

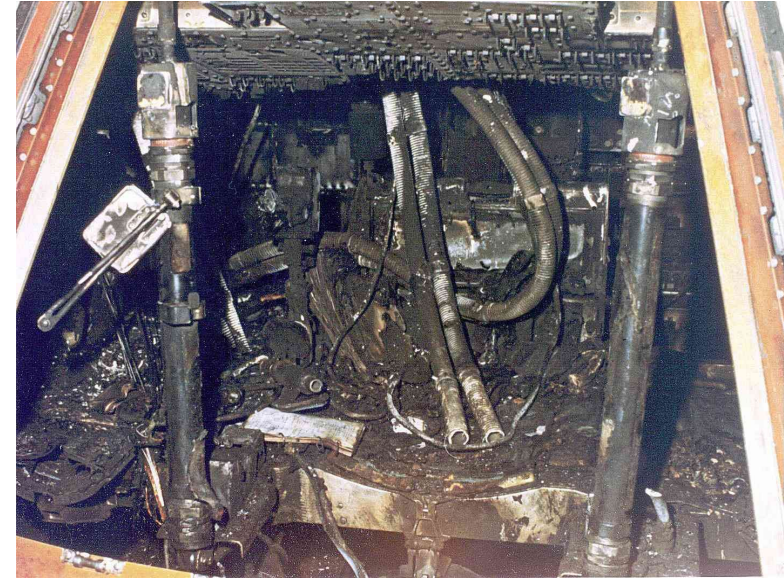
PHYSIOLOGIC CHANGES, INJURIES, AND FORENSIC CONSIDERATIONS ASSOCIATED WITH HUMAN SPACEFLIGHT - A REFERENCE GUIDE

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INTRODUCTION

- Notable Federal Spacecraft Mishaps
 - Apollo 1 (NASA)
 - Soyuz 11 (ROSCOSMOS)
 - Space Shuttle Columbia (NASA)
 - Space Shuttle Challenger (NASA)
- FAA requirements under 14 CFR 450
- Notable Commercial Spacecraft Mishaps
 - Virgin Galactic Spaceshiptwo
- Terrestrial ≠ Aviation ≠ Spaceflight



METHODS



Results

Section 1: General Considerations

1. Mishap Site Hazard Considerations
2. Mishap Site Remains and Autopsy Considerations
3. Predation

Section 2: Spaceflight Physiologic Changes Impacting Forensic Investigation

1. Neurological
2. Cardiovascular
3. Muskuloskeletal
4. HEmatologic & Immunologic
5. Renal & Electrolytes
6. Endocrine
7. Radiation

Section 3: Unique Injury/Illness Mechanisms in Spaceflight Accidents

1. Loss of Pressure
2. Mechanical
3. Thermal
4. Toxicological

147 Total Sources Utilized

EXAMPLE

3.3.2 Smoke and Fire

- I. General Principles
 1. Some spaceflight vehicles/suits utilize oxygen-rich environments within the crew cabin, which increase the risk of fire. Additionally, electronic apparatus and experiments may provide a source of heat and fire.¹⁶
- II. Forensic Implications for Mishaps
 1. Due to decreased air circulation in microgravity, smoke or other harmful gases may form “pockets” in which they are highly concentrated.¹²
 2. Smoke can include toxic substances such as cyanide and carbon monoxide (CO).⁷
 3. Smoke inhalation injury can be assessed through lung histopathology. The presence of significant burns without lung damage may indicate exposure to high temperatures without concomitant exposure to smoke.⁷
- III. Related Accident Reports
 1. Fires aboard the Mir space station caused increased CO and carboxyhemoglobin levels within the cabin. Headaches and nausea were reported by one crew member.⁹⁷
 2. Fire inside the Apollo 1 capsule lead directly to carbon monoxide poisoning and death of the three crewmembers. The fire was later found to be due to an electrical fire which was propagated by an internal nylon material and high oxygen atmosphere.⁹⁴

