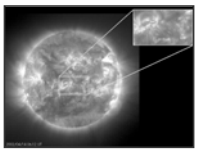

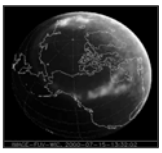

Space Weather

Prof. Daniel .N. Baker (APS, Physics)
Chair, Committee on Solar & Space Physics (NAS)
Co-Director, NSF Center for Integrated Space Weather Modeling
Director, Laboratory for Atmospheric and Space Physics
University of Colorado, Boulder

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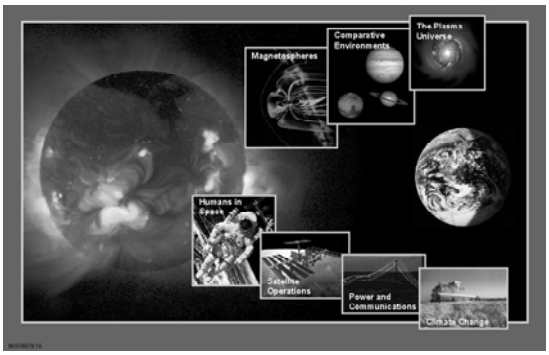
Understanding of Sun-Earth Connections



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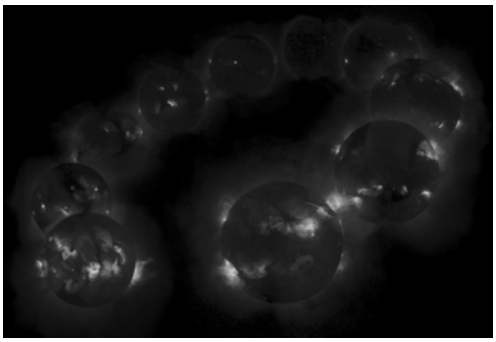
Yohkoh Soft X-rays: The 11-Year Solar Activity Cycle



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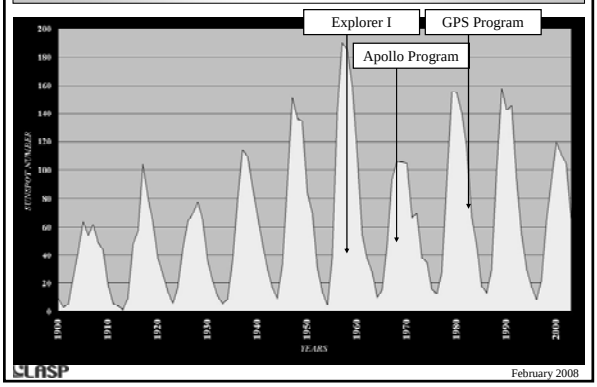
Annual Sunspot Number: 1900-2003



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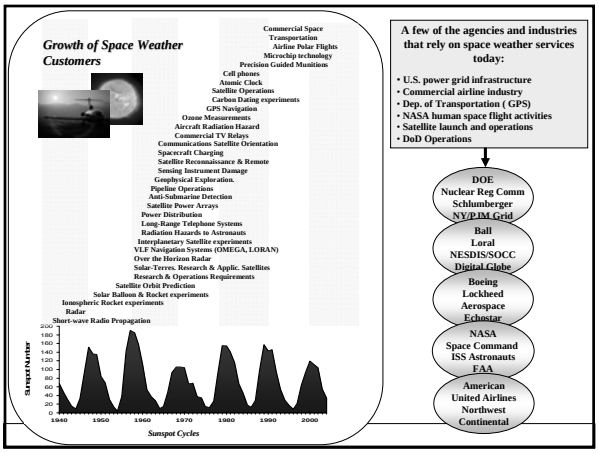
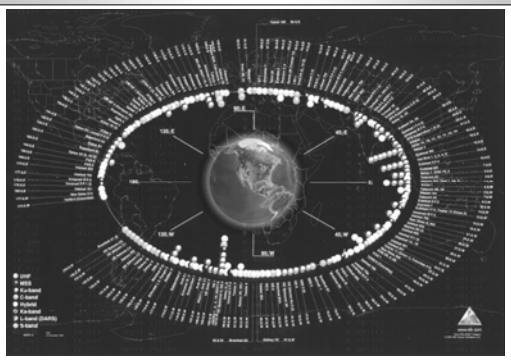


