Radiation Hardness Assurance & Test Facilities

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RADECS2003 short course notes

Space Radiation

- Radiation environment is a significant constraint for any space missions
- The Jupiter environment is particularly demanding
  - The electron environment is harsh
  - Proton environment not as harsh (current estimation equivalent to 7E10 50MeV p/cm^2)
  - Heavy ion environment similar to other interplanetary mission

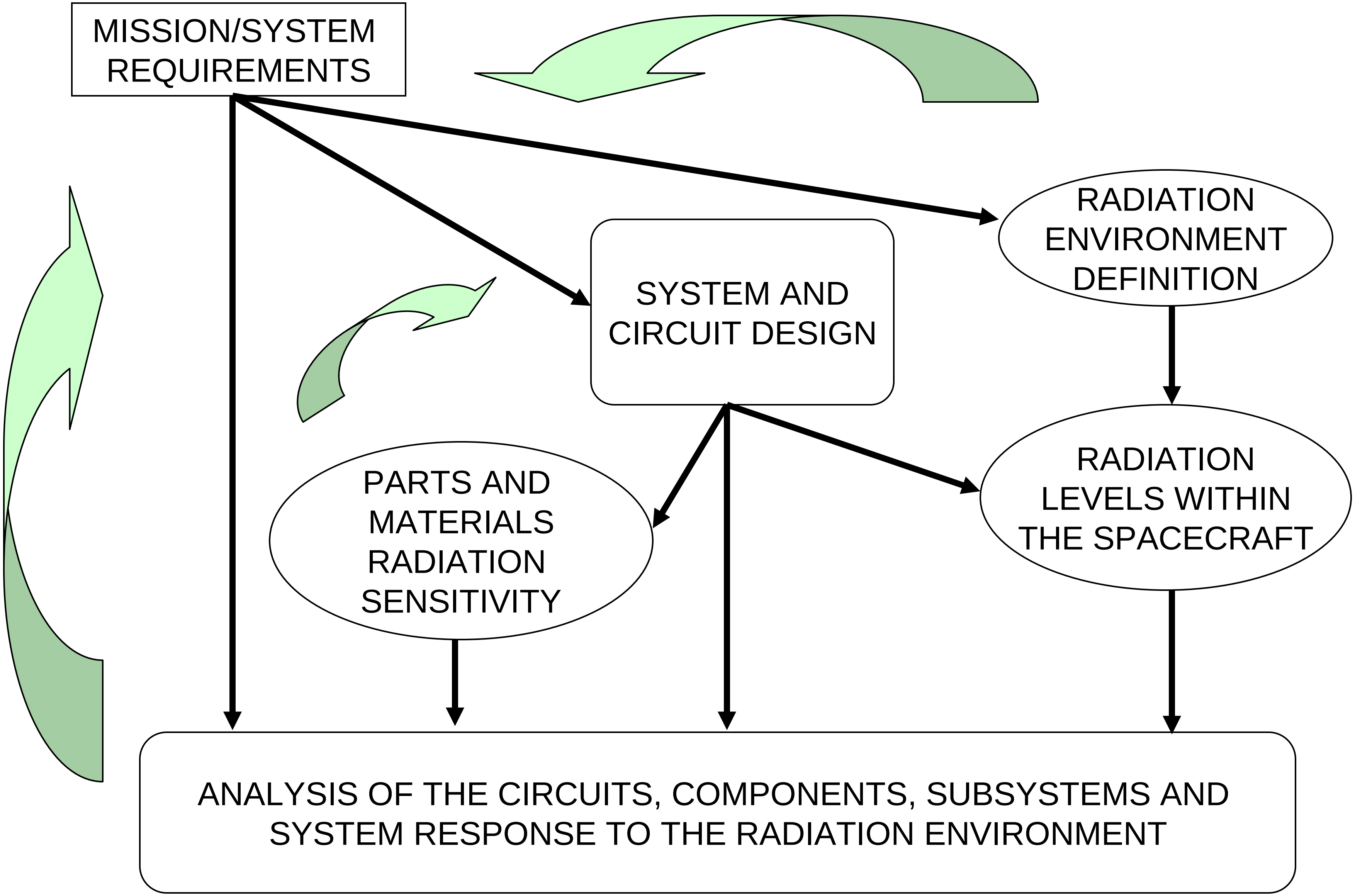
RHA definition

- RHA consists of all activities undertaken to ensure that the electronics and materials of a space system perform to their design specifications after exposure to the space radiation environment

- Deals with environment definition, part selection, part testing, spacecraft layout, radiation tolerant design, mission/system/subsystems requirements, mitigation techniques, etc.

- Radiation Hardness Assurance goes beyond the piece part level

RHA Overview



MISSION/SYSTEM REQUIREMENTS

SYSTEM AND CIRCUIT DESIGN

RADIATION ENVIRONMENT DEFINITION

PARTS AND MATERIALS RADIATION SENSITIVITY

RADIATION LEVELS WITHIN THE SPACECRAFT

ANALYSIS OF THE CIRCUITS, COMPONENTS, SUBSYSTEMS AND SYSTEM RESPONSE TO THE RADIATION ENVIRONMENT

RHA Requirements and TID test standard

- There is no European standard for RHA
  - Requirements are project specific
- *ECSS-Q-ST-60-15C*
  - in progress, planned end of 2010
- **ESA-TEC-QE/2009/22**
  - **ESA internal document**