Findings & Recommendations

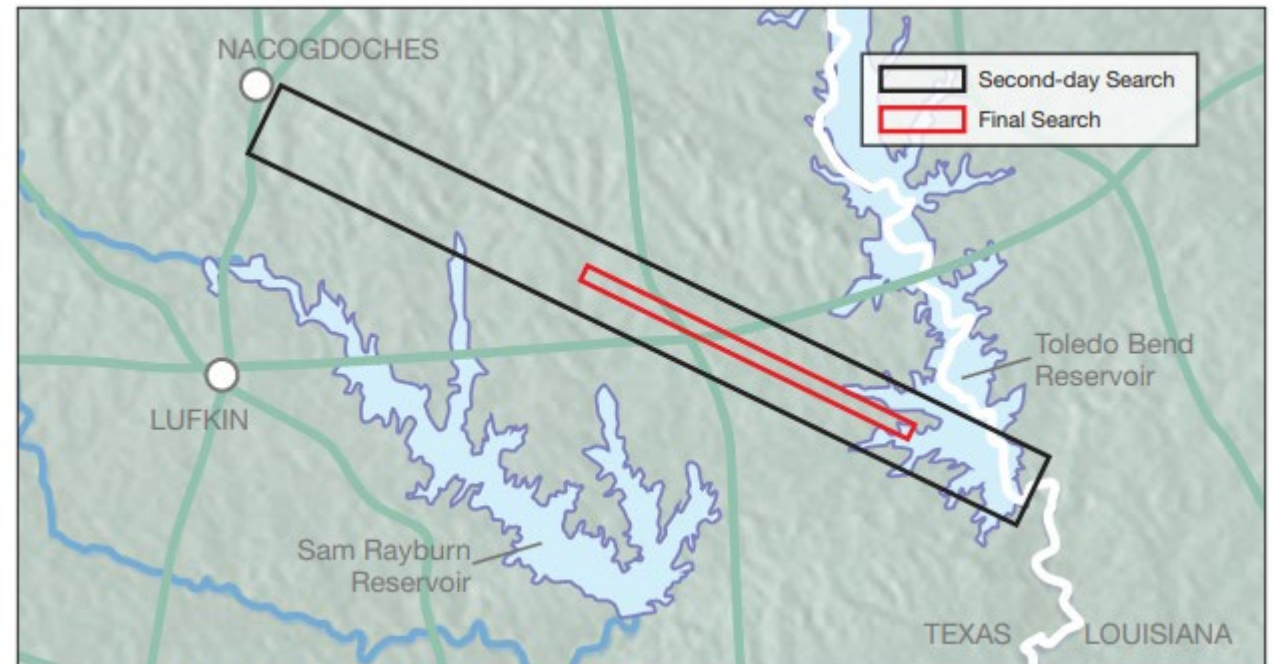
Major Forensic Differences Highlighted by Participants
Unique skin changes caused by ebullism, shock-shock interaction, molten metal depositions and extreme hypobaric and temperatures.
Unique respiratory damage due to ebullism
Remains subjected to extremes of temperature
Deposition of molten metal onto the remains
High kinetic energy causing limbs to be separated by flail and deposited miles from each other due to the high altitude and trajectory when the incident occurred.
Bubbles from ebullism in every tissue: brain, spinal cord, muscle, fat, lungs, heart.
Hollow organ expansion and overpressure from gas expansion (Boyle's Law)
High thermal followed by cold exposure once entering the atmosphere.
Exam and evidence extend beyond cause and manner
Changes in tissues brought about by prolonged exposure to microgravity
Need for temporal association of when injuries occurred to help mishap investigation
Potential differences in usual markers of death (livor mortis, algor mortis) due to space environment

Findings & Recommendations

- Recommended Specimen Collection
 - 100 mL urine
 - 100 g gastric contents
 - 300 g liver
 - 200 g kidney
 - 100 g heart
 - 200 g lung
 - 200 g spleen
 - 200 g brain
 - 200 g skeletal muscle
- If Autopsy Not Available
 - Vitreous Humor
 - Cardiac Blood
 - Urine from the bladder

