Cancer Model" -> "Estimated Mission Radiation Dose"
"Cancer Treatment" -> "Long Term Health Outcomes"
"Charged Particles" -> "Biologic Response"
"Charged Particles" -> "Detect Radiation"
"Charged Particles" -> Neutrons
"Crew Health and Performance System" -> "Medical Prevention Capability"
"Crew Health and Performance System" -> "Radiation Monitors"
"Detect Long Term Health Outcomes" -> "Cancer Treatment"
"Detect Radiation" -> "Cancer Model"
"Detect Radiation" -> "Estimated Dose Rate"
"Detect Radiation" -> "Estimated Mission Radiation Dose"
"Detect Radiation" -> "Intervention Measures"
"Distance from Earth" -> "Vehicle Design"
"Effective Mission Duration" -> "Estimated Mission Radiation Dose"
"Estimated Career Dose" -> "Flight Recertification"
"Estimated Dose Rate" -> "Biologic Response"
"Estimated Mission Radiation Dose" -> "Estimated Career Dose"
"Extraterrestrial Surface" -> Neutrons
"Galactic Cosmic Radiation" -> "Charged Particles"
"Gamma Rays" -> "Biologic Response"
"Gamma Rays" -> "Detect Radiation"
"HSIA (Risk)" -> "Crew Health and Performance System"
"HSIA (Risk)" -> "Vehicle Design"
"Intervention Measures" -> "Estimated Dose Rate"
"Intervention Measures" -> "Estimated Mission Radiation Dose"
"Medical Prevention Capability" -> "Biologic Response"
"Modifiable Individual Factors" -> "Biologic Response"
"Modifiable Individual Factors" -> Cancer
"Non-Modifiable Individual Factors" -> "Biologic Response"
"Non-Modifiable Individual Factors" -> Cancer
"Non-Modifiable Individual Factors" -> Surveillance
"Nuclear Technology" -> "Charged Particles"
```

Appendix C – Risk Formatting Instructions

"Nuclear Technology" -> "Effective Mission Duration"
"Nuclear Technology" -> "Gamma Rays"
"Nuclear Technology" -> Neutrons
"Nuclear Technology" -> Shielding
"Pharm (Risk)" -> "Medical Prevention Capability"
"Prior Mission Exposures" -> "Estimated Career Dose"
"Radiation Monitors" -> "Detect Radiation"
"Solar Cycle" -> "Galactic Cosmic Radiation"
"Solar Cycle" -> "Solar Particle Event"
"Solar Cycle" -> "Trapped Radiation"
"Solar Particle Event" -> "Charged Particles"
"Trapped Radiation" -> "Charged Particles"
"Vehicle Design" -> "Crew Health and Performance System"
"Vehicle Design" -> Shielding
Cancer -> "Detect Long Term Health Outcomes"
Cancer -> "Long Term Health Outcomes"
Neutrons -> "Biologic Response"
Neutrons -> "Detect Radiation"
Radiation -> "Charged Particles"
Radiation -> Neutrons
Shielding -> Neutrons
Surveillance -> "Detect Long Term Health Outcomes"
}

Appendix C – Risk Formatting Instructions

Renal Stone Risk

```
dag {
bb="-0.5,-0.5,0.5,0.5"
"Altered Gravity" [exposure,pos="-0.451,-0.281"]
"Astronaut Selection" [pos="-0.031,-0.457"]
"Bone Fracture (Risk)" [latent,pos="-0.395,-0.367"]
"Bone Remodeling" [pos="-0.296,-0.302"]
"CO2 (Risk)" [latent,pos="-0.384,-0.182"]
"Crew Capability" [pos="0.214,-0.369"]
"Crew Health and Performance System" [pos="-0.174,0.363"]
"Detect Long Term Health Outcomes" [pos="0.402,0.131"]
"Detect MRM/Stone" [pos="-0.048,0.017"]
"Distance from Earth" [exposure,pos="-0.434,0.381"]
"Flight Recertification" [outcome,pos="0.384,0.387"]
"Food and Nutrition (Risk)" [latent,pos="-0.405,-0.447"]
"HSIA (Risk)" [latent,pos="-0.308,0.403"]
"Hostile Closed Environment" [exposure,pos="-0.411,-0.040"]
"Individual Factors" [pos="-0.031,-0.282"]
"Individual Readiness" [pos="0.232,-0.256"]
"K+ Citrate" [pos="-0.122,0.124"]
"Long Term Health Outcomes" [outcome,pos="0.407,-0.012"]
"Loss of Crew Life" [outcome,pos="0.416,-0.162"]
"Loss of Mission Objectives" [outcome,pos="0.381,-0.442"]
"Loss of Mission" [outcome,pos="0.452,-0.470"]
"Medical Illness" [pos="0.207,-0.138"]
"Medical Monitoring Capability" [pos="0.027,0.360"]
"Medical Prevention Capability" [pos="-0.146,0.271"]
"Medical Treatment Capability" [pos="0.251,0.305"]
"Microhost (Risk)" [latent,pos="-0.175,-0.453"]
"Mineralized Renal Material" [pos="-0.179,-0.106"]
"Percutaneous Nephrostomy" [pos="0.125,0.169"]
"Pharm (Risk)" [latent,pos="0.187,0.401"]
"Resistive Exercise" [pos="-0.222,-0.352"]
"Task Performance" [outcome,pos="0.292,-0.416"]
"Ultrasound Manipulation" [pos="0.086,-0.019"]
"Urinary Retention (Risk)" [latent,pos="0.109,-0.307"]
"Urine Chemistry" [pos="-0.298,-0.142"]
"Urine Concentration" [pos="-0.283,-0.008"]
"Urine Flow" [pos="0.110,-0.142"]
"Vehicle Design" [pos="-0.316,0.294"]
"Water Intake" [pos="-0.274,0.173"]
Bisphosphonates [pos="-0.138,-0.267"]
Evacuation [outcome,pos="0.346,-0.310"]
Humidity [pos="-0.405,0.212"]
Hydration [pos="-0.347,0.090"]
Medications [pos="0.268,0.005"]
Microbiome [pos="-0.119,-0.365"]
Nephrolithiasis [pos="-0.085,-0.137"]
Nutrients [pos="-0.298,-0.435"]
Surveillance [pos="0.337,0.237"]
Tamsulosin [pos="0.200,0.086"]
Thiazides [pos="-0.067,0.133"]
Ultrasound [pos="0.031,0.121"]
Ureterolithiasis [pos="0.020,-0.138"]
"Altered Gravity" -> "Bone Remodeling"
"Astronaut Selection" -> "Individual Factors"
"Bone Fracture (Risk)" -> "Bone Remodeling"
"Bone Remodeling" -> "Urine Chemistry"
"CO2 (Risk)" -> "Urine Chemistry"
"Crew Capability" -> "Task Performance"
"Crew Health and Performance System" -> "Medical Monitoring Capability"
"Crew Health and Performance System" -> "Medical Prevention Capability"
"Crew Health and Performance System" -> "Medical Treatment Capability"
"Crew Health and Performance System" -> "Resistive Exercise"
"Detect MRM/Stone" -> "Ultrasound Manipulation"
"Distance from Earth" -> "Vehicle Design"
"Food and Nutrition (Risk)" -> Nutrients
"HSIA (Risk)" -> "Crew Health and Performance System"
"HSIA (Risk)" -> "Vehicle Design"
"Hostile Closed Environment" -> Hydration
"Individual Factors" -> Nephrolithiasis
"Individual Readiness" -> "Crew Capability"
"K+ Citrate" -> "Urine Chemistry"
"Long Term Health Outcomes" -> "Detect Long Term Health Outcomes"
"Loss of Mission Objectives" -> "Loss of Mission"
"Medical Illness" -> "Individual Readiness"
"Medical Illness" -> "Long Term Health Outcomes"
```

