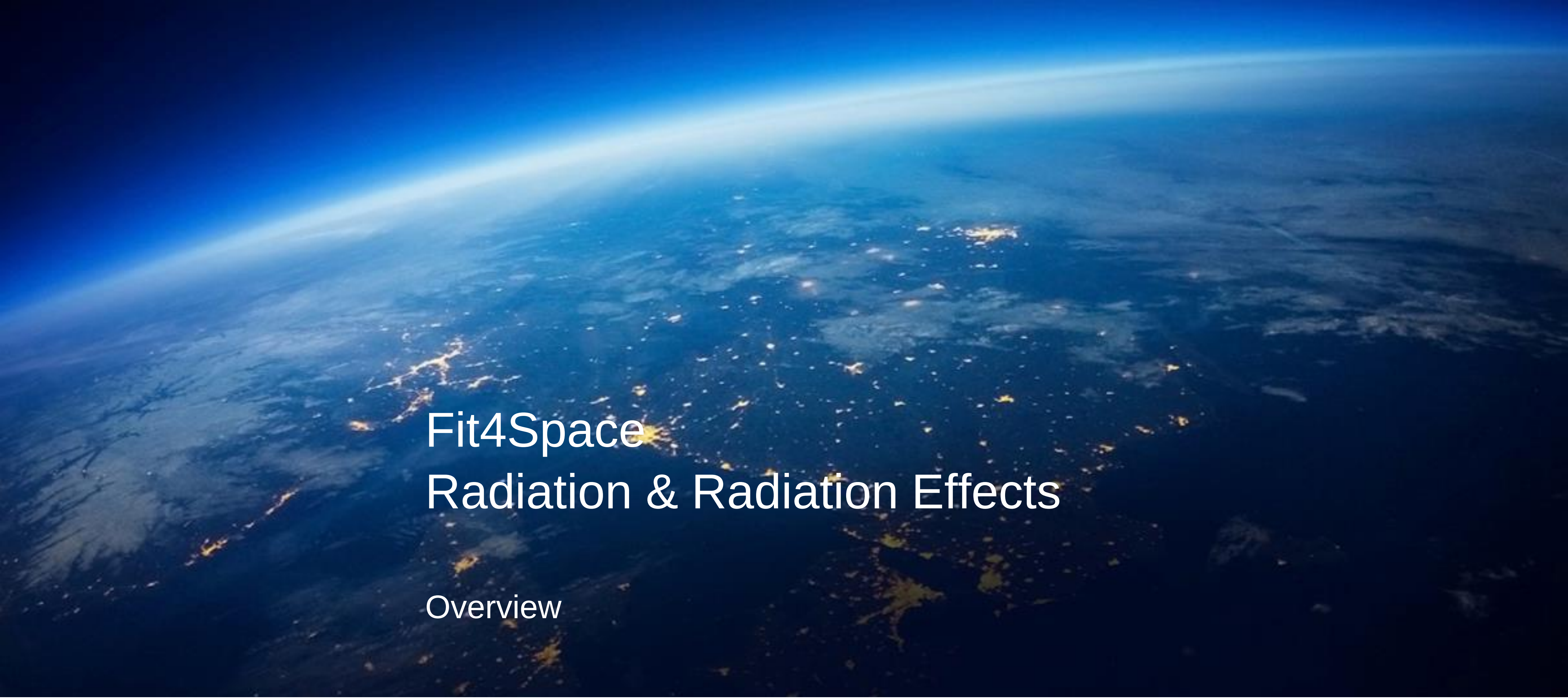

# Fit4Space
# Radiation & Radiation Effects

## Overview

DEFENCE AND SPACE

Lee Pater
06/03/2024

# Agenda

The intention of this presentation is to simply provide an overview of what radiation is, where it comes from (thinking of natural space environment specifically here) and also what needs to be considered when designing for space.

1) Discuss the source of the natural radiation in space – sun, other suns…CME, flares
2) Discuss the earth – magnetic field, trapped protons, trapped electrons, SAA
3) Discuss how the two are linked +GCR
4) Mission types (Observation, GPS, Telecoms, Scientific) and different altitudes.
5) Briefly discuss different sizes of satellites (Cubesat to Telecoms).
6) Show environment derivations (electrons, protons, DDC) and how this changes for LEO, MEO and GEO
7) Discuss analysis techniques – Ray-tracing, RMC, also effects of shielding (satellite, parts packaging, etc.)
8) Discuss radiation effects on components and materials – TID, TNID, SEE, DDD
9) Discuss RVT needs
10) Mission assurance – how do we ensure that a mission will be successful? Environment, analysis, RHA

# Introduction

## Welcome to the wonderful “world” of radiation ☺

No doubt, to the relief of many (including me!!) this presentation will not go deep into the physics of what, why and how radiation impacts electronics (or materials), this is simply intended to give an appreciation of space radiation issues

As hopefully will become apparent, this is rather a large subject so the best we can hope for in less than an hour is to give a “flavour” of what this topic is about, and give some food for thought when designing circuits and systems and procuring components…

Feel free to ask questions whenever you think of something. You don’t have to wait until the end of the presentation – I wont bite!!

# Introduction

ESA quote:

“There is no space system in which radiation effects can be neglected”

# Introduction

Underestimation of radiation induced “degradation” may endanger any space mission

Natural space is not radiation free

- Electrons, protons, heavy ions, UV (important in materials degradation)

Space system designers must take into account the impact of radiation

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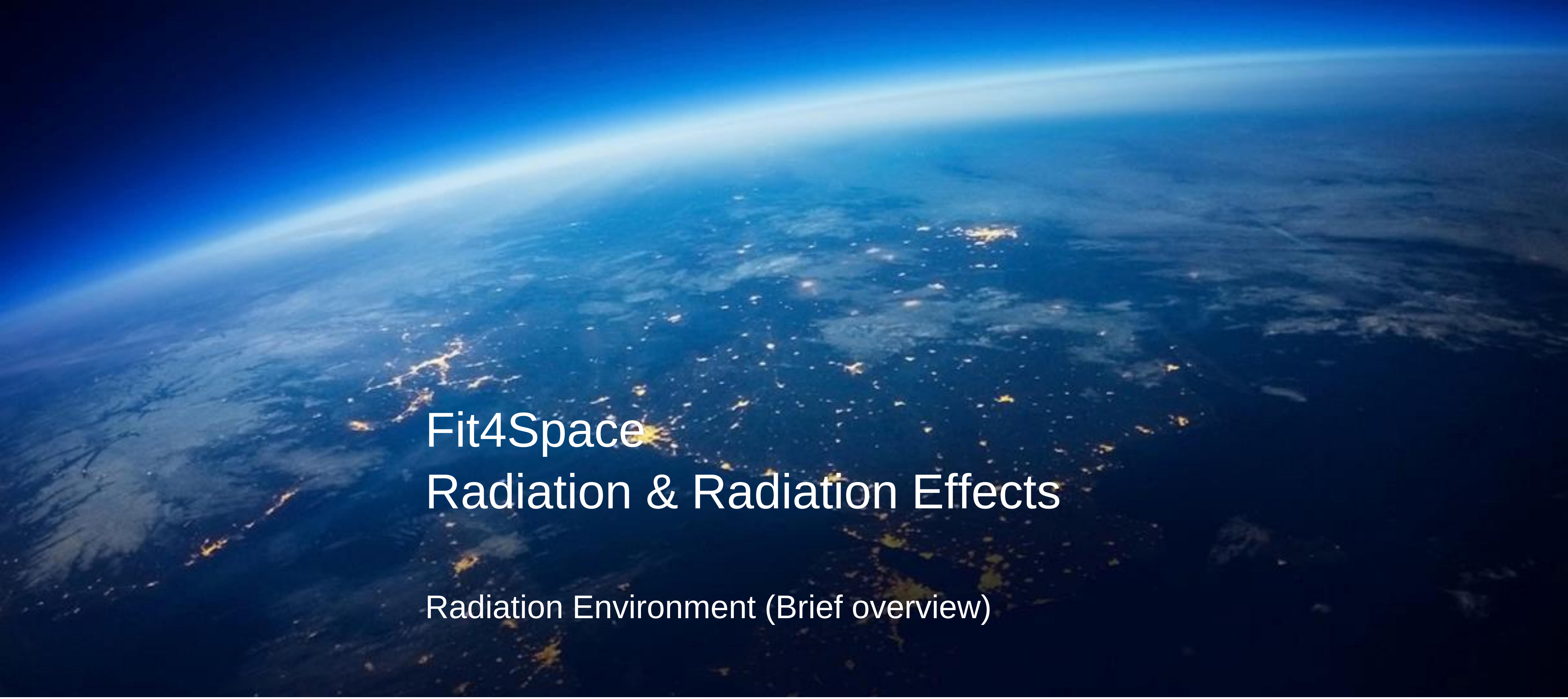
To address the radiation aspects of a mission, system or an equipment design requires the following basic inputs:

- Environment definition
- Radiation Hardness Assurance policy
- Component Test Data
- Satellite & Equipment models



# Fit4Space
# Radiation & Radiation Effects

## Radiation Environment (Brief overview)

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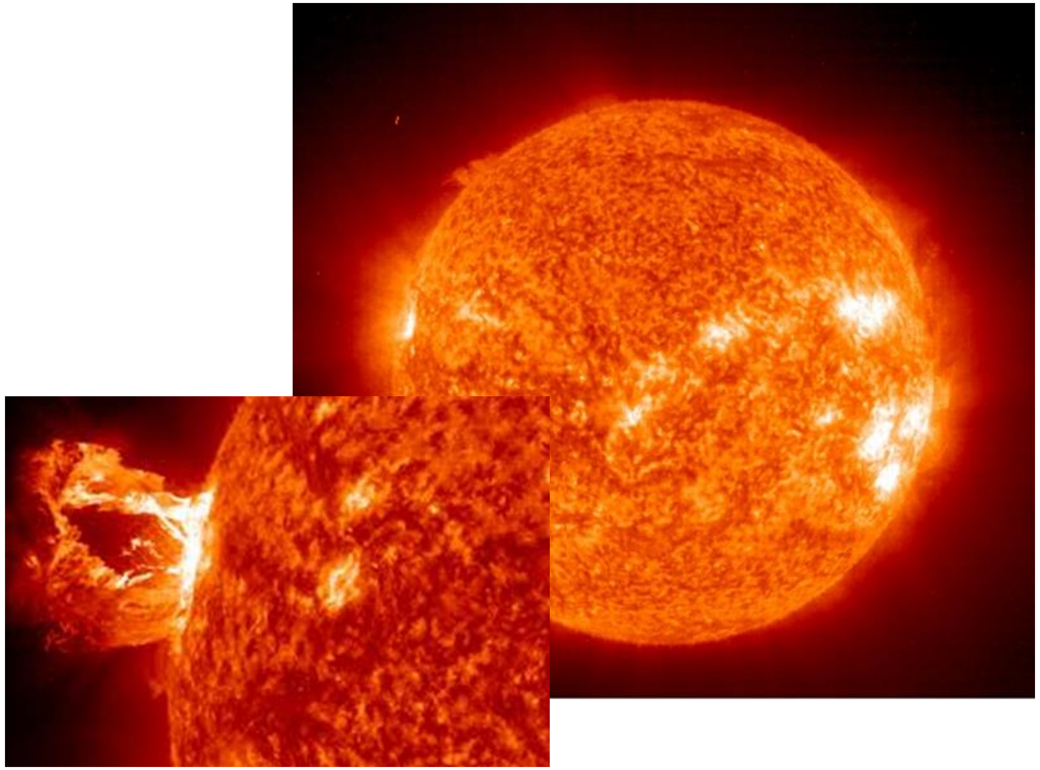
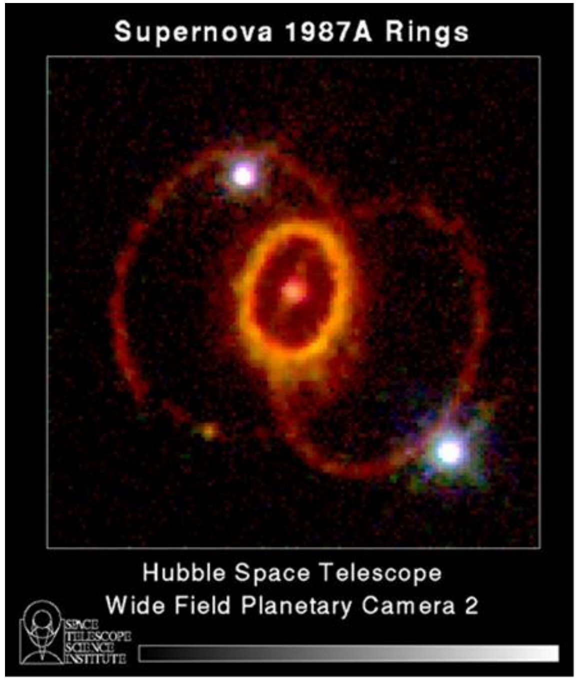
# Radiation Environment

Radiation originates from the Sun and from outside the galaxy.





# Radiation Environment

Radiation in space is typically considered in three different forms:

- Galactic Cosmic Rays (GCRs)
- Solar particles
- Trapped particles

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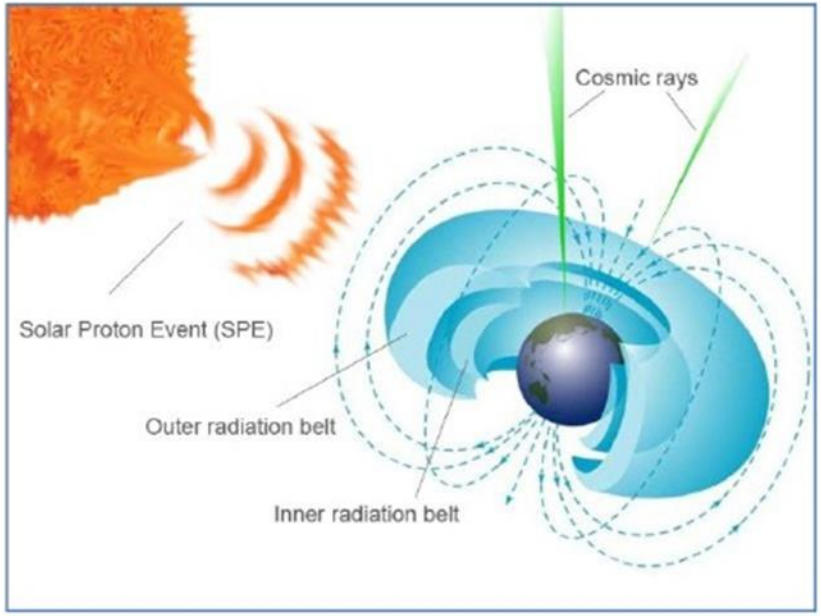
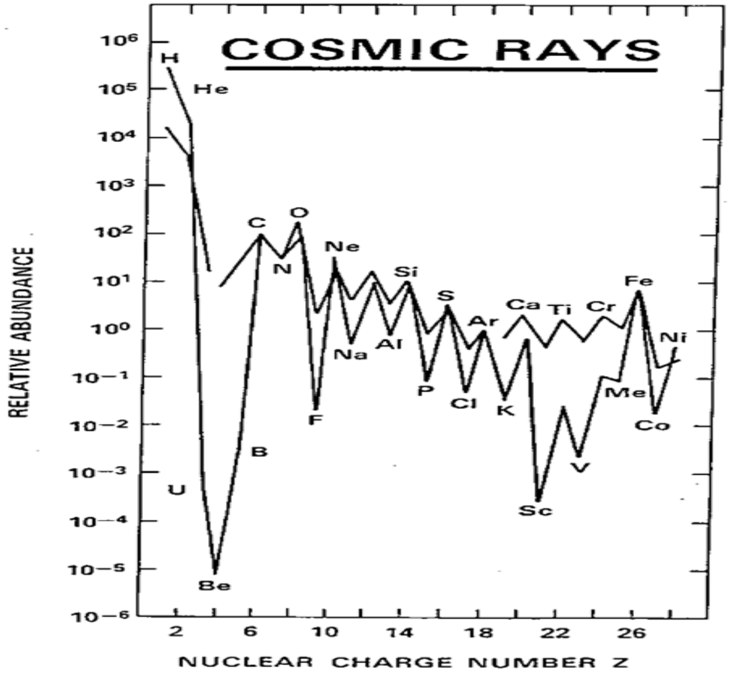


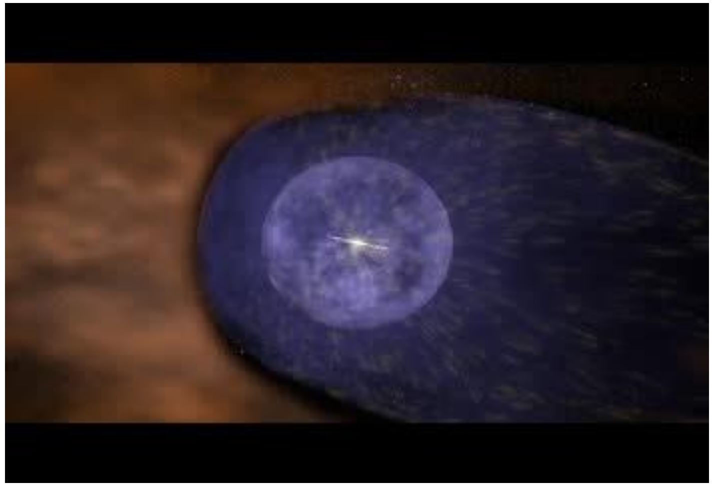
The colours of the aurora are determined by the composition of gases in the Earth's atmosphere, the altitude at which the aurora occurs, the density of the atmosphere, and the level of particle energy involved.

