Radiation Risk Management on Human Missions to the Moon and Mars

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Outline

- Background
- Systems Approach to Radiation Risk Management
- Conclusions/Observations

Space radiation poses a significant risk to astronauts embarking on exploration missions to the Moon and Mars. Meeting the challenge will involve the space physics research community as well as the mission planning and operations communities. This talk gives an overview of the radiation risk and discusses a systems architecture approach to reduce the risk. A key conclusion is that work must begin now to lay the groundwork necessary to ensure the appropriate space weather network is in place before humans return to the Moon by 2018.

The Myths, the Grail, the Reality

Solar Particle Events are killers

All you need is modest shielding

We'll never be able to forecast SPEs

We must have a far side solar observatory

The Myths, **the Grail**, the Reality

- **Science-based understanding and appropriate observations enabling operationally robust models forecasting the space environment in a timely fashion...**
- **...Contributing to an overall risk mitigation architecture that includes**
  - **Adequate shelter,**
  - **Effective radiation monitoring,**
  - **Reliable communications, and**
  - **Integrated mission planning and operations concepts**
- **...To ensure the safety of astronauts throughout the various phases of missions planned for the space exploration vision**

The Myths, the Grail, **the Reality**

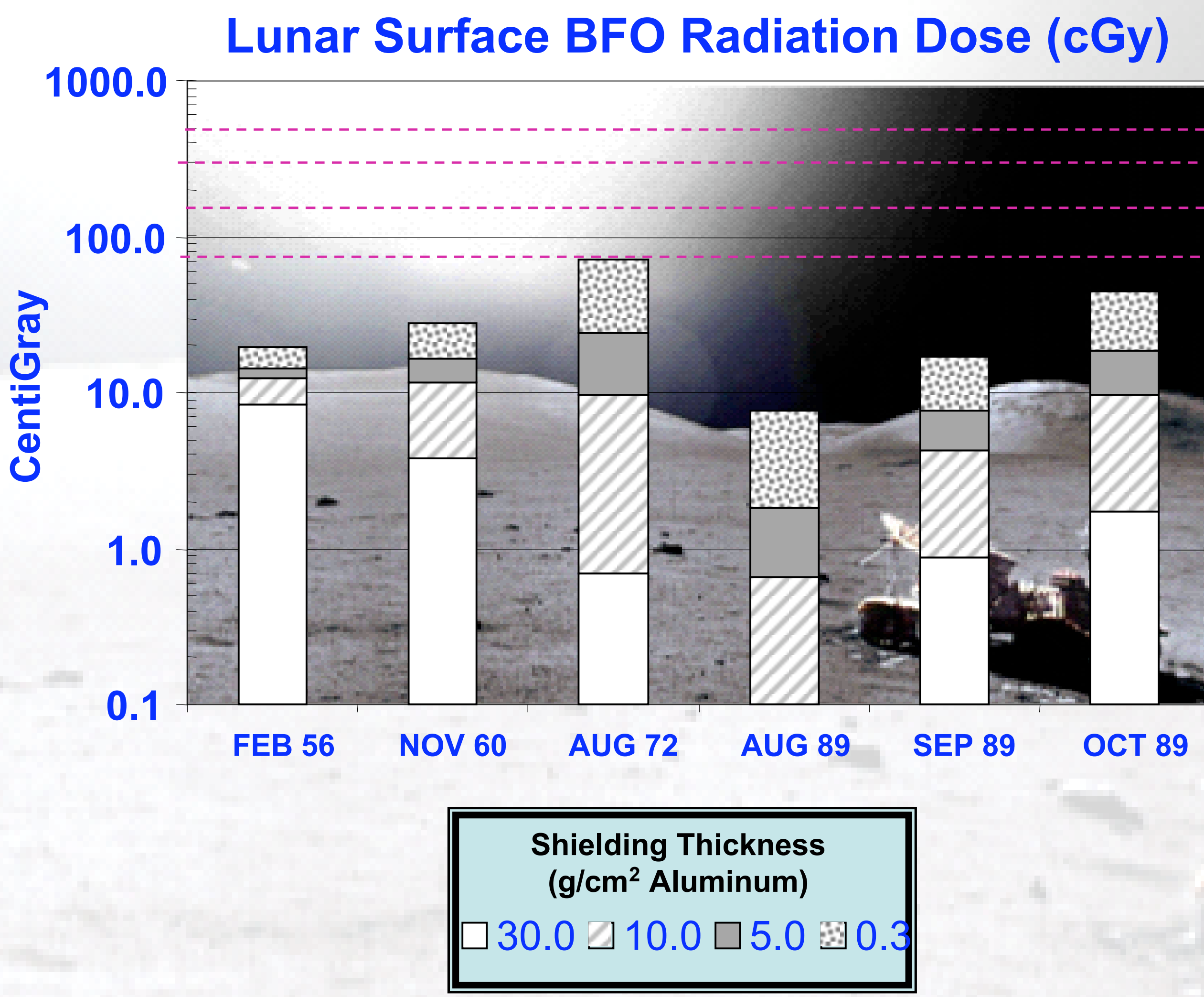
- **Each component of a risk management strategy must contribute to enhanced safety of the astronauts on exploration missions**
- **There is only one more solar cycle before humans return to the Moon**
- **The transition from research to operations is not easy**
- **Funding will always be limited**