Appendix C – Risk Formatting Instructions

"Medical Illness" -> "Loss of Crew Life"
"Medical Illness" -> Evacuation
"Medical Monitoring Capability" -> Ultrasound
"Medical Prevention Capability" -> "Bone Remodeling"
"Medical Prevention Capability" -> "K+ Citrate"
"Medical Prevention Capability" -> "Urine Chemistry"
"Medical Prevention Capability" -> "Water Intake"
"Medical Prevention Capability" -> Bisphosphonates
"Medical Prevention Capability" -> Thiazides
"Medical Treatment Capability" -> "Percutaneous Nephrostomy"
"Medical Treatment Capability" -> "Ultrasound Manipulation"
"Medical Treatment Capability" -> "Water Intake"
"Medical Treatment Capability" -> Medications
"Medical Treatment Capability" -> Tamsulosin
"Microhost (Risk)" -> Microbiome
"Mineralized Renal Material" -> "Detect MRM/Stone"
"Mineralized Renal Material" -> Nephrolithiasis
"Percutaneous Nephrostomy" -> "Medical Illness"
"Pharm (Risk)" -> "Medical Prevention Capability"
"Pharm (Risk)" -> "Medical Treatment Capability"
"Resistive Exercise" -> "Bone Remodeling"
"Task Performance" -> "Loss of Mission Objectives"
"Ultrasound Manipulation" -> Ureterolithiasis
"Urinary Retention (Risk)" -> "Urine Flow"
"Urine Chemistry" -> "Mineralized Renal Material"
"Urine Concentration" -> "Urine Chemistry"
"Urine Flow" -> "Medical Illness"
"Vehicle Design" -> "Crew Health and Performance System"
"Vehicle Design" -> Humidity
"Water Intake" -> "Urine Flow"
"Water Intake" -> Hydration
Bisphosphonates -> "Bone Remodeling"
Evacuation -> "Loss of Crew Life"
Evacuation -> "Loss of Mission Objectives"
Humidity -> Hydration
Hydration -> "Urine Concentration"
Medications -> "Individual Readiness"
Medications -> "Long Term Health Outcomes"
Medications -> "Loss of Crew Life"
Medications -> "Medical Illness"
Medications -> Evacuation
Microbiome -> "Urine Chemistry"
Nephrolithiasis -> "Detect MRM/Stone"
Nephrolithiasis -> "Flight Recertification"
Nephrolithiasis -> Ureterolithiasis
Nutrients -> "Bone Remodeling"
Surveillance -> "Detect Long Term Health Outcomes"
Tamsulosin -> "Urine Flow"
Thiazides -> "Urine Chemistry"
Ultrasound -> "Detect MRM/Stone"
Ultrasound -> "Percutaneous Nephrostomy"
Ureterolithiasis -> "Urine Flow"
}

Appendix C – Risk Formatting Instructions

SANS Risk

dag {
"Altered Gravity" [exposure,pos="-1.879,0.350"]
"Astronaut Selection" [pos="-1.840,1.350"]
"Brain Structural Changes" [pos="-1.430,0.948"]
"CO2 (Risk)" [latent,pos="-1.430,-0.438"]
"Cardiovascular (Risk)" [latent,pos="-0.721,-0.664"]
"Chorioretinal Folds" [pos="-0.226,-0.496"]
"Crew Capability" [pos="0.705,-1.715"]
"Crew Health and Performance System" [pos="-0.831,-2.948"]
"Detect Brain Structural Changes" [pos="-0.015,1.193"]
"Detect Intracranial Pressure Changes" [pos="-1.042,0.539"]
"Detect Long Term Health Outcomes" [pos="0.600,0.801"]
"Detect Ocular Structural Changes" [pos="-0.039,-1.701"]
"Detect Visual Changes" [pos="0.133,-2.151"]
"Distance from Earth" [exposure,pos="-1.845,-2.961"]
"Flight Recertification" [outcome,pos="0.698,-0.710"]
"Fluid Shifts" [pos="-1.590,0.356"]
"Food and Nutrition (Risk)" [latent,pos="-1.636,-2.233"]
"Globe Flattening" [pos="-0.555,-1.068"]
"HSIA (Risk)" [latent,pos="-1.239,-2.553"]
"Individual Factors" [pos="-0.523,1.350"]
"Individual Readiness" [pos="0.456,-1.443"]
"Intracranial Pressure Changes" [pos="-1.146,-0.053"]
"Intracranial Pressure Monitoring" [pos="-0.749,-1.552"]
"Long Term Health Outcomes" [outcome,pos="0.649,0.033"]
"Loss of Mission Objectives" [outcome,pos="0.657,-2.973"]
"Loss of Mission" [outcome,pos="0.761,-3.490"]
"Lower Body Negative Pressure" [pos="-1.767,-0.679"]
"Medical Prevention Capability" [pos="-1.710,-1.538"]
"Medical Treatment Capability" [pos="0.204,-2.941"]
"Optic Disc Edema" [pos="-0.597,-0.217"]
"Optical Coherence Tomography" [pos="-0.492,-2.021"]
"Pharm (Risk)" [latent,pos="-1.901,-1.804"]
"Physiologic Monitoring Capability" [pos="-0.805,-2.464"]
"Refractive Error Shift" [pos="0.009,-1.000"]
"Retinal Nerve Fiber Layer Atrophy" [pos="-0.171,0.335"]
"Sleep (Risk)" [latent,pos="-1.606,-0.149"]
"Task Performance" [outcome,pos="0.716,-2.226"]
"Thigh Cuffs" [pos="-1.617,-0.918"]
"Vascular Congestion" [pos="-1.141,-0.891"]
"Vehicle Design" [pos="-1.441,-2.948"]
"Visual Acuity Test" [pos="-0.262,-2.758"]
"Visual Field Defect" [pos="0.154,0.216"]
"Visual Fields Test" [pos="-0.299,-2.222"]
Fundoscopy [pos="-0.922,-1.804"]
Lenses [pos="0.380,-2.273"]
MRI [pos="-0.653,0.492"]
Medications [pos="-1.450,-1.102"]
Supplements [pos="-1.404,-1.708"]
Surveillance [pos="0.361,1.351"]
Ultrasound [pos="-1.104,-2.056"]
"Altered Gravity" -> "Fluid Shifts"
"Astronaut Selection" -> "Individual Factors"
"Brain Structural Changes" -> "Detect Brain Structural Changes"
"Brain Structural Changes" -> "Long Term Health Outcomes"
"CO2 (Risk)" -> "Intracranial Pressure Changes"
"Cardiovascular (Risk)" -> "Optic Disc Edema"
"Chorioretinal Folds" -> "Detect Ocular Structural Changes"
"Chorioretinal Folds" -> "Flight Recertification"
"Chorioretinal Folds" -> "Visual Field Defect"
"Crew Capability" -> "Task Performance"
"Crew Health and Performance System" -> "Medical Prevention Capability"
"Crew Health and Performance System" -> "Medical Treatment Capability"
"Crew Health and Performance System" -> "Physiologic Monitoring Capability"
"Detect Brain Structural Changes" -> "Detect Long Term Health Outcomes"
"Detect Intracranial Pressure Changes" -> "Detect Long Term Health Outcomes"
"Detect Intracranial Pressure Changes" -> "Flight Recertification"
"Detect Intracranial Pressure Changes" -> "Medical Treatment Capability"
"Detect Ocular Structural Changes" -> "Detect Long Term Health Outcomes"

"Detect Ocular Structural Changes" -> "Flight Recertification"
"Detect Visual Changes" -> "Medical Treatment Capability"
"Distance from Earth" -> "Vehicle Design"
"Fluid Shifts" -> "Brain Structural Changes"
"Fluid Shifts" -> "Intracranial Pressure Changes"
"Fluid Shifts" -> "Vascular Congestion"