- Test standards:
  - *ESCC 22900*
  - *US MIL-STD1019.7*

- Test Guidelines:
  - *ASTM F1892*

RHA Requirements, typical content

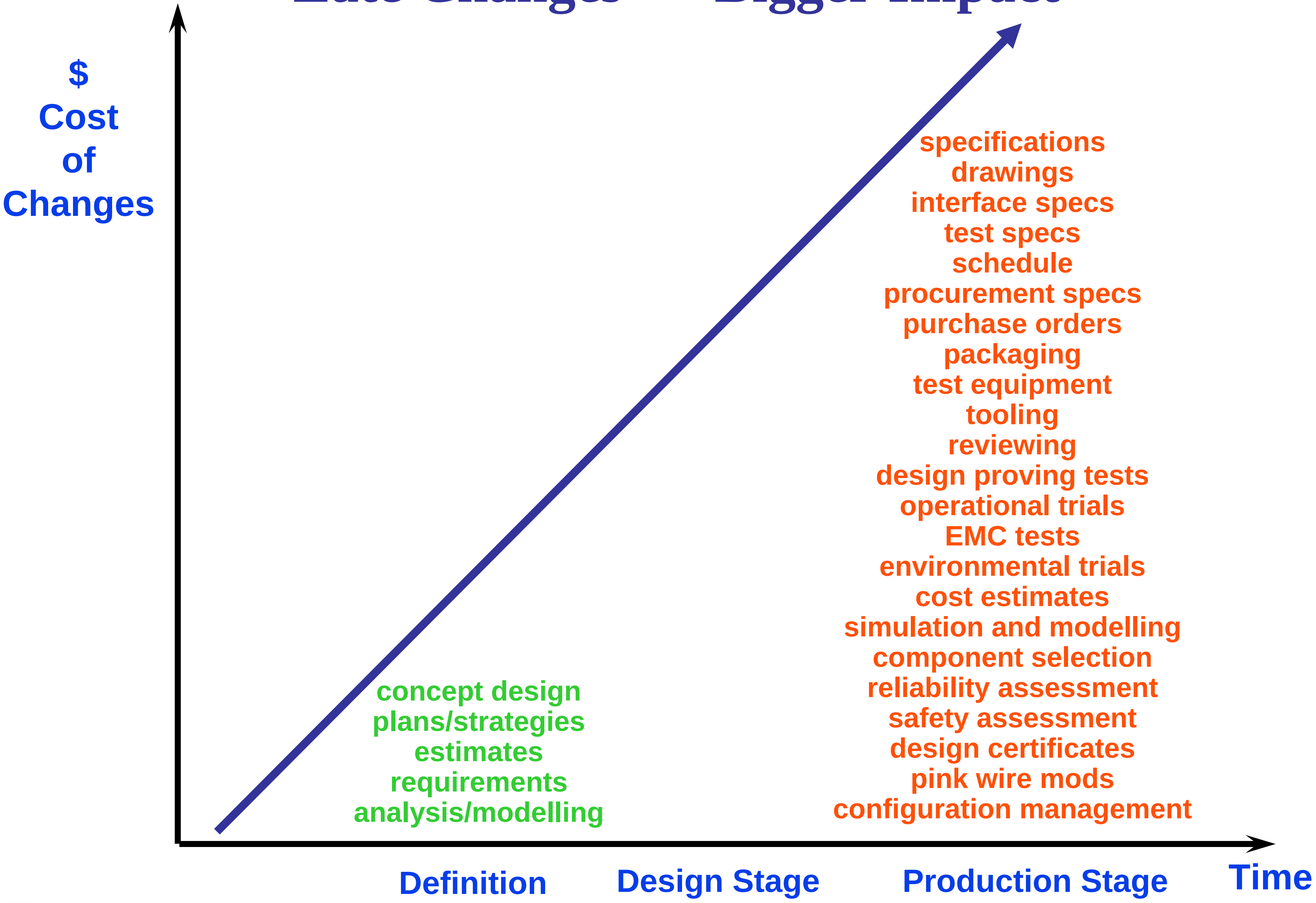
- **<u>TID hardness assurance</u>**
  - Possibly a top level TID requirement (e.g. 150krad(Si))
  - Information on components that are considered sensitive to TID
  - Acceptance criterion for available test data
  - Irradiation test criteria (when to perform irradiation testing)
  - ELDRS test criteria for bipolar based devices
  - When to perform WCA
  - Radiation Design Margin
  - Requirements for Radiation Analysis Reports

  - <u>RHA requirements tailored to specific missions</u>

Sensible RHA Programmatic

- Lead radiation PROJECT engineer
  - Integrate radiation like other engineering disciplines
    - Parts, thermal,...
  - Single point of contact for all radiation issues
    - Environment, parts evaluation, testing,…
- Follow a systematic approach to RHA
  - RHA active early in program reduces cost in the long run
    - Issues discovered late in programs can be expensive and stressful
- Mission requirements and RHA methodologies vary to ensure mission performance
  - What works for a shuttle mission may not apply to a deep-space mission