Findings & Recommendations

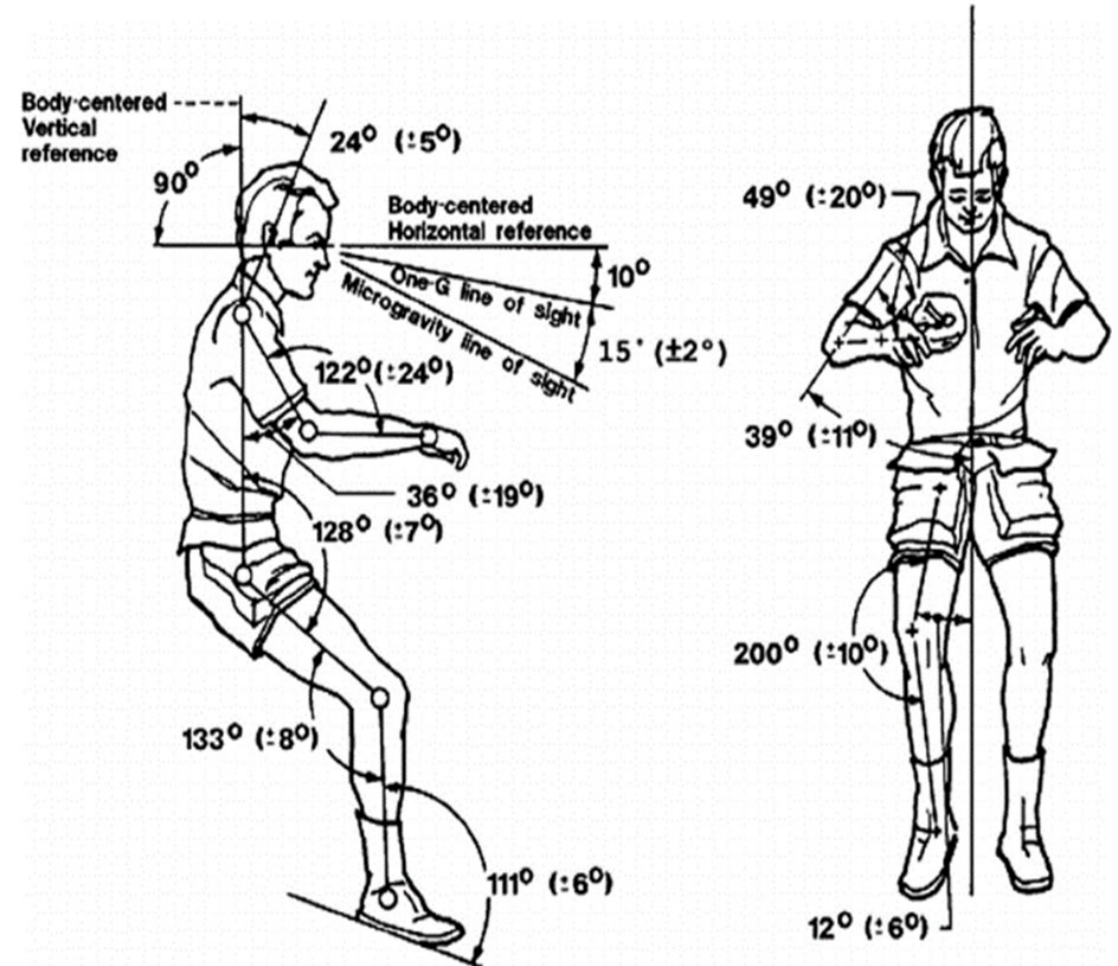
- Autopsy Considerations
 - Identification
 - Body Imaging
 - Predation



Second-day Search Area (60 mi x 5 mi) and Final Search Area (25 mi x 1 mi).