Civilian Spacecraft at Geostationary Orbit



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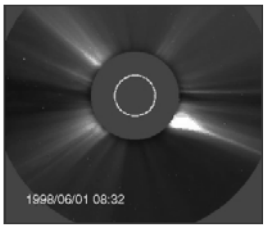
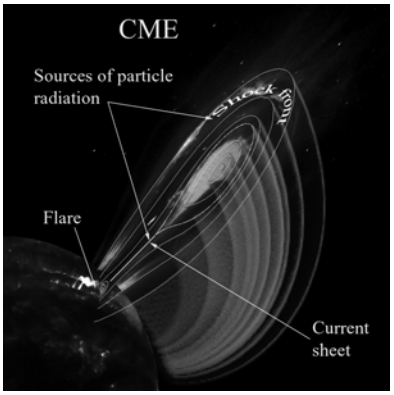
The Disturbed Solar Wind: Coronal Mass Ejections (CMEs)

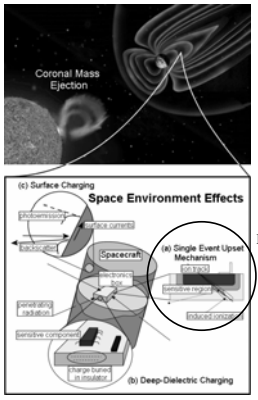


- Occur most often near the peak of the Sun's 11-year activity cycle
- Propel $>10^9$ tons of matter into interplanetary space
- Can travel at speeds exceeding 2000 km/s
- Drive interplanetary shocks
- Can trigger geomagnetic storms when they impact Earth's magnetosphere



Coronal Mass Ejection - Earth Impact

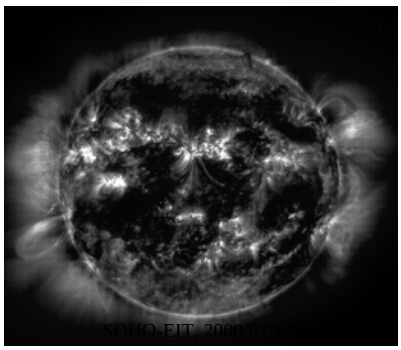
Courtesy of NASA



High-Energy Ion Effects

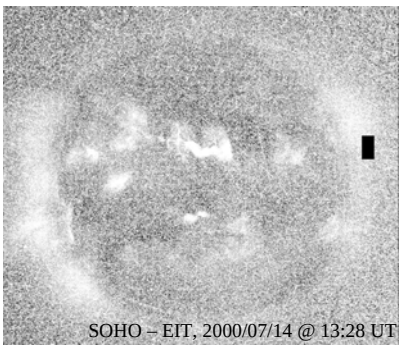
D.N. Baker "How to Cope with Space Weather," *Science, 297,* 1486, 2002

The Active Sun: July 2000



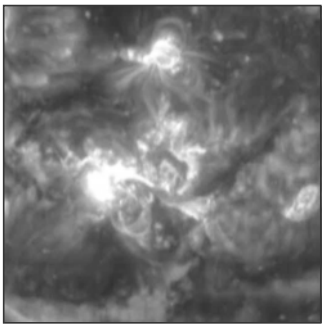
SOHO-EIT, 2000/07/14 @ 13:28 UT

Background Produced by Solar Energetic Particles



SOHO – EIT, 2000/07/14 @ 13:28 UT

SOHO: Pictures of the Sun—Halloween 2003



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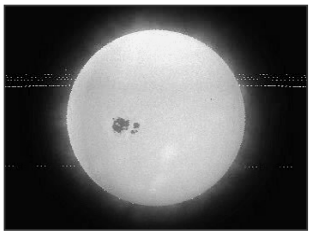
The Halloween Storms in the Heliosphere



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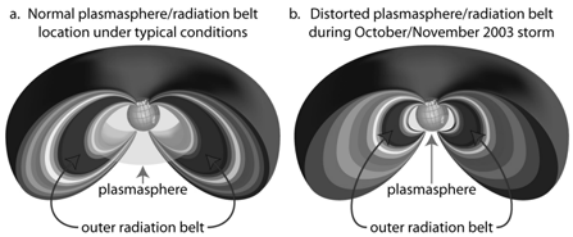
Dramatic Van Allen Belt Changes



D. N. Baker et al., Nature, December 2004

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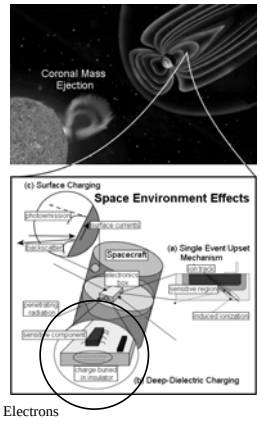