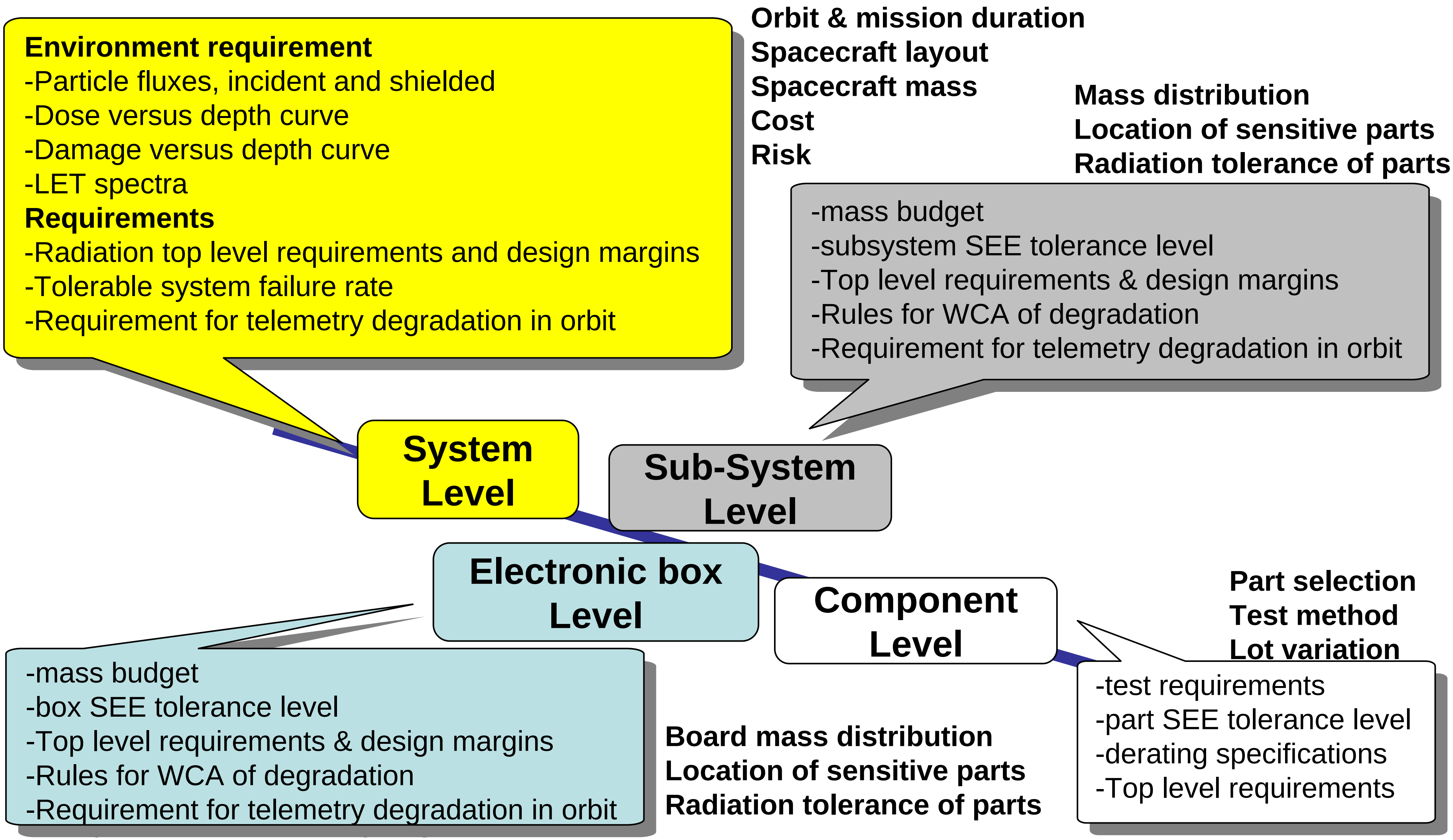
Late Changes => Bigger Impact



Radiation Hardness Assurance During the Program Life

- Pre Phase A, Phase A – (System Requirement Review, SRR)
  - Draft environment definition
  - Draft hardness assurance requirements (top level)
  - Preliminary studies (possible irradiation characterisation of critical components, sensors, etc.)
- Phase B – (Preliminary Design Review, PDR)
  - Final environment definition
  - Electronic design approach
  - Preliminary spacecraft layout for shielding analysis
  - Preliminary shielding analysis & hardness assurance requirements update
  - Preliminary Radiation Analysis Report
- Phase C – (Critical Design Review)
  - Radiation test results
  - Final shielding analysis & final hardness assurance requirement
  - Final Radiation Analysis Report (including Worst Case Analysis (WCA) and Failure Mode Effect Criticality Analysis (FMECA))
- Phase D
  - Radiation Lot Acceptance Tests (RLAT, typically before MRR)
- Phase E (Utilisation)
  - Failure analysis (Lessons learned)

RHA process Flow-Down



Environment requirement
-Particle fluxes, incident and shielded
-Dose versus depth curve
-Damage versus depth curve
-LET spectra
Requirements
-Radiation top level requirements and design margins
-Tolerable system failure rate
-Requirement for telemetry degradation in orbit

Orbit & mission duration
Spacecraft layout
Spacecraft mass
Cost
Risk

Mass distribution
Location of sensitive parts
Radiation tolerance of parts

-mass budget
-subsystem SEE tolerance level
-Top level requirements & design margins
-Rules for WCA of degradation
-Requirement for telemetry degradation in orbit

System Level

Sub-System Level

Electronic box Level

Component Level

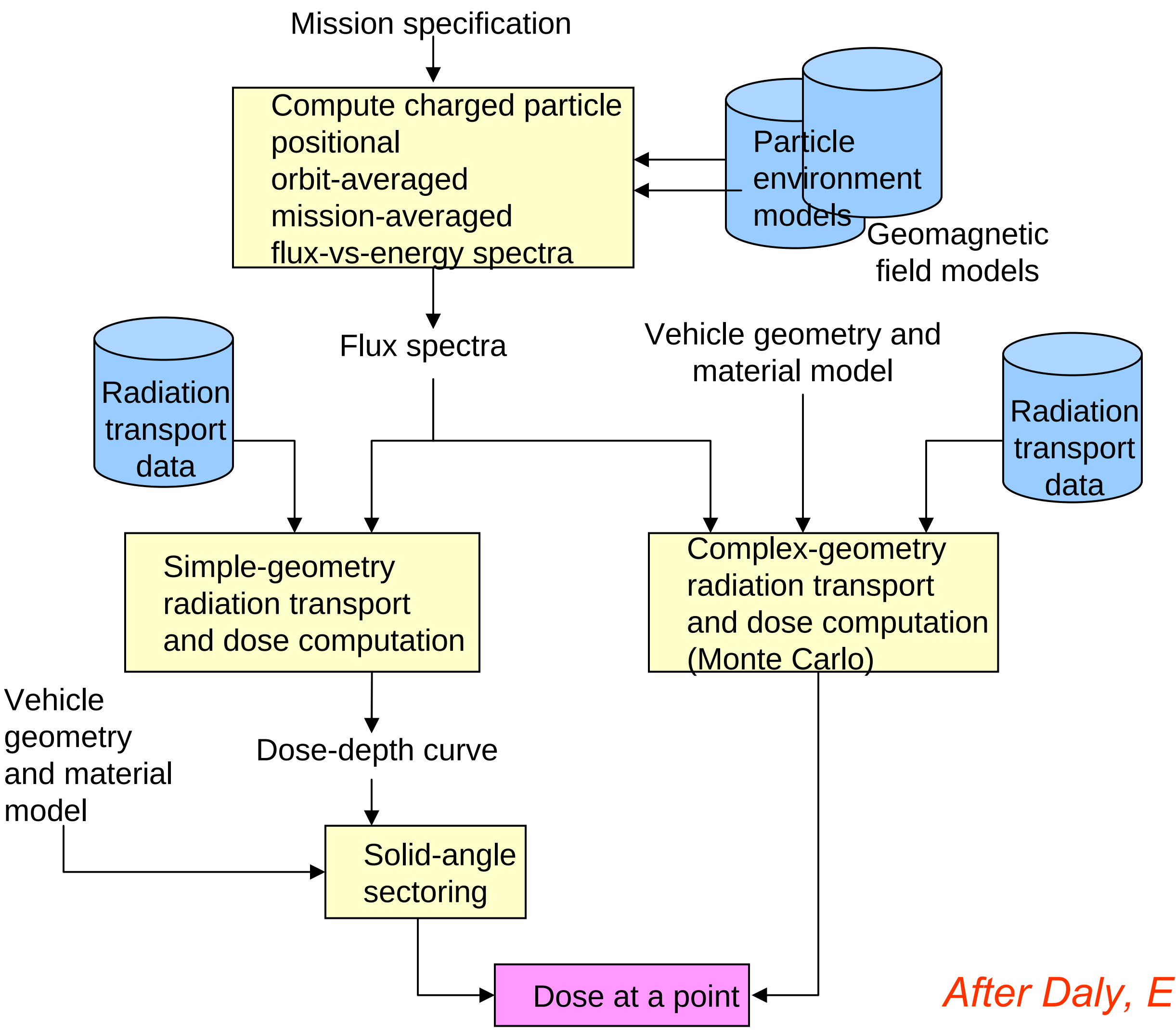
Part selection
Test method
Lot variation

-mass budget
-box SEE tolerance level
-Top level requirements & design margins
-Rules for WCA of degradation
-Requirement for telemetry degradation in orbit

Board mass distribution
Location of sensitive parts
Radiation tolerance of parts

-test requirements
-part SEE tolerance level
-derating specifications
-Top level requirements

Calculation of TID



Mission specification

Compute charged particle
positional
orbit-averaged
mission-averaged
flux-vs-energy spectra