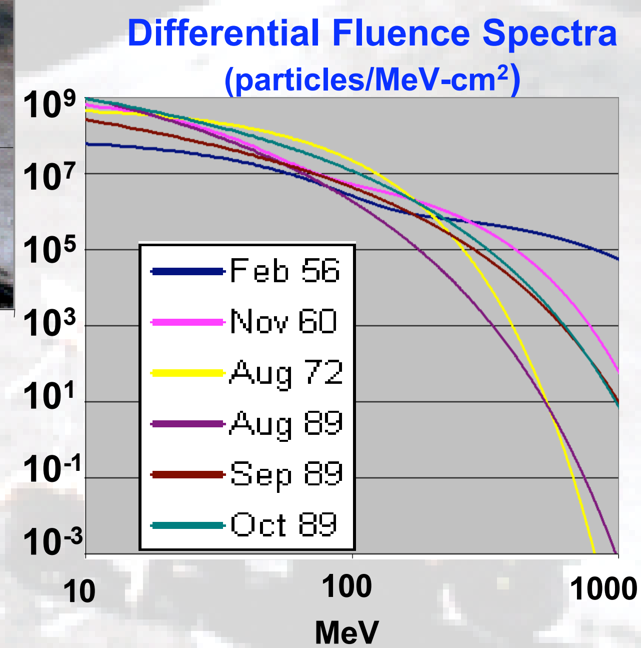
It is not clear who is in charge of the overall effort

Communities?

- Vision
- Funding levels
- Planners
- Developers
- Operators
  - Mission Control
  - Astronauts
  - Forecast Centers
- Science
  - Space Physics
  - Space Weather
  - Life Science

How Bad Can an SPE Be?
Selected Historical Events





Radiation Risk Mitigation Objective

Top Level Requirement

NASA has a legal requirement to establish radiation limits

Any mission must be designed to ensure that radiation exposures do not become comparable to these radiation limits

System Level Requirements

Reduce the impact of the radiation environment enough to achieve the top level requirement

Forecast the radiation environment with adequate timeliness to take appropriate actions

Potential Elements of an SPE Risk Mitigation Architecture

Detection/Forecast

Active and passive dosimeters, dose rate monitors

In situ particle, plasma monitors

Solar imagers, coronagraphs

Remote sensing of plasma properties

Forecast models, algorithms

Data/information communications infrastructure

Reduction

Active and Passive shielding

Storm shelters

Operational procedures, flight rules

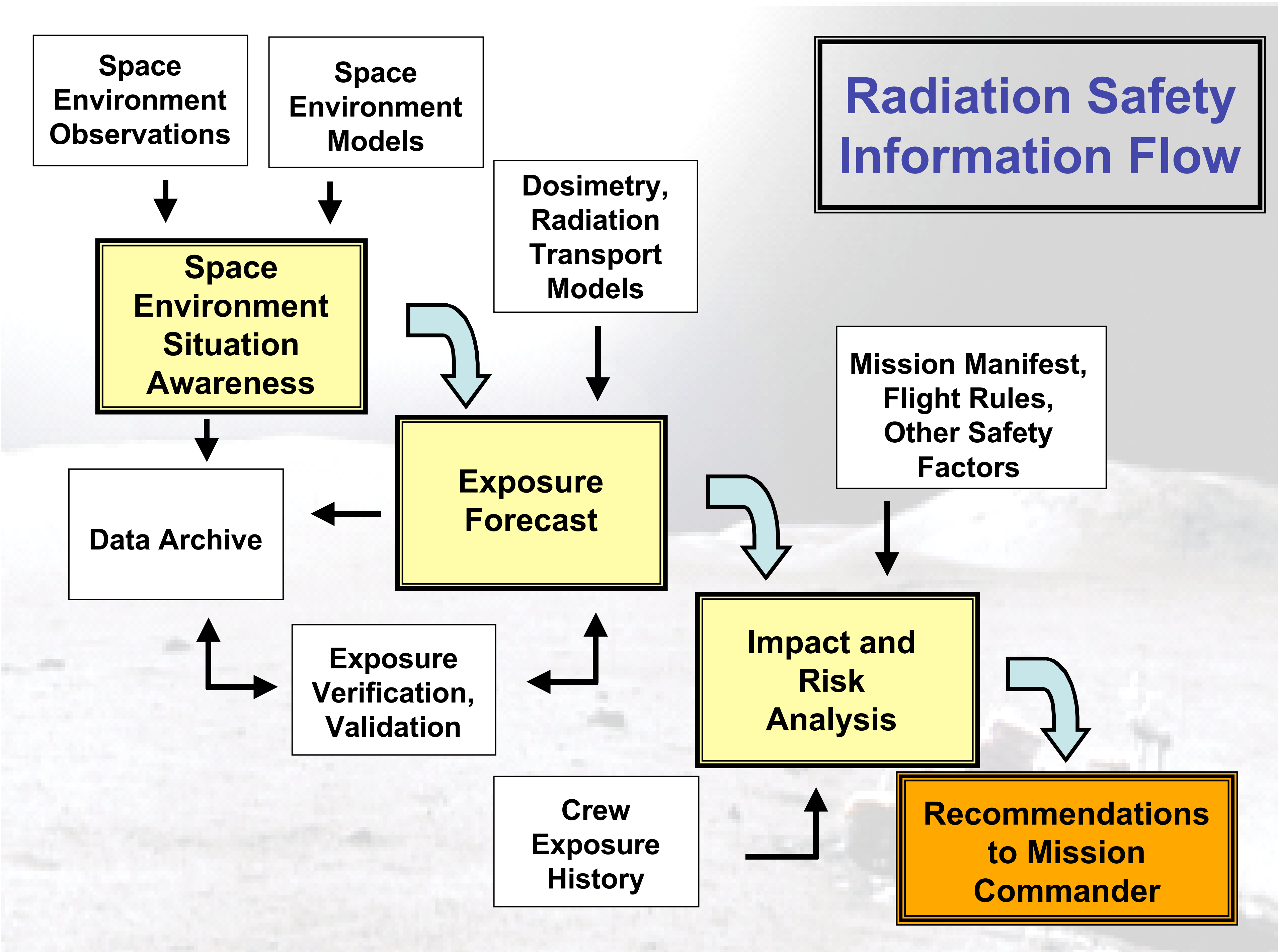
Reconfigurable shielding

Particle transport, biological impact models/algorithms

Prescreening for radiation tolerance

Pharmacological measures

Alert/warning communications infrastructure


Radiation Safety Information Flow
Space Environment Observations
Space Environment Models
Space Environment Situation Awareness
Dosimetry, Radiation Transport Models
Exposure Forecast
Data Archive
Mission Manifest, Flight Rules, Other Safety Factors
Exposure Verification, Validation
Impact and Risk Analysis
Crew Exposure History
Recommendations to Mission Commander