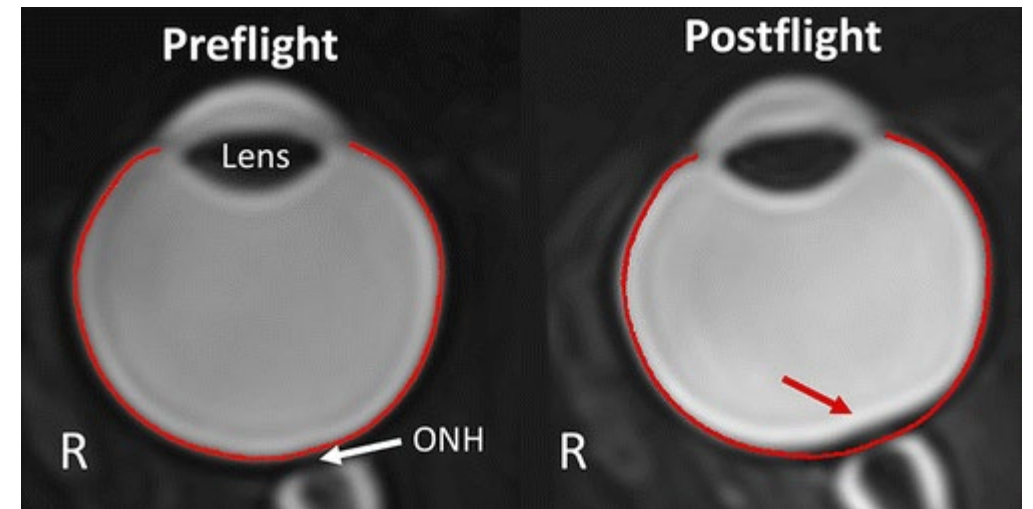
Findings & Recommendations

- Microgravity Neutral Position
 - Rigor Mortis
 - Livor Morits
 - Algor Mortis



Findings & Recommendations

- Spaceflight Associated Neuro-Ocular Syndrome (SANS)
 - Optic Disc Edema
 - Posterior Globe Flattening
 - Hyperopic Shift
 - Chorioretinal Folds
- Mechanism of Action?



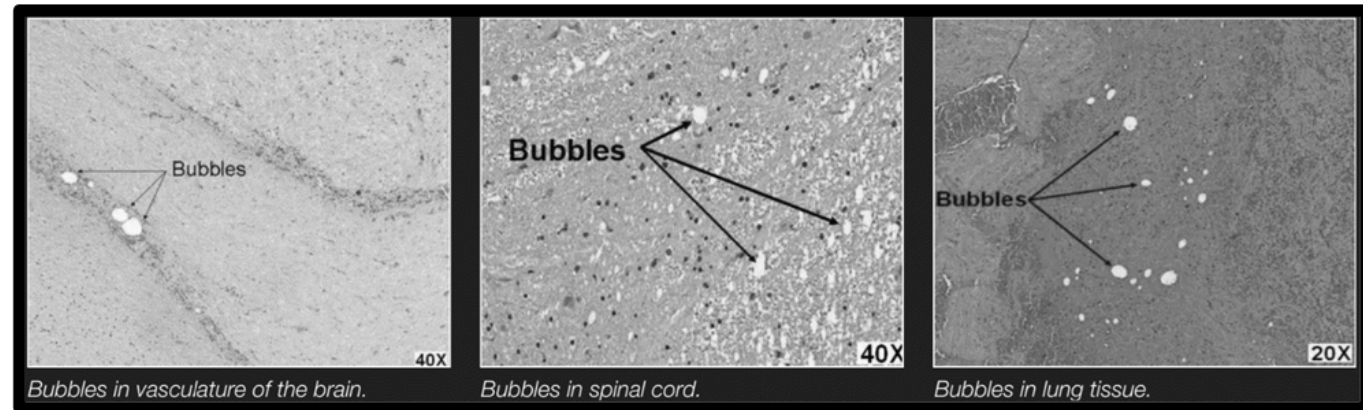
Findings & Recommendations

- Skeletal Changes
 - 1-2% BMD loss per month
 - Prominently in Femoral Trochanter and Neck, Pelvis and Lumbar Spine
 - Trabecular > Cortical
- Muscular Changes
 - 20% reduction in muscle mass
 - Prominently in the Quadriceps, Gastrocnemius, and Posterior Back muscles
 - Extensors > Flexors
- Available Countermeasures