# Radiation Environment - GCR

Galactic Cosmic Rays  (GCR)

- Are not “rays” and they are made up of around 85% protons, 14% $\alpha$ , and 1% heavy ions. The misnomer originates from when GCRs were thought to have been mostly electromagnetic radiation.
- They originate from Galactic and Extra Galactic sources
- Their Intensity varies with solar activity; as the heliosphere expands, it blocks more GCRs, and as it contracts, more GCRs get through and can affect satellites.
- We describe GCRs with their Linear Energy Transfer (LET) spectrum.

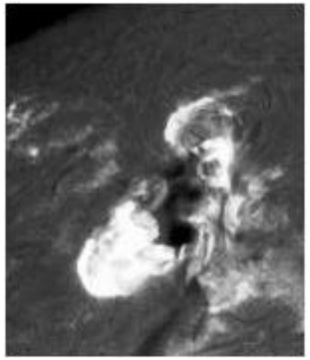




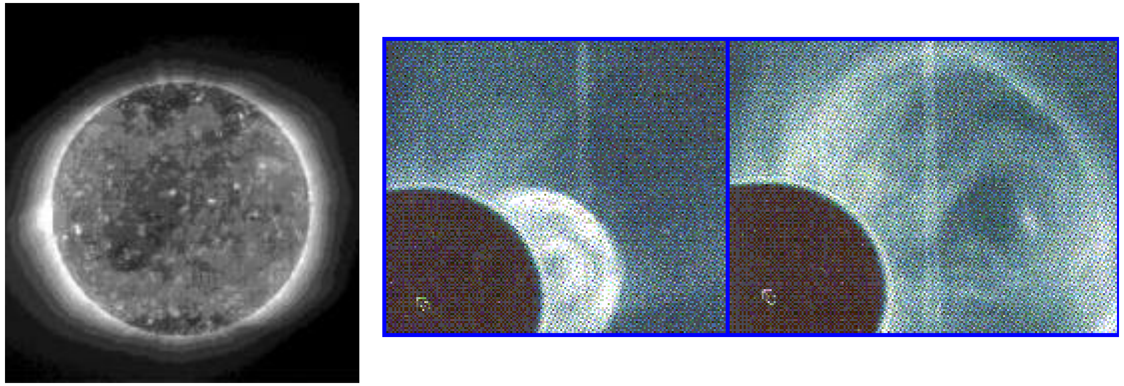
# Radiation Environment – The Sun and Solar Particle Events

Solar Particle Event (SPE) - the sporadic emission of solar particles accelerated towards the earth by magnetic coupling. The two storm phenomena occurring on the Sun that affect particle levels are solar flares and coronal mass ejections (CMEs).

- Solar flares are seen as sudden brightening's in the photosphere near sunspots
- CMEs occur in the layer of the sun outside of the photosphere called the chromosphere.



Brightening near a sunspot as seen with a solar flare.



Note: The chromosphere can be seen only when filtering out the bright light of the photosphere. The chromosphere is seen as a bright rim around the sun. CMEs are observed as large bubbles of gas and magnetic field

# Radiation Environment - The Sun and Solar Particle Events

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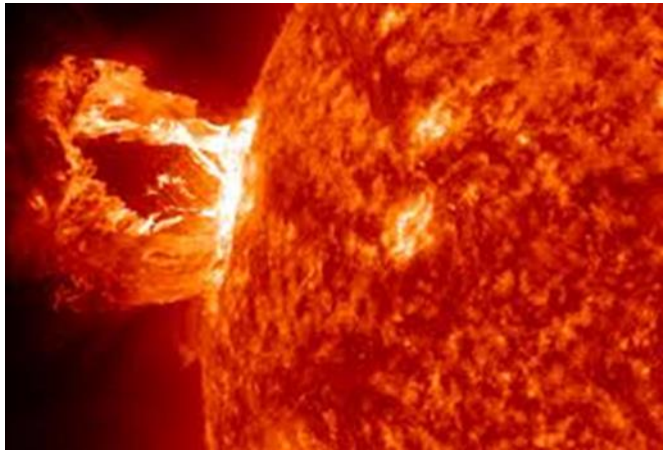
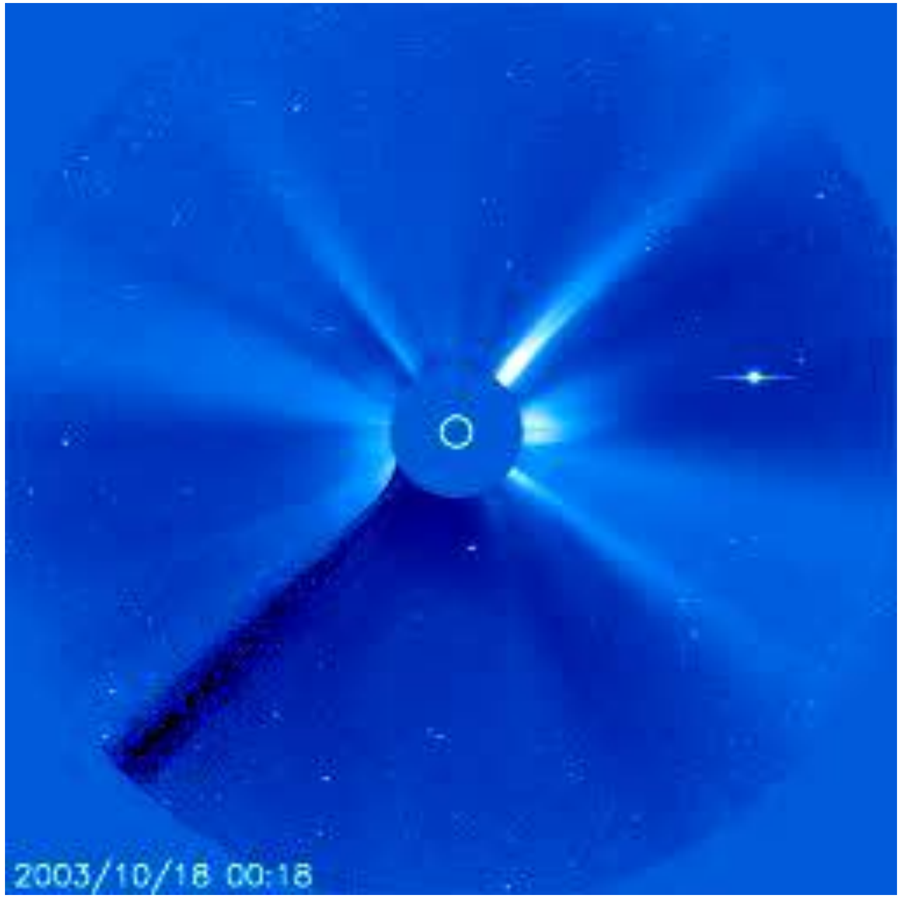
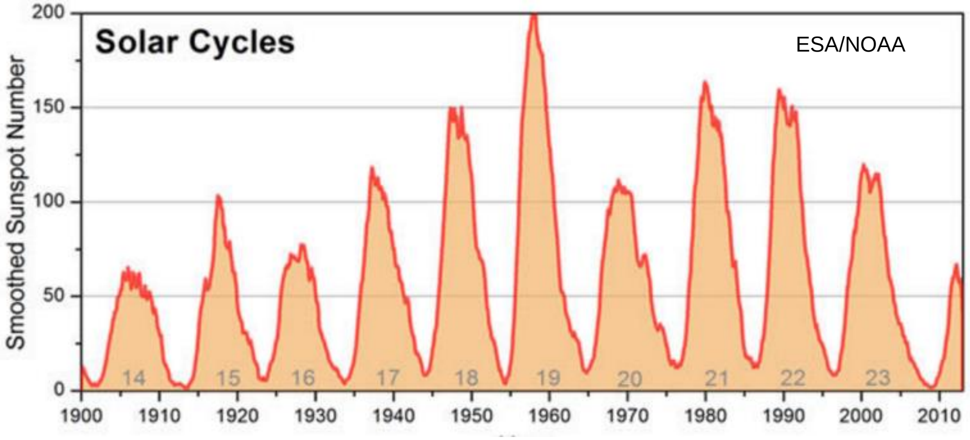
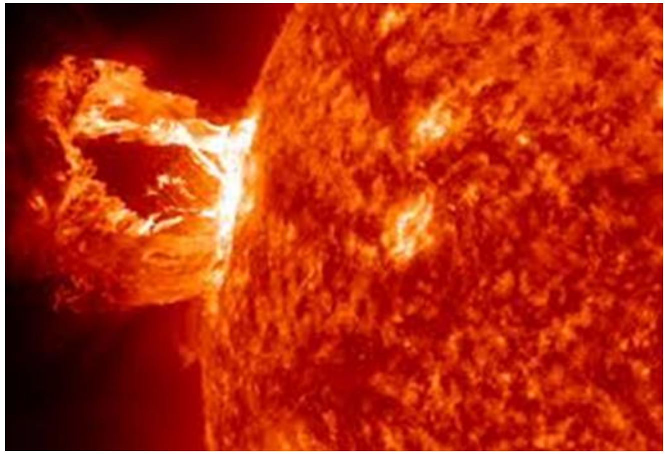




# Radiation Environment – The Sun and Solar Particle Events

- Frequency of SPE linked to the solar activity
- Solar cycle – typically 11 years duration with 7 years at solar maximum
- Strongest probability to occur during Solar maximum activity period
- Composition: mainly protons
- Duration: typically 1-2 days to a week

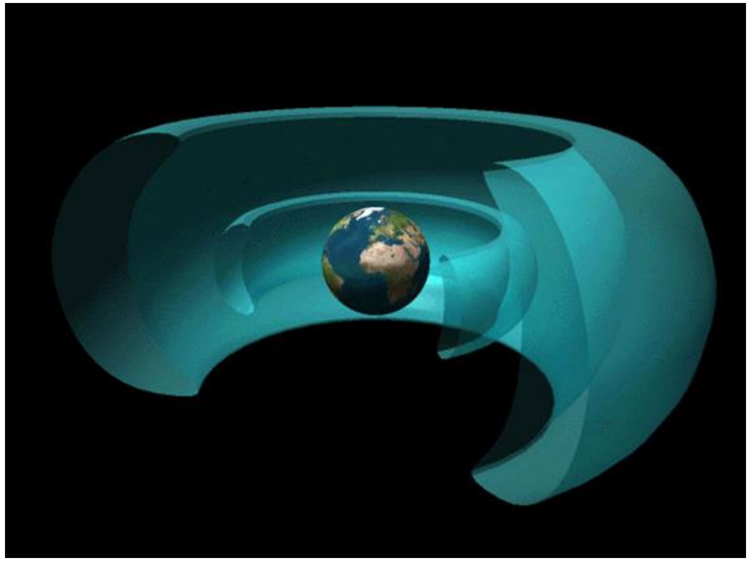


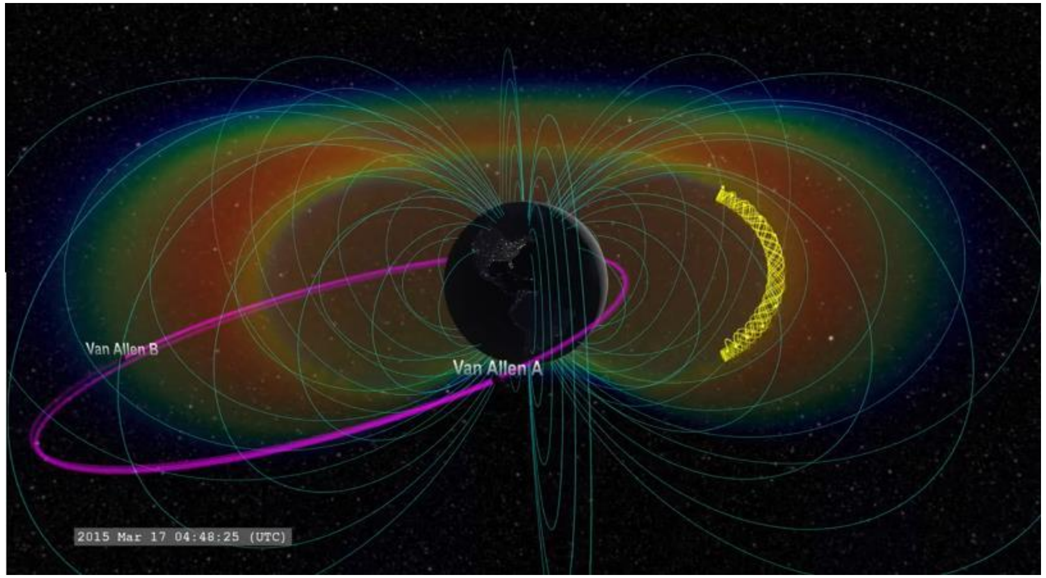


# Radiation Environment – Trapped Particles

Due to the presence of the Earth’s magnetic field, charged particles have become trapped and formed radiation belts around the Earth.

The presence of the Earth’s magnetic field is one of the reasons that life exists on Earth. However, the resulting radiation belts that have been formed are hazardous for man, materials, and electronics to traverse.