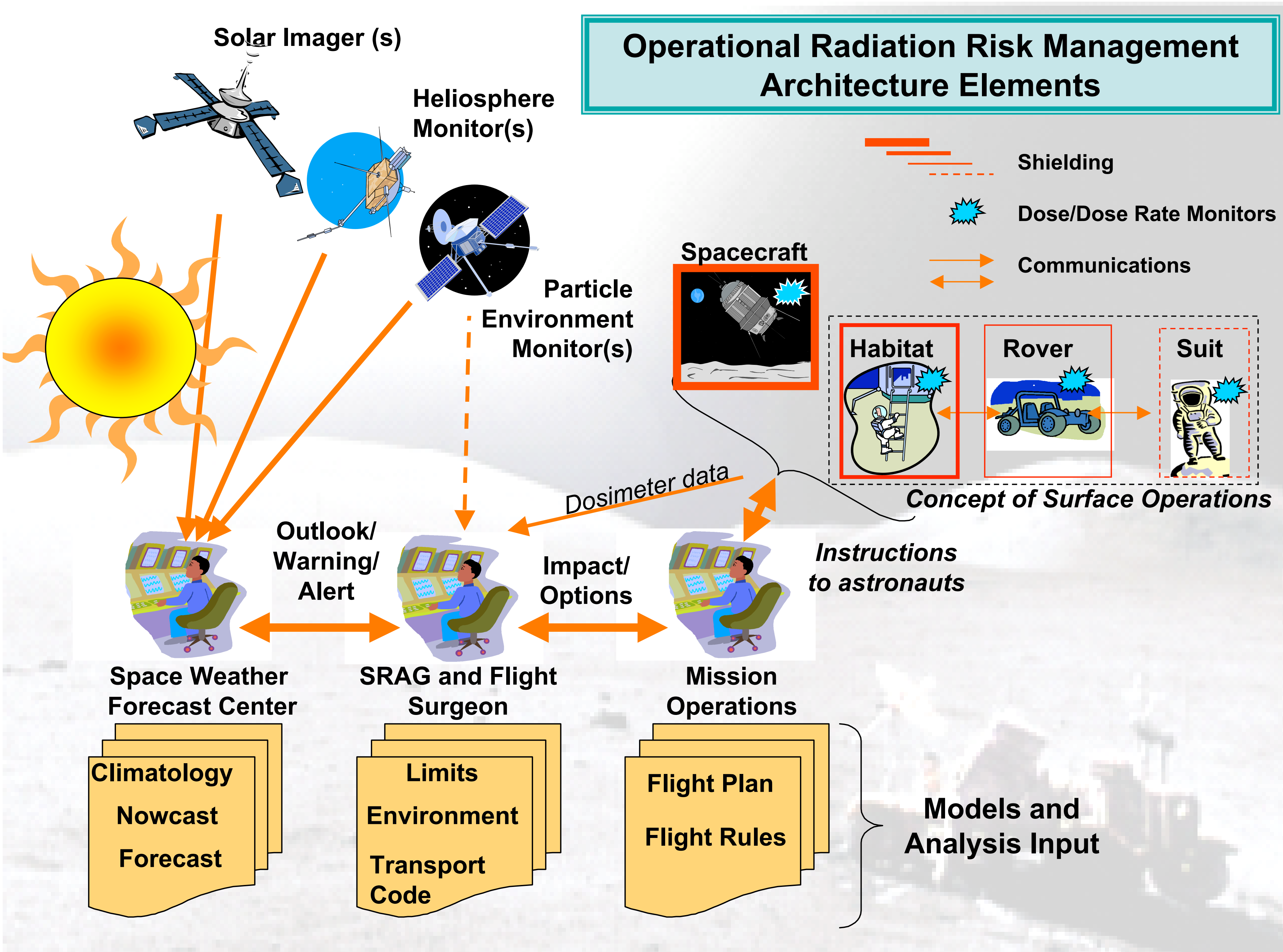
Forecasting SPE is a Multidiscipline Challenge

Predict the eruption of a CME

Predict the character of the CME

Predict the efficiency of the CME to accelerate particles

Predict the particle escape from shock and subsequent transport through heliosphere


Operational Radiation Risk Management
Architecture Elements
Solar Imager (s)
Heliosphere
Monitor(s)
Particle
Environment
Monitor(s)
Spacecraft
Shielding
Dose/Dose Rate Monitors
Communications
Habitat
Rover
Suit
Concept of Surface Operations
Dosimeter data
Outlook/
Warning/
Alert
Impact/
Options
Instructions
to astronauts
Space Weather
Forecast Center
SRAG and Flight
Surgeon
Mission
Operations
Climatology
Nowcast
Forecast
Limits
Environment
Transport
Code
Flight Plan
Flight Rules
Models and
Analysis Input