High-Energy Electrons

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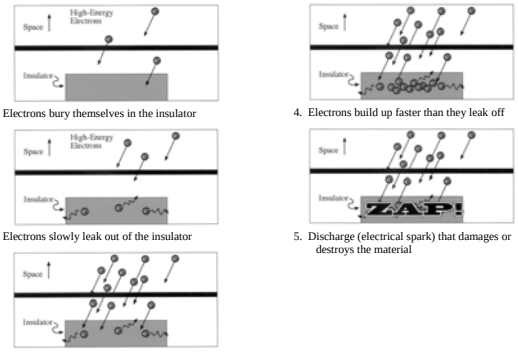
High-Energy Electrons: Deep-Dielectric Charging



1. Electrons bury themselves in the insulator
2. Electrons slowly leak out of the insulator
3. Influx of electrons increases to levels higher than the leakage rate
4. Electrons build up faster than they leak off
5. Discharge (electrical spark) that damages or destroys the material

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Electrostatic Discharge (ESD)

- Definition:
  - A transfer of electrostatic charge between bodies at different electrostatic potentials caused by direct contact or induced by an electrostatic field.

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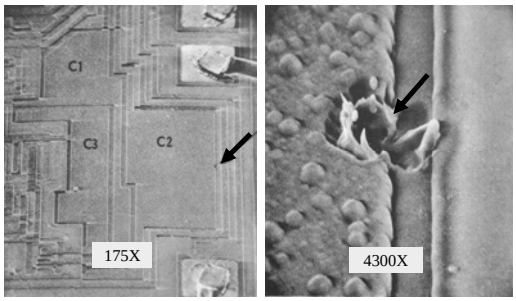
ESD Damage

HA-2700 surface damage in the C2 MOS capacitor
(Courtesy of JPL)



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News Accounts of Galaxy-4 Failure

It is not always possible to prove that conditions in the space environment cause problems with communication devices such as cell phones and pagers, but it is one explanation.

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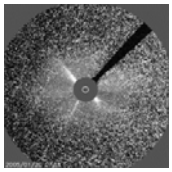
Satellite Industry

Solar storm warnings and alerts uses:

- Instruments and/or spacecraft turned off or safed
- Maneuver planning



- Anomaly assessments
- Orbit determination accuracy
- Increased spacecraft and instrument monitoring for health and safety during solar storms

"The SEC provides an invaluable and essential service to space operators" – Director of DG Space Operations – 22 March 2006

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Satellite Launch operations

Lockheed Martin's Atlas, Titan, and Athena rockets have a launch red line condition of 100 pfu at > 50 MeV

Launch of Kodiak Star Postponed Due to Solar Flare

The launch of Kodiak Star has been postponed for at least an additional 24 hours. A solar flare of significant magnitude occurred this morning at 7a.m ADT (11 a.m. EDT) producing a "proton flux" exceeding the allowable launch criteria for the Athena I. These high levels of charged particles can cause a "data upset" in the launch vehicle guidance system affecting its reliability. - Sep 2001

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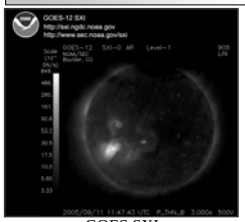
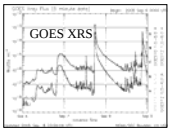
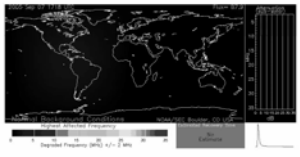
Airlines and Space Weather



GOES SXI





Loss of High Frequency (HF) communications during a solar flare.
The night-side of the Earth is unaffected

Image from NASA SOHO Satellite

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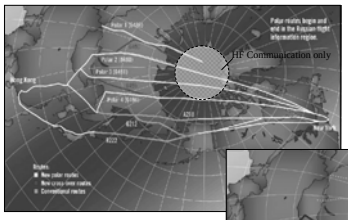

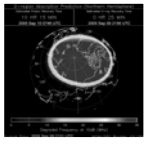

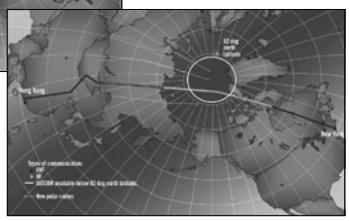

- Polar flights departing from North America use VHF (30-300 MHz) comm or Satcom with Canadian ATCs and Arctic Radio.
- Flights rely on HF (3 – 30 MHz) communication inside the 82 degree circle.