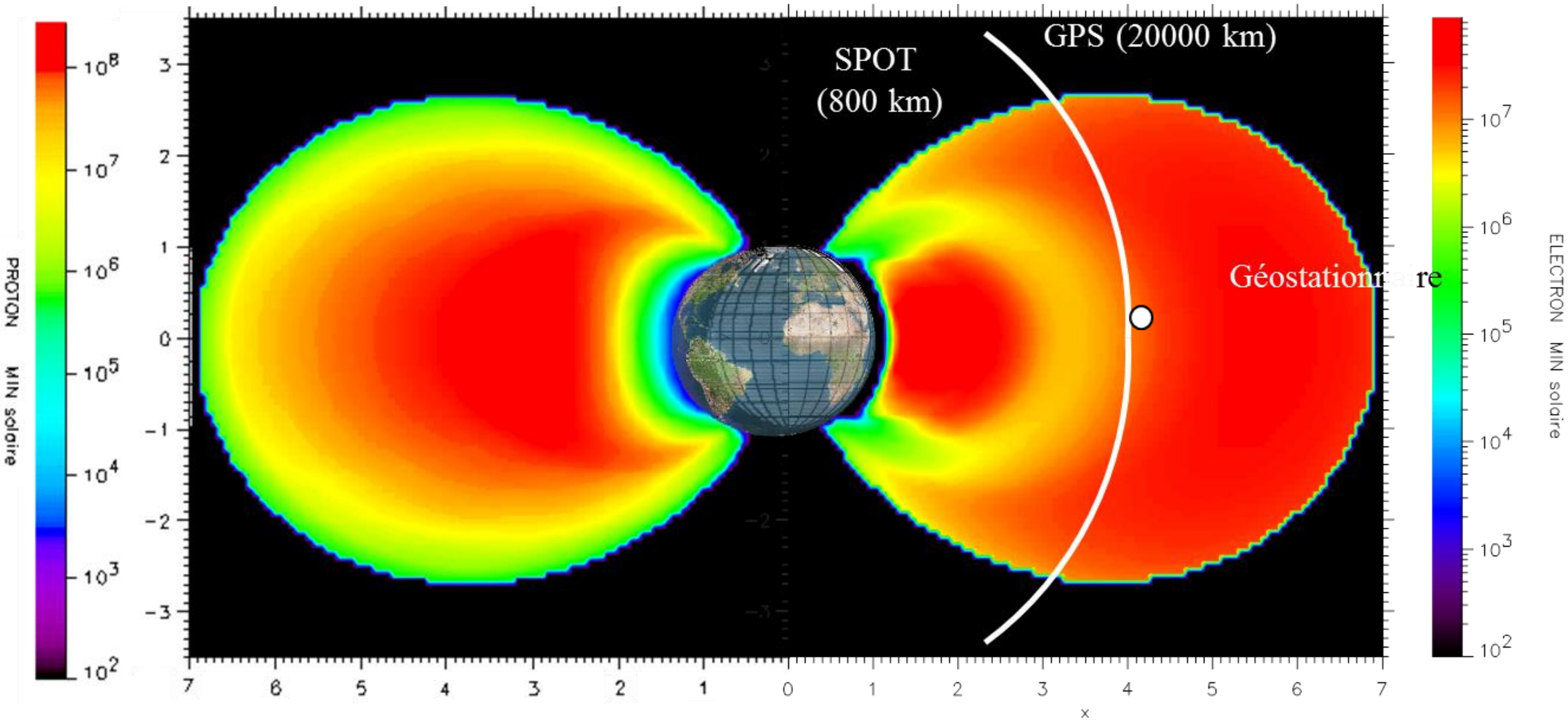




# Radiation Environment – Trapped Particles

Particles trapped around the Earth in radiation belts

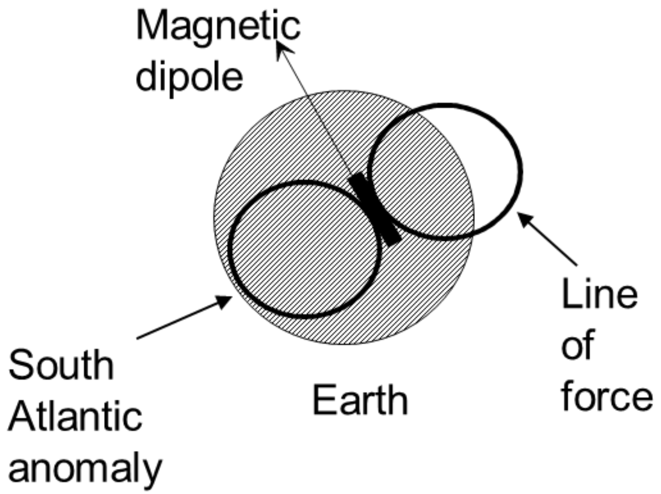
- Fluxes vary as a function of altitude and inclination
  - 2 maximum for electrons (internal and external belts), 1 maximum for protons

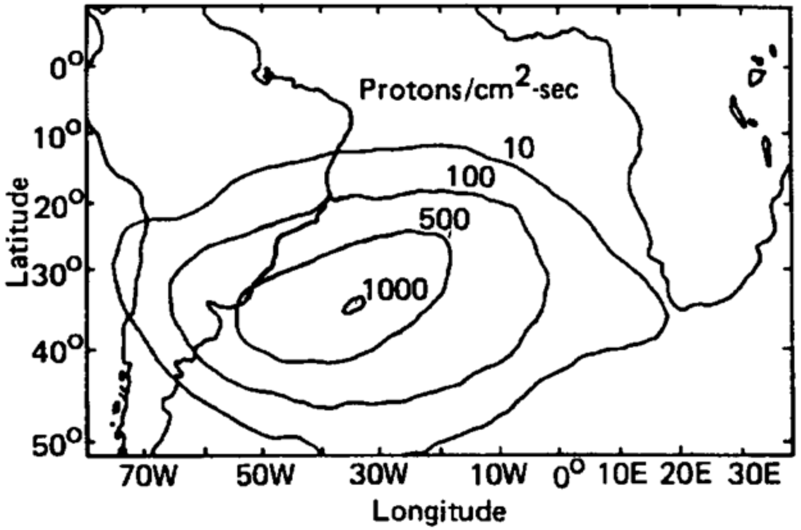


# Radiation Environment – South Atlantic Anomaly

Trapped particles and the South Atlantic Anomaly (SAA).

- Origin: Earth's magnetic dipole not centred
- Consequence: the lines of the magnetic field and the associated trapped-particle flux are closer to the surface of the Earth above the South Atlantic.

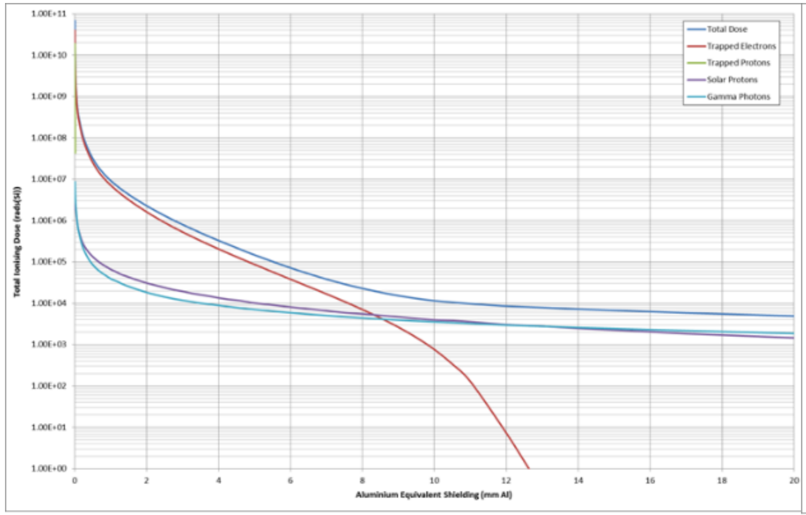




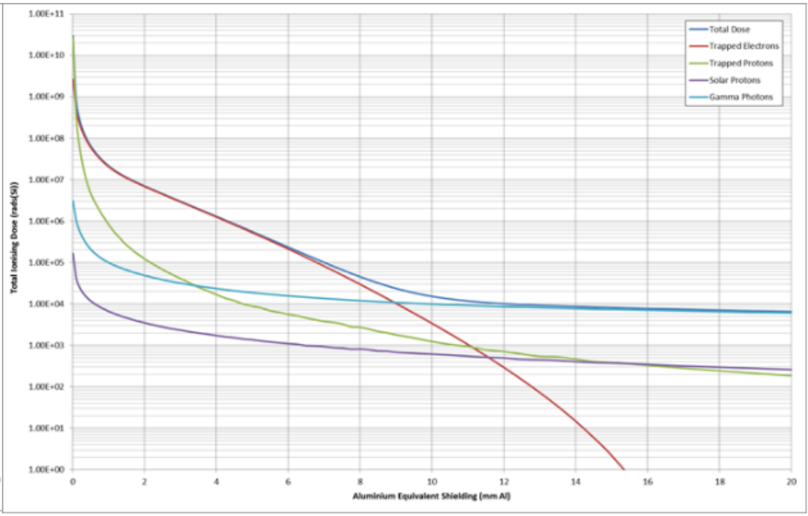
# Radiation Environment - TID Dose Depth Curve

As can be deduced the radiation environment is rather complex and to ease the situation a simplistic environment is derived and used for analysis purposes. This is known as the TID Dose Depth Curve.

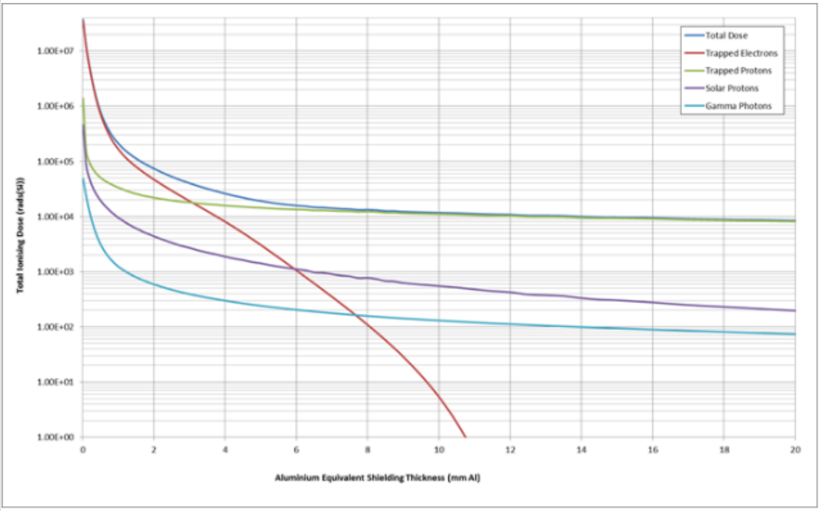
The following shows typical TID dose depth curves for different mission scenarios for use with ray-tracing analysis software



GEO (15years, 36,000km, 0°)



MEO (15years, 10,000km, 45°)



LEO (6 years, 1200km, 87.9°)

# Radiation Effects – Why different orbits?

There are a number of “Standard” orbits that are used in space missions:

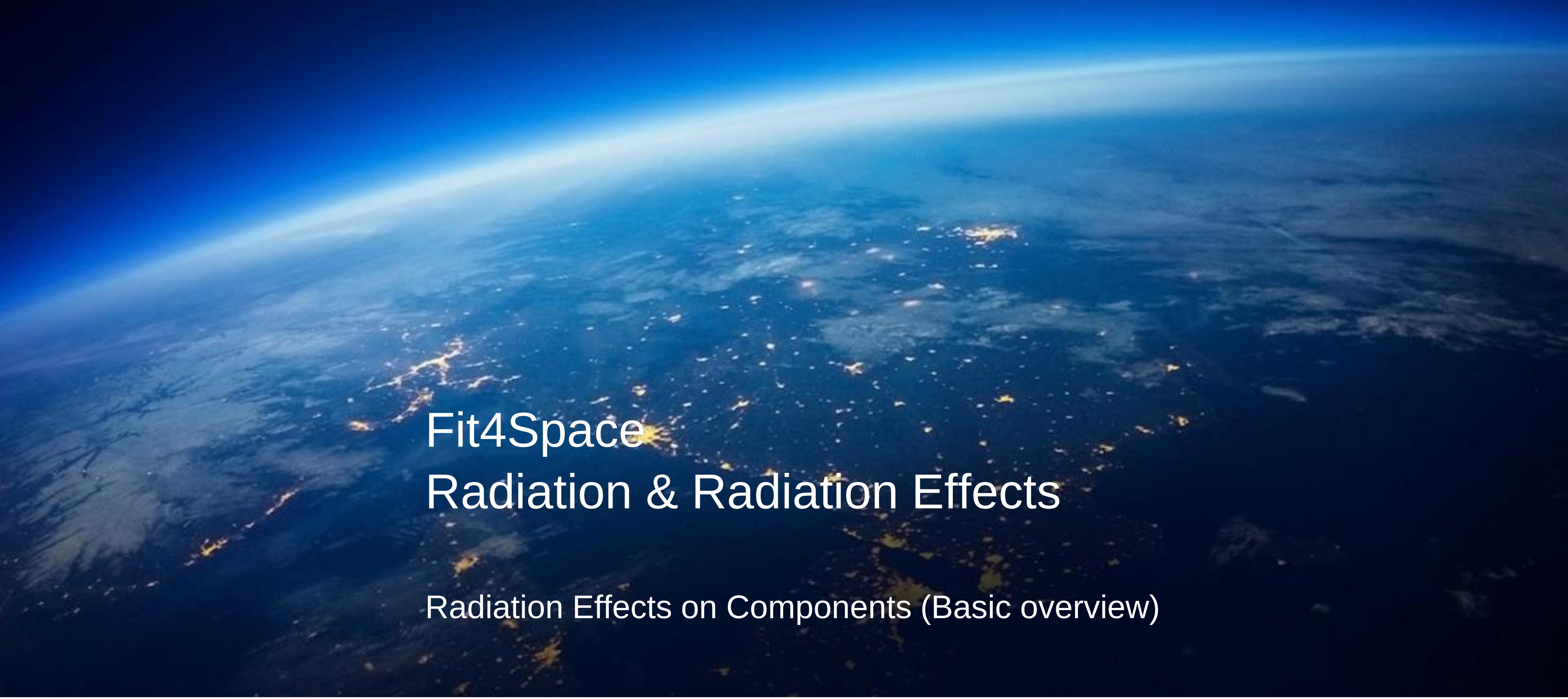
- Low Earth Orbit (LEO)
- Medium Earth Orbit (MEO)
- Geostationary Orbit (GEO)
- Highly Elliptical Orbit (HEO)

They all have different uses but typical applications are:

- LEO – earth observation (forest, ice, floods etc.)
- MEO – Sat Nav
- GEO – Telecoms
- HEO - Telecoms

but the orbits can be used for other applications…

Note: HEO is typically thought of as the Molniya orbit. A Molniya orbit is a type of satellite orbit designed to provide communications and remote sensing coverage over high latitudes. It is a highly elliptical orbit with an inclination of 63.4 degrees, an argument of perigee of 270 degrees, and an orbital period of approximately half a sidereal day. The name comes from the Molniya satellites, a series of Soviet/Russian civilian and military communications satellites which have used this type of orbit since the mid-1960s.



# Fit4Space
# Radiation & Radiation Effects

## Radiation Effects on Components (Basic overview)

DEFENCE AND SPACE

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06/03/2024

# Radiation Effects - Introduction

There are four main categories of radiation effects that have to be considered in any equipment/spacecraft radiation analysis:

**Total Ionising Dose (TID) effects**

- The effect accumulates over the course of the mission
- Effects electronic components
- Effects organic materials but typically at higher doses than EEE parts

**Total Non Ionising Dose (TNID or DD)**

- The effect accumulates over the course of the mission
- Effects electronic components
- Some effects on organic materials

**Single Event Effects (SEE)**

- Caused by a single particle and can happen anytime within the mission
- Can cause permanent damage to EEE parts (e.g. SEL, SEB)
- Can cause transient effects (e.g. SET/SEU)
- Effects electronic components only

**Deep Dielectric Discharge (DDD)**

- Caused by the presence of “floating” metals and insulators.