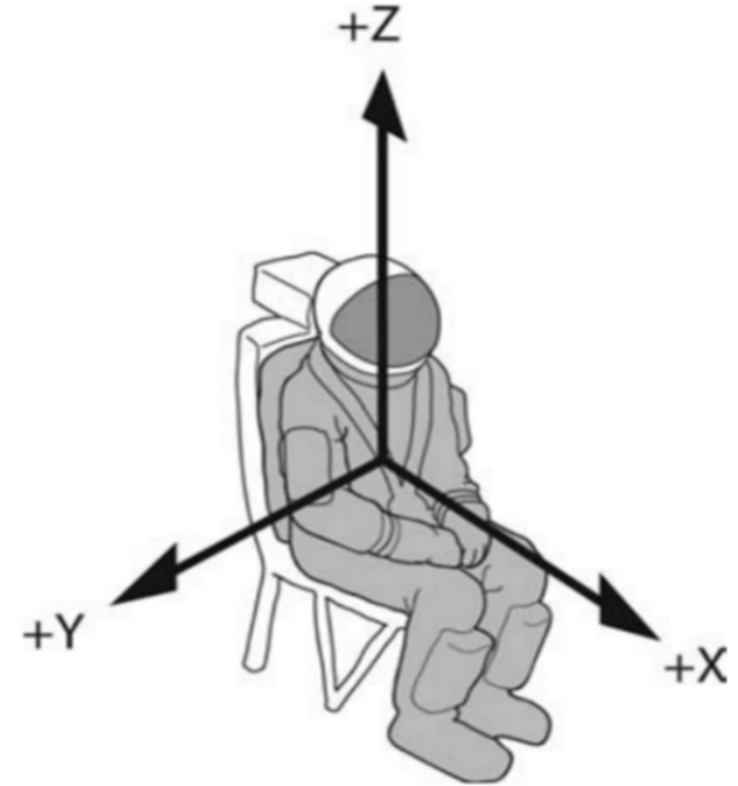
Findings & Recommendations

- Boyle's Law
 - Rapid Gas Expansion in Cavities
- Henry's Law
 - Decompression Sickness
- Armstrong's Line (63K Feet)
 - Ebullism
- Related Accident Reports
 - Soyuz 11
 - Space Shuttle Columbia