Systems Approach to Radiation Protection

Step One:
Establish Strategic Objectives

Step Two:
Identify Mission Architecture

Most of the Solution is Sufficient Shielding

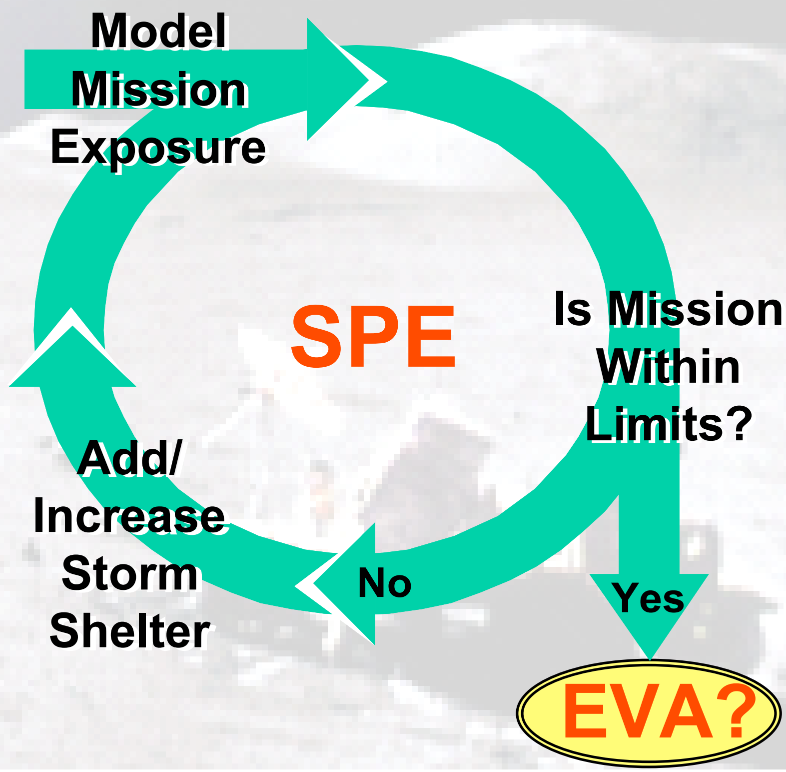
Step Three:
Conduct Shielding Analysis

The Most Important Component of Operations is Real-time Event Detection, Communication

Step Four:
Develop Surface Operations Concept

Major Role of Space Weather Community:
Provide Situation Awareness and Minimize False Alarms

One Approach to Radiation Safety



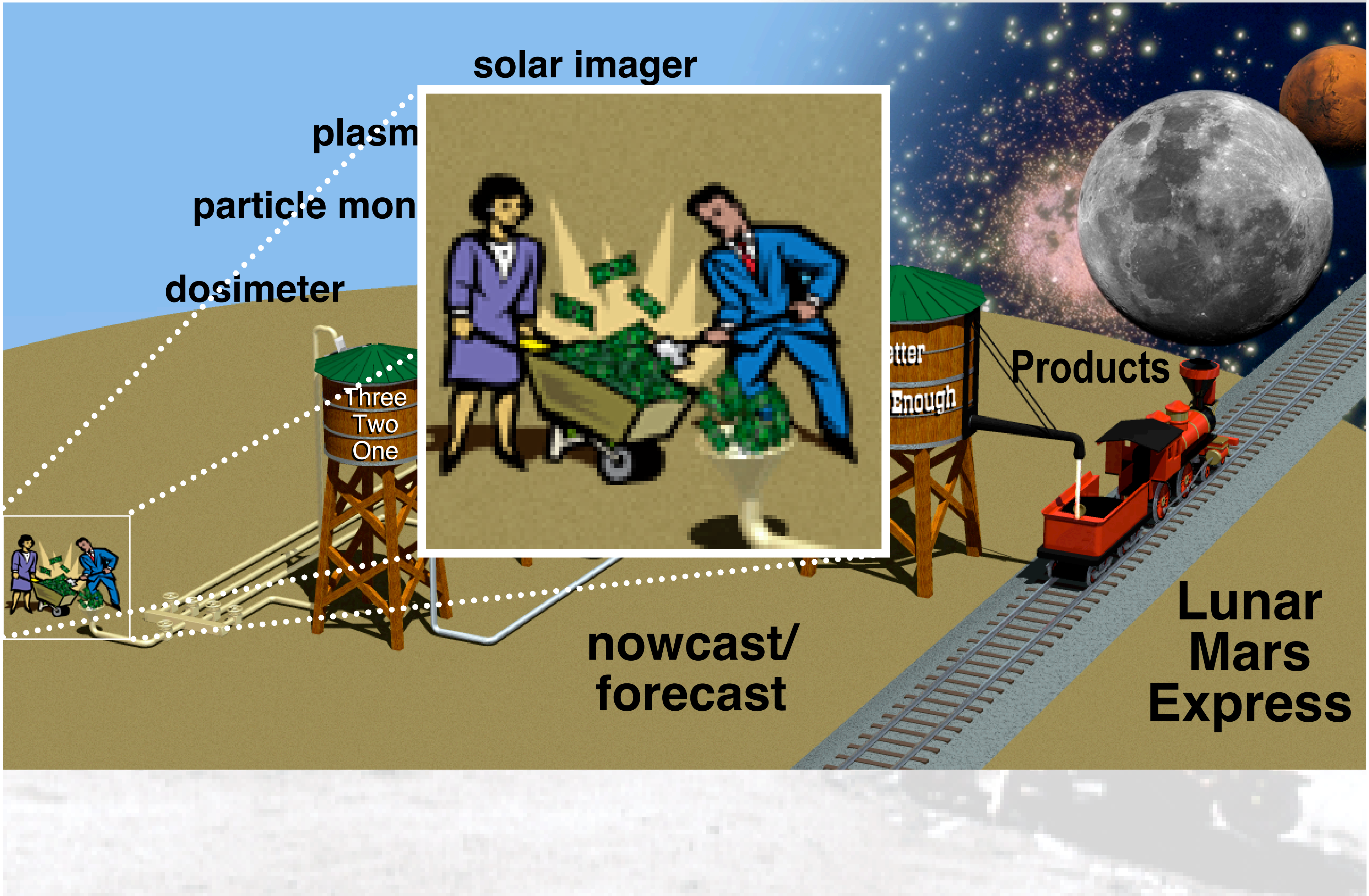
Shielding is the Main Defense against Radiation