# Radiation Effects - TID effects

Total Ionising Dose (TID)

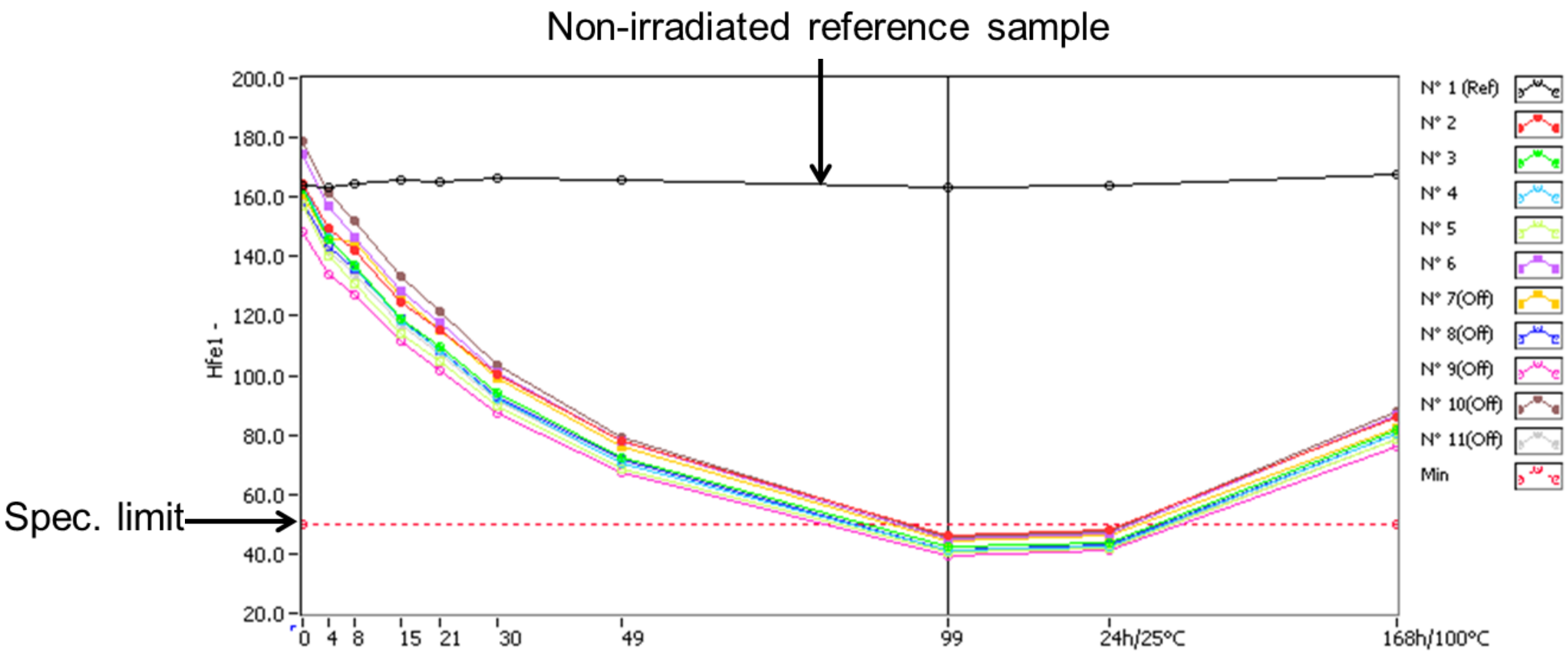
- A gradual degradation effect (parameters degrade over time due to the total radiation dose)
- TID degradation in electronic components is caused by charge trapping at the interface layer (oxide is present).
- TID degradation in organic materials is caused by scission and cross-linking.
- EEE parts are affected by TID regardless as to whether they are switched on or off.
- To determine the TID tolerance of a EEE part or material, intended for space flight, ground testing of the device or material is performed in a lab using a gamma-ray source.
- It’s possible to decrease the received dose by increasing the shielding to a sensitive component or materials.

*Note: The units of measurement for deposited dose within the space industry is the “rad”. A rad is a measure of absorbed energy (1 rad = 0.01 J / kg). You will also see sometimes that the there is another unit mentioned and this is the Gy (1Gy = 100rad)*

# Radiation Effects - TID effects

TID test results of a 2N2222 transistor.

- The device was irradiated using a 60Co gamma-ray source.
- The plot shows the degradation of the hfe (gain) with increasing TID.
- The plot shows that the device is out of it’s design specification before 100krad



Non-irradiated reference sample

Spec. limit

Note that to comply with standard RHA requirements then these raw results need to have statistics applied dependant on sample size (not shown here!)

# Radiation Effects - TNID effects

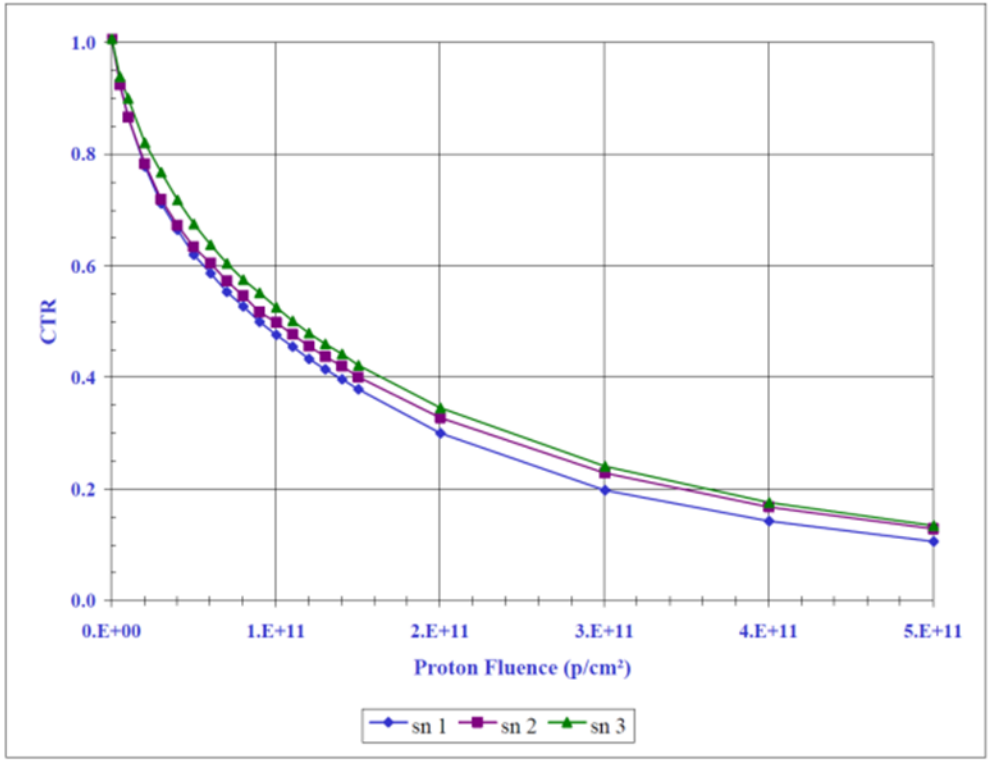
Total Non-ionising Dose (TNID) (also known as Displacement Damage)

- A gradual degradation effect with parameters degrading over time.
- TNID degradation is caused by atoms being displaced from their lattice sites in the bulk structure of the electronic components and organic materials.
- EEE parts that are sensitive to TNID are typically affected irrespective of whether or not they are in operational mode.
- EEE parts that are sensitive to TNID, and are intended for space flight, need to be ground tested in a lab with a particle accelerator.
- As with TID, it is possible to reduce the TNID received by a sensitive component by increasing the shielding.

# Radiation Effects - TNID effects

TNID test results of an 66191 opto-coupler.

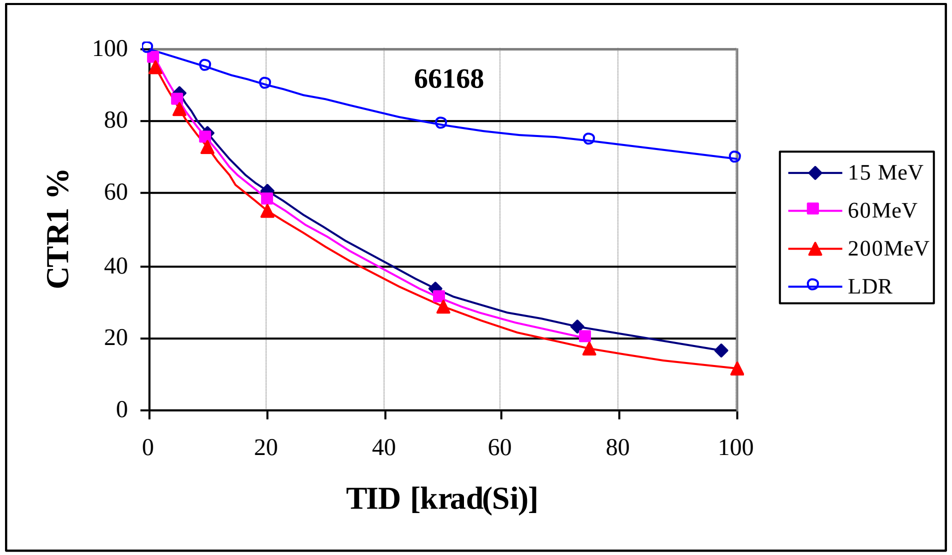
- The plot shows the degradation of the Current Transfer Ratio (CTR) with increasing proton fluence



# Radiation Effects - TNID effects

TID & TNID test results of an 66168 opto-coupler.

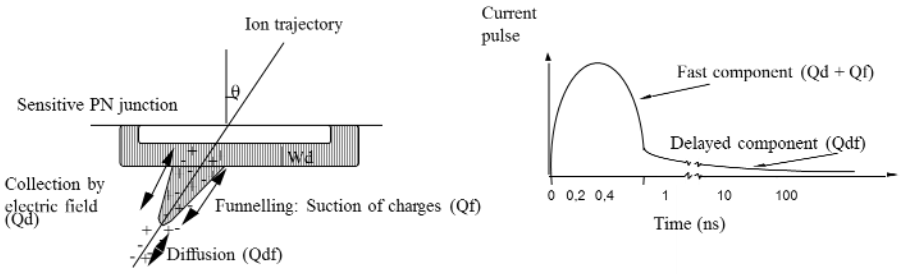
- The plot shows the degradation of the Current Transfer Ratio (CTR) with increasing proton fluence and compares this with the degradation caused by TID
- For a device that is susceptible to TNID then TID also needs to be taken into account to obtain the overall degradation



# Radiation Effects - SEE

Single Event Effects (SEE) or Single Event Phenomena (SEP) - “instantaneous” effects that can occur at any time during the mission.

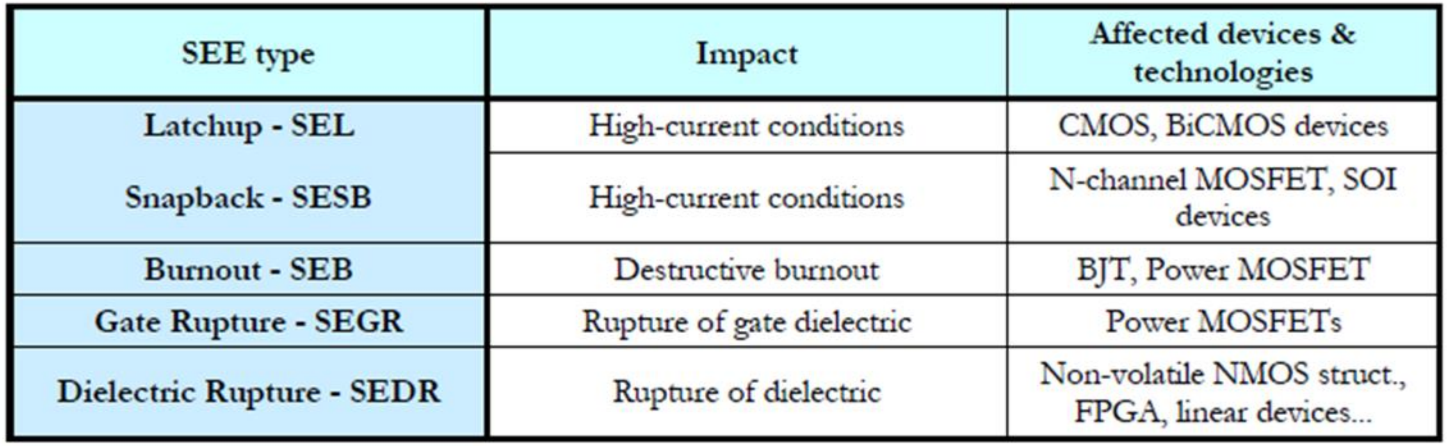
- SEE are caused by a single heavy-ion or proton striking a sensitive area of the electronic device.
- SEE can occur randomly during the mission
- SEE require the device to be in an operational mode.
- SEE can sometimes lead to complete device failure with no chance of recovery.
- SEE does not cause any significant degradation in organic materials.
- To understand how a device will respond to being struck by a heavy-ion, the device needs to be ground tested in a lab with a heavy-ion accelerator.
- There are several distinct types of SEE, all of which exhibit different physical characteristics and affect different types of component. The effects are generally categorised as either destructive or non-destructive.
- It’s not practical to increase the shielding to a sensitive component to prevent SEEs from occurring.



# Radiation Effects - SEE

Destructive Single Event Effects (SEE)

- The table below shows a list of destructive SEE. These effects result in the permanent damage and non-recoverable loss of the functionality of the component.
- Devices that are considered sensitive to these typically cannot be used, or require application conditions that prevent the possibility of the SEE occurring.

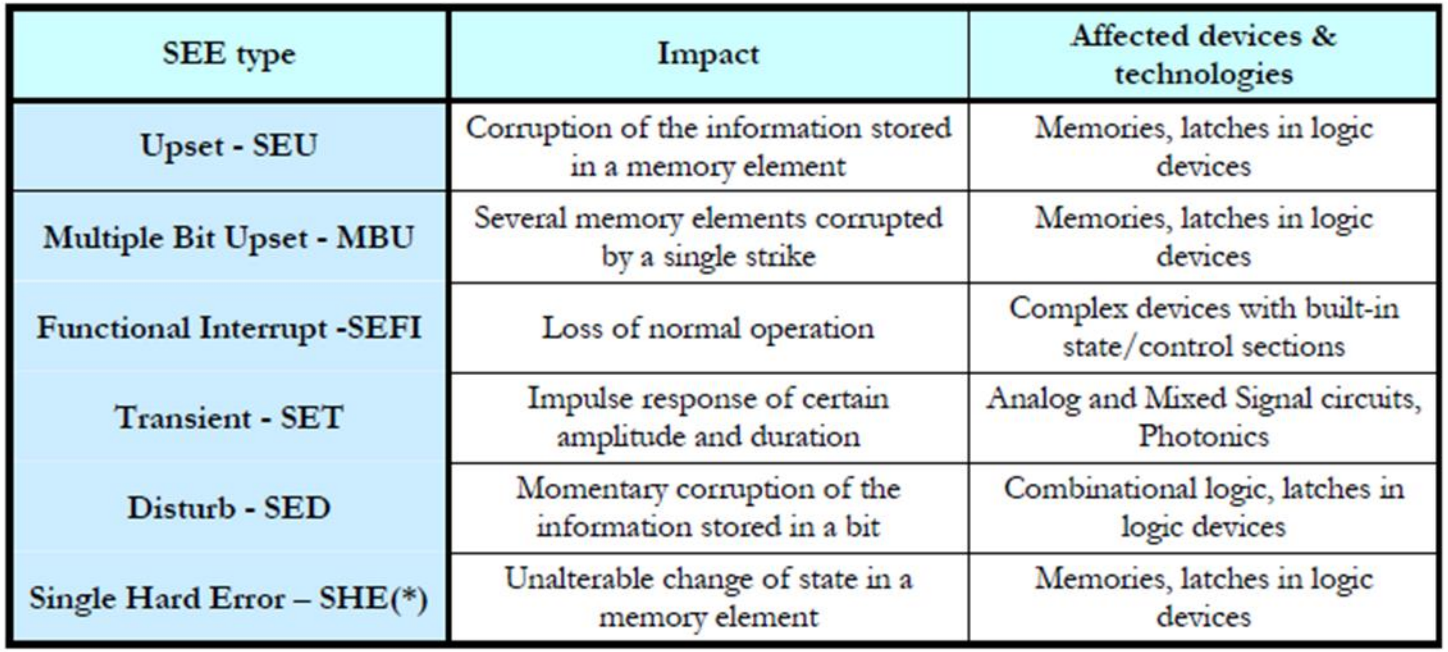


| SEE type | Impact | Affected devices & technologies |
|---|---|---|
| Latchup - SEL | High-current conditions | CMOS, BiCMOS devices |
| Snapback - SESB | High-current conditions | N-channel MOSFET, SOI devices |
| Burnout - SEB | Destructive burnout | BJT, Power MOSFET |
| Gate Rupture - SEGR | Rupture of gate dielectric | Power MOSFETs |
| Dielectric Rupture - SEDR | Rupture of dielectric | Non-volatile NMOS struct., FPGA, linear devices... |

# Radiation Effects - SEE

Non-destructive Single Event Effects (SEE)

- The table below shows a list of non-destructive SEE. These effects do not result in permanent damage to the component. However, their occurrence may result in unwanted behaviour in the component that could affect the circuit design/operation.
- Devices that are sensitive to these effects typically require a circuit analysis review to determine what impact the SEE will have on the circuit design/operation.