"Food and Nutrition (Risk)" -> Supplements
"Globe Flattening" -> "Chorioretinal Folds"
"Globe Flattening" -> "Detect Ocular Structural Changes"
"Globe Flattening" -> "Refractive Error Shift"
"HSIA (Risk)" -> "Crew Health and Performance System"
"HSIA (Risk)" -> "Vehicle Design"
"Individual Factors" -> "Brain Structural Changes"
"Individual Factors" -> "Chorioretinal Folds"
"Individual Factors" -> "Globe Flattening"
"Individual Factors" -> "Intracranial Pressure Changes"
"Individual Factors" -> "Optic Disc Edema"
"Individual Factors" -> "Refractive Error Shift"
"Individual Factors" -> "Retinal Nerve Fiber Layer Atrophy"
"Individual Factors" -> "Vascular Congestion"
"Individual Factors" -> "Visual Field Defect"
"Individual Readiness" -> "Crew Capability"
"Intracranial Pressure Changes" -> "Brain Structural Changes"
"Intracranial Pressure Changes" -> "Detect Intracranial Pressure Changes"
"Intracranial Pressure Changes" -> "Globe Flattening"
"Intracranial Pressure Changes" -> "Long Term Health Outcomes"
"Intracranial Pressure Changes" -> "Optic Disc Edema"
"Intracranial Pressure Monitoring" -> "Detect Intracranial Pressure Changes"
"Long Term Health Outcomes" -> "Detect Long Term Health Outcomes"
"Loss of Mission Objectives" -> "Loss of Mission"
"Lower Body Negative Pressure" -> "Vascular Congestion"
"Medical Prevention Capability" -> "Lower Body Negative Pressure"
"Medical Prevention Capability" -> "Thigh Cuffs"
"Medical Prevention Capability" -> Medications
"Medical Prevention Capability" -> Supplements
"Medical Treatment Capability" -> Lenses
"Optic Disc Edema" -> "Chorioretinal Folds"
"Optic Disc Edema" -> "Detect Ocular Structural Changes"
"Optic Disc Edema" -> "Retinal Nerve Fiber Layer Atrophy"
"Optic Disc Edema" -> "Visual Field Defect"
"Optical Coherence Tomography" -> "Detect Ocular Structural Changes"
"Pharm (Risk)" -> "Medical Prevention Capability"
"Physiologic Monitoring Capability" -> "Intracranial Pressure Monitoring"
"Physiologic Monitoring Capability" -> "Optical Coherence Tomography"
"Physiologic Monitoring Capability" -> "Visual Acuity Test"
"Physiologic Monitoring Capability" -> "Visual Fields Test"
"Physiologic Monitoring Capability" -> Fundoscopy
"Physiologic Monitoring Capability" -> Ultrasound
"Refractive Error Shift" -> "Detect Visual Changes"
"Refractive Error Shift" -> "Individual Readiness"
"Retinal Nerve Fiber Layer Atrophy" -> "Visual Field Defect"
"Sleep (Risk)" -> "Intracranial Pressure Changes"
"Task Performance" -> "Loss of Mission Objectives"
"Thigh Cuffs" -> "Vascular Congestion"
"Vascular Congestion" -> "Globe Flattening"
"Vascular Congestion" -> "Intracranial Pressure Changes"
"Vascular Congestion" -> "Optic Disc Edema"
"Vehicle Design" -> "Crew Health and Performance System"
"Visual Acuity Test" -> "Detect Visual Changes"
"Visual Field Defect" -> "Detect Visual Changes"
"Visual Field Defect" -> "Individual Readiness"
"Visual Field Defect" -> "Long Term Health Outcomes"
"Visual Fields Test" -> "Detect Visual Changes"
Fundoscopy -> "Detect Ocular Structural Changes"
Lenses -> "Individual Readiness"
MRI -> "Detect Brain Structural Changes"
MRI -> "Detect Ocular Structural Changes"
Medications -> "Intracranial Pressure Changes"
Medications -> "Vascular Congestion"
Supplements -> "Intracranial Pressure Changes"
Surveillance -> "Detect Long Term Health Outcomes"
Ultrasound -> "Detect Ocular Structural Changes"
}

Appendix C – Risk Formatting Instructions

Sensorimotor Risk

dag {
"Altered Gravity" [exposure,pos="-1.687,-1.418"]
"Artificial Gravity" [pos="-1.717,-0.920"]
"Astronaut Selection" [pos="-0.694,-2.494"]
"Balance Training" [pos="0.371,0.343"]
"Crew Capability" [pos="0.668,-1.296"]
"Crew Health and Performance System" [pos="-0.940,1.204"]
"Distance from Earth" [exposure,pos="-1.684,0.867"]
"Exercise Hardware" [pos="-0.734,0.764"]
"Fine Motor Control" [pos="0.034,-1.055"]
"Fluid Shifts" [pos="-1.406,-2.461"]
"HSIA (Risk)" [latent,pos="-1.442,1.241"]
"Hostile Closed Environment" [exposure,pos="-1.615,-2.058"]
"Individual Factors" [pos="-0.588,-1.188"]
"Individual Readiness" [pos="0.499,-1.045"]
"Loss of Crew Life" [outcome,pos="0.724,-0.434"]
"Loss of Mission Objectives" [outcome,pos="0.689,-2.314"]
"Loss of Mission" [outcome,pos="0.735,-2.826"]
"Medical Prevention Capability" [pos="-0.197,0.807"]
"Medical Treatment Capability" [pos="0.646,0.867"]
"Morphological G-Receptor Changes" [pos="-1.578,-0.356"]
"Motion Sickness" [pos="-0.071,-2.551"]
"Multi-Sensory Integration Alterations" [pos="-0.549,-0.453"]
"Muscle (Risk)" [latent,pos="-0.550,-0.002"]
"Muscle Physiologic Changes" [pos="-1.102,0.385"]
"Musculoskeletal Loads" [pos="-1.638,0.424"]
"Pharm (Risk)" [latent,pos="0.237,1.213"]
"Postural Control and Locomotion" [pos="-0.042,0.159"]
"Proprioception Change" [pos="-0.885,-0.114"]
"SANS (Risk)" [latent,pos="-1.027,-2.537"]
"Self-Administered Rehab" [pos="0.477,-0.024"]
"Sensory Augmentation" [pos="0.218,0.657"]
"Spatial Orientation" [pos="-0.328,-1.358"]
"Strobe Goggles" [pos="0.499,-0.385"]
"Task Performance" [outcome,pos="0.720,-1.867"]
"Traumatic Injury" [pos="0.408,-2.616"]
"Vehicle Design" [pos="-1.445,0.824"]
"Vehicle Dynamics" [pos="-0.338,-2.142"]
"Vestibular Gain Change" [pos="-1.288,-1.195"]
"Vestibular Motor Neuron Change" [pos="-0.930,-0.965"]
"Vison and Gaze Control" [pos="-0.944,-1.616"]
Exercise [pos="-0.616,0.411"]
Radiation [exposure,pos="-1.694,-2.764"]
"Altered Gravity" -> "Fluid Shifts"
"Altered Gravity" -> "Morphological G-Receptor Changes"
"Altered Gravity" -> "Multi-Sensory Integration Alterations"
"Altered Gravity" -> "Musculoskeletal Loads"
"Altered Gravity" -> "Vestibular Gain Change"
"Artificial Gravity" -> "Altered Gravity"
"Astronaut Selection" -> "Individual Factors"
"Balance Training" -> "Motion Sickness"
"Balance Training" -> "Postural Control and Locomotion"
"Balance Training" -> "Spatial Orientation"
"Crew Capability" -> "Task Performance"
