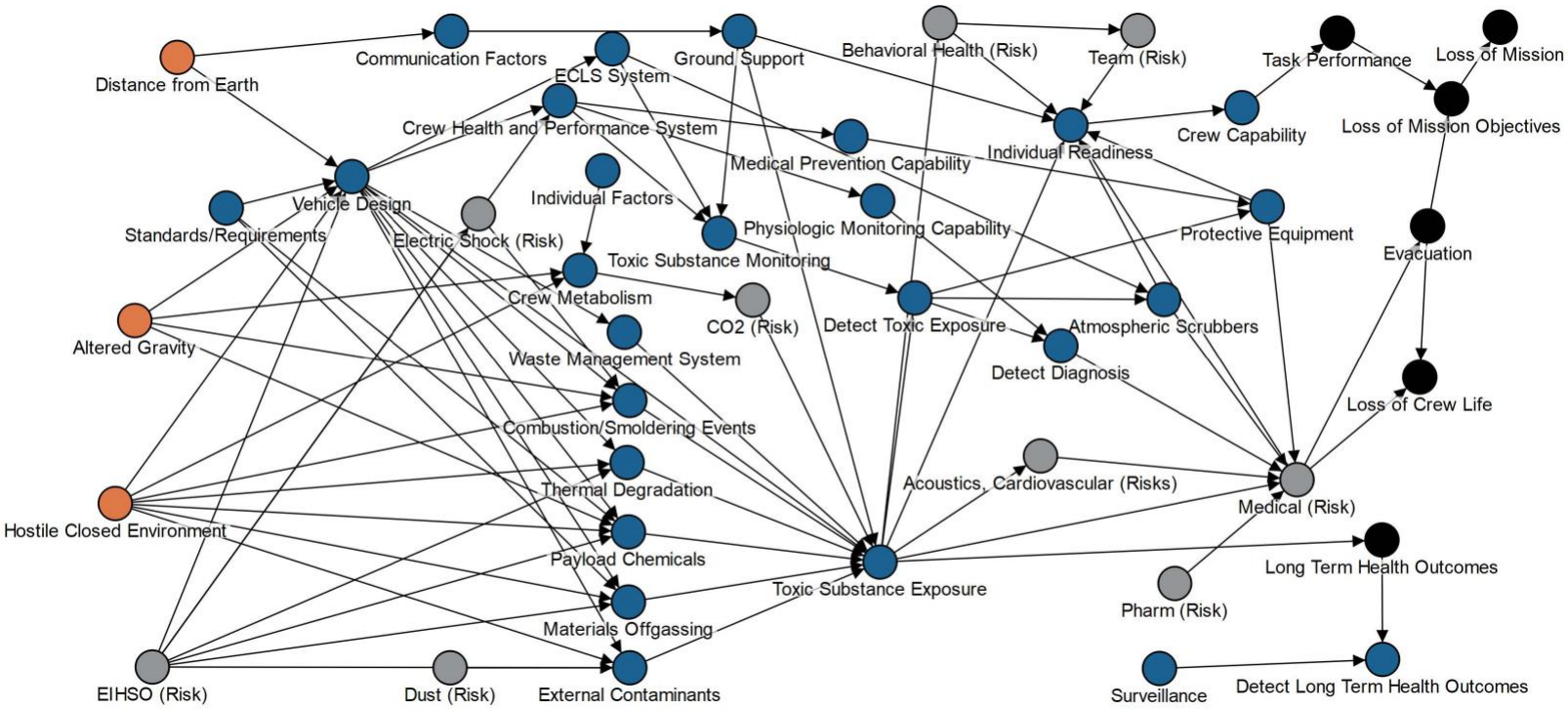
Toxic Exposure Directed Acyclic Graph – DAG (Narrative)