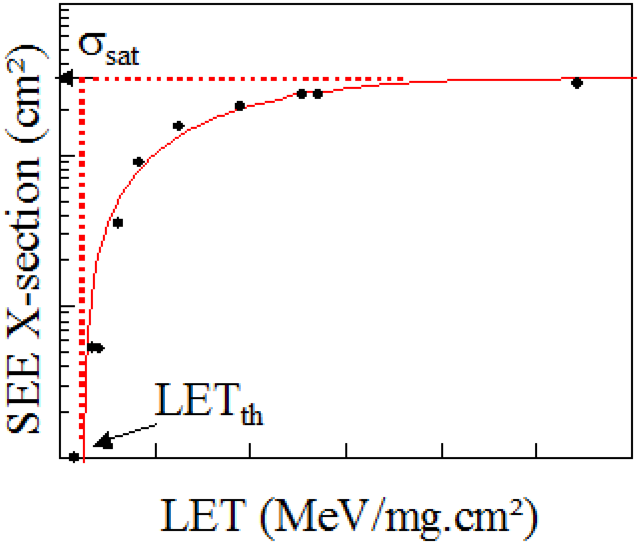


| SEE type | Impact | Affected devices & technologies |
|---|---|---|
| **Upset - SEU** | Corruption of the information stored in a memory element | Memories, latches in logic devices |
| **Multiple Bit Upset - MBU** | Several memory elements corrupted by a single strike | Memories, latches in logic devices |
| **Functional Interrupt -SEFI** | Loss of normal operation | Complex devices with built-in state/control sections |
| **Transient - SET** | Impulse response of certain amplitude and duration | Analog and Mixed Signal circuits, Photonics |
| **Disturb - SED** | Momentary corruption of the information stored in a bit | Combinational logic, latches in logic devices |
| **Single Hard Error – SHE(*)** | Unalterable change of state in a memory element | Memories, latches in logic devices |

# Radiation Effects - SEE

SEE basic concepts and models: Device Sensitivity

- Cross Section (CS or σ) : probability for a given SEE to occur (number of events caused per unit fluence of particles)
- The σ curve measures the LET-dependent sensitive area of the chip.



# Radiation Effects - SEE

A single ion can trigger several SEU: (Multiple Bit Upset, MBU)

- The cells located close to the impact may be switched
- Affects IC with high integration and high sensitivity to SEU
- Practical implications on the error correction strategy

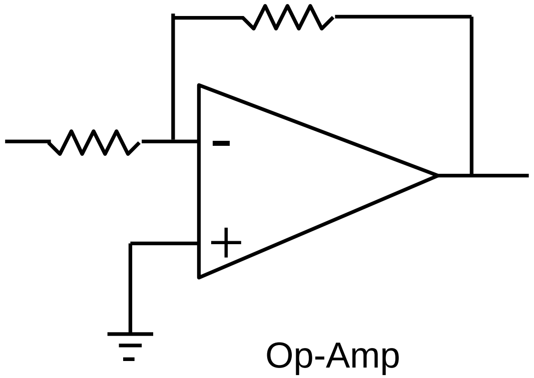
Single Event Functional Interrupt (SEFI)

- Applicable to VLSIs: high capacity memories, FPGAs…
- Reversible switching of a component in a specific mode (self-test for example) following a SEU on the internal logic controlling the mode in question.
- During a SEFI, reading is erroneous and writing is no longer controlled.
- An ON-OFF power cycling of the component can be necessary for resetting the SEFI and restoring normal device operation

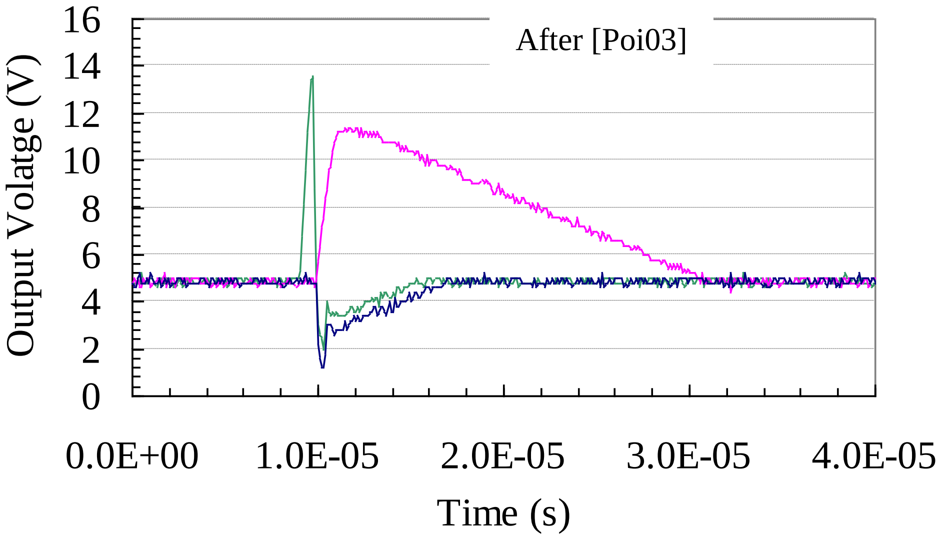
# Radiation Effects - SEE

Single Event Transient (SET)

- The passage of a heavy ion generates a transient at the output of an analogue circuit.
  - This transient may be of sufficient amplitude and duration for inducing an error in a digital IC connected to the analogue IC.



Op-Amp



# Radiation Effects - DDD

Deep Dielectric Discharge (DDD)

- DDD is caused by a  gradual charging of materials due high energy electrons.
- DDD results in electrostatic discharge and can cause damage to materials and components.
- Investigating DDD can be complex, and requires a deep understanding of the environment, spacecraft, materials etc.
- The effects of DDD can be disastrous and should not be ignored. For example, in the mid 1990’s television, radio, telephone and scientific operations were interrupted when two communications satellites experienced operational problems within days of each other, after being submersed in a cloud of high velocity electrons. It took operators 8 hours to regain control of one satellite and many months to regain control of the second. The problem was traced back to deep dielectric discharges within the spacecraft circuitry after many days of being bombarded by dangerous levels of high speed electrons.

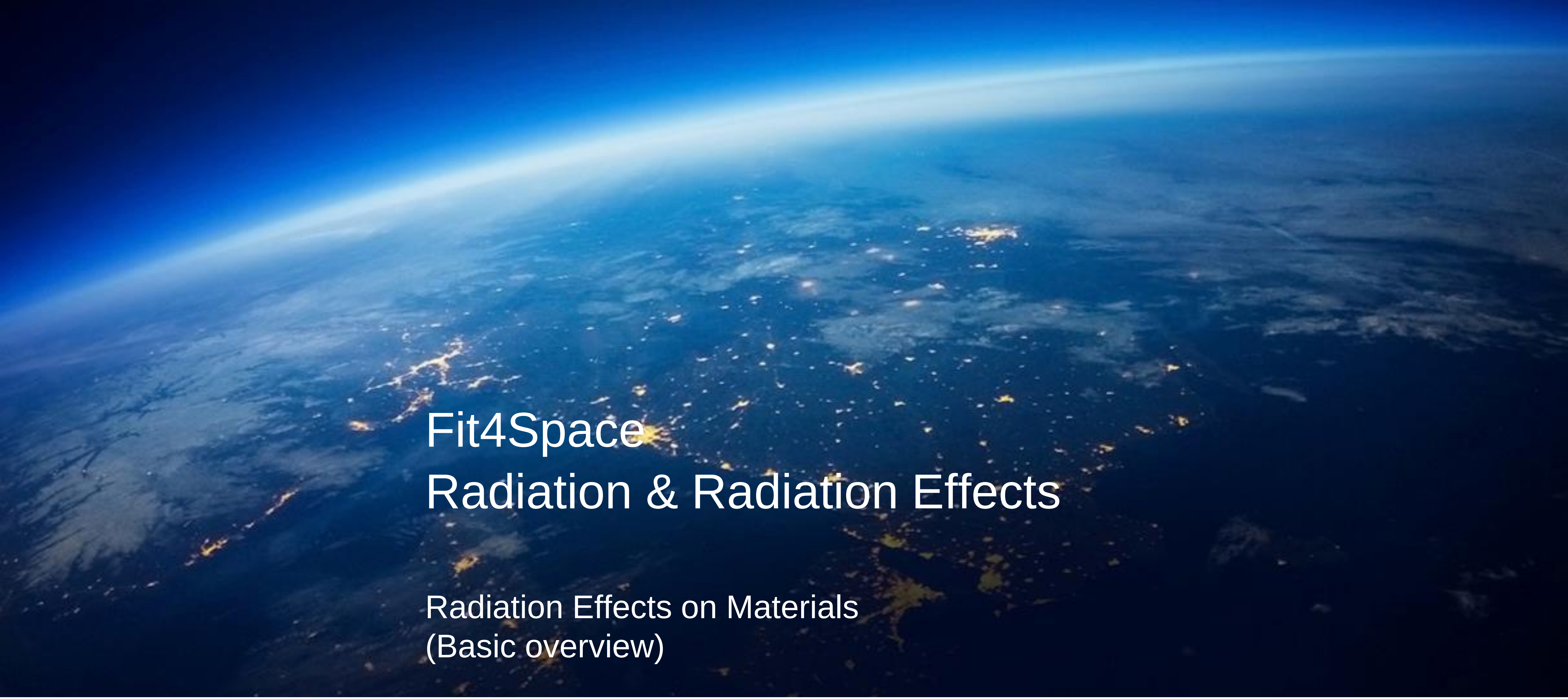
# Radiation Effects – Use of COTS components

Historically commercial satellite missions use Space Grade components which have a wealth of information associated with them (wafer lot, wafer fabrication facility, die mask version etc.). However, recently there has been a move towards the use of COTS components given easier availability and much cheaper.

However, the use of Commercial-off-the-Shelf (COTS) components in space is not as cheap an option as they initially appear. There are numerous issues

Customers are generally used to having high reliability satellites. The drive is always to reduce costs but unfortunately the Customer still expects the same reliability. To achieve this reliability we need to know detailed information for each electronic component – wafer traceability is key.

A lot of work is going on in the background between Industry and Institutions (ESA, NASA etc.) regarding the use of COTS in Space, and in the future there may be developments which allow easier use e.g. changes to RHA requirements. Presently that is not the case and the amount of testing etc. (Cost of Ownership) remains very high – in some cases much higher than previous Space Grade component use.



# Fit4Space
# Radiation & Radiation Effects

## Radiation Effects on Materials
## (Basic overview)

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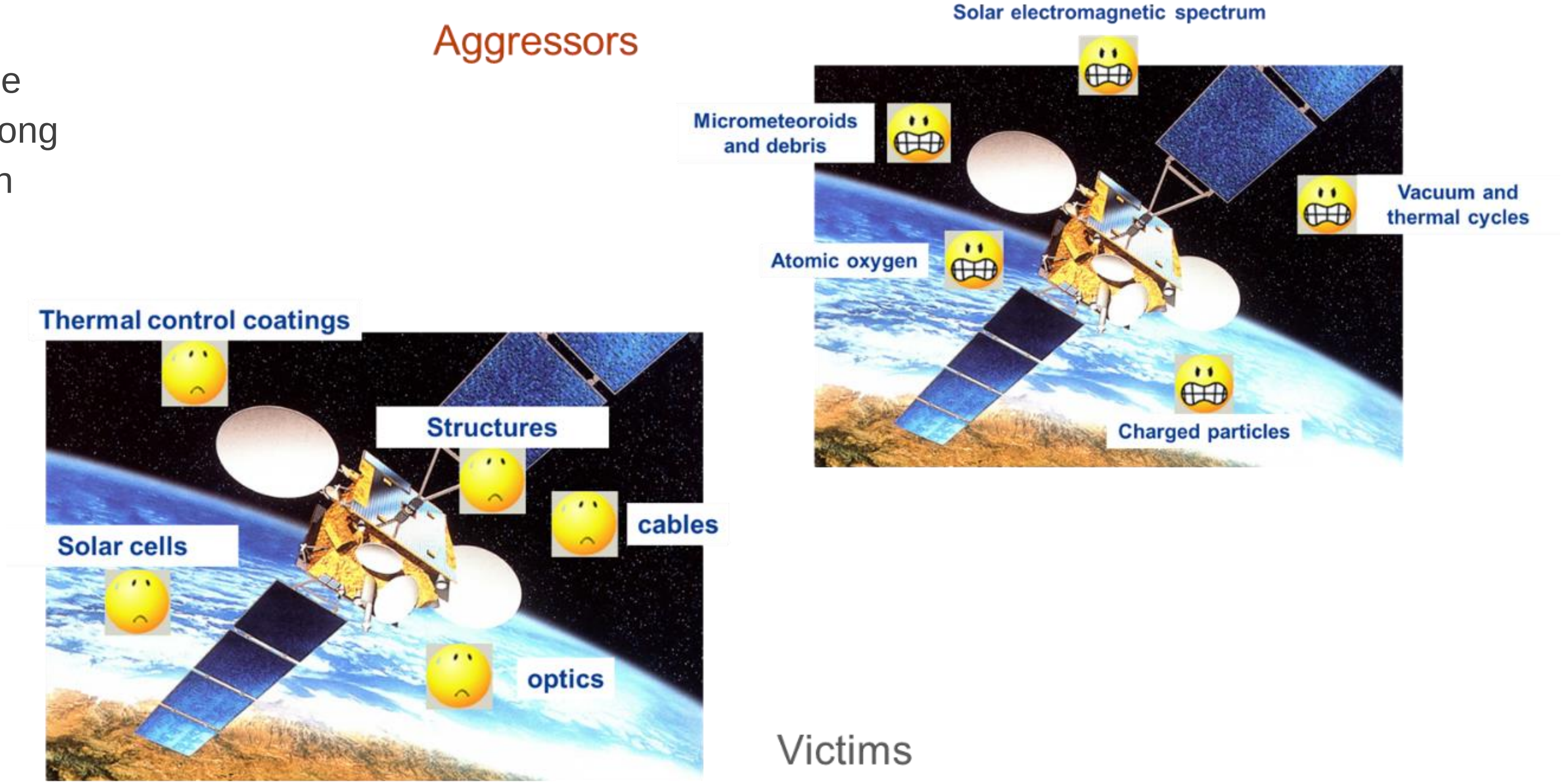
06/03/2024

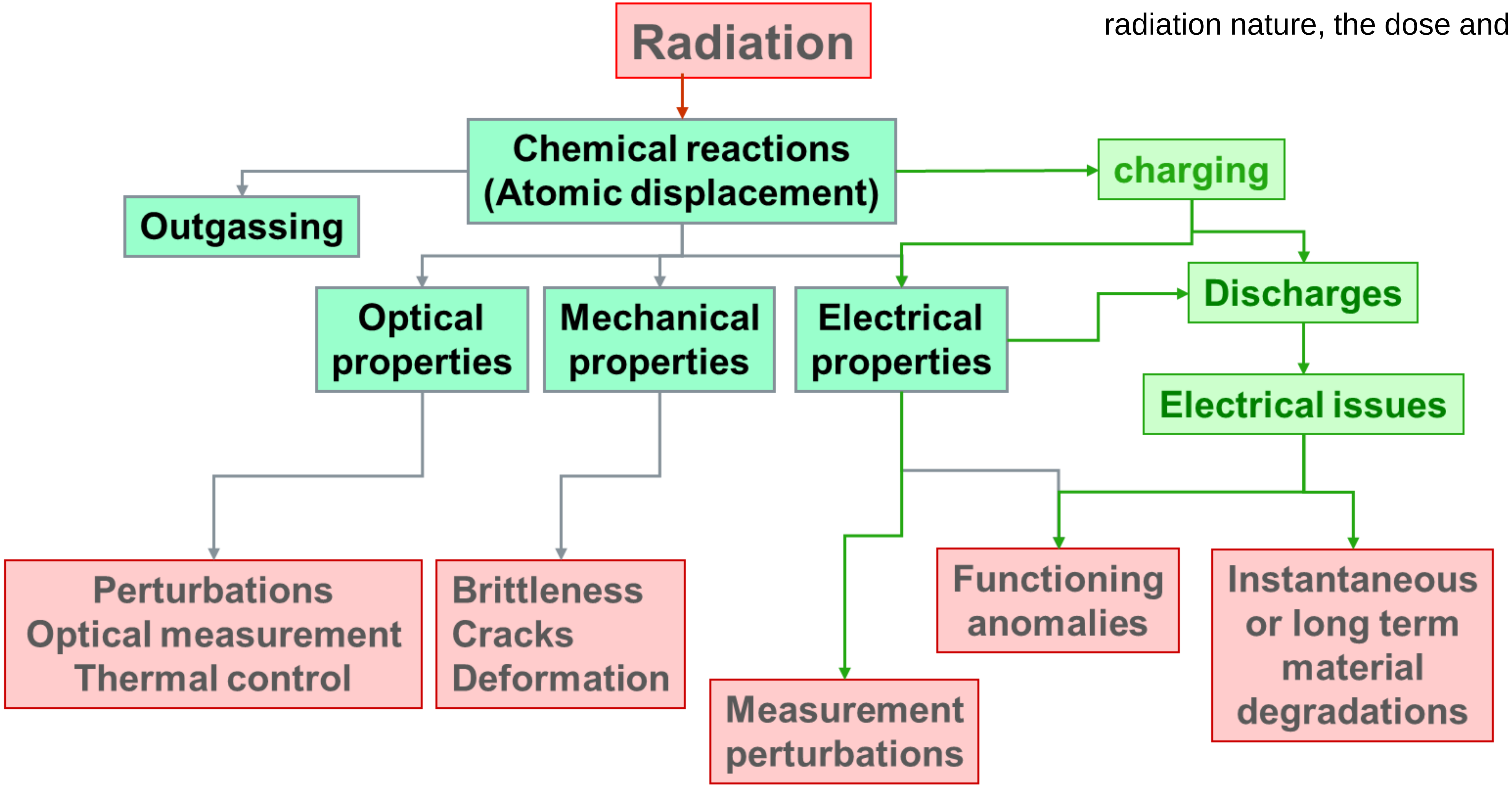
# Radiation effects on materials – context

- Interactions between a material and the different environments to which it is exposed are quite often synergistic and not simply additive
- Radiation effects on materials shall be considered as a degrading factor among others in the frame of the qualification status of materials
- Main degradation mechanism for materials is Total Ionizing Dose (TID)



# Radiation effects on materials – potential impacts

The defects distribution depends on the radiation nature, the dose and the dose rate.



