User’s needs

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I. Introduction

The purpose of this document is to delineate, on a worldwide basis, user needs for improved models of the Earth's radiation belts. Radiation belt particles have a variety of impacts upon space systems including total dose to surfaces and internally, displacement damage, surface and internal charging, and single event effects. Space radiation effects upon humans add significant additional requirements. The gamut of impacts drives the requirements for new radiation belt models including particle species, energy spectra, pitch-angle distributions, time and spatial coverage. Guidance is needed from the worldwide community of space radiation model users to permit prioritizing of the modeling efforts to ensure that the modeling effort is focused in areas of greatest perceived need.

II. Context

The NASA radiation belt models AP8 and AE8 are in almost universal use. However it now is well known that there are significant deficiencies in these models including energy ranges and pitch-angle coverage. The solar cycle dependence in AE8 has been found to be incorrect as well as the energy spectra. Furthermore AP8 and AE8 are average models and do not provide information on the variability of the radiation environment. In particular neither worst-case models are provided nor estimates of the variability from one solar cycle to the next.
Significant work has been carried out on new models including CRRESPRO, CRRESELE, Japanese min and max models, and POLE (Figure 1). However these models have limited applicability, for example POLE is only for GEO electrons and does not go down the energies that dominate surface dose. However POLE is important beyond its regional, energy limitations because it clearly shows an effective way forward in the modeling enterprise.
An important question to answer with new models is how accurate will be a prevision for the next solar cycle with a given model and what is the representativity of any model (Figure 2).