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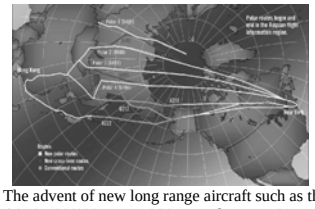
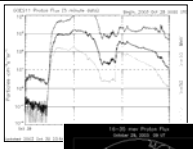
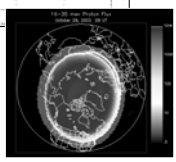
Aviation Growth…







The advent of new long range aircraft such as the A340-500/600, B777-300ER and B777-200LR

Next 6 Years:

Airlines operating China-US routes go from 4 to 9
Number of weekly flights from 54 to 249

Next 12 Years:

1.8 million polar route passengers by 2018

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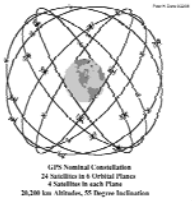
Global Positioning System Customers

- Deep-sea drilling operations
- Surveying companies—land surveying, topographic work, and property boundary analysis
- FAA WAAS (Wide-Area Augmentation System)
- Various DoD operations



GPS Nominal Constellation
24 Satellites in 6 Orbital Planes
4 Satellites in each Plane
20,200 km Altitudes, 55 Degree Inclination

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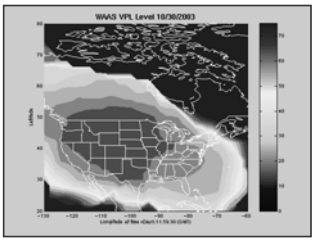
Wide Area Augmentation System (WAAS)

Ionosphere Disturbances impact vertical error limits, defined by the FAA's Lateral Navigation Vertical Navigation (LNAV/VNAV) specification to be no more that 50 meters.

Commercial aircraft unable to use WAAS for precision approaches.



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GPS Growth

Global Positioning System used: In-vehicle navigation systems, railway control, highway traffic management, emergency response, commercial aviation, and much more…

NAVSTAR - USA
GLONASS - Russia
Galileo - Europe

GPS Global Production Value—expected growth:
2003 - $13 billion
2008 - $21.5 billion
2017 - $757 billion
Industrial Technology Research Institute (ITRI) – Mar 2005

Space weather creates positioning errors larger than 50 meters
—A mid-latitude problem (where most users reside!)

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Electrical Power Grid…

The grid is becoming increasingly vulnerable to space weather events *Future Directions in Satellite-derived Weather and Climate Information for the Electric Energy Industry – Workshop Report Jun 2004*

"…blackouts could exceed even that of the very large blackout that occurred in August 14, 2003. And there is no part of the U.S. power grid that is immune to this… we could impact over 100 million population in the worst case scenario." John Kappenman - before U.S. House Subcommittee on Environment, Technology & Standards Subcommittee Hearing on *"What is Space Weather and Who Should Forecast It?"*

Transformer winding failure

Transformer exit lead overheating

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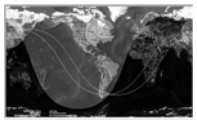
Human Space Flight

- Shuttle missions and EVAs require particular attention. Note: *The EVA-1 hr briefing is the last opportunity to abort an EVA due to space weather. (>30 MeV events are primary concern)*



NASA SRAG will report to Mission Control when:
>K6 observed *(1 observed period after decay)*
>M5 observed
Protons (All >100 MeV events).

- Electron belt enhancements can delay or postpone an EVA.

ISS: 50 pfu at > 100 MeV - shutdown the robotic arm
100 pfu at > 100 MeV - alert Mission Control. The Flight Team will start to evaluate a plan to shutdown equipment to prevent damage to electronics.
200 pfu > 100 MeV - plan is implemented

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Space Exploration…

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Cover design by Timothy Warchocki.
Image courtesy of NASA

AD HOC COMMITTEE ON THE SOLAR SYSTEM RADIATION ENVIRONMENT AND NASA'S VISION FOR SPACE EXPLORATION: A WORKSHOP

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Radiation Risks

- Carcinogenesis
  - Leukemia
  - Solid Cancers
  - Age/Gender Differences
- Degenerative Tissue Effects
  - Heart Disease
  - Cataracts
  - Respiratory Disease
  - Digestive Diseases
- Damage to the Central Nervous
  - Motor Skills
  - Behavior
  - Accelerated Aging
- Acute Risks
  - Death
  - Vomiting/Nausea

Potential Outcomes

- Mortality: Reduced Lifespan
- Mortality: In-flight (Acute from SEP Events)
- Performance Degradation:
- Morbidity: Post-Flight

Figure 1.2

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Task Statement

An ad hoc committee of the Space Studies Board sponsored a cross-disciplinary workshop on the radiation environments in the inner solar system (1-1.5 AU) and their effects on astronauts and operational systems in space. The workshop consisted of overview talks and group discussions in the following areas:

- Characterization of the heliospheric radiation environment as understood to date, including required data sources
- Physical mechanisms of energetic particle acceleration and transport in the heliosphere as understood to date
- Radiation health hazards to astronauts
- Radiation effects on materials and spacecraft systems
- Mitigation techniques and strategies, including forecasting and operational schemes

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Workshop Goals

- The objectives of the workshop were to:
  - Increase awareness and understanding of the complex array of solar and space physics issues pertinent to the environments of Earth, the Moon, and Mars
  - Identify compelling research goals necessary to ensure the success of the Vision for Space Exploration in these environments
  - Discuss the directions that research in these fields should take over the coming decades in order to achieve these goals.

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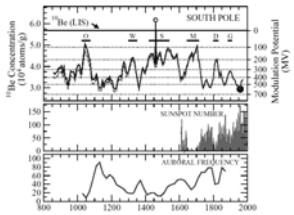

^{10}Be concentrations measured in ice core samples from the South Pole provide a record of the variability in the GCR flux at 1 AU for the period 850 CE to 1958 CE. Intensities are highest during secular minima in solar activity, as denoted in the top panel by the letters and bold horizontal bars and indicated in the second and third panels by the sunspot number and auroral frequency. respectively. (O = Oort minimum; W = Wolf minimum; S = Spoerer minimum; M = Maunder minimum; D = Dalton minimum; and G = Gleissberg minimum) [from *McCracken et al.*, 2004]

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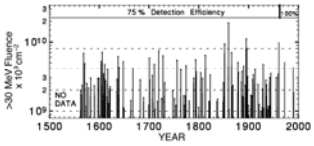

Spikes in the NO_3 concentration in Greenland ice core samples converted to proton fluences (black vertical lines) document the occurrence of large fluence solar energetic particle events over a period of nearly four and a half centuries beginning in 1561. Proton events that were detected directly between 1965 and 2000 are indicated by the red lines. [from *Smart et al.*, 2005, based on *McCracken et al.*, 2001]

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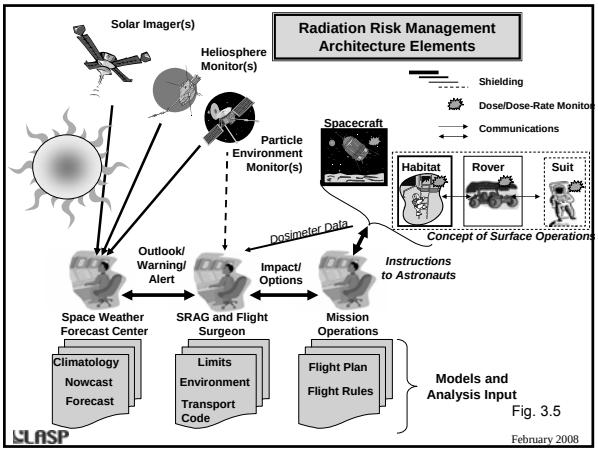

Fig. 3.5

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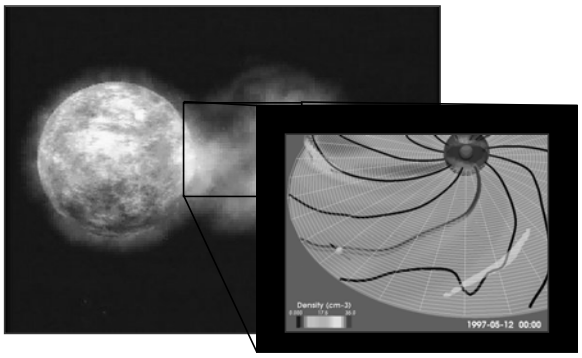
CISM Advanced Numerical Simulations



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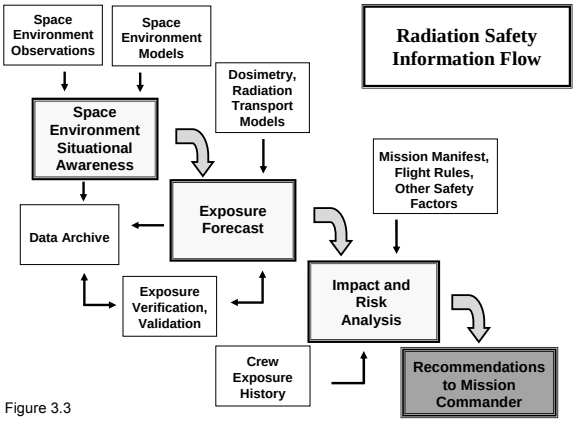

Figure 3.3

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