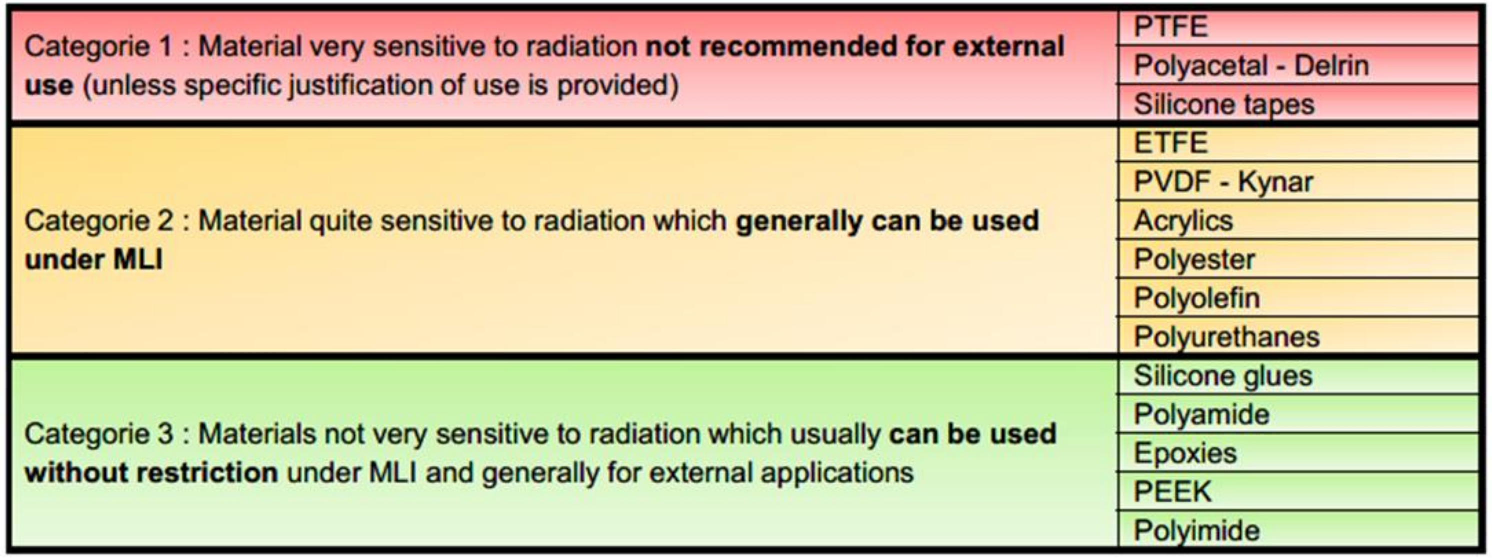
# Evaluation of material radiation hardness – M&P sensitivity – 1/2

- Only critical materials to be included in Materials Radiation Analysis (MRAD)
  - Materials non sensitive to absorbed dose are for example metal alloys without coating (Al1200 and passivation are not critical)
  - Materials very resistant to UV and radiation need only a light analysis in the MRAD (for example, polyimide)
  - Materials qualified for GEO (Telecom) applications are by default qualified for LEO applications.
  - Criticality analysis to be performed for coatings even for low absorbed dose given their possible sensitivity.

- For internal subsystems, few materials are critical because of the low level of absorbed dose
  - Definition of Internal: inside (X,Y,Z) walls volume
  - Definition of External: outside (X,Y,Z) walls volume, unprotected or protected by MLI (means that subsystems under MLI are NOT internal)

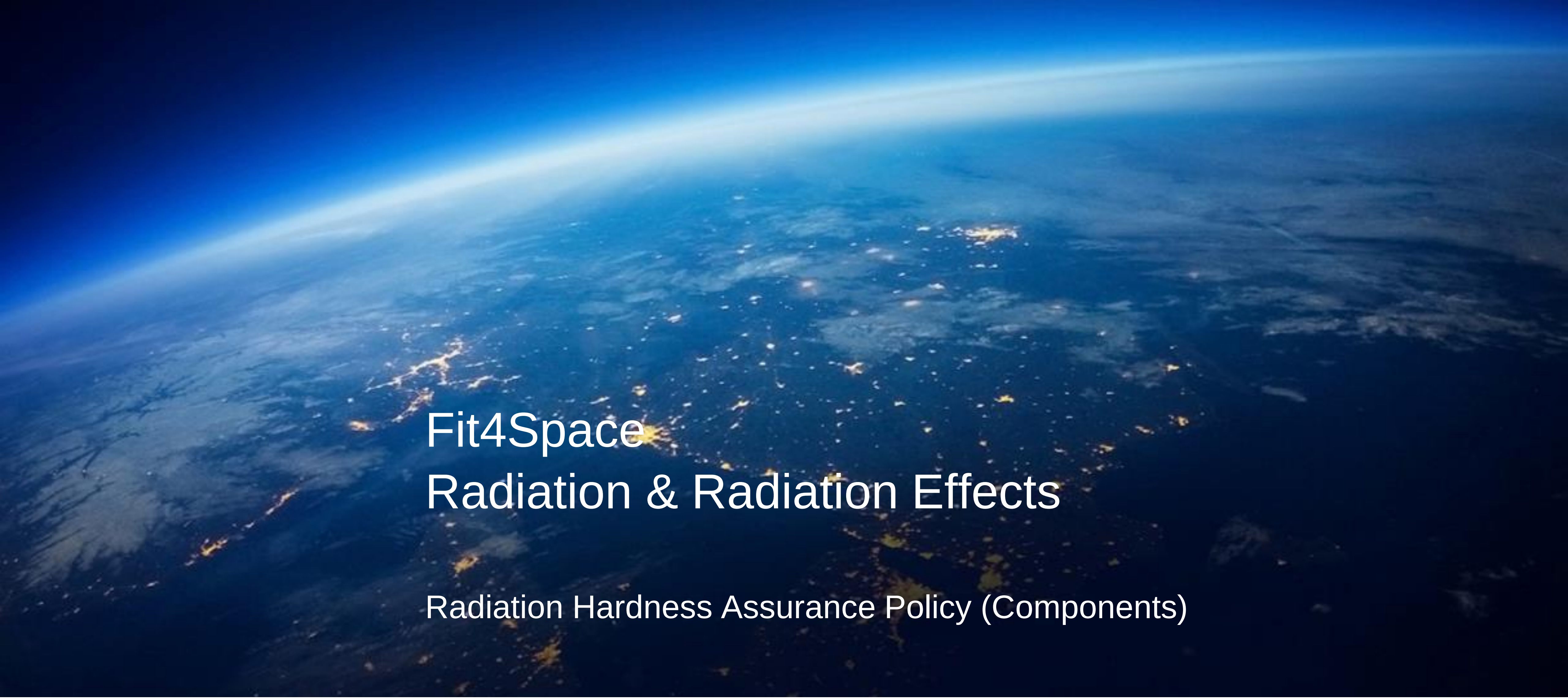
# Evaluation of material radiation hardness – M&P sensitivity – 2/2

For polymers, three categories can be considered (for generic 15yr GEO environment)



| | |
|---|---|
| Categorie 1 : Material very sensitive to radiation **not recommended for external use** (unless specific justification of use is provided) | PTFE |
| | Polyacetal - Delrin |
| | Silicone tapes |
| Categorie 2 : Material quite sensitive to radiation which **generally can be used under MLI** | ETFE |
| | PVDF - Kynar |
| | Acrylics |
| | Polyester |
| | Polyolefin |
| | Polyurethanes |
| Categorie 3 : Materials not very sensitive to radiation which usually **can be used without restriction** under MLI and generally for external applications | Silicone glues |
| | Polyamide |
| | Epoxies |
| | PEEK |
| | Polyimide |

- Description of the materials sensitivity to absorbed dose and /or UV w.r.t. critical parameter(s) is then provided in MRAD



# Fit4Space
# Radiation & Radiation Effects

## Radiation Hardness Assurance Policy (Components)

DEFENCE AND SPACE

Lee Pater
06/03/2024

AIRBUS

# Radiation Hardness Assurance

So, you have the environment specified, you have the component radiation susceptibility specified but what next?

The answer is an RHA. The question is therefore: what is an RHA?

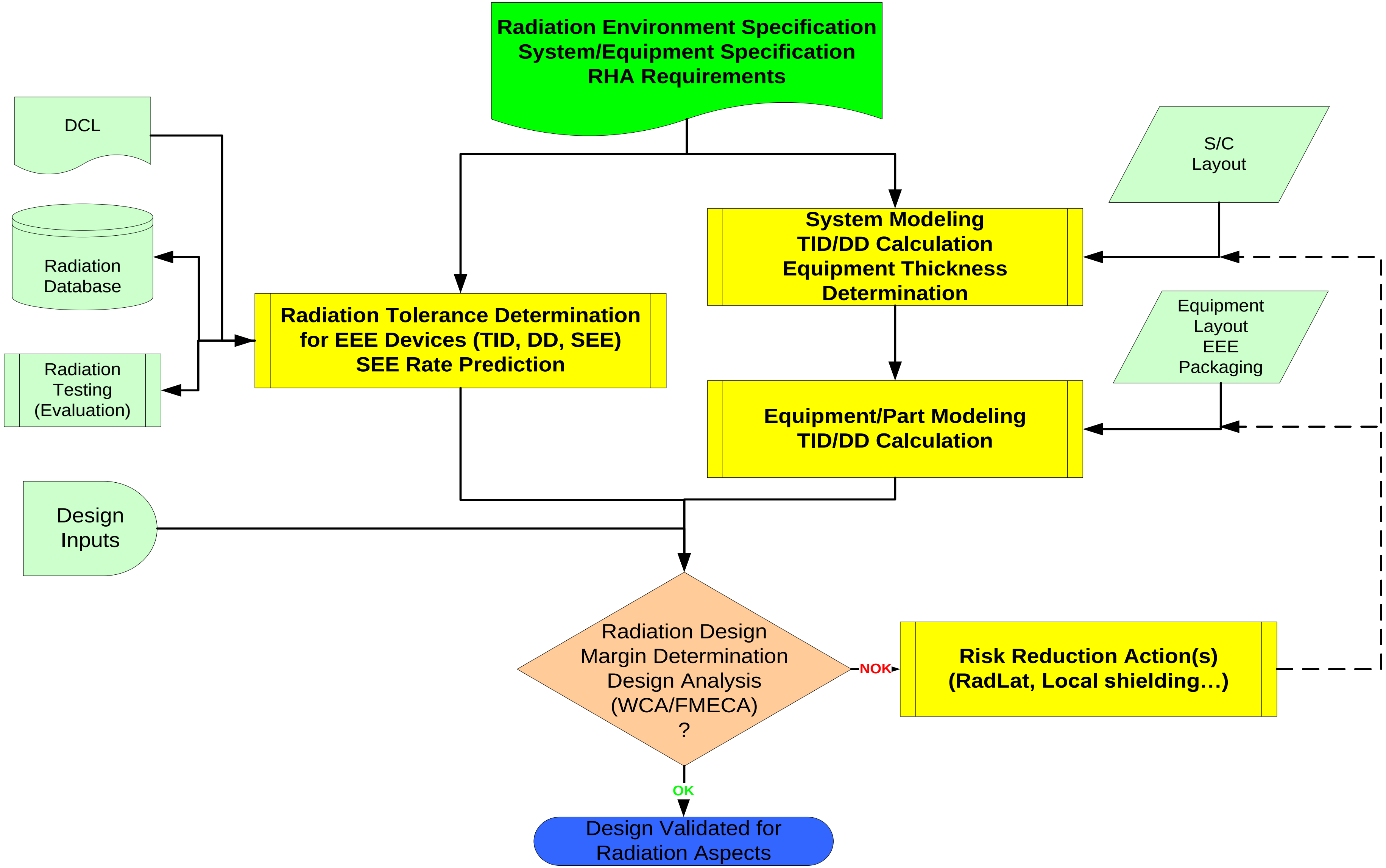
Basically it consists of all activities undertaken to ensure that the radiation sensitive elements of a space system perform to their design specifications after exposure to the space radiation environment

It deals with environment definition, part selection, part testing, spacecraft layout, radiation tolerant design, and mission/system/subsystems requirements.

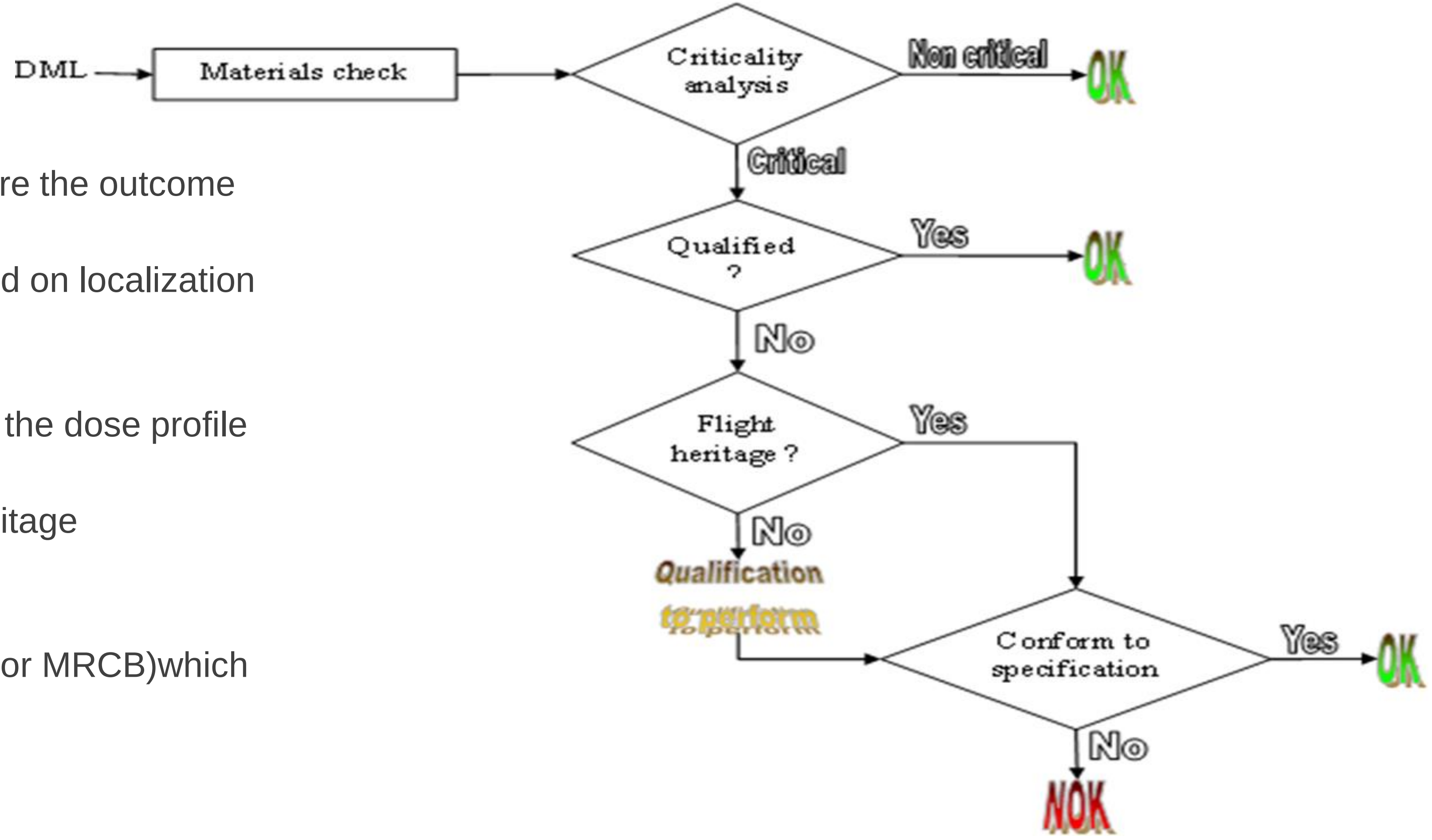
The RHA and the requirements imposed can be very different depending on the mission. For example, a Class 1 Telecoms mission has to extremely reliable and cannot afford any downtime, whereas a scientific mission in LEO may be able to miss a download of scanned information and send it next time around.