Particle
environment
models

Geomagnetic
field models

Flux spectra

Radiation
transport
data

Vehicle geometry and
material model

Radiation
transport
data

Simple-geometry
radiation transport
and dose computation

Complex-geometry
radiation transport
and dose computation
(Monte Carlo)

Vehicle
geometry
and material
model

Dose-depth curve

Solid-angle
sectoring

Dose at a point

After Daly, ESA report 1989

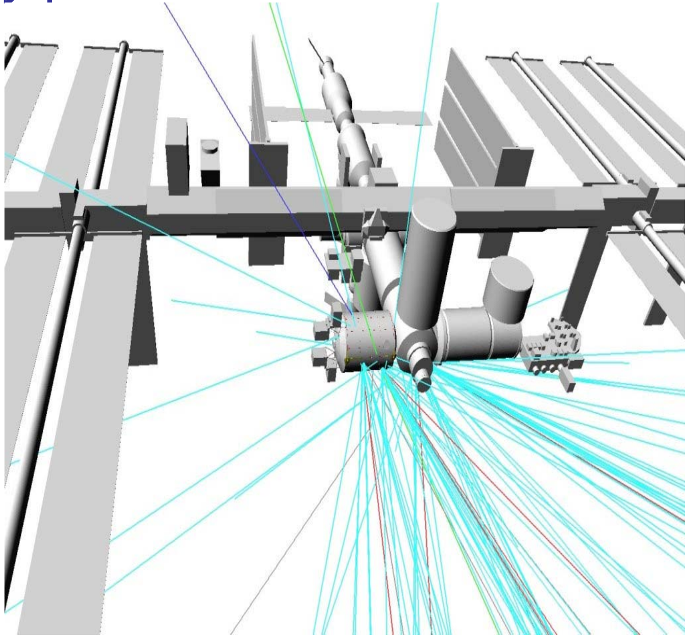
Sector Analysis

Based on “straight ahead” approximation
4π space around the detector is divided into N elementary solid angles ω_i
Calculate the dose d_i for each elementary solid angle by using dose depth curve
Sum the contribution of all the sectors.

- Influence of material type is neglected. Different materials are approximated to equivalent mass of a single material type (typically Al) by a proportional change in density.
- The sector shielding approach does not consider the physics involved in the
  - performance of graded shields, dose enhancement,
  - or in calculating the X-ray bremsstrahlung dose in a location shielded by tantalum
- Sectoring is not appropriate for the assessment of secondary hadron levels from materials with significantly different atomic mass number from the original target material.
- For electron dominated orbits (GEO, Navigation), sector/ray tracing analysis can overestimate or (sometimes) underestimate the dose levels.
- For proton dominated orbits (LEO), sector analysis give a good estimation of the dose level.
- Examples of Sectoring Analysis tools: ESABase. Fastrad, SSAT (capable of implementing Geant4 geometry)

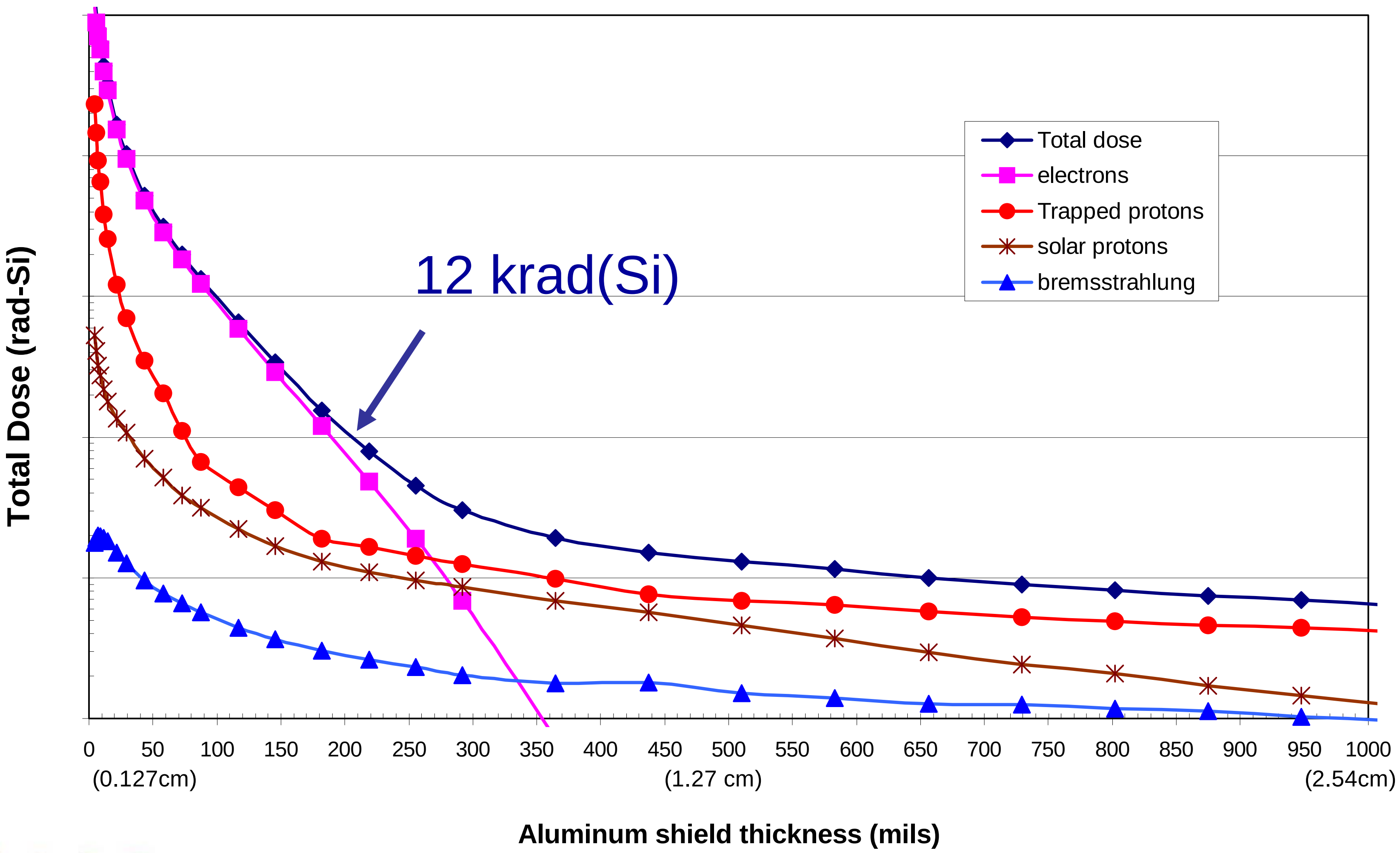
Monte Carlo Particle Transport

- Detailed radiation "transport" calculations provide a more accurate treatment of the radiation interaction processes. Calculates:
  - particle numbers, species, energy, and direction of propagation
- MC required when accurate part level dose calculation necessary.
- MC Calculations based on the actual material employed
- MC calculations also include secondary particle information
- Example MC tools
  - Geant4 based tools
  - NOVICE
  - MCNPX (limited accessibility)