Surface Operations are Rule-Driven

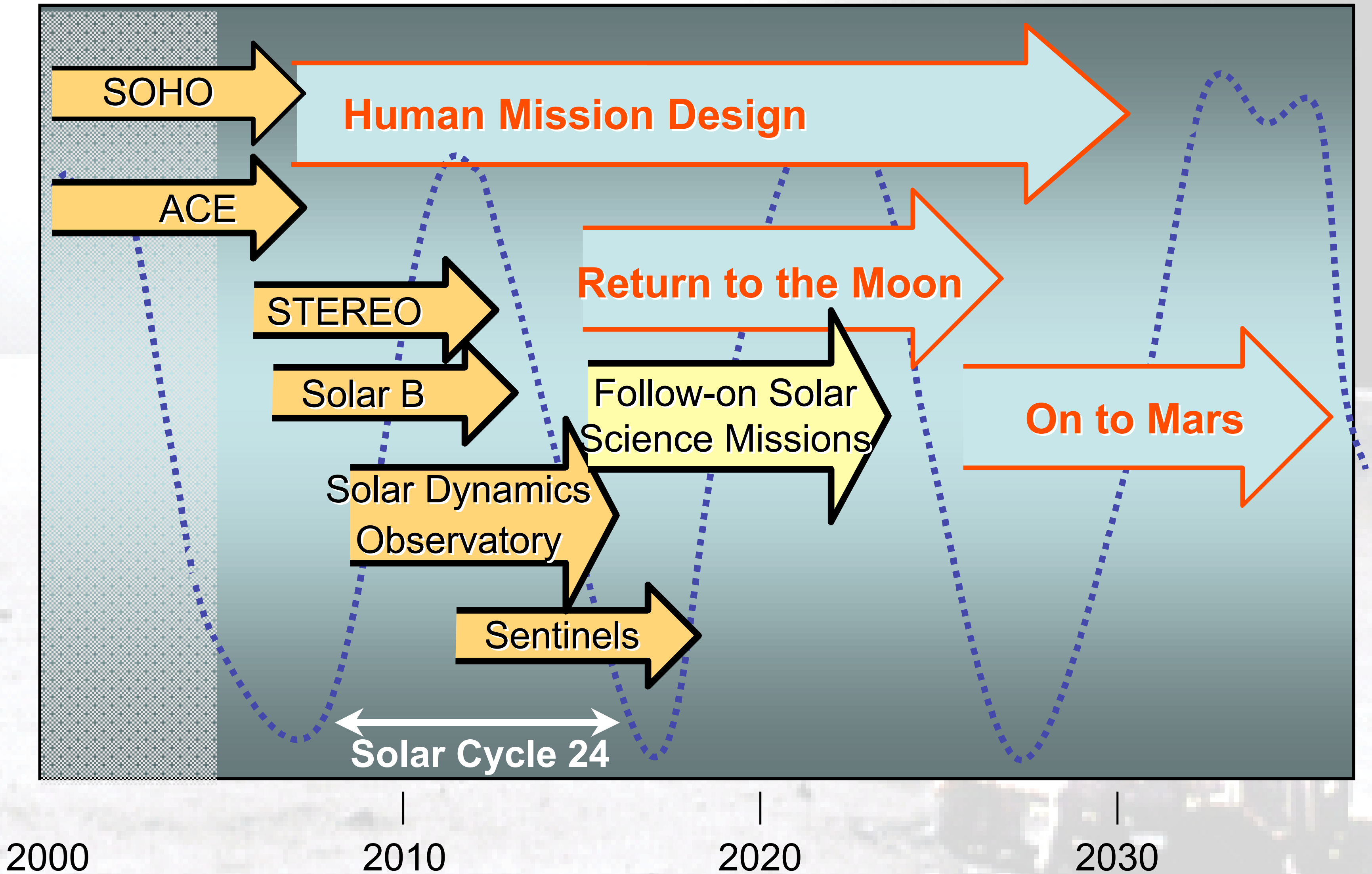
- **Astronaut activities are managed against a set of "Flight Rules"**
- **These Rules define the overall Concept of Operations (CONOPS)**
- **CONOPS should reflect the best science available to the mission planners**
- **Translation of research to operations is not trivial and needs thoughtful scientist input**