- Numerous sources of toxic substances on board spacecraft are impacted by the following hazards:
  - **Altered Gravity** increases the risk of exposure to floating particles and liquids, reduces dispersion of gases in areas that are not well ventilated, and results in greater difficulty capturing and removing a release.
  - A **Hostile Closed Environment** limits removal capabilities and increases exposure likelihood (small volume for gases and volatiles to fill).
- **Toxic Substance Exposure** depends on the release of toxic substances into the interior of the spacecraft or spacesuit, which can affect the health and performance of the astronauts. Exposure to toxic substances can be caused by the following:
  - **Crew Metabolism** results in the exhalation of carbon dioxide (**CO_2 Risk)**, which can reach toxic levels. Biovariability is determined by **Individual Factors.**
  - **Waste Management System** includes the above as well as chemicals used for neutralizing and cleaning waste from bodily functions.
  - **Combustion and Smoldering Events** have happened during spaceflight and can result in the release of carbon monoxide, weak acids, and other toxic substances. This is dependent, in part, on the **Electric Shock (Risk)**.
  - **Thermal Degradation** of heated materials such as non-combustible plastics that release toxic vapors into the local atmosphere.
  - **Payload Chemicals** that may be brought 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 **EIHSO (Risk).**
- If a **Toxic Substance Exposure** occurs, several pathways affect **Individual Readiness** and **Crew Capability**, including the following:
  - Some toxicants have cardiovascular toxicities—**Cardiovascular (Risk)**—that can lead to dysrhythmias and myocardial tissue damage.
  - Some toxicants are ototoxicants and can affect the **Acoustics (Risk)**.
  - Several toxicants can cause **Environmental Injuries** such as carbon monoxide poisoning or ammonia inhalation, which can occur from coolant release, and other **Medical (Risk)** issues that can lead to consequences such as **Evacuation**, **Loss of Crew Life** or **LTH Outcomes**.
  - Toxicants can also lead to decrements in **Behavioral Health (Risk)**, including altered mental status, and can affect **Cognitive Function** and **Psychological Status**, which can affect the **Team (Risk)**.
- If a **Toxic Substance Exposure** occurs, then the ability of the crew to mitigate the problem depends on the **Vehicle Design**, including the **Crew Health Care System/Crew Health and Performance System** and the Environmental Control Life Support **(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 Care System/Crew Health and Performance**

System.

- **Physiologic Monitoring Capability** can include biomarkers that identify the physiologic response of an astronaut who has been exposed to a toxic substance and can help **Detect Diagnosis** to tailor medical care, which is part of the **Medical (Risk)**.
- The effectiveness of medical interventions will, in part, depend on the **Pharm (Risk)** for **Pharmaceutical Effectiveness**.
- Historically the detection of vehicle system issues that can lead to **Release of Toxic Substances** has, in large part, depended on **Ground Support** from **Mission Control**. This support is available in low Earth orbit (LEO), but **Communication Factors** must be considered for DRMs that are more **Distance from Earth**. The need for increased crew autonomy during these missions may require increased monitoring capability to reduce the risk of toxic exposures.
- Some **Toxic Substance Exposures** can lead to **LTH Outcomes** such as cardiovascular, pulmonary, renal, and other medical conditions. **Surveillance**, such as occupational health surveillance after flight and post career, is critical to **Detect LTH Outcomes** and better characterize the magnitude of the LTH risks.


Distance from Earth
Communication Factors
ECLS System
Ground Support
Behavioral Health (Risk)
Team (Risk)
Task Performance
Loss of Mission
Crew Health and Performance System
Loss of Mission Objectives
Crew Capability
Medical Prevention Capability
Individual Readiness
Vehicle Design
Individual Factors
Standards/Requirements
Electric Shock (Risk)
Physiologic Monitoring Capability
Protective Equipment
Evacuation
Toxic Substance Monitoring
Crew Metabolism
CO2 (Risk)
Detect Toxic Exposure
Atmospheric Scrubbers
Altered Gravity
Waste Management System
Detect Diagnosis
Loss of Crew Life
Combustion/Smoldering Events
Thermal Degradation
Acoustics, Cardiovascular (Risks)
Medical (Risk)
Hostile Closed Environment
Payload Chemicals
Long Term Health Outcomes
Toxic Substance Exposure
Pharm (Risk)
Materials Offgassing
EIHSO (Risk)
Dust (Risk)
External Contaminants
Surveillance
Detect Long Term Health Outcomes