There are also potential issues with the quality of components being used: Space Grade components are well controlled by the supplier to comply with the strict rules for such components but even these can vary as regards radiation tolerance between batches; at the other extreme we have COTS where the cost is small but the cost of ownership can be very expensive and they are not well controlled – manufacturers changes are not notified

# Radiation Hardness Assurance Process - EEE



# Radiation Hardness Assurance Process - Materials



- Material Radiation Analysis (MRAD) capture the outcome of the M&P radiation qualification process
  - Evaluation of critical properties, based on localization and functional need
  - Received dose level estimation
  - Description of materials sensitivity to the dose profile and/or UV
  - Justification: qualification or flight heritage
  - Evaluation of radiation hardness

- Approval and closure done during MPCB (or MRCB)which should occur before CDR

# Radiation Hardness Assurance - TID

**Total Ionizing Dose Hardness Assurance**

- Comparison between expected in flight level (TIDL) and TID Sensitivity (TIDS) of the device
  - TIDL may be estimated by Monte Carlo technique (NOVICE, GEANT4…) or by Ray Tracing technique (NOVICE, FASTRAD, SYSTEMA/DOSRAD…)
  - TID Device Sensitivity (TIDS) is determined by:
    - Manufacturer guarantee (TID hardened devices)
    - Technological assessment
    - TID ground testing

**TIDL and TIDS shall be validated through compliance to requirements applicable in RHA specification**

  - TIDL: validation of calculation methodology, radiation tool, nature of geometrical modelling.
  - TIDS: validation of radiation test data and test methodology, applicability of these data to used devices, usage rules for radiation test data.

# Radiation Hardness Assurance - TID

**RHA methodologies for TID & electronics**

Radiation Design Margin (RDM) is defined as being the ratio between TIDS and TIDL

Several empirical methods exists for RDM determination

- Design Margin Breakpoint
- Part categorisation Criteria

Airbus uses the DMBP method

- RDM(low)=1.2
- RDM(high)=2

# Radiation Hardness Assurance – TID & ELDRS

The term Enhanced Low Dose Rate Sensitivity (ELDRS) was coined in the mid 1990s before a full understanding of the mechanisms of ELDRS were understood.

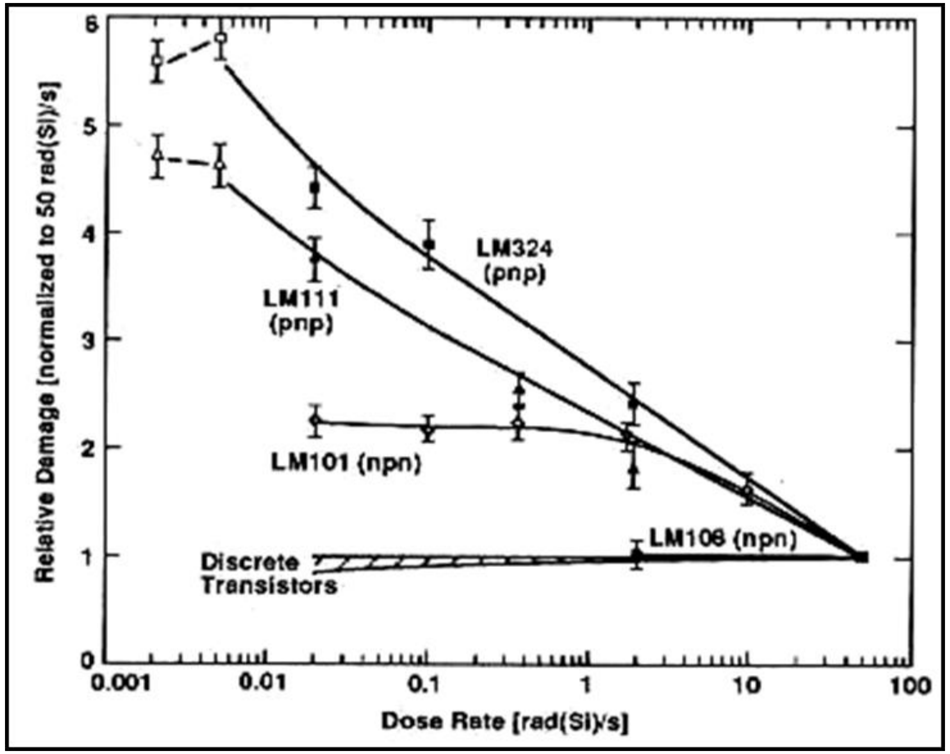
ELDRS is defined by low dose rate “enhancement” factor, EF

- EF is ratio of degradation at low dose rate to degradation at high dose rate
- Comparison is made for data taken immediately after irradiation

ELDRS applies to components which use Bipolar or BICMOS devices within their construction.

Airbus requirement for ELDRS is (extract from ADS.E.0631 issue 2)

***High dose rate can be used for MOS technologies (except when "rebound“ phenomena is observed) but not for bipolar and BiCMOS technologies. For these latter technologies, requirement is to use dose rate specified in the ESA/SCC22900 low dose rate window (36 to 360 rad(Si)/h)***



**From Johnston, et al. TNS Dec. 94**

# Radiation Hardness Assurance – TNID/DD

Displacement Damage (DD) Hardness Assurance

Comparison between expected in flight level (TNIDL) and TNID/DD Sensitivity (TNIDS) of the concerned device

- TNIDL may be estimated by Monte Carlo technique (NOVICE, GEANT4…)
- TNID/DD Device Sensitivity (TNIDS) is determined by:
  - Manufacturer guarantee (TID hardened devices)
  - Technological assessment
  - TNID ground testing

TNIDL and TNIDS shall be validated through compliance to requirements applicable in RHA specification

- TNIDL: validation of calculation methodology, radiation tool, nature of geometrical modelling.
- TNIDS: validation of radiation test data and test methodology, applicability of these data to used devices, usage rules for radiation test data.

# Radiation Hardness Assurance – TNID/DD

Most of the devices sensitive to DD are also sensitive to TID

- One shall consider DD and TID degradation in the overall radiation degradation budget
- Categorisation methodology applied afterwards

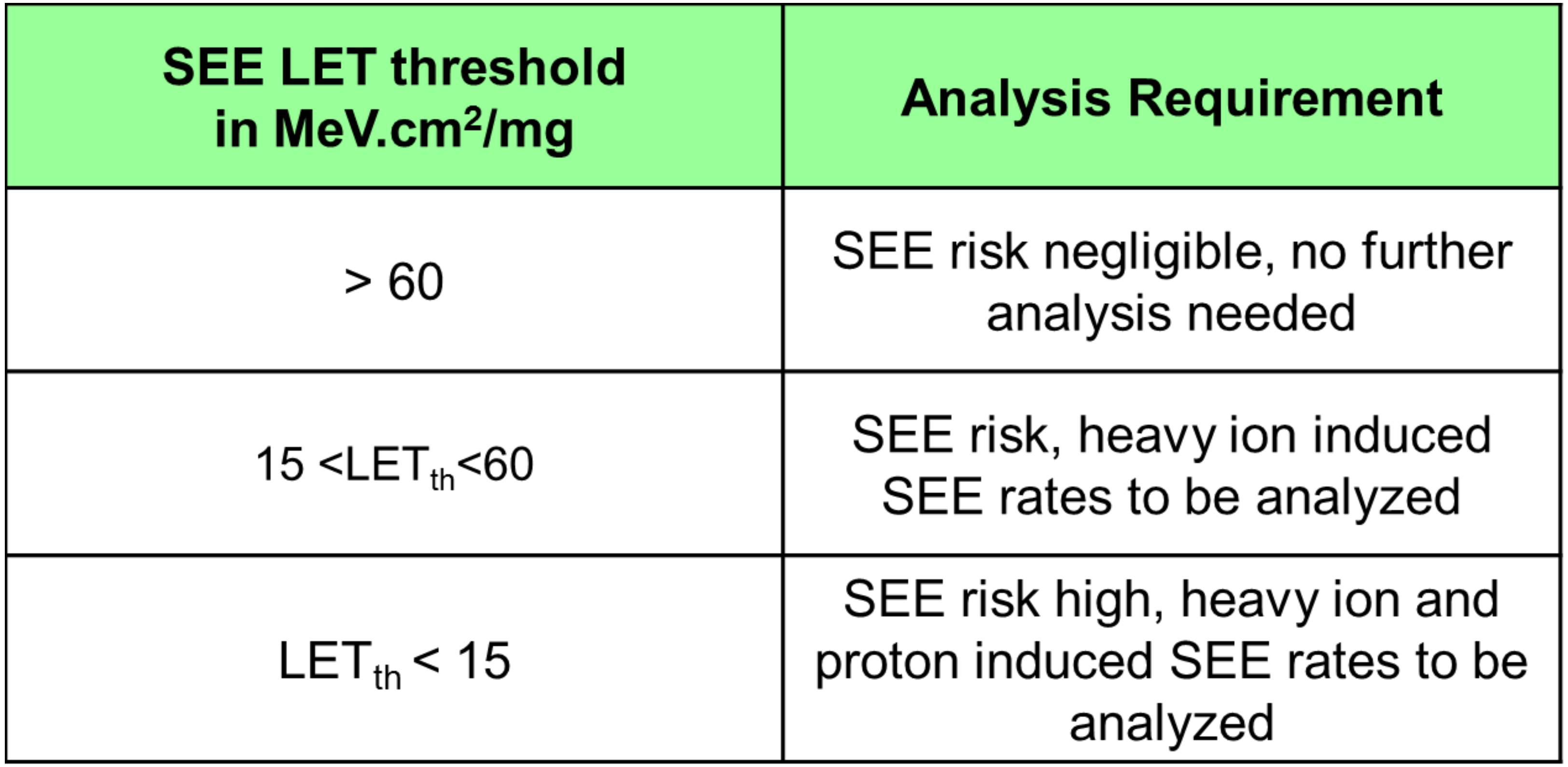
Definition of standard test methods is difficult

- Effects are application specific
- Complex degradation modes (particularly detector arrays)
- ESA/SCC Basic Specification 22500 has recently been issued to address TNID Testing

Test program will need to be tailored to requirements

# Radiation Hardness Assurance - SEE

Basically, Industry standard methodology relies on device categorization



| **SEE LET threshold in MeV.cm$^2$/mg** | **Analysis Requirement** |
|---|---|
| > 60 | SEE risk negligible, no further analysis needed |
| 15 <$LET_{th}$<60 | SEE risk, heavy ion induced SEE rates to be analyzed |
| $LET_{th}$ < 15 | SEE risk high, heavy ion and proton induced SEE rates to be analyzed |

Note: LET value shall be obtained in valid conditions

# Radiation Hardness Assurance - SEE

If a device falls into group2/group3 category, RHA methodology may rely on SEE rate predictions, or, Derating rules (derating is employed in the RHA program to ensure that the device operates in a manner so as to be insensitive to SEE effects)

SEE rate prediction methodology has to be validated

SEE test data have to be validated

- Beware of “similar” devices!

**The RHA process for SEE is based on the consideration of acceptable risks and rates and therefore involve system level considerations**

# Radiation Hardness Assurance - Testing

The cost and schedule impacts of testing a component type can be very high…

Typical device quantities:

- TID – need 11 devices to test (5 biased, 5 unbiased, 1 control)
- TNID – need 11 devices to test (5 biased, 5 unbiased, 1 control)
- SEE – need a minimum of 3 devices to test (with package lid removed)

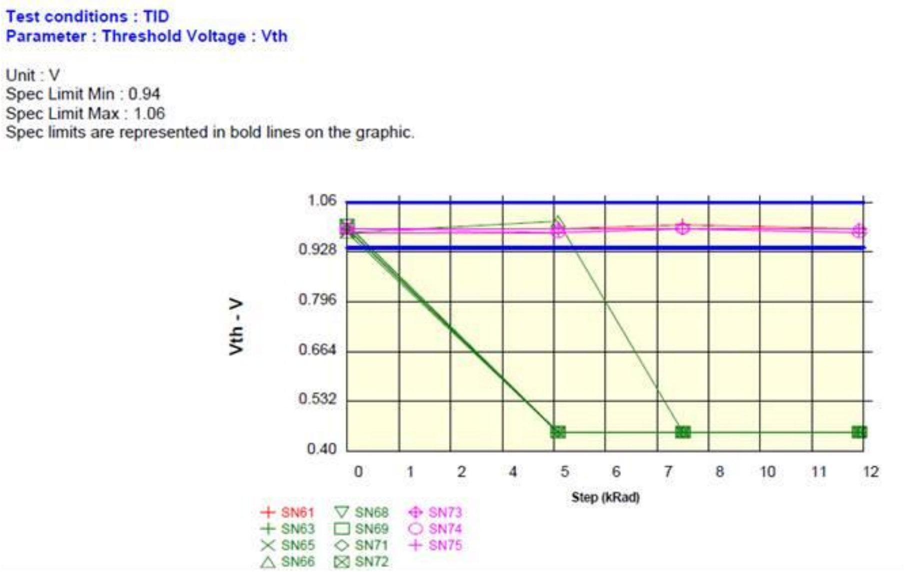
Note: these would tend to require flight lot devices to be used

Test facilities hire cost and availability:

- TID – around £8k – availability is usually very good
- TNID – around £15k – availability around 6 months notice
- SEE – around £30k – availability is generally poor (>6 months)

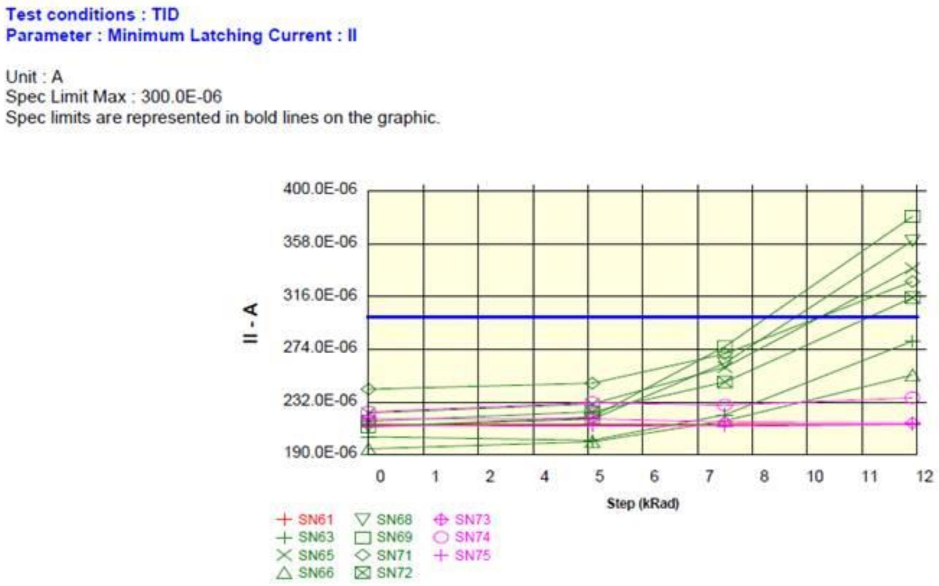
# Radiation Hardness Assurance - Testing

A question always comes about the need for both biased and unbiased testing of device (for TID and TNID). The following shows an example of why this can be critical….These are for a UCC1806 from TI. Purple lines are unbiased devices, green biased.