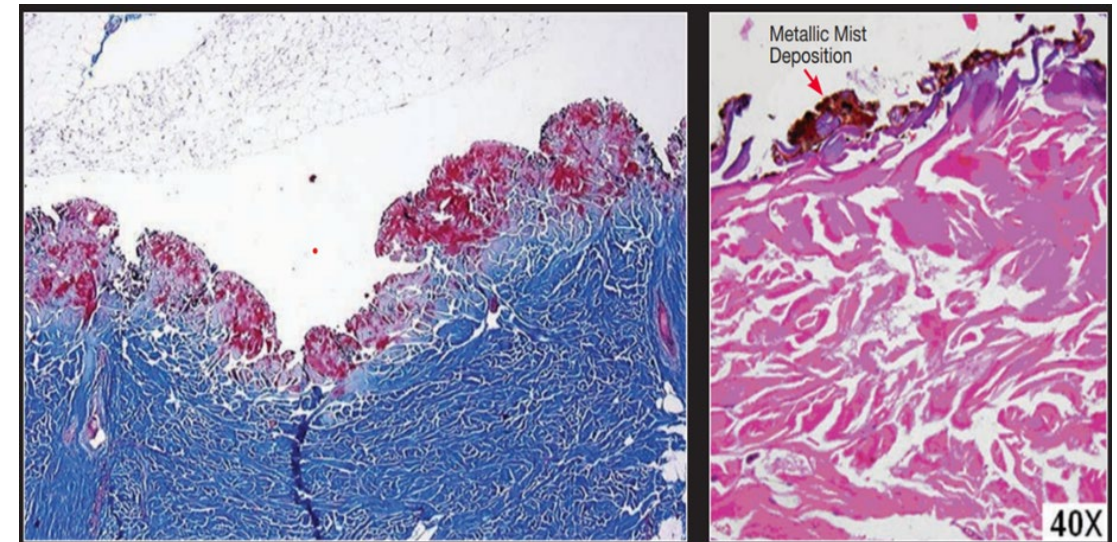
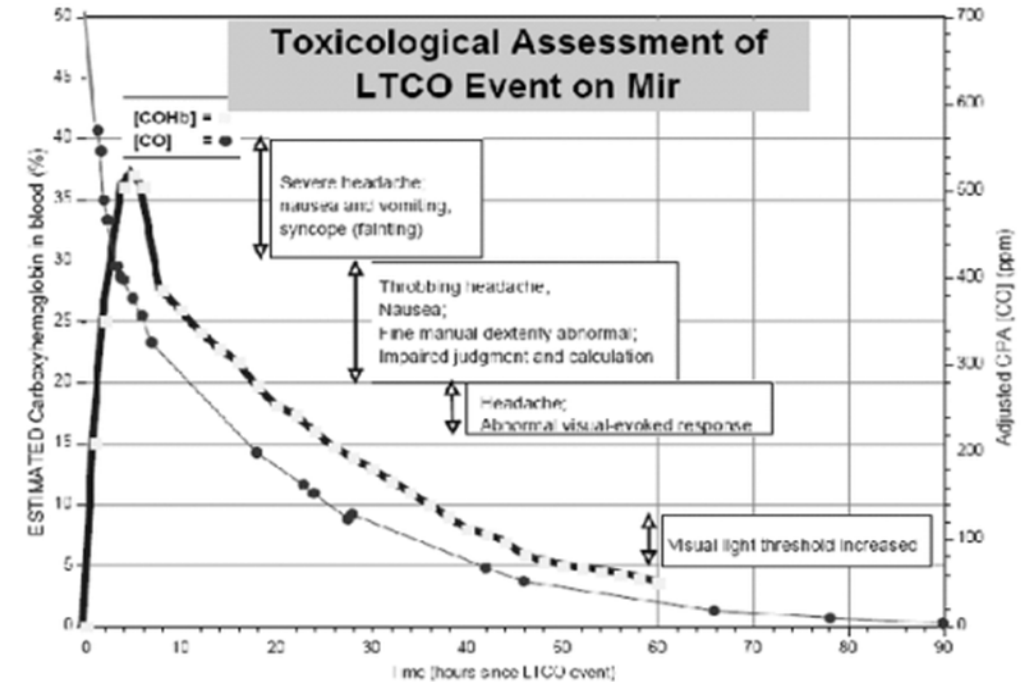
Findings & Recommendations

- Spaceflight Acceleration
 - G Tolerances
 - Transient Vs Sustained Acceleration
 - Axis-Specific Considerations
 - Flail
 - Bracing Injuries
- Spaceflight Specific Considerations
 - Helmets



Findings & Recommendations

- Smoke and Fire
 - Oxygen Rich Environment
 - Carbon Monoxide Pockets
 - MIR Space Station Fire
 - Apollo 1 Fire
- Molten Metal
 - High temperature mishaps
 - Space Shuttle Columbia