"Crew Health and Performance System" -> "Exercise Hardware"
"Crew Health and Performance System" -> "Medical Prevention Capability"
"Crew Health and Performance System" -> "Medical Treatment Capability"
"Distance from Earth" -> "Vehicle Design"
"Exercise Hardware" -> Exercise
"Fine Motor Control" -> "Individual Readiness"
"Fine Motor Control" -> "Postural Control and Locomotion"
"Fluid Shifts" -> "SANS (Risk)"
"Fluid Shifts" -> "Vison and Gaze Control"
"HSIA (Risk)" -> "Crew Health and Performance System"
"HSIA (Risk)" -> "Vehicle Design"
"Hostile Closed Environment" -> "Multi-Sensory Integration Alterations"
"Hostile Closed Environment" -> "Vison and Gaze Control"
"Individual Factors" -> "Fine Motor Control"
"Individual Factors" -> "Motion Sickness"
"Individual Factors" -> "Multi-Sensory Integration Alterations"
"Individual Factors" -> "Postural Control and Locomotion"
"Individual Factors" -> "Proprioception Change"
"Individual Factors" -> "Spatial Orientation"
"Individual Factors" -> "Vestibular Motor Neuron Change"
"Individual Factors" -> "Vison and Gaze Control"

"Individual Readiness" -> "Crew Capability"
"Loss of Mission Objectives" -> "Loss of Mission"
"Medical Prevention Capability" -> "Balance Training"
"Medical Prevention Capability" -> "Self-Administered Rehab"
"Medical Prevention Capability" -> "Sensory Augmentation"
"Medical Prevention Capability" -> "Strobe Goggles"
"Medical Treatment Capability" -> "Individual Readiness"
"Morphological G-Receptor Changes" -> "Vestibular Gain Change"
"Motion Sickness" -> "Fine Motor Control"
"Motion Sickness" -> "Individual Readiness"
"Motion Sickness" -> "Postural Control and Locomotion"
"Multi-Sensory Integration Alterations" -> "Fine Motor Control"
"Multi-Sensory Integration Alterations" -> "Motion Sickness"
"Multi-Sensory Integration Alterations" -> "Postural Control and Locomotion"
"Multi-Sensory Integration Alterations" -> "Spatial Orientation"
"Muscle (Risk)" -> "Individual Readiness"
"Muscle Physiologic Changes" -> "Multi-Sensory Integration Alterations"
"Muscle Physiologic Changes" -> "Muscle (Risk)"
"Muscle Physiologic Changes" <-> Exercise
"Musculoskeletal Loads" -> "Muscle Physiologic Changes"
"Musculoskeletal Loads" -> "Proprioception Change"
"Musculoskeletal Loads" -> "Vestibular Gain Change"
"Pharm (Risk)" -> "Medical Treatment Capability"
"Postural Control and Locomotion" -> "Individual Readiness"
"Postural Control and Locomotion" -> "Traumatic Injury"
"Proprioception Change" -> "Multi-Sensory Integration Alterations"
"SANS (Risk)" -> "Individual Readiness"
"Self-Administered Rehab" -> "Fine Motor Control"
"Self-Administered Rehab" -> "Motion Sickness"
"Self-Administered Rehab" -> "Postural Control and Locomotion"
"Self-Administered Rehab" -> "Spatial Orientation"
"Sensory Augmentation" -> "Fine Motor Control"
"Sensory Augmentation" -> "Spatial Orientation"
"Spatial Orientation" -> "Fine Motor Control"
"Spatial Orientation" -> "Motion Sickness"
"Strobe Goggles" -> "Motion Sickness"
"Task Performance" -> "Loss of Crew Life"
"Task Performance" -> "Loss of Mission Objectives"
"Traumatic Injury" -> "Individual Readiness"
"Vehicle Design" -> "Crew Health and Performance System"
"Vehicle Design" -> "Vehicle Dynamics"
"Vehicle Dynamics" -> "Motion Sickness"
"Vestibular Gain Change" -> "Multi-Sensory Integration Alterations"
"Vestibular Gain Change" -> "Muscle Physiologic Changes"
"Vestibular Gain Change" -> "Proprioception Change"
"Vestibular Gain Change" -> "Spatial Orientation"
"Vestibular Gain Change" -> "Vestibular Motor Neuron Change"
"Vestibular Gain Change" -> "Vison and Gaze Control"
"Vestibular Motor Neuron Change" -> "Multi-Sensory Integration Alterations"
"Vison and Gaze Control" -> "Multi-Sensory Integration Alterations"
Exercise -> "Postural Control and Locomotion"
Radiation -> "Multi-Sensory Integration Alterations"
Radiation -> "Vestibular Motor Neuron Change"
Radiation -> "Vison and Gaze Control"
}

Appendix C – Risk Formatting Instructions

Sleep Risk

dag {
bb="-0.5,-0.5,0.5,0.5"
"Altered Gravity" [exposure,pos="-0.393,-0.177"]
"Astronaut Selection" [pos="-0.153,-0.447"]
"Behavioral (Risk)" [latent,pos="0.072,-0.460"]
"CO2, Hypoxia, Acoustic (Risks)" [latent,pos="-0.398,0.178"]
"Circadian Misalignment" [pos="0.031,-0.267"]
"Crew Capability" [pos="0.270,-0.317"]
"Crew Health and Performance System" [pos="-0.173,0.306"]
"Detect Environmental Conditions" [pos="-0.125,0.122"]
"Detect Long Term Health Outcomes" [pos="0.376,0.176"]
"Distance from Earth" [exposure,pos="-0.428,0.290"]
"ECLS System" [pos="-0.016,0.402"]
"EVA (Risk)" [latent,pos="-0.317,-0.454"]
"Environmental Conditions" [pos="-0.289,0.063"]
"Environmental Control" [pos="-0.112,0.003"]
"Environmental Monitoring Capability" [pos="-0.145,0.206"]
"Food and Nutrition (Risk)" [latent,pos="-0.399,-0.046"]
"HSIA (Risk)" [latent,pos="-0.381,0.402"]
"Hostile Closed Environment" [exposure,pos="-0.403,-0.283"]
"Immune (Risk)" [latent,pos="0.010,0.021"]
"Individual Factors" [pos="-0.111,-0.245"]
"Individual Readiness" [pos="0.193,-0.274"]
"Isolation and Confinement" [exposure,pos="-0.413,-0.390"]
"Long Term Health Outcomes" [outcome,pos="0.402,0.047"]
"Loss of Crew Life" [outcome,pos="0.434,-0.204"]
"Loss of Mission Objectives" [outcome,pos="0.398,-0.434"]
"Loss of Mission" [outcome,pos="0.458,-0.465"]
"Medical (Risk)" [latent,pos="0.275,-0.021"]
"Medical Prevention Capability" [pos="0.066,0.117"]
"Medical Treatment Capability" [pos="0.184,0.186"]
"Pharm (Risk)" [latent,pos="0.071,0.364"]
"Schedule Shifting" [pos="-0.264,-0.115"]
"Sleep Deficiencies" [pos="-0.040,-0.110"]
"Sleep Inertia" [pos="0.141,-0.154"]
"Task Performance" [outcome,pos="0.309,-0.403"]
"Team (Risk)" [latent,pos="0.166,-0.460"]
"Vehicle Design" [pos="-0.309,0.287"]
Fatigue [pos="-0.040,-0.400"]
Insomnia [pos="0.058,-0.052"]
Radiation [exposure,pos="-0.423,0.078"]
Stress [pos="-0.234,-0.229"]
Surveillance [pos="0.277,0.280"]
Workload [pos="-0.261,-0.353"]
