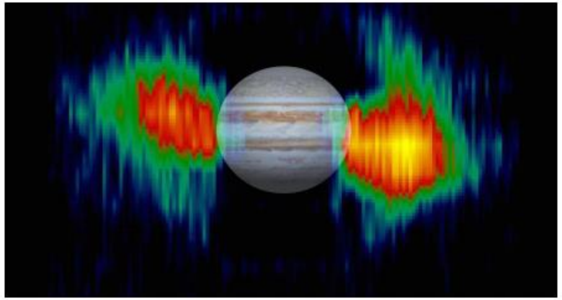
Radiation Test Challenges with High-Energy Electrons

CALIFES Workshop 2016
10-12 October, CERN
Radiation Tests Session



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Outline

- Introduction
- JUICE mission and Jovian environment
- Electron induced radiation effects: DD and TID
- Electron facility overview
- VESPER test requests and possible HEP applications
- Summary

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Context and Overview

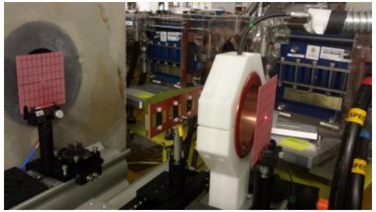
- CERN/ESA meeting in December 2014 to discuss about the potential use of CALIFES for electron radiation testing applications
- Since then:
  - 2015: proof of concept through first tests with well-known detectors
  - 2016:
    - improvements in beam line and instrumentation for dedicated dosimetry
    - Further tests, both internal and external

2014

Perspectives for e- beam irradiation tests in CTF3/CALIFES

R. Corsini

2016



(High-energy) electrons at NSREC 2016

- **International conference** on radiation effects on electronics
- Increasing interest in the community, mainly driven by the future **Jovian missions**
- Examples of presented studies on **electron effects**:

- *“Gamma and Electron NIEL Dependence of Irradiated GaAs” M. El Allam et al. (PC-2)*
- *“Low-Energy Electron Irradiation of NAND Flash Memories” M. J. Gadlage et al. (D-2)*
- *“Heavy Ion, Proton and Electron Single-Event Effect Measurements of a Commercial Samsung NAND Flash Memory” F. Irom et al (W-44)*
- *“Shielding a MCP Detector for a Spaceborne Mass Spectrometer Against the Harsh Jupiter Radiation Environment” M. Tujet et al (J-3)*

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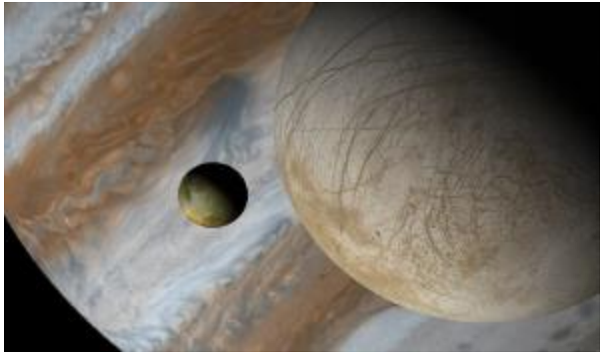
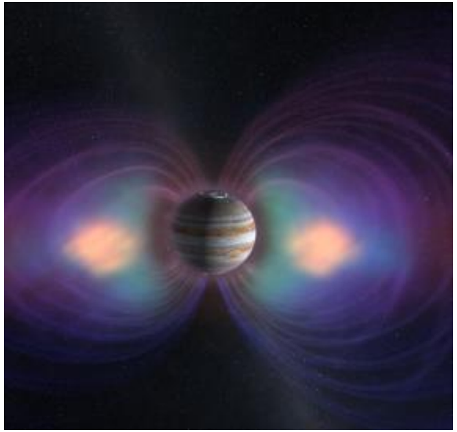
JUICE ESA Mission

