This Directed Acyclic Graph and write-up is an excerpt from a larger NASA document.

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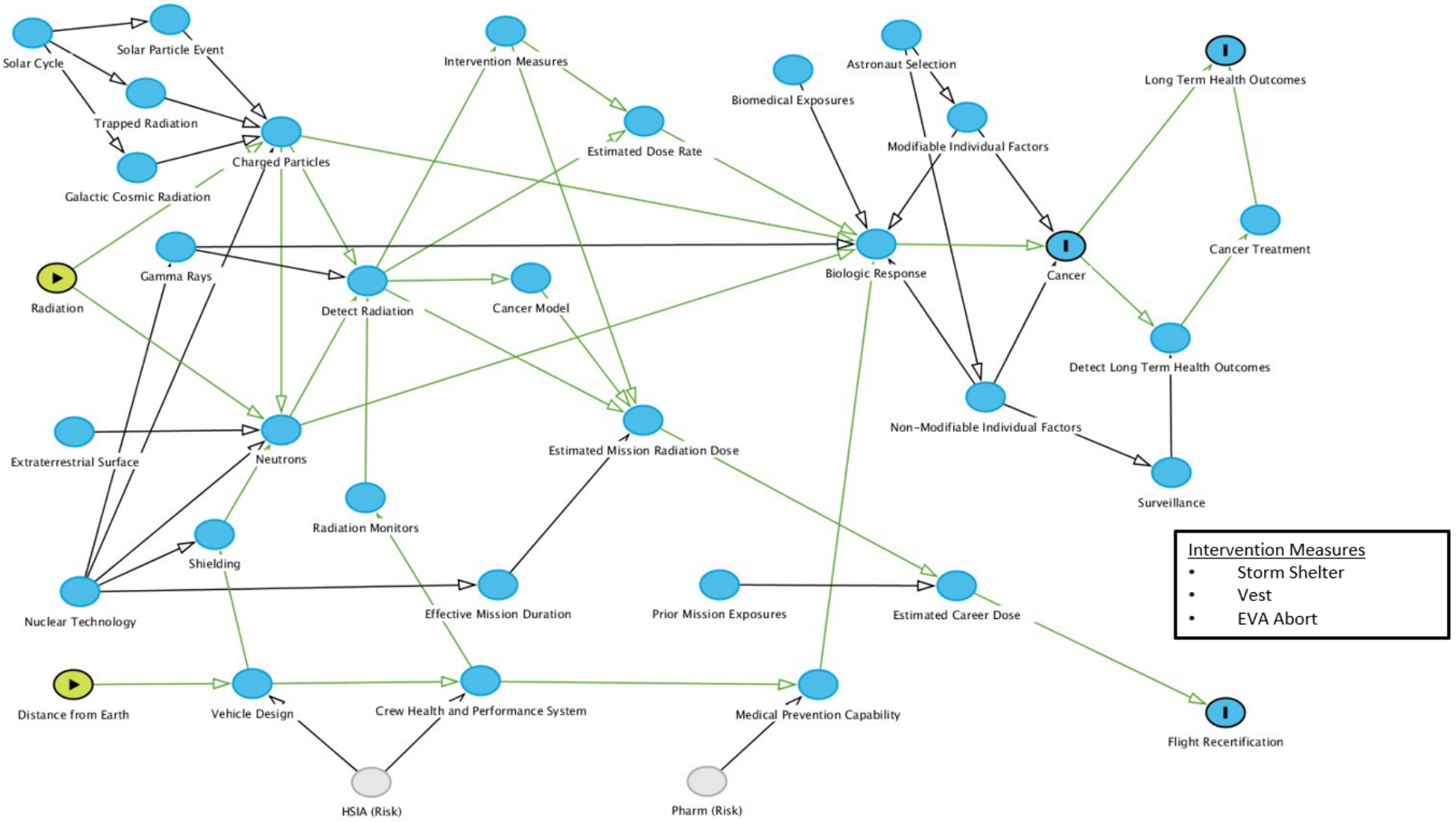
Directed Acyclic Graphs: A Tool for Understanding the NASA Spaceflight Human System Risks

Human System Risk Board

October 2022

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.