"Altered Gravity" -> "Environmental Conditions"
"Altered Gravity" -> Stress
"Astronaut Selection" -> "Individual Factors"
"Behavioral (Risk)" -> "Individual Readiness"
"Behavioral (Risk)" -> "Team (Risk)"
"CO2, Hypoxia, Acoustic (Risks)" -> "Environmental Conditions"
"Circadian Misalignment" -> "Behavioral (Risk)"
"Circadian Misalignment" -> "Sleep Deficiencies"
"Circadian Misalignment" -> "Sleep Inertia"
"Circadian Misalignment" -> Fatigue
"Crew Capability" -> "Task Performance"
"Crew Health and Performance System" -> "Environmental Monitoring Capability"
"Crew Health and Performance System" -> "Medical Prevention Capability"
"Crew Health and Performance System" -> "Medical Treatment Capability"
"Detect Environmental Conditions" -> "Environmental Control"
"Detect Environmental Conditions" -> "Medical Prevention Capability"
"Detect Environmental Conditions" -> "Schedule Shifting"
"Detect Environmental Conditions" -> Stress
"Distance from Earth" -> "Vehicle Design"
"ECLS System" -> "Environmental Control"
"ECLS System" -> "Environmental Monitoring Capability"
"EVA (Risk)" -> Workload
"Environmental Conditions" -> "Circadian Misalignment"
"Environmental Conditions" -> "Detect Environmental Conditions"
"Environmental Conditions" -> "Sleep Deficiencies"
"Environmental Control" -> "Sleep Deficiencies"
"Environmental Monitoring Capability" -> "Detect Environmental Conditions"
"Food and Nutrition (Risk)" -> "Sleep Deficiencies"
"HSIA (Risk)" -> "Crew Health and Performance System"

Appendix C – Risk Formatting Instructions

"HSIA (Risk)" -> "ECLS System"
"HSIA (Risk)" -> "Vehicle Design"
"HSIA (Risk)" -> Workload
"Hostile Closed Environment" -> Stress
"Immune (Risk)" -> "Medical (Risk)"
"Individual Factors" -> "Circadian Misalignment"
"Individual Factors" -> "Sleep Deficiencies"
"Individual Factors" -> "Sleep Inertia"
"Individual Factors" -> Insomnia
"Individual Factors" -> Stress
"Individual Readiness" -> "Crew Capability"
"Individual Readiness" -> "Loss of Crew Life"
"Isolation and Confinement" -> Stress
"Isolation and Confinement" -> Workload
"Long Term Health Outcomes" -> "Detect Long Term Health Outcomes"
"Loss of Mission Objectives" -> "Loss of Mission"
"Medical (Risk)" -> "Individual Readiness"
"Medical (Risk)" -> "Long Term Health Outcomes"
"Medical Prevention Capability" -> "Sleep Inertia"
"Medical Prevention Capability" -> Insomnia
"Medical Treatment Capability" -> "Individual Readiness"
"Medical Treatment Capability" -> "Medical (Risk)"
"Medical Treatment Capability" -> "Sleep Inertia"
"Pharm (Risk)" -> "Medical Prevention Capability"
"Pharm (Risk)" -> "Medical Treatment Capability"
"Schedule Shifting" -> "Circadian Misalignment"
"Schedule Shifting" -> "Sleep Deficiencies"
"Schedule Shifting" -> Stress
"Sleep Deficiencies" -> "Immune (Risk)"
"Sleep Deficiencies" -> "Sleep Inertia"
"Sleep Deficiencies" -> Fatigue
"Sleep Deficiencies" -> Insomnia
"Sleep Inertia" -> "Individual Readiness"
"Task Performance" -> "Loss of Mission Objectives"
"Team (Risk)" -> "Individual Readiness"
"Vehicle Design" -> "Crew Health and Performance System"
"Vehicle Design" -> "ECLS System"
"Vehicle Design" -> "Environmental Conditions"
Fatigue -> "Behavioral (Risk)"
Fatigue -> "Individual Readiness"
Insomnia -> "Medical (Risk)"
Insomnia -> "Sleep Inertia"
Radiation -> "Environmental Conditions"
Radiation -> "Sleep Deficiencies"
Stress -> "Sleep Deficiencies"
Stress -> Fatigue
Surveillance -> "Detect Long Term Health Outcomes"
Workload -> Fatigue
Workload -> Stress
}

Appendix C – Risk Formatting Instructions

Team Risk

dag {
"Acoustics, Medical, Sleep, CO2, Food and Nutrition (Risks)" [latent,pos="-1.418,-1.352"]
"Astronaut Selection" [pos="-1.216,-2.101"]
"BHP Countermeasures" [pos="0.640,0.287"]
"Behavioral (Risk)" [latent,pos="-1.499,-1.770"]
"Communications Delay" [pos="-0.316,1.562"]
"Crew Capability" [pos="0.614,-0.968"]
"Crew Health and Performance System" [pos="-0.889,1.287"]
"Crew Size" [pos="-0.419,-1.933"]
"Detect Team Performance and Cohesion" [pos="0.622,0.800"]
"Distance from Earth" [exposure,pos="-1.752,1.378"]
"Effective Mission Duration" [pos="-1.651,0.194"]
"Family Effects" [pos="0.010,0.724"]
"Ground Support" [pos="0.159,1.555"]
"HSIA (Risk)" [latent,pos="-1.443,1.683"]
"Individual Factors" [pos="-1.033,-1.713"]
"Individual Readiness" [pos="-0.537,-1.311"]
"Interpersonal Relationships" [pos="-0.498,0.205"]
"Isolation and Confinement" [exposure,pos="-1.706,-0.467"]
"Loss of Crew Life" [outcome,pos="1.162,0.225"]
"Loss of Mission Objectives" [outcome,pos="1.069,-1.595"]
"Loss of Mission" [outcome,pos="1.171,-2.025"]
"Loss of Vehicle" [pos="0.890,-0.289"]
"Net Habitable Volume" [pos="-0.934,0.675"]
"Privacy/Team Space" [pos="-0.493,0.953"]
"Private Astronaut Missions" [pos="0.152,-1.950"]
"Social Support" [pos="0.057,0.265"]
"Task Performance" [outcome,pos="0.856,-1.126"]
"Team Cognition" [pos="-0.498,-0.615"]
"Team Cohesion" [pos="0.073,-0.397"]
"Team Composition" [pos="-0.159,-1.528"]
"Team Functionality" [pos="0.259,-0.815"]
"Team Monitoring" [pos="0.411,1.276"]
"Team Skills" [pos="-1.006,-0.972"]
"Team Training" [pos="-1.394,-0.622"]
"Technical Training" [pos="-1.294,0.478"]
"Vehicle Design" [pos="-1.476,1.016"]
Evacuation [outcome,pos="1.203,-0.892"]
"Acoustics, Medical, Sleep, CO2, Food and Nutrition (Risks)" -> "Behavioral (Risk)"
"Acoustics, Medical, Sleep, CO2, Food and Nutrition (Risks)" -> "Individual Readiness"
"Astronaut Selection" -> "Individual Factors"
"Astronaut Selection" -> "Team Composition"
"BHP Countermeasures" -> "Social Support"
"BHP Countermeasures" -> "Team Cognition"
"BHP Countermeasures" -> "Team Cohesion"
"Behavioral (Risk)" -> "Individual Readiness"
"Behavioral (Risk)" -> "Interpersonal Relationships"
"Communications Delay" -> "Family Effects"
"Communications Delay" -> "Ground Support"
"Crew Capability" -> "Task Performance"
"Crew Health and Performance System" -> "Communications Delay"