Geant4 simulation of ISS ATV module

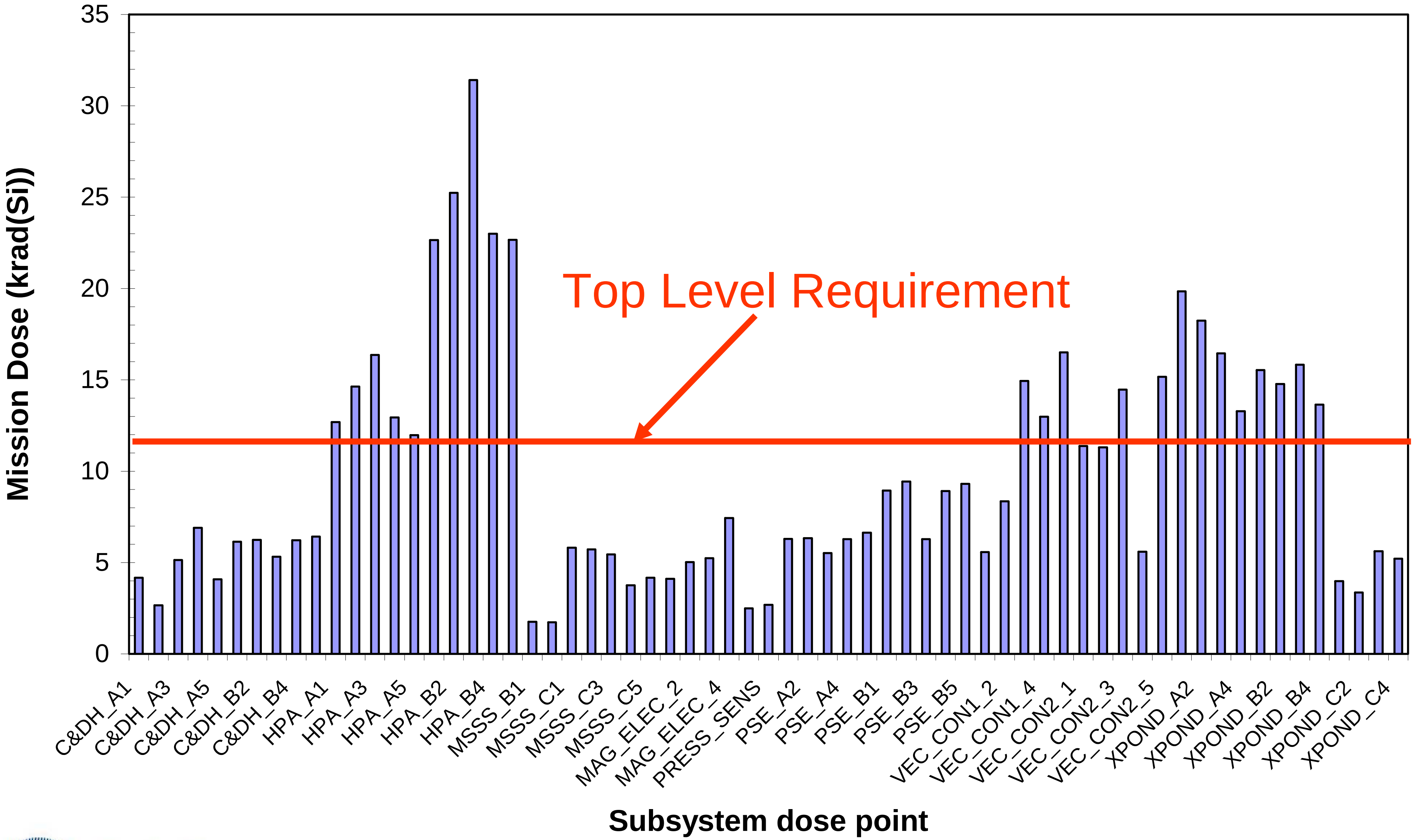
TID Top Level Requirement : Dose-Depth Curve



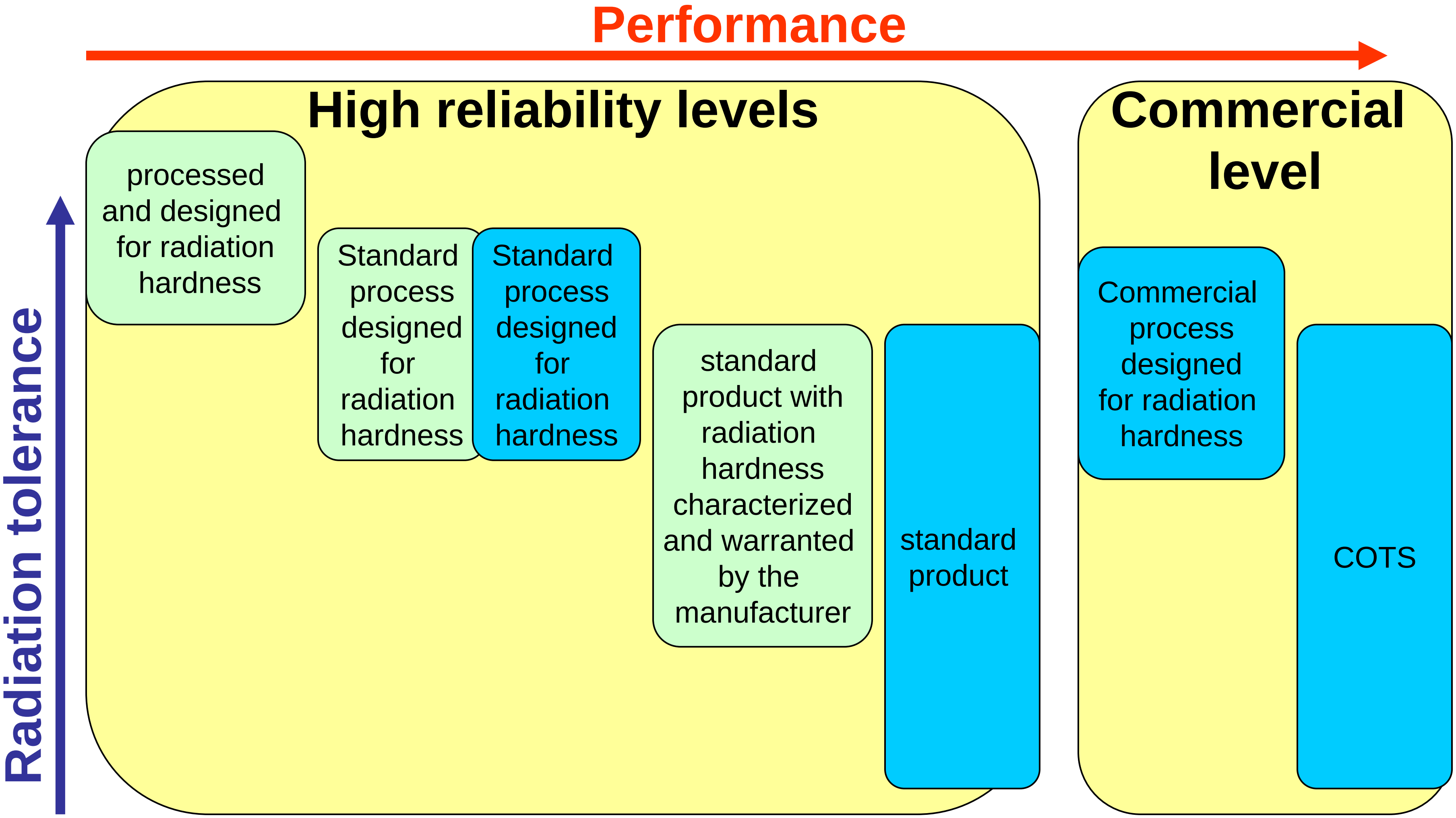
Total dose at the center of Solid Aluminum Sphere
ST5: 200-35790 km, 0 degree inclination, three months