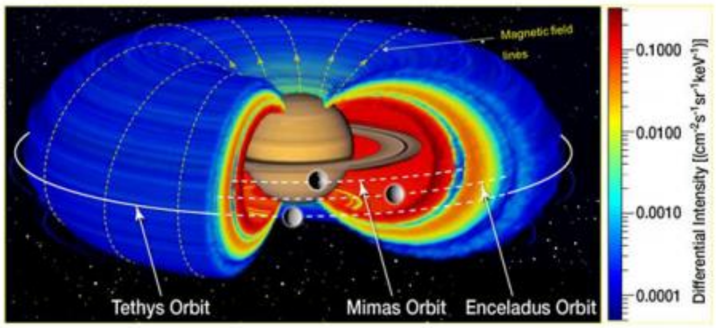


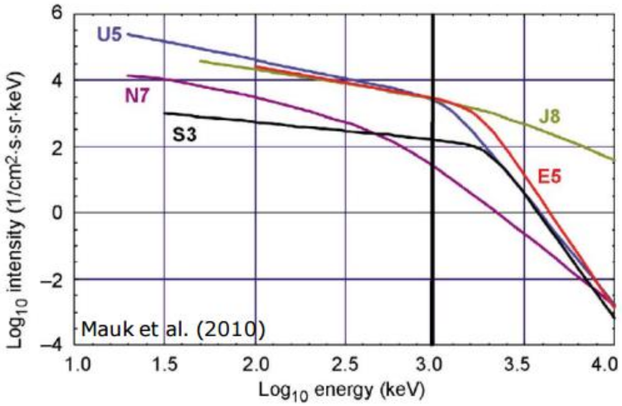
- JUpiter ICy moons Explorer: first L-class launch slot in ESA's Comic Vision Programme, foreseen for **2022**
- Objective: investigation of **Jupiter and its icy moons**, Callisto, Ganymede and Europa
- Mission overview:
  - Launch in June 2022 with Ariane 5
  - Interplanetary transfer about 7.5 years
  - Scientific measurements around Europa (35 days), Jupiter high latitude phase (6 months), eccentric orbit around Ganymede (4 months), circular phase at 500 km (5 months)



Jovian Radiation Environment

- Jupiter is by far the strongest magnetic trap in the solar system
- **>5 MeV electron fluxes at Jupiter**: 1-2 orders of magnitude higher than at other planets





E. Roussos, RADECS 2016 Topical Day

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Radiation effects on electronics

