Probabilistic Risk Assessment of a Sustained Lunar Presence

A discussion of PRA techniques used in evaluating the operational risks of a sustained lunar presence

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Introduction

- **“Beginning with missions beyond low-Earth orbit, the United States will lead the return of humans to the Moon for long-term exploration and utilization, followed by human missions to Mars and other destinations”**
  - Space Policy Directive 1, December 11, 2017
- **Long term Human Exploration of new environments leads to new challenges in understanding the risks to the safety of the crew and science.**
- **How can Probabilistic Risk Assessment (PRA) help to understand the risk of this mission profile and what techniques can we use to better manage the risk?**

BASTION TECHNOLOGIES

Probabilistic Risk Assessment (PRA) at NASA

- **PRA is used by NASA to "understand and effectively manage risk, and thus more effectively ensure mission and programmatic success, and to achieve and maintain high safety standards at NASA"**
  - From PRA practitioners guide
- **NASA PRA methodology is similar to methodologies used in several high-risk industries (nuclear, oil & gas, medical) to quantify risks throughout the lifecycle.**
- **NASA has extensive experience in use of PRA to understand Loss of Mission (LOM) and Loss of Crew (LOC) quantitative risk for the shuttle program, International Space Station, Constellation, Orion, Space Launch System, and the Human Lander System.**
- **This methodology, along with expert solicitation, is also used to support mission risk acceptance by decision makers.**

How Does NASA's PRA Usage Differ from Industry?

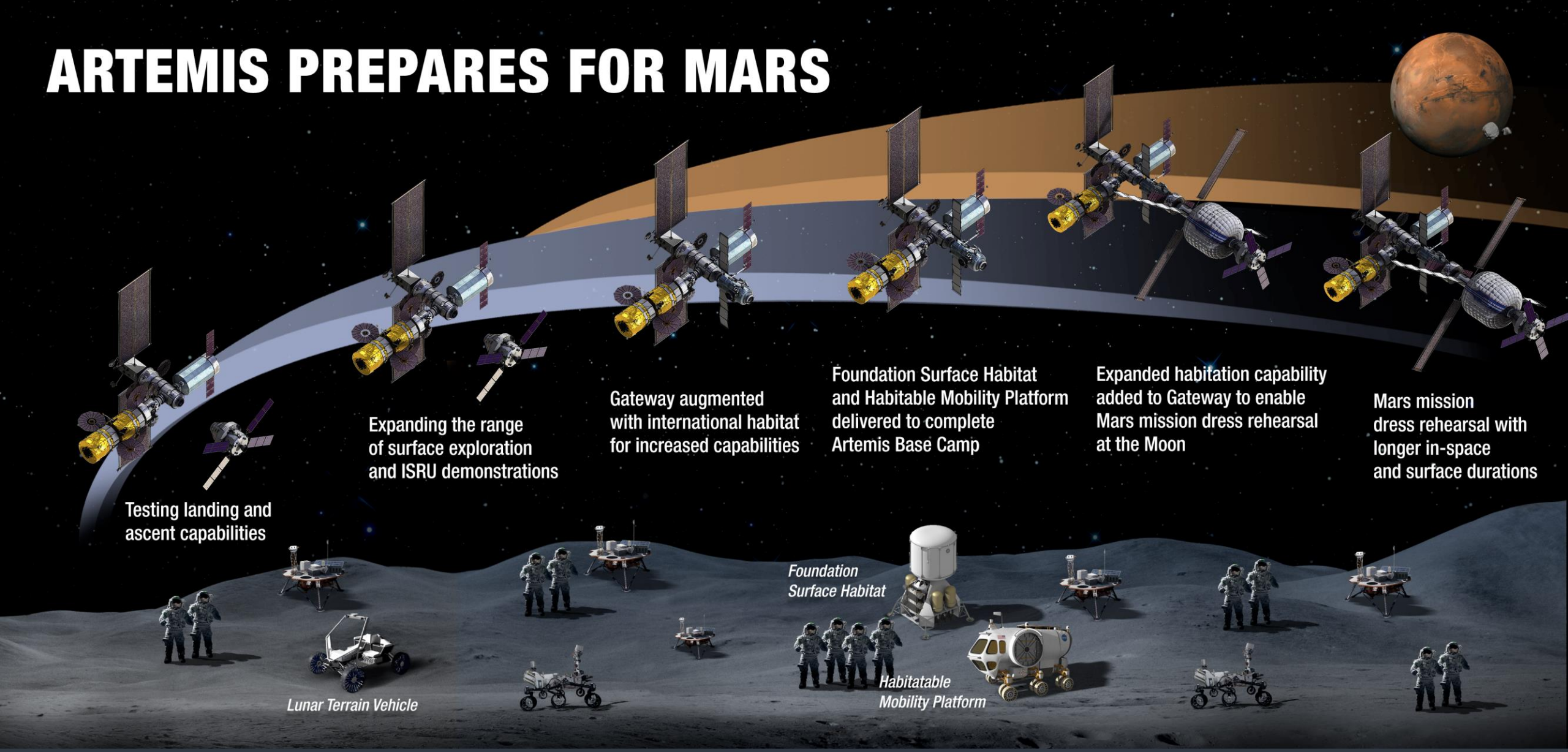
- **Nuclear plants have multiple trains of safety related systems, with some systems providing backup capability to functions of others. While single point failures exist, focus is on defense-in-depth and maintenance.**
  - Example: Several plants have multiple ways to inject boricide in the reactor coolant system, with cross ties and operator action. The main responsibility falls to a single system.
- **Space systems typically have limited redundancy due to mass constraints. Components often support a single system function and lack defense in depth. Therefore, PRAs for space systems are often focused on single point failures.**
  - Limited test data is available in the given environmental conditions (lunar gravity, dust, solar radiation, etc.)