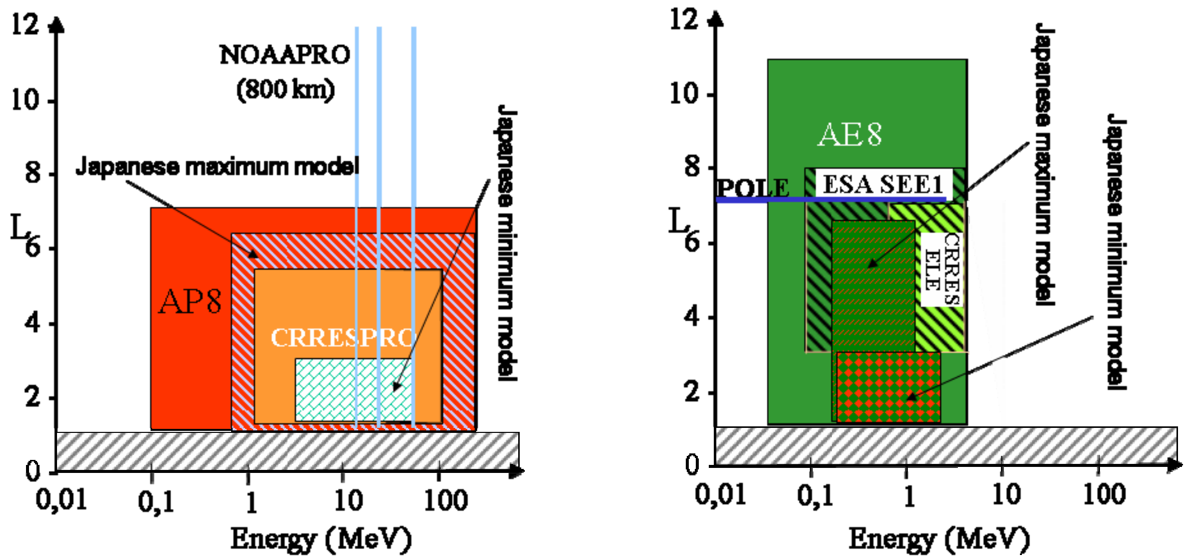

Figure 1 : Energy and L coverage of existing radiation belt models

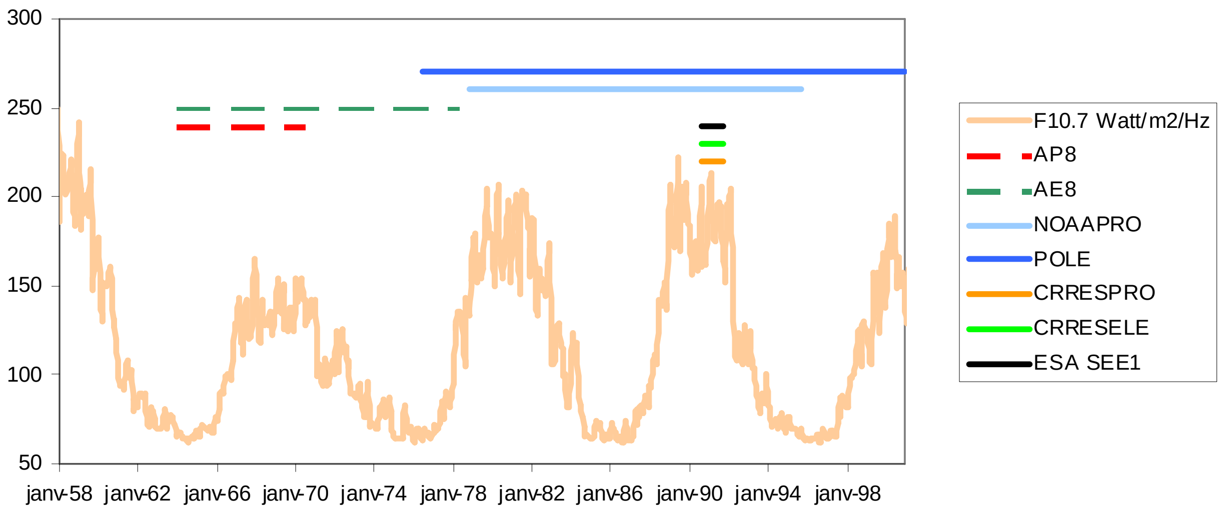

Figure 2 : Representativity of existing radiation belt models as a function of solar cycle modulation

As a result, having new radiation belt models becomes critical. They are needed to:

- improve capability of spacecraft and instruments (to reduce risk and cost, to improve performance and to increase system lifetime).
- Reduce risk to astronauts (international space station – ISS, and travel through radiation belts).

In recent years several contributors have been identified to increase risk and cost:

- Resource constraints
- Increasing complexity of space systems
- Lack of availability of space-validated components
- Unknowns in space environment effects mechanisms
- Inadequate space environment models (large uncertainties in some regions, environment definitions do not exist for some energy ranges and models lack functionality for contemporary applications, averages and worst case are insufficient.

The consequences of space environment effects on systems range from minor to dramatic. The link between a space environment component and expected damages is shown in Figure 3 (From J. Barth/NASA-GSFC). The net effect on space system are summarized below:

- Loss of data (single event upsets on flight data recorder, interruption of data transmission)
- Performance degradation (reduced microelectronics functionality, degraded imagers)
- Interference on instruments (noise on imagers, biasing of instrument readings)
- Service outages (System resets, safeholds)
- Shortened mission lifetime (Solar array degradation, microelectronics degradation)
- Loss of system or entire spacecraft (catastrophic failure)