In-situ Radiation Monitoring is the Main Input to Operations

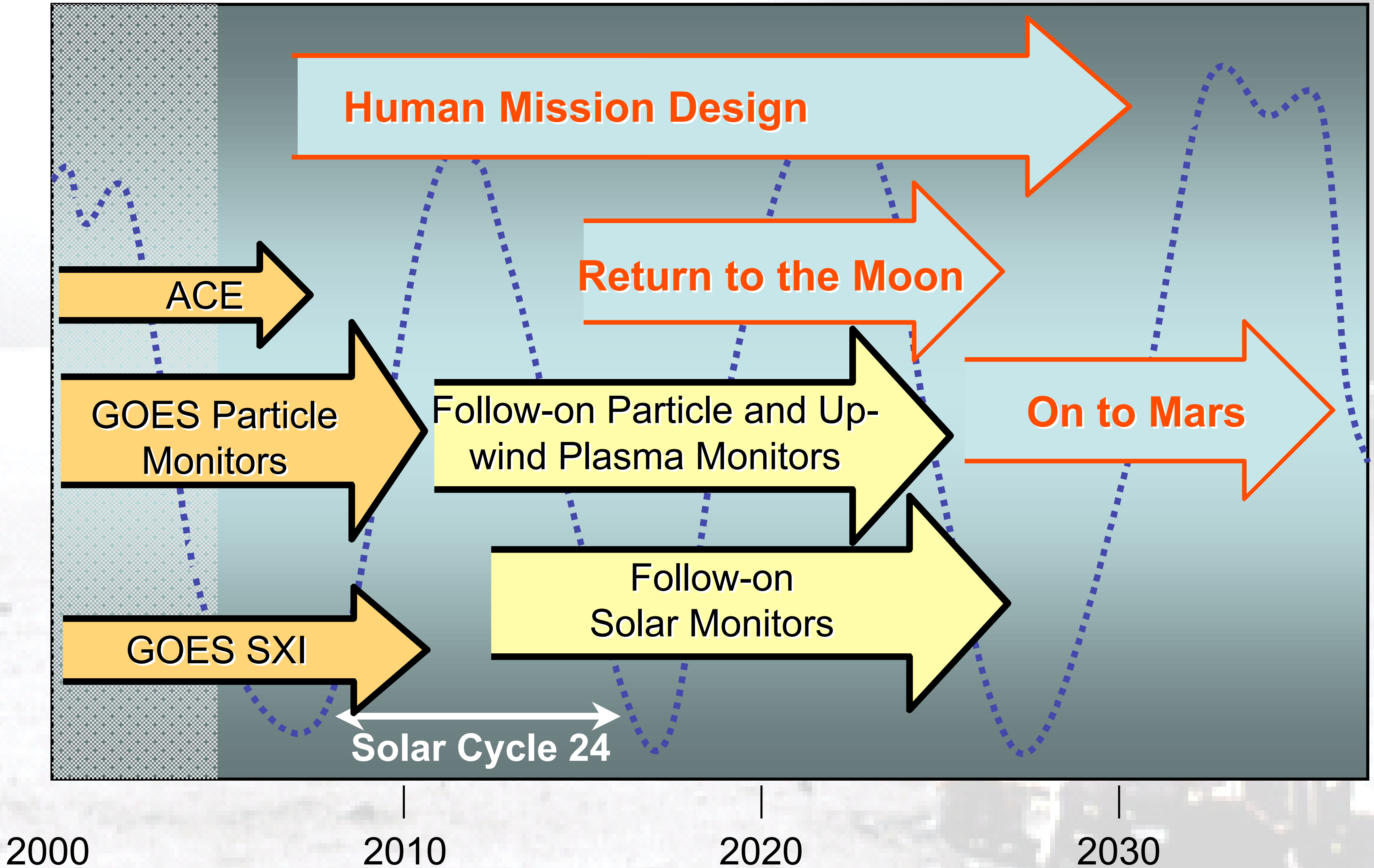
Radiation Risk Management Investment Strategy
SW Architecture Investment Strategy



Only One More Solar Cycle to Learn What We Must Learn



We Must Begin Now to Identify the Operational Spacecraft Requirements



Operational vs. Research Spacecraft and Instruments

Operational

Focus is on operational decision support

- Validated and verified
- To sufficient
  - Accuracy
  - Reliability
  - Availability
- In a usable form
- In a timely fashion

Minimal downtime for maintenance

Failure has significant operational consequences

Research

Focus is on specific science questions

- Validated and verified
- High accuracy
- As needed to support retrospective analysis

Little to no requirement for:

- Timeliness
- Consistent continuous coverage

Significant downtime can be scheduled

Failure is a disappointment

Interagency, International, Commercial Opportunities

- System solution is inherently interagency
  - NASA
  - NOAA
  - NSF
  - DoD
- Significant opportunity for international participation
  - Spacecraft
  - Instruments
  - Models
  - Communications support
- Potential roles for commercial involvement
  - Develop models
  - Provide instrumentation
  - Support data verification validation
  - Perhaps even End-to-End “Acu-Space-Radiation-Weather” support services

Operational Requirements

- **Who is responsible for developing the operational requirements for the space weather architecture?**
- **Beyond the science community, who is the advocate for *operational*:**
  - **High-cadence chronographs**
  - **Stereo observations**
  - **Far-side monitors**
  - **Multiple heliospheric monitors**

Proposed Study

- A challenge NASA faces is to follow the pending heliophysics missions with operationally useful space weather spacecraft in time to support lunar missions
- If NASA does not address this issue up front from a systems perspective, then a less-than-optimal architecture will be in place during the lunar missions
- NASA should begin a study on options for operational space weather architectures to support the exploration program
- Elements of the study should include:
  - Needs and constraints of operational exploration missions
  - Current use of both operational and Space Science assets in operational forecasts
  - Trends of space weather theory and models
  - Goals of the pending space weather science missions
  - Realistic timeframes for acquisition of new operational assets
- Output of the study should include three notional architectures:
  - "status quo" (extending today's capability into the future)
  - "modestly evolutionary" (improved operations reflecting current state of the art)
  - "breakthrough" (what might be deployed incorporating expected findings from planned missions)

Conclusions

- Important time for radiation protection, with advances underway in physics, biology, and increased complexity of missions
- Need for quantification of benefits beyond ALARA
- Need for operators, biologists, physicists, and others to work together to define optimal system approach
- Time is right to lay the groundwork for an effective radiation protection architecture
  - Science-based understanding
  - Operational instruments and models
  - Interagency, International, and Commercial Opportunities

Backup Slides

Radiation Risk Management Investment Strategy
Step One: Strategic Decisions

Biological Effects Including Uncertainty

Risk Philosophy

→

Radiation Limits:
- Lifetime
- Annual
- 30-Day
- Peak Dose Rate?