**Test conditions : TID**
**Parameter : Threshold Voltage : Vth**

Unit : V
Spec Limit Min : 0.94
Spec Limit Max : 1.06
Spec limits are represented in bold lines on the graphic.



**Test conditions : TID**
**Parameter : Minimum Latching Current : Il**

Unit : A
Spec Limit Max : 300.0E-06
Spec limits are represented in bold lines on the graphic.

# Radiation Hardness Assurance - “hardened” devices

A word of caution here….

**RH (and even more for RT) doesn’t mean radiation immunity**

**Manufacturer guarantee:**

The manufacturers may declare their parts insensitive to radiation but …

- don’t trust the commercial label (RH119 for example) and only follow MIL marking (5962…)*
- RH label does not mean insensitive to all radiation phenomena (TID vs DD vs SEE).
- For RH parts (formal radiation guarantee), read the specs in detail!
- RT (Rad Tolerant) parts are warranted by manufacturers thanks to tests performed in their own radiation conditions.

Radiation guarantees offered by the EEE manufacturers may not well address the space radiation conditions.

*It has been noted that even on the 5962 sheets the manufacturers sometimes do say a bipolar device test at a high dose rate then claim a tolerance and simply put a note that the devices may be susceptible to ELDRS – *meaning that you would need to test the devices at the correct dose rate if you wanted to use them, and that the claim of tolerance they have made is not actually correct. In addition to this; not all parameters are guaranteed for some components!*

# Radiation Hardness Assurance - flight heritage

The question sometimes raised is “Can we make use of parts with flight heritage and no ground data for new mission?”

Similar flow to using archival ground data exist, but consider as well
- Statistical significance of the flight data
- Environment severity?
- Number of samples?
- Length of mission?
- Has storage of devices affected radiation tolerance or reliability?

And so forth

This approach is recommended to be used with great caution – I would rarely accept flight heritage as an argument because, as an example, the flight being referenced may not have been there long enough to accumulate a full 15 years dose (for a GEO mission) so there is no flight heritage. The device may have changed in construction/manufacturer in the between the reference mission and now.

In addition, many customers require a “great deal” of flight heritage in order to feel comfortable with the use of a device, they generally would prefer to have a radiation test carried out

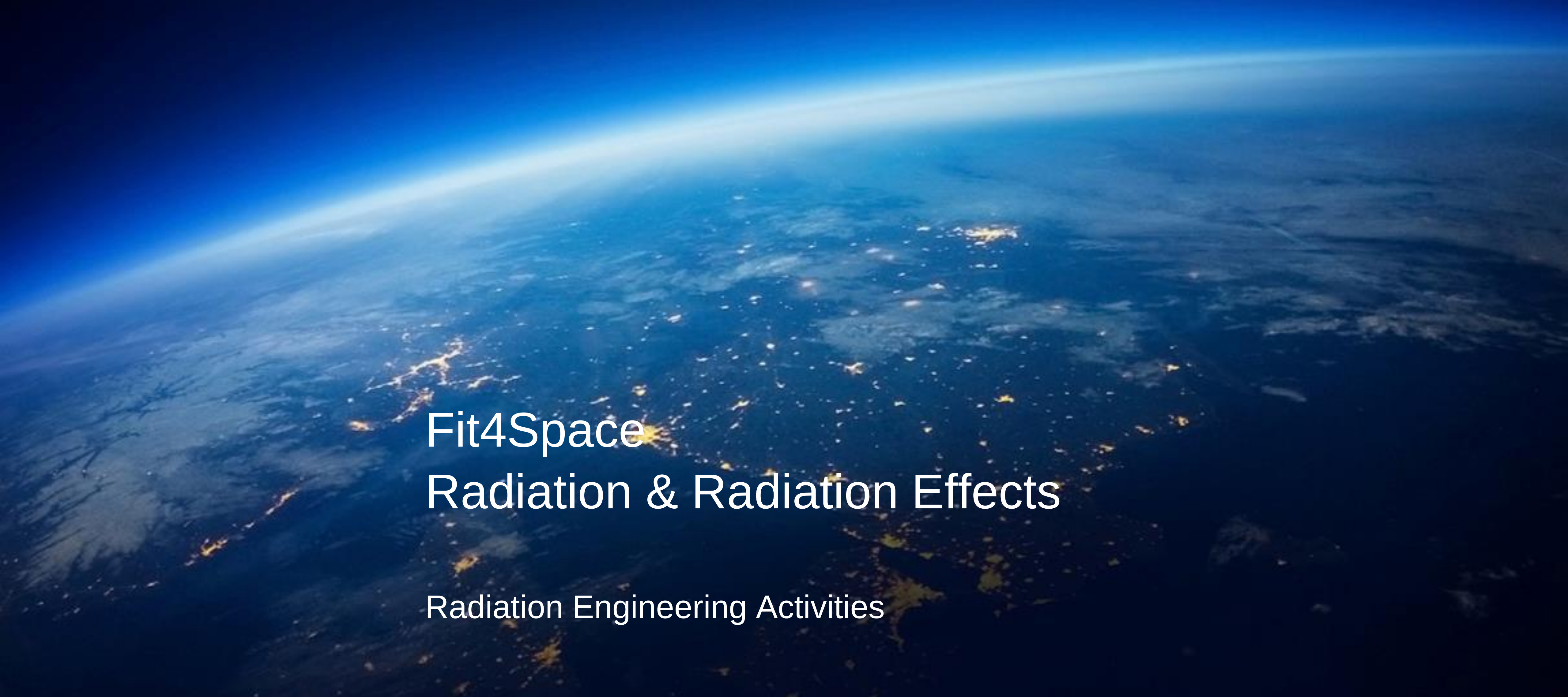
# Radiation Hardness Assurance

The RHA approach on space systems is based on risk management and not on risk avoidance

RHA process is not confined to the part level

- Spacecraft layout
- System/subsystem/circuit design
- System requirements and system operations

RHA requirements should be taken into account in the early phases of a program development, including the proposal and feasibility analysis phases



# Fit4Space
# Radiation & Radiation Effects

## Radiation Engineering Activities

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Lee Pater
06/03/2024

# Radiation Engineering Activities - Intro

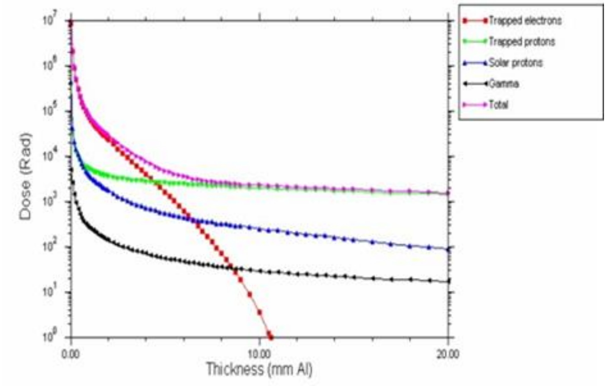
Among the tasks that Radiation Engineering have to perform the following is a selection of some of the most critical:

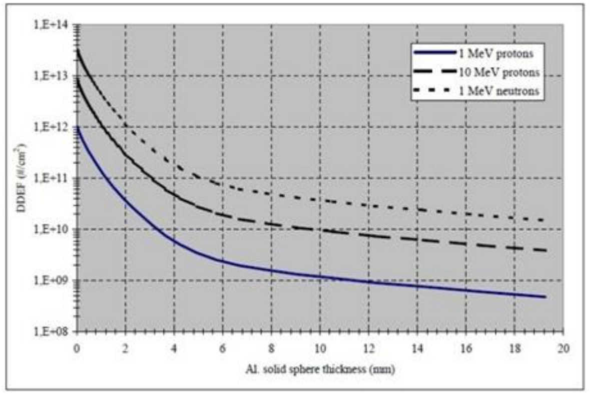
- Radiation Environment derivation.
- Spacecraft level analysis to determine the amount of spacecraft radiation shielding available to all the equipment used on the spacecraft.
- Equipment level analysis to determine the amount and type of radiation being received by all the sensitive EEE parts and materials used in an equipment. The analysis will also compare the received radiation doses, for each component, with the known tolerance to determine whether or not it fulfils its design specification.
- Radiation Verification Testing (RVT) of the sensitive EEE parts and materials to determine their tolerance.
- Perform external supplier equipment reviews to ensure that the equipment satisfies the programs Radiation Hardness Assurance (RHA) requirements, as well as meeting the radiation quality requirements.
- Support EEE procurement activities by ensuring that applicable radiation test data is available for each sensitive component, for a given program.

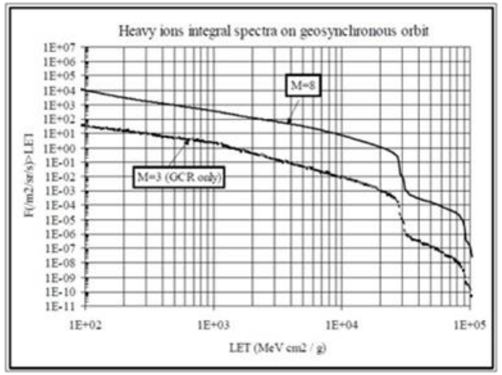
# Radiation Engineering Activities – Environment definition

Radiation Environment definition

- Involves creating the mission radiation environment input data required to analyse each of the radiation effects: TID, TNID (Displacement Damage) and SEE.
- The data is then included in the Radiation Environment Specification or equivalent document to be used by the equipment suppliers.



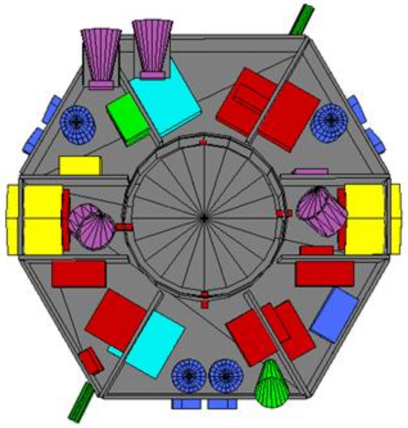




# Radiation Engineering Activities – SC analysis

Spacecraft level radiation analysis

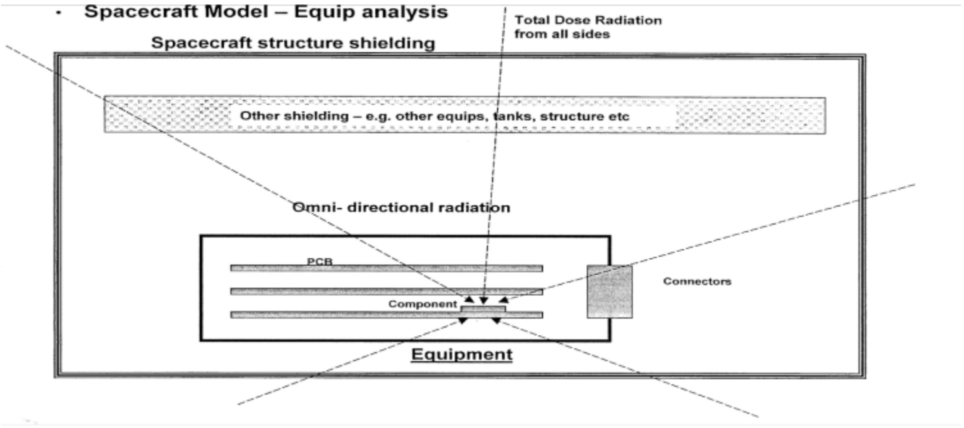
- Typically involves determining the spacecraft shielding available to an equipment supplier.
- The spacecraft is typically modelled based on relative dimensions, with approximations made as to the amount of shielding one equipment will provide to all others.
- The analysis software calculates how much shielding is available to each equipment, this information is then used by the equipment supplier in the equipment level analysis.

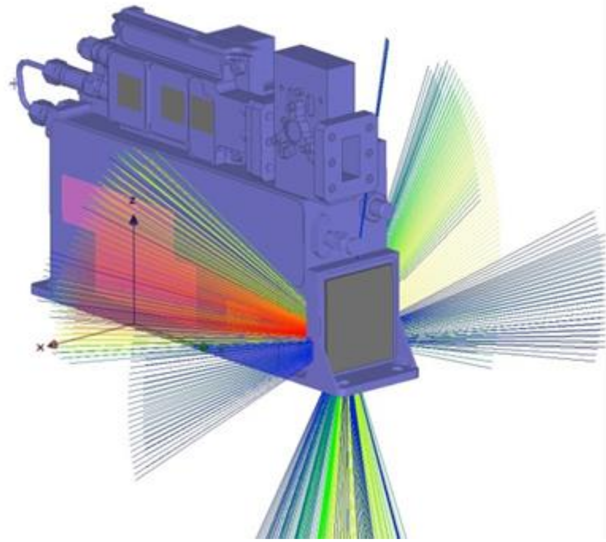


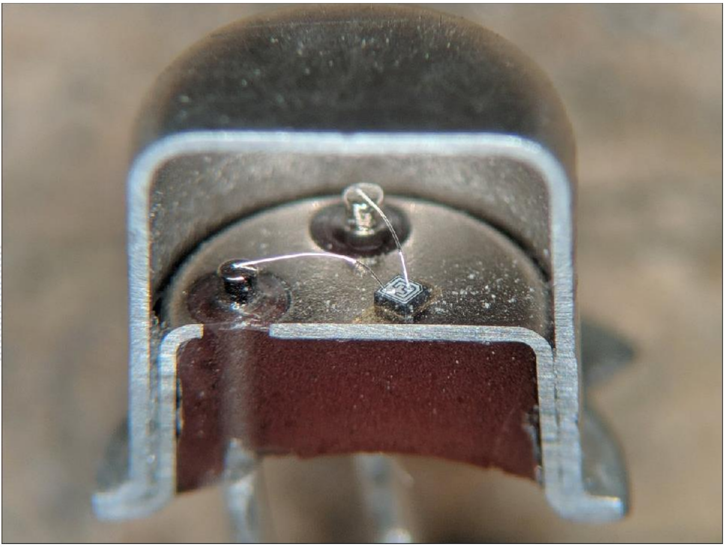
# Radiation Engineering Activities – Equipment analysis

Equipment analysis

- Involves modelling the equipment and demonstrating that it is suitable for the mission, given the expected radiation environment and the program RHA requirements.
- A 3D software model of the equipment is usually constructed, and is used to calculate the received TID and TNID received by each of the sensitive components and materials used in the equipment.
- Calculating the probability of a SEE events occurring for the sensitive EEE parts, given the radiation environment and the available SEE test data.







# Radiation Engineering – Support from other disciplines

For all equipment or systems the responsibility for the radiation analysis rests with the Radiation Engineer.

However, Radiation Engineers are generally not Design Engineers or System Engineers (though some have been before becoming Radiation Engineers) and therefore need their support to fully cover the radiation aspects.

- For equipment the Radiation Engineer needs help from the Design Engineer to enable them to set the TIDS & TNIDS levels for each component - *what does the circuit design need the component to have as regards functionality before it stops working (e.g. hfe>40 with Ic=20mA).* In addition the Design Engineer will use inputs from the Radiation Engineer for SEE aspects and report back their findings – *does the equipment lock-up, does a transient appear on the output of the equipment etc.*

- Similarly, once the analysis moves away from the equipment then the Radiation Engineer requires the support of the Systems Engineer in order to check for system effects – *what effects do equipment malfunction (e.g. SET) have on the overall system performance?*

# Thank you