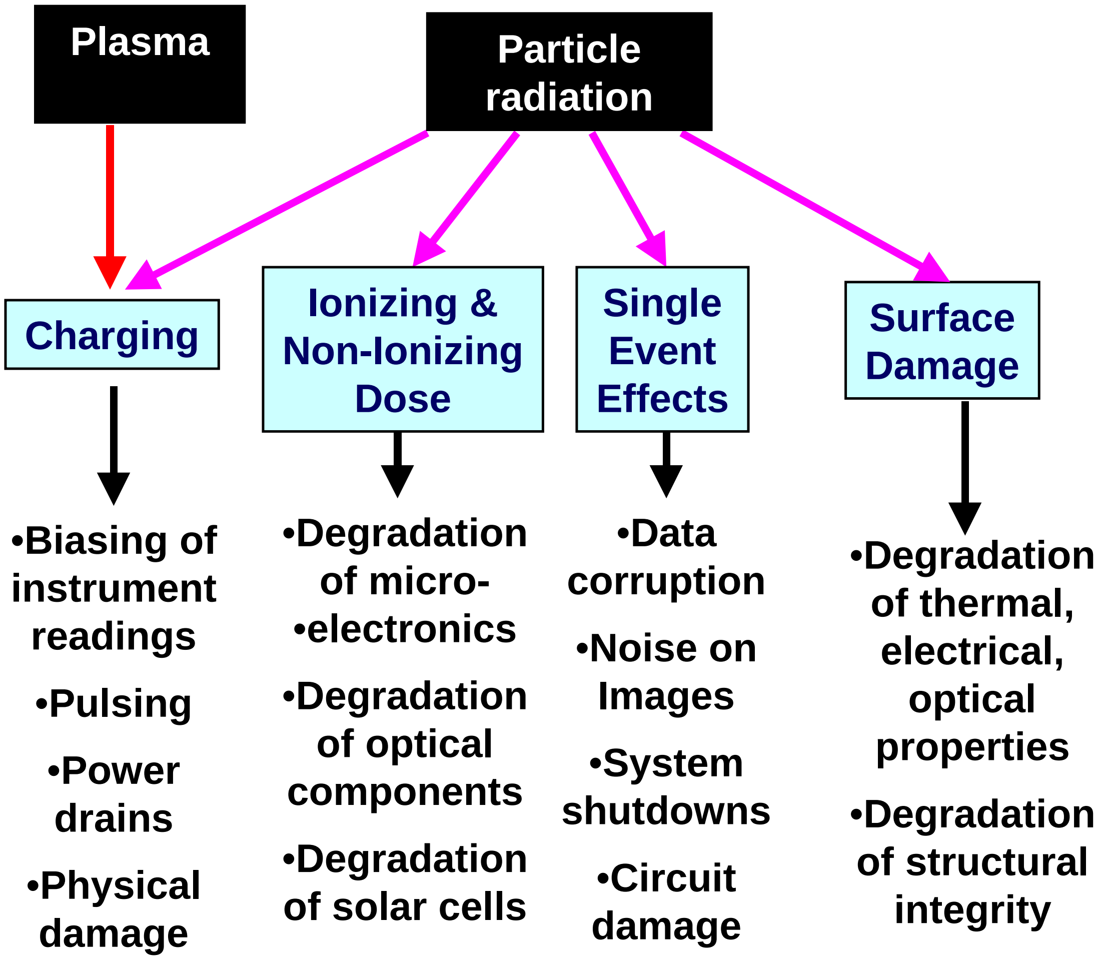

Figure 3 : Effects of radiation environment on space systems (mechanism and manifestation) from J. Barth/NASA-GSFC

The hazard for Humans are of course all important:

- Failure of life support systems
- Failure of space systems operational infrastructure
- The exposure received by humans from space radiation exposure is an important occupational health risk (major concern is increased risk of cancer morbidity/mortality, other possible health risks such as cataracts, coronary disease, damage to neurologic system and genetic damage to offspring, the probability is very small of death during or immediately following a mission due to space radiation exposure)

The ultimate goal in space radiation modeling is to provide the radiation environment details adequate to enable the successful engineering of space systems for flight anywhere within the Earth's radiation belts. Attainment of this goal is a major challenge for the radiation belt environmental modeling community.

Space industries have indicated the following orbits and associated mission lifetimes are of prime importance:

GEO: > 15 years
GPS, HEO, MEO: > 10 years

LEO, PEO: 5-7 years, up to 1000 km now, 2000 km in future

Models for a single orbit can still be useful, particularly in the case of GEO where variations in the magnetosphere coordinates are limited.. Because of complexity to describe the entire system single models for all missions can be done later.

III Plasma model requirements

These models are required for surface charging and thermal coating degradation evaluation. In the following notation P stands for Plasma, UR* for User's Requirements number * and P* for priority number *.

P_UR1: Energy coverage for electron → 50 eV to 100 keV
P_UR2: Energy coverage for proton → 50 eV to 100 keV
P_UR3: Information on ion species
P_UR4: Spatial coverage → 0.9 < L < 60 Re with complete 3D description (L, magnetic latitude, magnetic local time)
P_UR5: Time resolution → one year time resolution/solar cycle
P_UR6: Worst case estimate for electrons: 1min, 15 min, 1 hour
P_UR7: Error estimates

A high priority must be given to describe first plasma environment for energies greater than 1 keV.
Priority can be defined as follow:
P_P1: Energy → > 1 keV (GEO, MEO, HEO, LEO and PEO - < 1000km)
P_P2: Energy → as defined in P_UR1 and P_UR2, all orbits

IV Trapped proton model requirements

These models are required for total dose, displacement damage and single events effects predictions. In the following notation TP stands for Trapped Proton, UR* for User's Requirements number * and P* for priority number *.

TP_UR1: Energy coverage → > 0.1 MeV
TP_UR2: Spatial coverage → 0.9 < L < 8
TP_UR3 : Directionality → only at low altitudes (e.g ISS)
TP_UR4: Time resolution → represent long-term variation over the solar cycle with at least one year resolution.
TP_UR5: Worst case estimate: 1mn, 15 mn, 1 hour, ½ day, 1 day and 1 week
TP_UR6: Error estimates
TP_UR7: Definition of transient belts (how often, how intense, how long, highest energy, heavy ion content)

Priority can be defined as follow:
TP_P1: Energy → > 50 MeV (All orbits)
TP_P2: Energy → > 5 MeV (MEO, LEO)
TP_P3: Energy → As described in TP_UR1

V Trapped electron model requirements

These models are required for total dose and internal charging predictions. In the following notation TE stands for Trapped Electron, UR* for User's Requirements number * and P* for priority number *.

TE_UR1: Energy coverage → 0.1 MeV < E < 7 MeV
TE_UR2: Spatial coverage → 0.9 < L < 8
TE_UR3 : Directionality → no requirements
TE_UR4: Time resolution → represent long-term variation over the solar cycle with at least one year resolution.
TE_UR5: Worst case estimate: 1 hour, ½ day, 1 day,1 week, 1 month, 3 months and 6 months
TE_UR6: Error estimates
TE_UR7: Definition of transient belts (how often, how intense, how long, highest energy)

Priority can be defined as follow:
TE_P1: Energy → > 1 MeV (All orbits)
TE_P2: Energy → > 500 keV (GEO, PEO, MEO)
TE_P3: Energy → > 100 keV (GEO, PEO, MEO)
TE_P4: Energy → As described in TE_UR1, all orbits