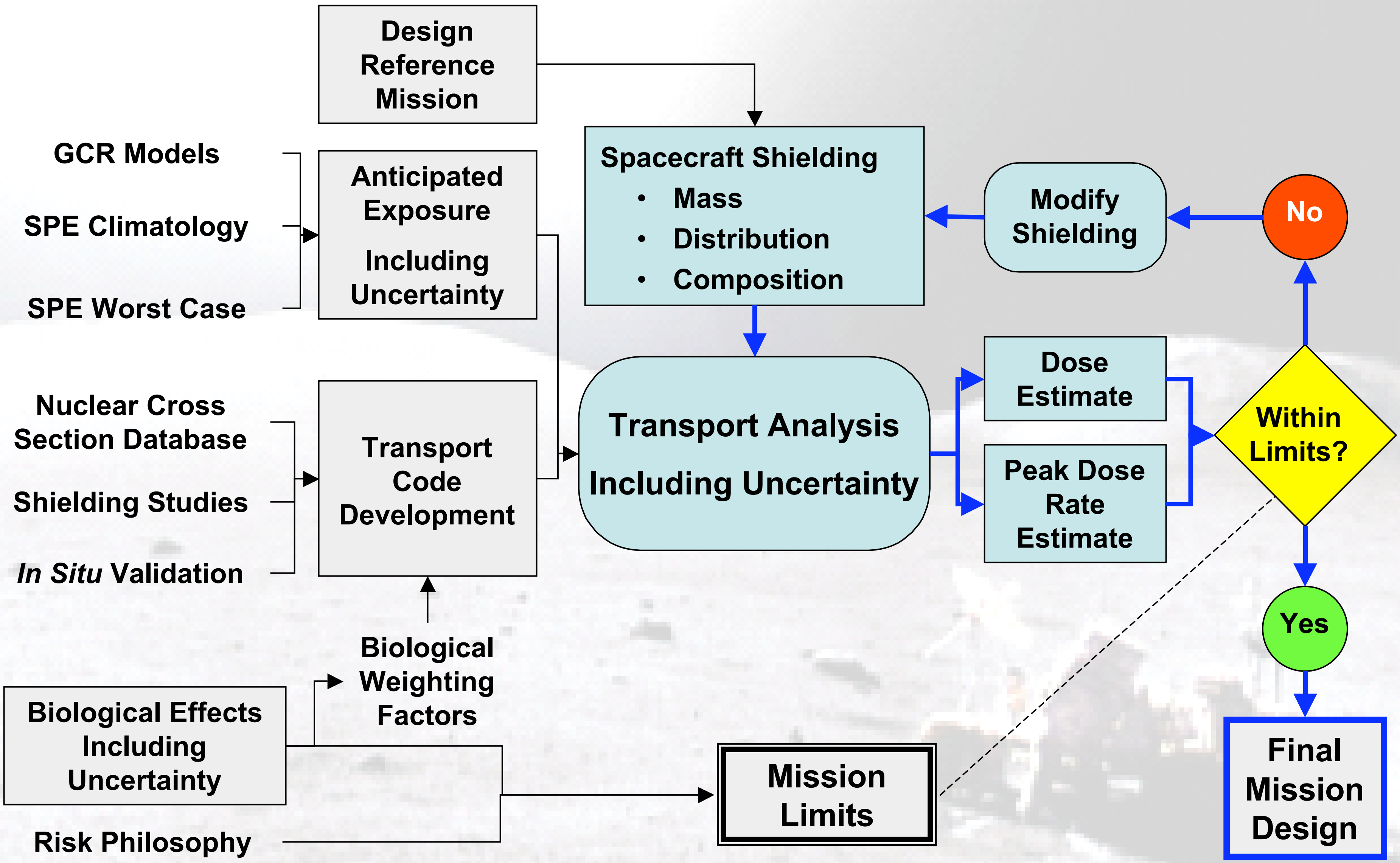
Radiation Risk Management Strategy:
- Cope and Avoid
- Anticipate and React