"Crew Health and Performance System" -> "Privacy/Team Space"
"Crew Health and Performance System" -> "Team Monitoring"
"Crew Health and Performance System" -> "Technical Training"
"Crew Size" -> "Crew Capability"
"Crew Size" -> "Team Composition"
"Detect Team Performance and Cohesion" -> "BHP Countermeasures"
"Distance from Earth" -> "Communications Delay"
"Distance from Earth" -> "Crew Size"
"Distance from Earth" -> "Effective Mission Duration"
"Distance from Earth" -> "Vehicle Design"
"Effective Mission Duration" -> "Interpersonal Relationships"
"Family Effects" -> "Individual Readiness"
"Family Effects" -> "Social Support"
"Ground Support" -> "Crew Capability"
"Ground Support" -> "Social Support"
"Ground Support" -> "Team Cognition"
"HSIA (Risk)" -> "Crew Health and Performance System"
"HSIA (Risk)" -> "Vehicle Design"
"Individual Factors" -> "Individual Readiness"
"Individual Factors" -> "Team Composition"
"Individual Readiness" -> "Crew Capability"
"Individual Readiness" -> "Detect Team Performance and Cohesion"
"Individual Readiness" -> "Team Cognition"
"Individual Readiness" -> "Team Composition"
"Interpersonal Relationships" -> "Detect Team Performance and Cohesion"
"Interpersonal Relationships" -> "Social Support"
"Interpersonal Relationships" -> "Team Cognition"
"Interpersonal Relationships" -> "Team Cohesion"

"Isolation and Confinement" -> "Interpersonal Relationships"
"Loss of Mission Objectives" -> "Loss of Mission"
"Loss of Vehicle" -> "Loss of Crew Life"
"Loss of Vehicle" -> Evacuation
"Net Habitable Volume" -> "Privacy/Team Space"
"Privacy/Team Space" -> "Interpersonal Relationships"
"Private Astronaut Missions" -> "Team Composition"
"Social Support" -> "Team Cognition"
"Social Support" -> "Team Cohesion"
"Task Performance" -> "Loss of Crew Life"
"Task Performance" -> "Loss of Mission Objectives"
"Task Performance" -> "Loss of Vehicle"
"Team Cognition" -> "Team Functionality"
"Team Cohesion" -> "Team Functionality"
"Team Composition" -> "Interpersonal Relationships"
"Team Composition" -> "Team Cognition"
"Team Composition" -> "Team Cohesion"
"Team Functionality" -> "Crew Capability"
"Team Monitoring" -> "Detect Team Performance and Cohesion"
"Team Skills" -> "Individual Readiness"
"Team Skills" -> "Interpersonal Relationships"
"Team Skills" -> "Social Support"
"Team Skills" -> "Team Cognition"
"Team Skills" -> "Team Functionality"
"Team Training" -> "Ground Support"
"Team Training" -> "Interpersonal Relationships"
"Team Training" -> "Team Cognition"
"Team Training" -> "Team Skills"
"Technical Training" -> "Individual Readiness"
"Technical Training" -> "Team Cognition"
"Vehicle Design" -> "Crew Health and Performance System"
"Vehicle Design" -> "Net Habitable Volume"
"Vehicle Design" -> "Privacy/Team Space"
"Vehicle Design" -> "Technical Training"
Evacuation -> "Loss of Crew Life"
Evacuation -> "Loss of Mission Objectives"
}

Appendix C – Risk Formatting Instructions

Tox Risk

```
dag {
bb="-0.5,-0.5,0.5,0.5"
"Acoustics, Cardiovascular (Risks)" [latent,pos="0.166,0.115"]
"Altered Gravity" [exposure,pos="-0.438,-0.042"]
"Atmospheric Scrubbers" [pos="0.175,-0.166"]
"Behavioral (Risk)" [latent,pos="0.138,-0.466"]
"CO2 (Risk)" [latent,pos="-0.047,-0.099"]
"Combustion/Smoldering Events" [pos="-0.138,0.039"]
"Communication Factors" [pos="-0.270,-0.467"]
"Crew Capability" [pos="0.266,-0.353"]
"Crew Health and Performance System" [pos="-0.190,-0.372"]
"Crew Metabolism" [pos="-0.143,-0.148"]
"Detect Diagnosis" [pos="0.181,-0.036"]
"Detect Long Term Health Outcomes" [pos="0.369,0.349"]
"Detect Toxic Exposure" [pos="0.073,-0.102"]
"Distance from Earth" [exposure,pos="-0.434,-0.396"]
"Dust (Risk)" [latent,pos="-0.271,0.405"]
"ECLS System" [pos="-0.151,-0.443"]
"Electric Shock (Risk)" [latent,pos="-0.250,-0.217"]
"External Contaminants" [pos="-0.138,0.405"]
"Ground Support" [pos="-0.057,-0.467"]
"HSIA (Risk)" [latent,pos="-0.337,-0.384"]
"Hostile Closed Environment" [exposure,pos="-0.393,0.235"]
"Individual Factors" [pos="-0.158,-0.276"]
"Individual Readiness" [pos="0.189,-0.383"]
"Long Term Health Outcomes" [outcome,pos="0.419,0.230"]
"Loss of Crew Life" [outcome,pos="0.447,0.007"]
"Loss of Mission Objectives" [outcome,pos="0.406,-0.419"]
"Loss of Mission" [outcome,pos="0.460,-0.457"]
"Materials Offgassing" [pos="-0.139,0.315"]
"Medical (Risk)" [latent,pos="0.267,0.075"]
"Medical Prevention Capability" [pos="0.029,-0.383"]
"Payload Chemicals" [pos="-0.139,0.219"]
"Pharm (Risk)" [latent,pos="0.168,0.214"]
"Physiologic Monitoring Capability" [pos="0.046,-0.248"]
"Protective Equipment" [pos="0.135,-0.320"]
"Standards/Requirements" [pos="-0.437,-0.225"]
"Task Performance" [outcome,pos="0.349,-0.332"]
"Team (Risk)" [latent,pos="0.238,-0.468"]
"Thermal Degradation" [pos="-0.140,0.124"]
"Toxic Exposure" [pos="0.013,0.078"]
"Toxic Substance Monitoring" [pos="-0.041,-0.204"]
"Vehicle Design" [pos="-0.344,-0.268"]
"Waste Management System" [pos="-0.142,-0.055"]
Evacuation [outcome,pos="0.362,-0.190"]
Surveillance [pos="0.254,0.406"]
"Acoustics, Cardiovascular (Risks)" -> "Medical (Risk)"
"Altered Gravity" -> "Combustion/Smoldering Events"
"Altered Gravity" -> "Crew Metabolism"
"Altered Gravity" -> "Payload Chemicals"
"Altered Gravity" -> "Vehicle Design"
"Atmospheric Scrubbers" -> "Individual Readiness"
"Atmospheric Scrubbers" -> "Medical (Risk)"
"Behavioral (Risk)" -> "Individual Readiness"
"Behavioral (Risk)" -> "Team (Risk)"
"CO2 (Risk)" -> "Toxic Exposure"
"Combustion/Smoldering Events" -> "Toxic Exposure"
"Communication Factors" -> "Ground Support"
"Crew Capability" -> "Task Performance"
"Crew Health and Performance System" -> "Medical Prevention Capability"
"Crew Health and Performance System" -> "Physiologic Monitoring Capability"
"Crew Health and Performance System" -> "Toxic Substance Monitoring"
"Crew Metabolism" -> "CO2 (Risk)"
"Detect Diagnosis" -> "Medical (Risk)"
"Detect Toxic Exposure" -> "Atmospheric Scrubbers"
