### Health Risks from Space Radiation

#### Risk of Radiation Carcinogenesis
- Melanoma and other cancers may occur for HUs.

#### Risk of Acute (in Flight) & Late Central Nervous System Effects
- Possible in-flight: altered cognitive function including short-term memory, reduced motor function, and behavioral changes, which may affect performance.

#### Risk of Cardiovascular Disease and Other Degenerative Tissue Effects
- Degenerative changes in the heart, vascular, and renal tissues.
- Chronic stress and aging, including cognitive, respiratory, pulmonary, gastrointestinal, and immune system function.

#### Risk of Acute Radiation Syndromes due to Solar Particle Events
- Prostration—emesis, vomiting, diarrhea, and pain.

#### Cardiovascular Disease and Other Degenerative Tissue Effects from Radiation

#### Risk of Degenerative Tissue Effects
- Arterial and microvascular changes.
- Diabetic complications.

#### Other Health Effects
- Disease-related aging, including cognitive, respiratory, pulmonary, gastrointestinal, and immune system function.

#### Driving Evidence
- **High Doses > 5 Gy**
  - **Radiotherapy Data**
    - High doses (>5 Gy exposures) associated with damage to the structures of the brain and to the coronary, central, and peripheral arteries including mental affluence, mental damage, especially of the pericardium and myocardium, coronary artery obstruction, microvascular damage of the distal arteries and stenosis of the arteries in patients receiving RT as well as in experimental animals (Little, 2013).
    - **Deterministic effect (tissue reaction)**
    - **Mechanisms** involving cell killing or inactivation of a large number of cells—functional impairment.

- **Moderate Doses 0.5 - 5 Gy**
  - **Life Span Study, Clinical, and Occupational Exposures**
    - Moderate doses (0.5 - 5 Gy exposures) associated with aftereffects, organ, and microvascular damage.
    - Possibly a stochastic reaction.
    - Mechanisms may involve inflammation and oxidative stress, endothelial dysfunction/atherosclerosis.
    - **Low Doses < 0.5 Gy**
      - **Meta-Analysis of Low Dose Studies**
        - Low doses (<0.5 Gy) associated with systemic effects, severe microvascular damage.
        - Possibly a stochastic reaction.
        - Mechanisms may involve non-targeted effects, kidney dysfunction, monocytic dysfunction.
      - **Confounding effects are large**
      - Although mean cumulative radiation doses were ≤0.2 Gv in most of studies, the small numbers of participants exposed at high cumulative doses (≥0.5 Gy) drive the observed trends in most cohorts with these higher dose groups.

#### Low Dose Confounders & Uncertainties
- **Suggests increased risks for IHD and non-IHD heart diseases**
- Data suggest that circulatory disease risk is significantly elevated only for acute or cumulative doses of about 0.5 Gy and above—data is not statistically significant at lower doses.

#### Dose Rate Effects
- **Tuberculosis patients in Canadian Fluoroscopy Cohort Study**
  - 8370 patients (91% unexposed, 9% ≤0.5 Gy, mean dose=0.79 Gy)
- **ER/Gy:0.17 for IHD after adjustment for dose fractionation. ER/Gy:0.143 for doses >0.5 Gy**
- **Highest risks were for those with lowest fluoroscopy procedures per year**

#### Potential Mechanisms of Radiation-Induced CVD
- **Cardiovascular and circulatory changes**
  - **2013**
  - Impact of heavy ions largely unknown
  - **Cataract formation**
  - Deterministic effect
  - **2030 and beyond:** 6 and correlated tissue damage
  - **40 weeks**
  - Mechanisms may involve
  - Possibly a stochastic
  - Data at low doses is
  - **Outside Earth’s magnetosphere and radiation belts**
  - Distinct patterns of DNA damage
  - **Design Reference Mission currently being formulated**
  - In most of studies, the
  - Cause
  - Mechanisms involve
  - Damage and stenosis of the
  - Synergistic modifiers of risk
  - Although mean cumulative radiation doses were ≤0.2 Gy in some studies, the small numbers of participants exposed at high cumulative doses (≥0.5 Gy) drive the observed trends in most cohorts with these higher dose groups.
  - **IHD heart disease subtypes. Red line shows aggregate random effects model of radiation on IHD heart disease risk (Apley et al., 2013)**
  - **Risk Mitigation Strategy**
  - **Evidence**: \( P \leq 0.05 \), \( P > 0.05 \), \( P < 0.05 \)
  - **Characterization**: \( \leq 0.5 \), \( > 0.5 \), \( < 0.5 \), \( > 0.5 \)
  - **Modeling**: \( \leq 0.5 \), \( > 0.5 \), \( < 0.5 \), \( > 0.5 \)

#### DEGEN RISK SUMMARY
- **Association between exposure to high doses of low-LET (≤5 Gy) radiation during radiotherapy to the chest and increased risk for development of cardiovascular disease at late times post-exposure is clearly established**
- **Other stressors** associated with cardiovascular diseases include diabetes, obesity, increased blood pressure, smoking, and infections.
- **Low Dose Exposures**
  - **Data at low doses is confounded by lifestyle factors, diabetes, hypertension, and smoking**
  - **Recent evidence showing risk at low doses questions this assumption**
  - **Dose rates are considered deterministic, with an associated threshold dose; however, recent evidence showing risk at low doses questions this assumption**
  - **Hypothetical mechanisms of radiation-induced CVD**
  - **Co-medication with radiation therapy does not appear to affect risk; however, the risk is still higher for those with low doses**
  - **Lack of evidence on radiation quality, disease spectrum, latency and dose rate at low levels of exposures**
  - **The additional morbidity and mortality risks for non-cancer diseases of the cardiovascular system are major concerns because they could increase RVD substantially**