Radiation Risk Management Investment Strategy
Step Two: Mission Design Concept

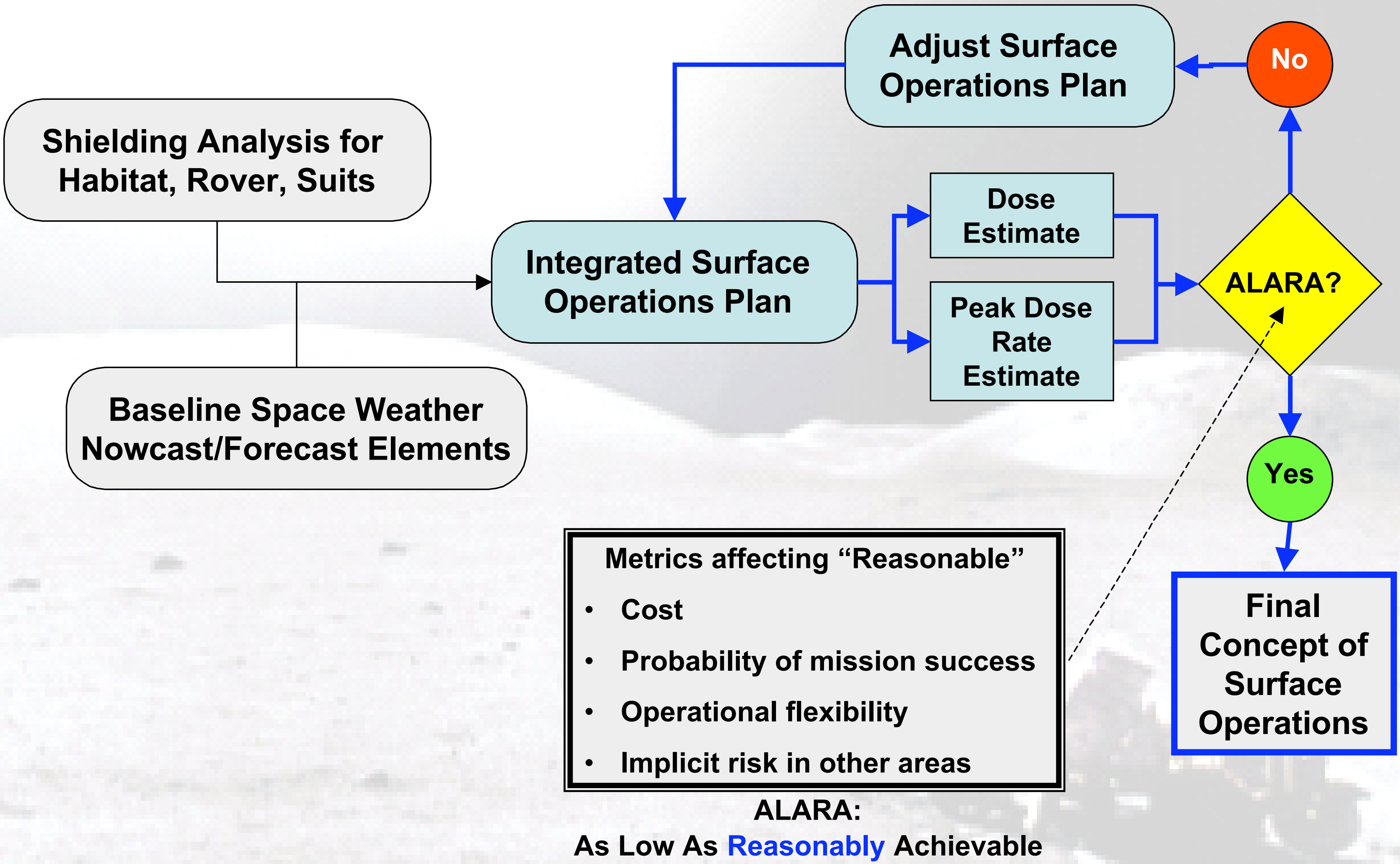
Mission Architecture Elements
- Spacecraft
- Habitat
- Rover
- Suit (space and surface)

Radiation Architecture Elements
- Shielding
- Dosimeters
- Concept of surface operations
- Space weather architecture

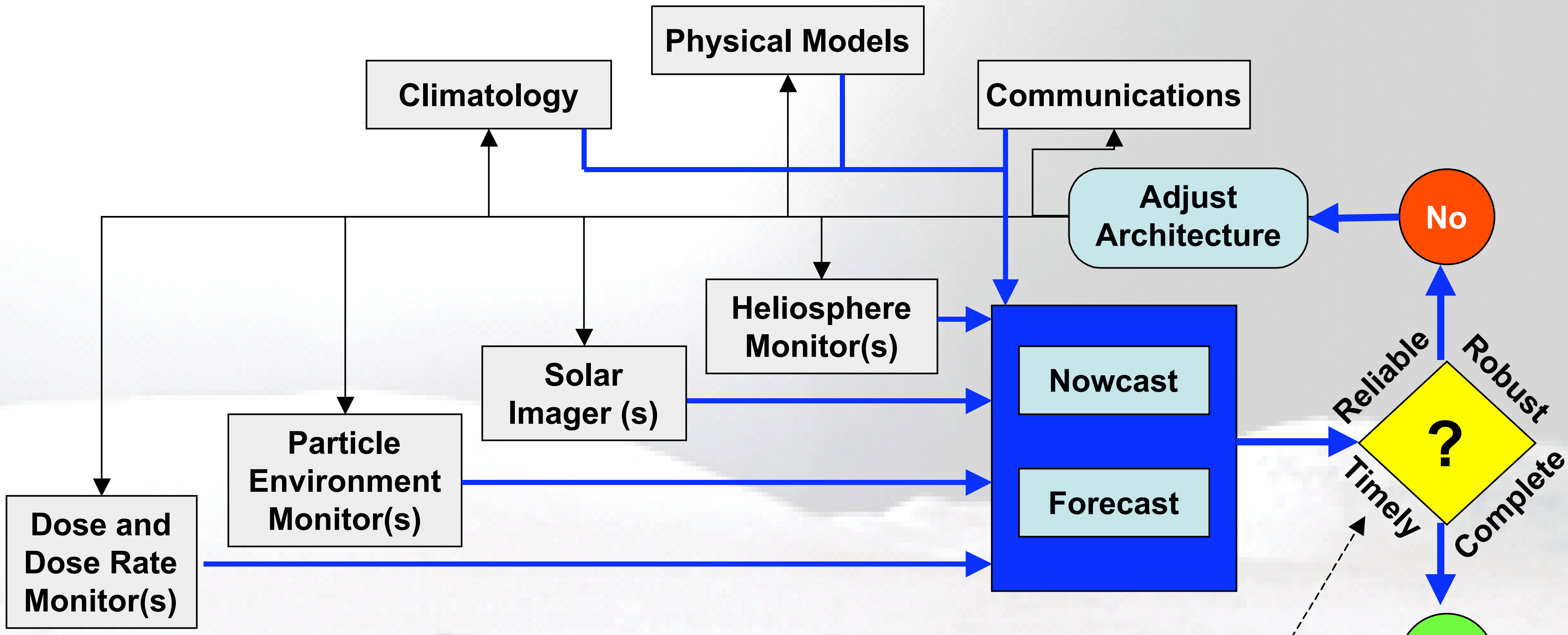
Radiation Risk Management Investment Strategy
Step Three: Transit Phase Shielding Analysis



Radiation Risk Management Investment Strategy
Step Four: Surface Operations Concept Development



Radiation Risk Management Investment Strategy
Baseline Space Weather Nowcast/Forecast Elements



Metrics Affecting "Performance"

- Cost
- Accuracy/Precision
- Timeliness
- Reliability
- Availability