BASTION TECHNOLOGIES

What does a Sustained Lunar Presence look like?

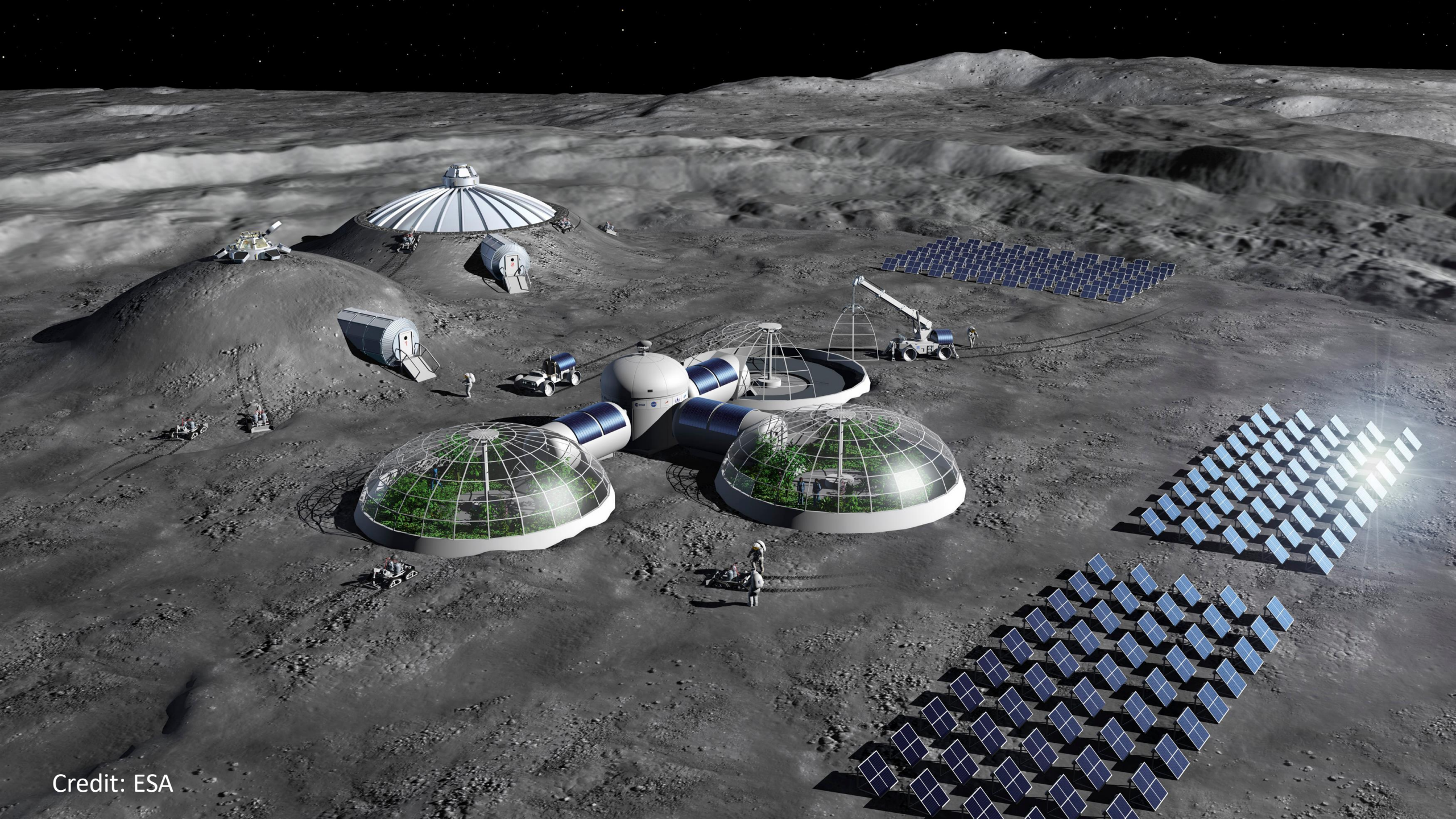
- **NASA's Human Exploration architecture includes an Artemis Base Camp at the South Pole of the Moon.**
  - Advantages to South Pole Location
- **Will be the first sustainable foothold on the lunar frontier, with one to two-month stays to learn more about the Moon and the universe.**
  - NASA's Plan for Sustained Lunar Exploration and Development
- **In future Artemis missions, Gateway will establish U.S. leadership and a sustained presence in the region between the Moon and Earth, offering astronauts easier crew returns, a safe haven, ability to navigate to different orbits, and advancement in human life support systems.**