12 krad(Si)

TID at Part level, Example, ST5



Parts Selection



Performance

Radiation tolerance

High reliability levels

processed and designed for radiation hardness

Standard process designed for radiation hardness

Standard process designed for radiation hardness

standard product with radiation hardness characterized and warranted by the manufacturer

standard product

Commercial level

Commercial process designed for radiation hardness

COTS

Reliability? Availability? Cost?

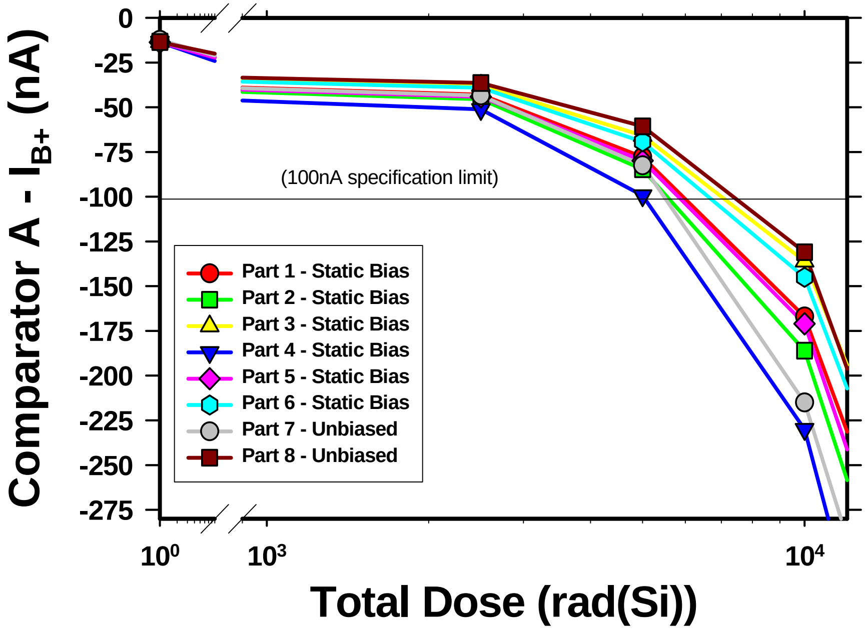
Parts Selection continued

- Digital CMOS OK, concentrate efforts on mixed signal ASIC, analogue front end ASIC, photonics (e.g. optocouplers, CCDs), bipolar based linear ICs, power components.
- Manufacturers of radiation hard high-rel parts on the decline
- However, there are manufacturers providing Rad Hard parts (11 RHA DSCC QML suppliers). Additionally, some manufacturers provide ELDRS free parts
- Sensors / detectors / ASICs need to be characterised early in the project
- Optocouplers, large variation. Depending on Ifwd (higher better for radiation) some do well up to 100krad(Si) but some very sensitive need to test for displacement damage + TID
- Power MOSFTEs OK, however other power components such as MOSFET drivers, PWMs, etc. may be sensitive
- Small signal transistors, take care. Difficult to replace their function, always needed
- Digital logic exist in 100 to 300 krad(Si) versions
- Many linear bipolar based parts available in R version (100krad(Si)) and some F versions (300krad) but mostly not ELDRS tested by manufacturer.
- In a number of cases ELDRS free parts guarantied only up to 50krad(Si)
- Example of manufacturers providing ELDRS free or ELDRS characterise parts:
    - Linear Technology, National Semiconductors, Intersil

Example : Voltage Comparator

	TID tolerance	SEE tolerance
HS139RH/Intersil	**300 krad** ?	**SET LETth>20MeVcm^2/mg** ?
LM39AJQMLV/NSC	**50 krad** ⊘	?
139/Maxwell	**>100 krad depending upon orbit and space mission** ?	**SEL LETth>59.8MeVcm^2/mg** ?

NSC low dose rate test data →



After NAVSEA/CRANE test report, 2002

NSC 50 krad
radiation tolerant

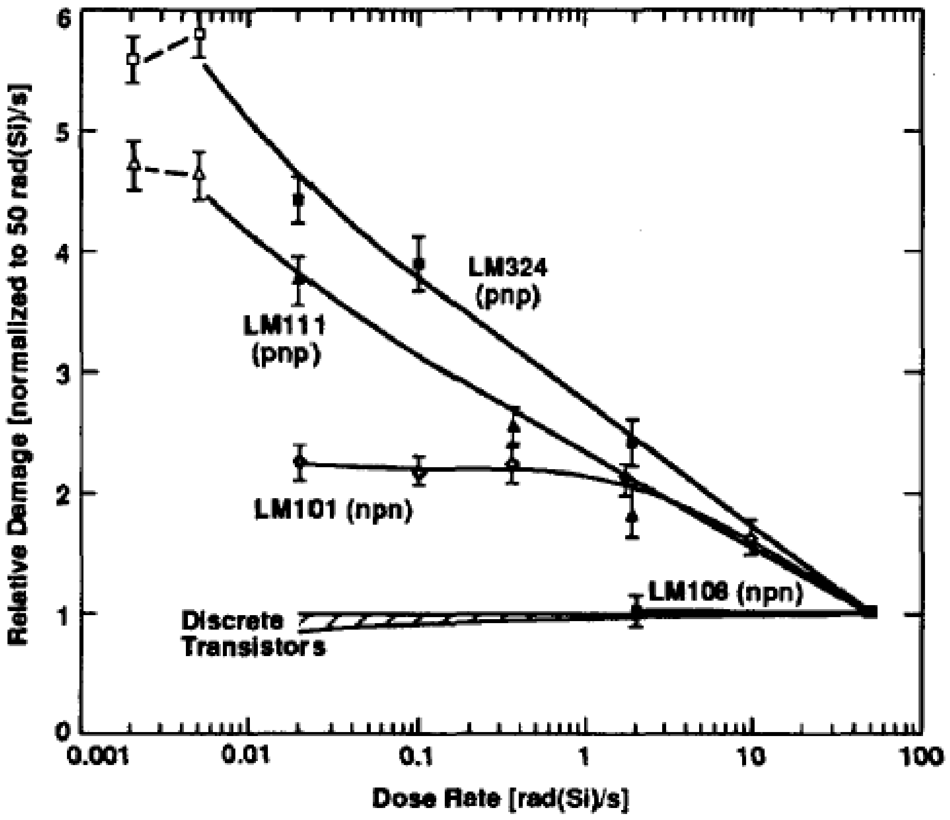
Parameter	Pre irradiation limit	Post irradiation limit
Vio	+/- 2 mV	+/- 2.5 mV
Iib	100 nA	110 nA
trLH	0.8 ns	0.9 ns