"Detect Toxic Exposure" -> "Detect Diagnosis"
"Detect Toxic Exposure" -> "Protective Equipment"
"Distance from Earth" -> "Communication Factors"
"Distance from Earth" -> "Vehicle Design"
"Dust (Risk)" -> "External Contaminants"
"ECLS System" -> "Atmospheric Scrubbers"
"ECLS System" -> "Toxic Substance Monitoring"
"Electric Shock (Risk)" -> "Combustion/Smoldering Events"
"External Contaminants" -> "Toxic Exposure"
"Ground Support" -> "Individual Readiness"
"Ground Support" -> "Toxic Exposure"
```

"Ground Support" -> "Toxic Substance Monitoring"
"HSIA (Risk)" -> "Crew Health and Performance System"
"HSIA (Risk)" -> "Electric Shock (Risk)"
"HSIA (Risk)" -> "External Contaminants"
"HSIA (Risk)" -> "Materials Offgassing"
"HSIA (Risk)" -> "Payload Chemicals"
"HSIA (Risk)" -> "Thermal Degradation"
"HSIA (Risk)" -> "Vehicle Design"
"Hostile Closed Environment" -> "Combustion/Smoldering Events"
"Hostile Closed Environment" -> "Crew Metabolism"
"Hostile Closed Environment" -> "External Contaminants"
"Hostile Closed Environment" -> "Materials Offgassing"
"Hostile Closed Environment" -> "Payload Chemicals"
"Hostile Closed Environment" -> "Thermal Degradation"
"Hostile Closed Environment" -> "Vehicle Design"
"Individual Factors" -> "Crew Metabolism"
"Individual Readiness" -> "Crew Capability"
"Long Term Health Outcomes" -> "Detect Long Term Health Outcomes"
"Loss of Mission Objectives" -> "Loss of Mission"
"Materials Offgassing" -> "Toxic Exposure"
"Medical (Risk)" -> "Individual Readiness"
"Medical (Risk)" -> "Loss of Crew Life"
"Medical (Risk)" -> Evacuation
"Medical Prevention Capability" -> "Protective Equipment"
"Payload Chemicals" -> "Toxic Exposure"
"Pharm (Risk)" -> "Medical (Risk)"
"Physiologic Monitoring Capability" -> "Detect Diagnosis"
"Protective Equipment" -> "Individual Readiness"
"Protective Equipment" -> "Medical (Risk)"
"Standards/Requirements" -> "Materials Offgassing"
"Standards/Requirements" -> "Payload Chemicals"
"Standards/Requirements" -> "Vehicle Design"
"Task Performance" -> "Loss of Mission Objectives"
"Team (Risk)" -> "Individual Readiness"
"Thermal Degradation" -> "Toxic Exposure"
"Toxic Exposure" -> "Acoustics, Cardiovascular (Risks)"
"Toxic Exposure" -> "Behavioral (Risk)"
"Toxic Exposure" -> "Detect Toxic Exposure"
"Toxic Exposure" -> "Individual Readiness"
"Toxic Exposure" -> "Long Term Health Outcomes"
"Toxic Exposure" -> "Medical (Risk)"
"Toxic Substance Monitoring" -> "Detect Toxic Exposure"
"Vehicle Design" -> "Combustion/Smoldering Events"
"Vehicle Design" -> "Crew Health and Performance System"
"Vehicle Design" -> "ECLS System"
"Vehicle Design" -> "External Contaminants"
"Vehicle Design" -> "Materials Offgassing"
"Vehicle Design" -> "Payload Chemicals"
"Vehicle Design" -> "Thermal Degradation"
"Vehicle Design" -> "Toxic Exposure"
"Vehicle Design" -> "Waste Management System"
"Waste Management System" -> "Toxic Exposure"
Evacuation -> "Loss of Crew Life"
Evacuation -> "Loss of Mission Objectives"
Surveillance -> "Detect Long Term Health Outcomes"
}

Urinary Retention Risk

```
dag {
bb="-0.5,-0.5,0.5,0.5"
"Altered Gravity" [exposure,pos="-0.416,-0.052"]
"Astronaut Selection" [pos="-0.060,-0.455"]
"Crew Capability" [pos="0.288,-0.341"]
"Crew Health and Performance System" [pos="-0.146,0.285"]
"Detect Long Term Health Outcomes" [pos="0.399,0.271"]
"Detect Post-Void Residual" [pos="-0.058,-0.067"]
"Distance from Earth" [exposure,pos="-0.436,0.285"]
"EVA (Risk)" [latent,pos="-0.408,0.107"]
"HSIA (Risk)" [latent,pos="-0.309,0.409"]
"Hostile Closed Environment" [exposure,pos="-0.413,-0.218"]
"Individual Factors" [pos="-0.149,-0.382"]
"Individual Readiness" [pos="0.228,-0.282"]
"Isolation and Confinement" [exposure,pos="-0.420,-0.317"]
"Long Term Health Outcomes" [outcome,pos="0.417,0.105"]
"Loss of Crew Life" [outcome,pos="0.416,-0.043"]
"Loss of Mission Objectives" [outcome,pos="0.392,-0.446"]
"Loss of Mission" [outcome,pos="0.457,-0.471"]
"Mechanical Obstruction" [pos="-0.231,-0.285"]
"Medical Illness" [pos="0.229,-0.166"]
"Medical Prevention Capability" [pos="0.042,0.241"]
"Medical Treatment Capability" [pos="0.144,0.333"]
"Pharm (Risk)" [latent,pos="0.017,0.108"]
"Post-Void Residual" [pos="-0.089,-0.290"]
"Sensorimotor (Risk)" [latent,pos="-0.303,0.187"]
"Task Performance" [outcome,pos="0.376,-0.364"]
"Urinary Muscle Changes" [pos="-0.279,-0.128"]
"Urinary Retention" [pos="0.035,-0.288"]
"Urine Flow" [pos="0.130,-0.288"]
"Vehicle Design" [pos="-0.309,0.287"]
"Void Trial" [pos="0.028,-0.168"]
Anticholergics [pos="-0.233,0.085"]
Catheterization [pos="0.135,-0.022"]
Evacuation [outcome,pos="0.386,-0.235"]
Inflammation [pos="-0.278,-0.419"]
Radiation [exposure,pos="-0.419,-0.428"]
Surveillance [pos="0.307,0.389"]
Sympathomimetics [pos="-0.300,-0.005"]
Tamsulosin [pos="-0.195,-0.019"]
Ultrasound [pos="-0.096,0.189"]
"Altered Gravity" -> "Urinary Muscle Changes"
"Astronaut Selection" -> "Individual Factors"
"Crew Capability" -> "Task Performance"
"Crew Health and Performance System" -> "Medical Prevention Capability"
"Crew Health and Performance System" -> "Medical Treatment Capability"
"Crew Health and Performance System" -> Ultrasound
"Detect Post-Void Residual" -> "Void Trial"
"Detect Post-Void Residual" -> Catheterization
"Distance from Earth" -> "Vehicle Design"
"EVA (Risk)" -> Sympathomimetics
"EVA (Risk)" -> Ultrasound
"HSIA (Risk)" -> "Crew Health and Performance System"
"HSIA (Risk)" -> "Vehicle Design"
"Hostile Closed Environment" -> Inflammation
"Individual Factors" -> "Mechanical Obstruction"
"Individual Readiness" -> "Crew Capability"
"Isolation and Confinement" -> Inflammation
"Long Term Health Outcomes" -> "Detect Long Term Health Outcomes"
"Loss of Mission Objectives" -> "Loss of Mission"
"Mechanical Obstruction" -> "Post-Void Residual"
"Medical Illness" -> "Individual Readiness"
"Medical Illness" -> "Long Term Health Outcomes"
"Medical Illness" -> "Loss of Crew Life"
"Medical Illness" -> Evacuation