ARTEMIS PREPARES FOR MARS



SUSTAINABLE LUNAR ORBIT STAGING CAPABILITY AND SURFACE EXPLORATION

MULTIPLE SCIENCE AND CARGO PAYLOADS | INTERNATIONAL PARTNERSHIP OPPORTUNITIES | TECHNOLOGY AND OPERATIONS DEMONSTRATIONS FOR MARS



Credit: ESA

Challenges

- **Lunar Base Camp will need water, power, shelter, waste disposal, and landing pad.**
- **Will consist of a combination of surface habitats, mobile platforms, and cargo landers.**
  - # of launches, launch vehicles types, staging orbits, and different mission profiles will all factor into risk acceptance.
- **Emphasis on lunar infrastructure, similar to the International Space Station (ISS).**
  - Systems will be under continuous use.
- **PRA will be one of the tools used by NASA to understand key drivers of LOC and LOM risk and to influence the evolving architecture to mitigate the risks**

The Unknowns

- **Long term effects of lunar dust to equipment reliability (modified bathtub curve) and human error.**
  - "I think dust is probably one of our greatest inhibitors to a nominal operation on the Moon. I think we can overcome other physiological or physical or mechanical problems except dust“; Apollo 17 Commander Gene Cernan Technical Debrief
  - “The more time you spend there, the more you get covered from helmet to boots with lunar dust”; Apollo 11 Astronaut Buzz Aldrin
  - Lunar dust caused Apollo 17's Harrison "Jack" Schmitt’s cartilage plates in the walls of his nasal chambers to swell
- **Lunar Day/Night Cycle**
  - Temperature Cycle: 100°C to -173°C [212°F to -279°F]
  - Power generation
  - Temperature cycles
  - Somewhat mitigated in the lunar south pole (near constant position of the sun)
- **Long Term Human Physiology effects on Human Error Analysis**
- **New Environmental Hazards; MMOD; Radiation; Long term effects of solar storms on reliability**

Lessons Learned: Lunar Dust

- **Effects of desert dust on machine reliability**
  - Effects of abrasive paste, sand & lubricant, is mitigated through preventive maintenance (keep sand out of maintenance areas, frequent oil changes, correct viscosity of oil, filters, etc.) Some components experience reduced operating life (e.g., rotor heads)
- **Particle ingression leads to contact fatigue, spalling, pitting, brinelling and cratering**
- **No erosion on the Moon**
- **ISS Design philosophy was to use high reliability components. Dust will affect reliability/failure rates, therefore there is a need for "design for maintainability"**
- **<u>Takeaway: Systems level PRAs will need to correct for reduced reliability in active components.</u>**

Lessons Learned: Aging Management

- **Management of aging effects are used in both risk-based well integrity analyses as well as extended-life programs of nuclear power plants. Aging Management Programs are used at nuclear power plants to allow for operation past their original design life and manage the aging mechanisms to increase availability.**
  - Aging effects include stress-corrosion cracking, acid corrosion, abnormal wear
- **Over time, increased monitoring may be needed but could be used initially to manage risk of highly degradative mechanisms (MMOD damage, lunar dust)**
- **<u>Takeaway: Monitoring programs can help decrease uncertainty of system operations.</u>**

Conclusion

- By looking to lessons learned and operational experience from NASA's prior use of PRA, as well as it's use within other industries, PRA can be used to understand risks associated with complex Artemis missions.
- Not every risk can be quantified prior to the mission.
- As we learn more about extraterrestrial system operations and working in a lunar environment, we can use those experiences and apply them for a successful mission to Mars.

References

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