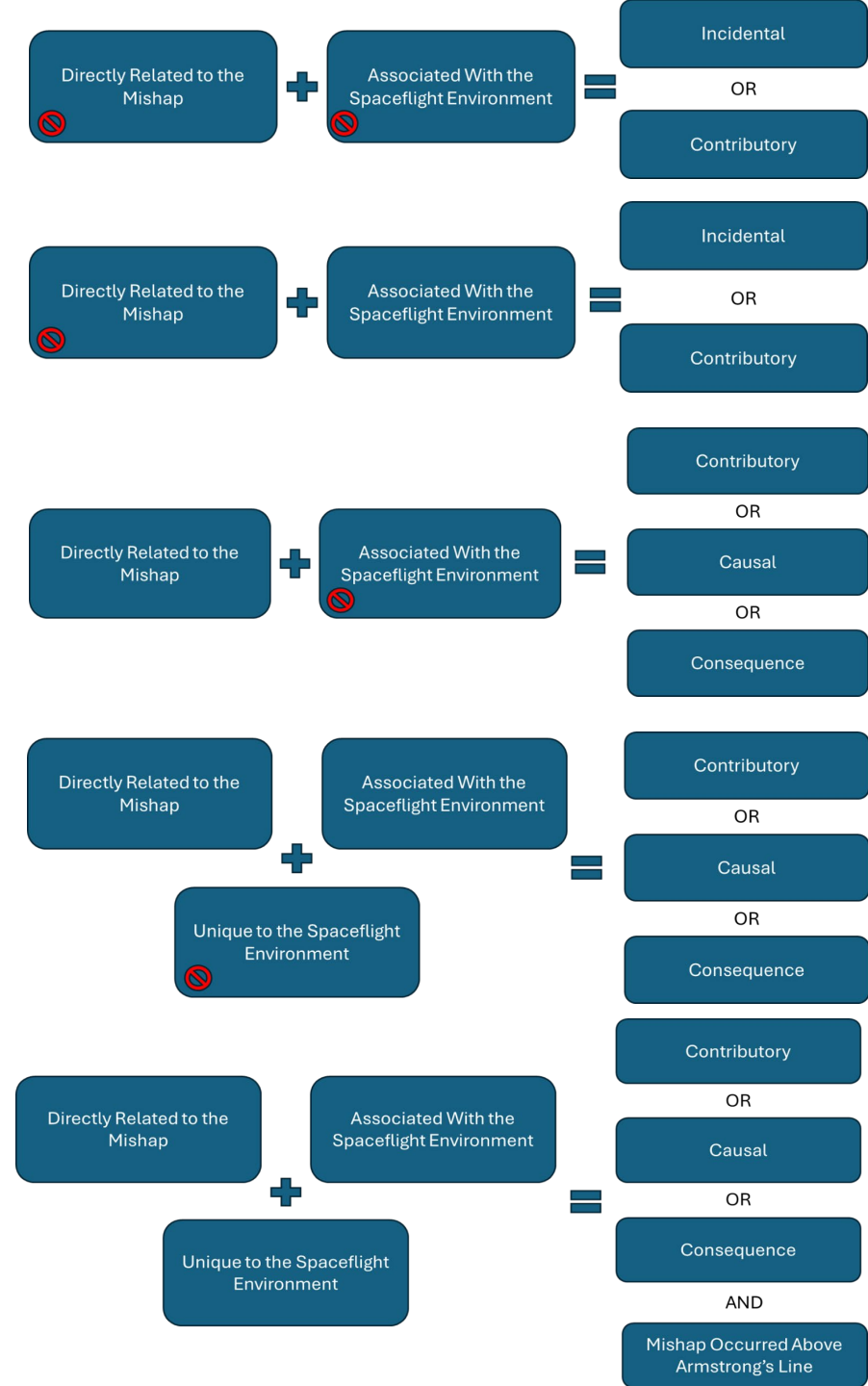
Findings & Recommendations

- Toxicological
 - CO₂
 - Fuels
 - Methane
 - Nitrogen Tetroxide
 - Hydrazine
 - Lithium Hydroxide
 - Anhydrous Ammonia



Discussion

- Framework through which findings can be interpreted:
 - Unrelated or contributory
 - Unrelated or contributory
 - Contributory, causal, or resulting from the mishap
 - Contributory, causal, or resulting from the mishap
 - Contributory, causal, or resulting from the mishap, mishap occurred above Armstrong's line



Discussion

- The Human Body and the Vehicle External Environment
 - Incomplete Protection
 - Off-nominal Events
 - Environmental Control Systems
- Expanding the knowledge of the Medical Examiner



Questions?



THANK YOU

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