The ELDRS effect

Low quality of the oxide ⇒ Increase in the net positive charge in the oxide covering the emitter-base junction.

JGO receives most of its TID following Jupiter arrival and when orbiting Ganymede.

The top level TID requirement of 150krad(Si) with a mission duration of ~1month result in an average dose rate of <36rad(Si)/h to 100rad(Si)/h



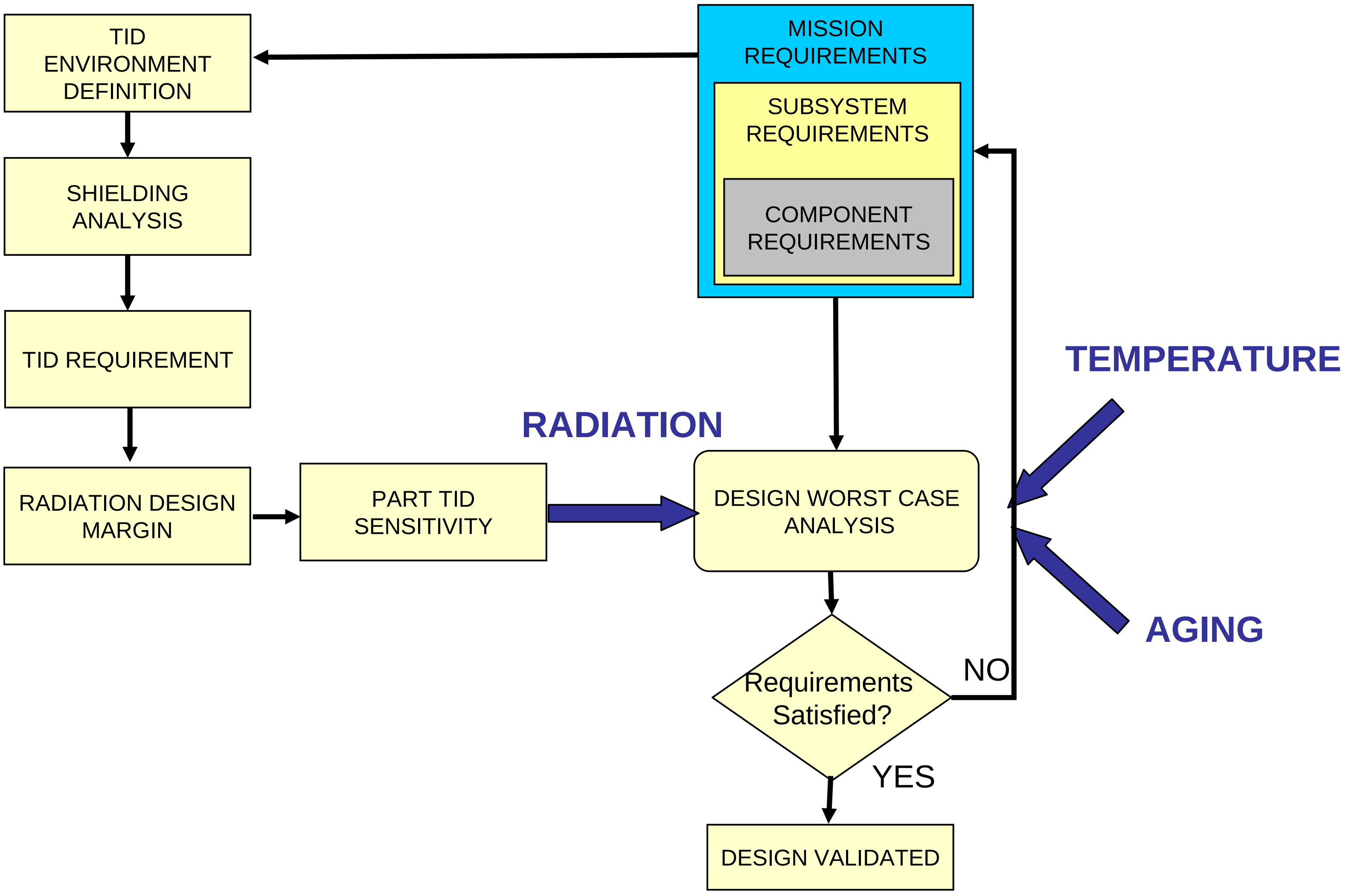
A. H. Johnston, IEEE Tran. Nuc. Sci. Vol41, NO 6, December 1994.

Thoughts COTS

- Why use
  - Complexity of function
  - Performance
  - Availability
- Drawback
  - Little or no traceability
  - Rapid and un-announced design and process changes
  - Rapid obsolescence
  - Packaging issues (plastic)
    - Effects of burn-in on radiation effects
    - Deep dielectric charging in space
- Use of COTS
  - The use of COTS does *NOT* necessarily result in cost saving
  - Cost of ownership is the important consideration
  - First choice should always be HI-Rel devices
  - A great deal of knowledge available for some components (a little more expensive). Preferable to standardize on these components (do not always be seduced by newer technologies, more complexity, better performance)