"Medical Prevention Capability" -> Tamsulosin
"Medical Treatment Capability" -> "Medical Illness"
"Medical Treatment Capability" -> Catheterization
"Pharm (Risk)" -> "Medical Prevention Capability"
"Pharm (Risk)" -> Anticholergics
"Pharm (Risk)" -> Sympathomimetics
"Post-Void Residual" -> "Detect Post-Void Residual"
"Post-Void Residual" -> "Medical Illness"
"Post-Void Residual" -> "Urinary Retention"
"Sensorimotor (Risk)" -> Anticholergics
"Sensorimotor (Risk)" -> Sympathomimetics
"Sensorimotor (Risk)" -> Ultrasound
"Task Performance" -> "Loss of Mission Objectives"
"Urinary Muscle Changes" -> "Mechanical Obstruction"
"Urinary Retention" -> "Medical Illness"
"Urinary Retention" -> "Urine Flow"
```

"Urine Flow" -> "Medical Illness"
"Vehicle Design" -> "Crew Health and Performance System"
"Void Trial" -> "Urinary Retention"
Anticholergics -> "Mechanical Obstruction"
Catheterization -> "Medical Illness"
Catheterization -> "Urine Flow"
Inflammation -> "Mechanical Obstruction"
Radiation -> Inflammation
Surveillance -> "Detect Long Term Health Outcomes"
Sympathomimetics -> "Urinary Muscle Changes"
Tamsulosin -> "Urinary Muscle Changes"
Ultrasound -> "Detect Post-Void Residual"
}

VTE Concern

```
dag {
bb="-0.5,-0.5,0.5,0.5"
"Altered Gravity" [exposure,pos="-0.452,-0.461"]
"Astronaut Selection" [pos="-0.432,-0.378"]
"Atmospheric Conditions" [pos="-0.416,-0.074"]
"Blood Stagnation" [pos="0.061,-0.448"]
"Blood Viscosity" [pos="-0.134,-0.151"]
"CO2 (Risk)" [latent,pos="-0.301,-0.033"]
"Crew Capability" [pos="0.219,-0.284"]
"Crew Health and Performance System" [pos="-0.148,0.408"]
"Detect Long Term Health Outcomes" [pos="0.396,0.225"]
"Detect Thrombosis" [pos="0.158,0.088"]
"Distance from Earth" [exposure,pos="-0.437,0.407"]
"Endocrine Factors" [pos="-0.023,0.211"]
"Endothelial Damage" [pos="-0.016,-0.232"]
"Fluid Shifts" [pos="-0.314,-0.457"]
"Food and Nutrition (Risk)" [latent,pos="-0.145,0.156"]
"Hematologic Index Alterations" [pos="-0.203,-0.285"]
"Hostile Closed Environment" [exposure,pos="-0.419,-0.285"]
"Hypoxia (Risk)" [latent,pos="-0.300,-0.161"]
"Individual Factors" [pos="-0.315,-0.344"]
"Individual Readiness" [pos="0.207,-0.191"]
"Isolation and Confinement" [exposure,pos="-0.421,0.263"]
"Long Term Health Outcomes" [outcome,pos="0.413,0.086"]
"Loss of Crew Life" [outcome,pos="0.448,-0.035"]
"Loss of Mission Objectives" [outcome,pos="0.340,-0.444"]
"Loss of Mission" [outcome,pos="0.443,-0.470"]
"Medical (Risk)" [latent,pos="0.208,-0.038"]
"Medical Monitoring Capability" [pos="0.104,0.284"]
"Medical Prevention Capability" [pos="0.067,0.410"]
"Medical Treatment Capability" [pos="0.281,0.282"]
"Oral Contraceptives" [pos="-0.047,0.320"]
"Oxidative Stress" [pos="-0.346,0.056"]
"Pharm (Risk)" [latent,pos="0.246,0.412"]
"Task Performance" [outcome,pos="0.256,-0.369"]
"Vascular Structure/Function" [pos="-0.131,-0.453"]
"Vehicle Design" [pos="-0.323,0.405"]
"Venous Thrombosis" [pos="0.066,-0.038"]
Anticoagulants [pos="0.280,0.111"]
Coagulability [pos="-0.047,0.065"]
Evacuation [outcome,pos="0.334,-0.216"]
Inflammation [pos="-0.223,0.087"]
Radiation [exposure,pos="-0.451,0.053"]
Stress [pos="-0.333,0.199"]
Surveillance [pos="0.408,0.396"]
Ultrasound [pos="0.146,0.190"]
"Altered Gravity" -> "Fluid Shifts"
"Astronaut Selection" -> "Individual Factors"
"Atmospheric Conditions" -> "CO2 (Risk)"
"Atmospheric Conditions" -> "Hypoxia (Risk)"
"Blood Stagnation" -> "Venous Thrombosis"
"Blood Viscosity" -> "Blood Stagnation"
"Blood Viscosity" -> Coagulability
"CO2 (Risk)" -> Inflammation
```

"Crew Capability" -> "Task Performance"
"Crew Health and Performance System" -> "Medical Monitoring Capability"
"Crew Health and Performance System" -> "Medical Prevention Capability"
"Crew Health and Performance System" -> "Medical Treatment Capability"
"Detect Thrombosis" -> Anticoagulants
"Distance from Earth" -> "Vehicle Design"
"Endocrine Factors" -> Coagulability
"Endothelial Damage" -> "Venous Thrombosis"
"Fluid Shifts" -> "Hematologic Index Alterations"
"Fluid Shifts" -> "Vascular Structure/Function"
"Food and Nutrition (Risk)" -> Coagulability
"Hematologic Index Alterations" -> "Blood Viscosity"
"Hostile Closed Environment" -> "Atmospheric Conditions"
"Hypoxia (Risk)" -> "Hematologic Index Alterations"
"Hypoxia (Risk)" -> Coagulability
"Hypoxia (Risk)" -> Inflammation
"Individual Factors" -> "Endocrine Factors"
"Individual Factors" -> "Vascular Structure/Function"
"Individual Factors" -> Coagulability
"Individual Readiness" -> "Crew Capability"
"Isolation and Confinement" -> Stress
"Long Term Health Outcomes" -> "Detect Long Term Health Outcomes"
"Loss of Mission Objectives" -> "Loss of Mission"
"Medical (Risk)" -> "Individual Readiness"
"Medical (Risk)" -> "Long Term Health Outcomes"
"Medical (Risk)" -> "Loss of Crew Life"
"Medical (Risk)" -> Evacuation
"Medical Monitoring Capability" -> Ultrasound
"Medical Prevention Capability" -> "Oral Contraceptives"
"Medical Prevention Capability" -> "Venous Thrombosis"
"Medical Treatment Capability" -> Anticoagulants
"Oral Contraceptives" -> "Endocrine Factors"
"Oxidative Stress" -> Inflammation
"Pharm (Risk)" -> "Medical Prevention Capability"
"Pharm (Risk)" -> "Medical Treatment Capability"
"Task Performance" -> "Loss of Mission Objectives"
"Vascular Structure/Function" -> "Blood Stagnation"
"Vascular Structure/Function" -> "Endothelial Damage"
"Vehicle Design" -> "Atmospheric Conditions"
"Vehicle Design" -> "Crew Health and Performance System"
"Venous Thrombosis" -> "Detect Thrombosis"
"Venous Thrombosis" -> "Medical (Risk)"
Anticoagulants -> "Medical (Risk)"
Coagulability -> "Venous Thrombosis"
Evacuation -> "Loss of Crew Life"
Evacuation -> "Loss of Mission Objectives"
Inflammation -> "Endothelial Damage"
Inflammation -> "Vascular Structure/Function"
Radiation -> "Oxidative Stress"
Stress -> Inflammation
Surveillance -> "Detect Long Term Health Outcomes"
Ultrasound -> "Detect Thrombosis"
}