From L. Adams, radiation training course may 2003

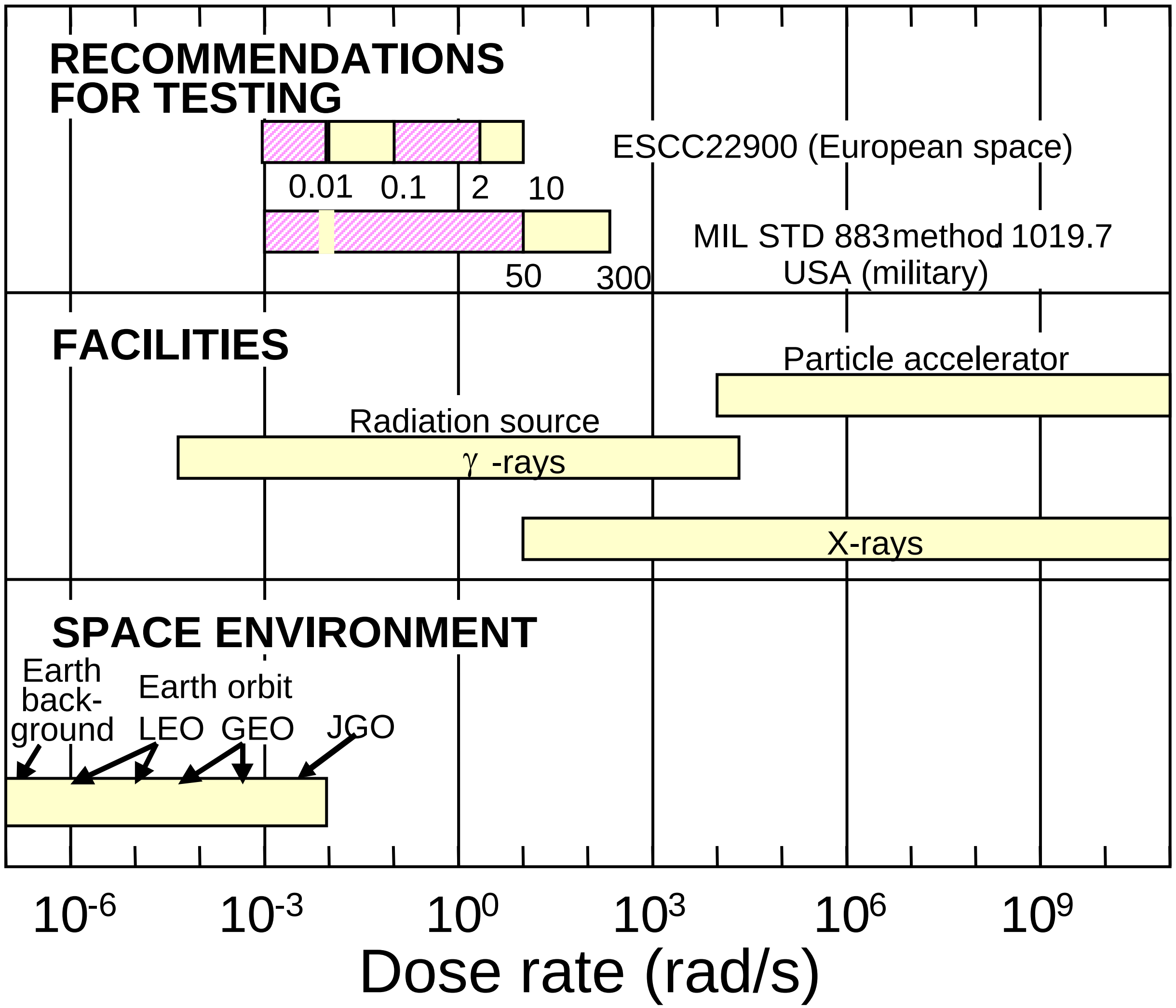
TID - Analysis flow



What laboratory radiation source is best for simulating the space TID environment?

- ESCC22900 TID irradiation test guideline indicates that 60Co, x-rays, electrons and protons may be used for TID irradiation testing.
- Co-60 and x-ray sources predominantly used for device characterization
- Co-60 sources normally used for hardness assurance testing of EEE components
- Charge yield for Co-60 and x-ray irradiations can be very different - especially at low electric fields
- Large differences in radiation-induced charge buildup in SOI buried oxides observed between x-ray and Co-60 irradiations
  - Fleetwood et al. 1988, Schwank et al. 2000
- Response of pMOSFET dosimeters observed to be different for Co-60 and proton irradiations
  - Pease et al., IEEE Trans. Nucl. Sci. 48, 908 (2001).

TID - Radiation Sources and Dose Rates



The laboratory dose rates are significantly higher than the actual space dose rates, testing according to test standards gives conservative estimates of CMOS devices TID sensitivity

After A Holmes Siedle and L Adams, Oxford Un. Press, 1993

At the Facility

- Before coming to the facility ensure that your system is compliant with facility requirements.
- Ensure that facility is compliant with your requirements
  - Need to be able to cater intermidiate parmaetric measurements within reuqired time (less than 1 to 2 hours).
  - Possibly maintain equipment for annealing tests
- Dosimetry usually done by facility staff and accurate to ~ ±5% to ±10%
  - ion chambers (TID, DD)
  - faraday cup (DD)
  - silicon surface barrier detectors (TID)
  - Geiger-müller, (TID)
  - Termo-luminescent dosimeters (TID)
- Dosimetry is important and human errors can occur!
  - Take care
  - Possibly dosimetry performed by customer (bring reference dosimeter)
  - Spare devices can be useful if re-test needed

TID Irradiation Test Facilities

- Isotron UK: providing 60Co, electron beam and protons up to 10MeV. http://www.isotron.com/
- ENEA-Casaccia (Rome , Italy) Calliope 60Co gamma ray facility (in pool) http://www.casaccia.enea.it/
- Náyade-CIEMAT (Madrid, Spain) 60Co irradiation test facility (in a pool) http://www.ciemat.es
- UCL (Louvain-la-Neuve, Belgium) 60Co facility, http://www.uclouvain.be/en-universite.html
- CEA (Saclay, France) 60Co facility http://www.cea.fr/le_cea/les_centres_cea/saclay
- ONERA DESP (Toulouse, France) 60 Co facility, http://www.onera.fr/desp-en/facilities.php
- ESTEC (Noordwijk, The Netherlands) 60Co facility, https://escies.org/ReadArticle?docId=251

Conclusion

- 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 should be taken into account in the early phases of a program development, including the proposal and feasibility analysis phases
- For the JGO mission ensure that EEE component families (such as linear bipolar devices) considered sensitive are well assessed.
- Co60 facilities are recommended for TID testing
- Dosimetry very important. Make sure is performed correctly (humans make mistakes)

KNOW WHAT YOU ARE FLYING

Radiation Effects at ESA

- TEC-QEC (Technical and quality management /PA/Material and Component Evaluation Division/Component)
  - Radiation Effects (characterization, testing)
  - Radiation Hardness Assurance (RHA)
  - For more info contact ali.mohammadzadeh@esa.int
  - Homepage: https://escies.org/ReadArticle?docId=227
- TEC-EES (Technical and quality management/Electrical Engineering/ Electromagnetics & Space Environment Division/Space Environment)
  - Radiation Environment
  - Radiation Effects (modelisation)
  - For more info contact eamonn.daly@esa.int