next presentation

this presentation

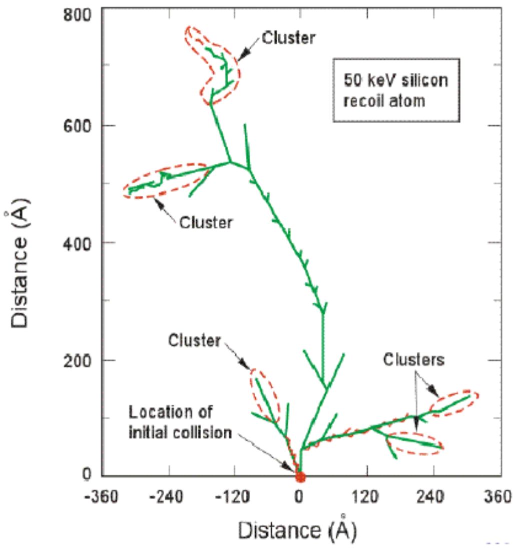
Single Event Effects

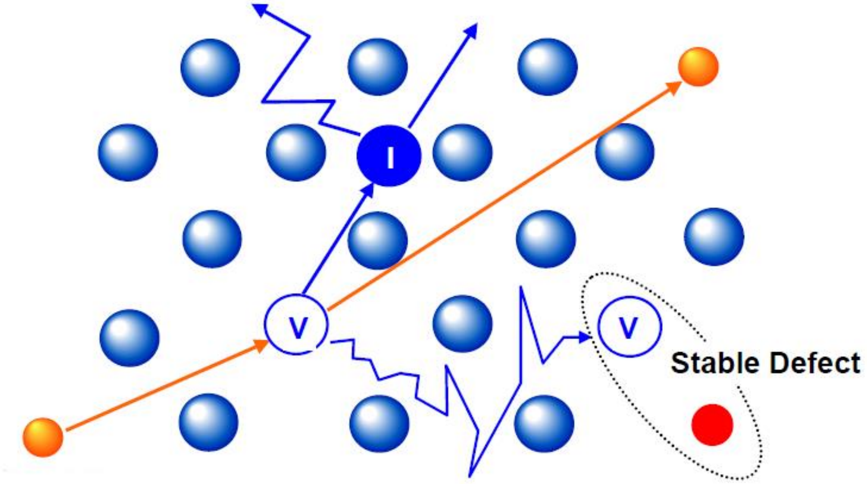
Displacement Damage

Total Ionizing Dose

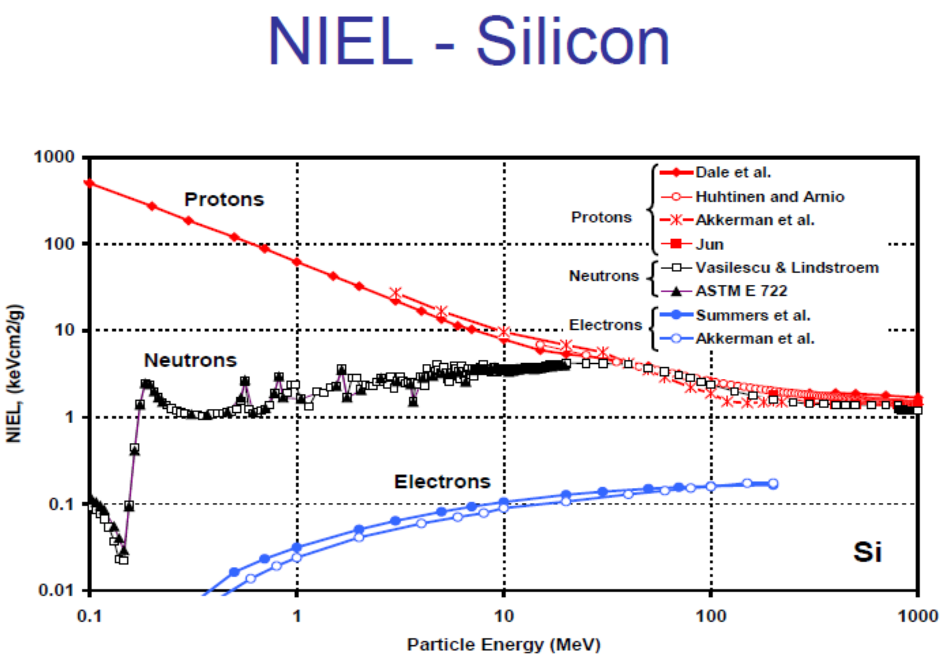
Displacement Damage (DD)

- Semiconductor materials (Si, GaAs…) are usually crystalline and interactions of energetic particles with it can lead to a disruption in the lattice, degrading the electrical performances of the device





DD by electrons

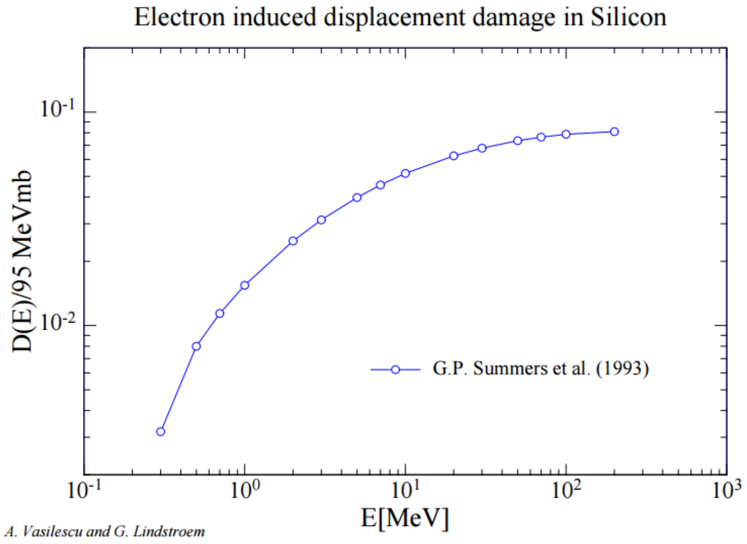


- **NIEL scaling hypothesis**: proportionality between Non Ionizing Energy Loss and resulting damage effects
- How well does this hold for **high energy electrons** and **state-of-the-art technologies**?

C. Poivey and G. Hopkinson, "Displacement Damage Mechanisms and Effects" , presentation at EPFL Space Center (2009)

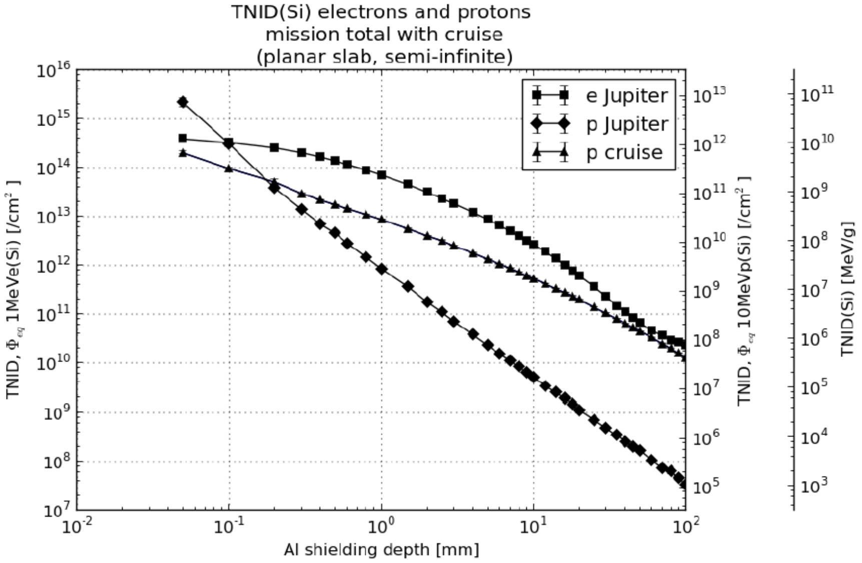
Electron hardness factor

- For silicon, relationship between displacement damage cross section and NIEL is **100 MeVmb = 2.144 keVcm^2/g**
- Hardness factor **$k = D_{particle}(E)/D_{neutron}$(1 MeV)**, where $D_{neutron}$(1 MeV) = 95 MeVmb



DD in Jovian environment

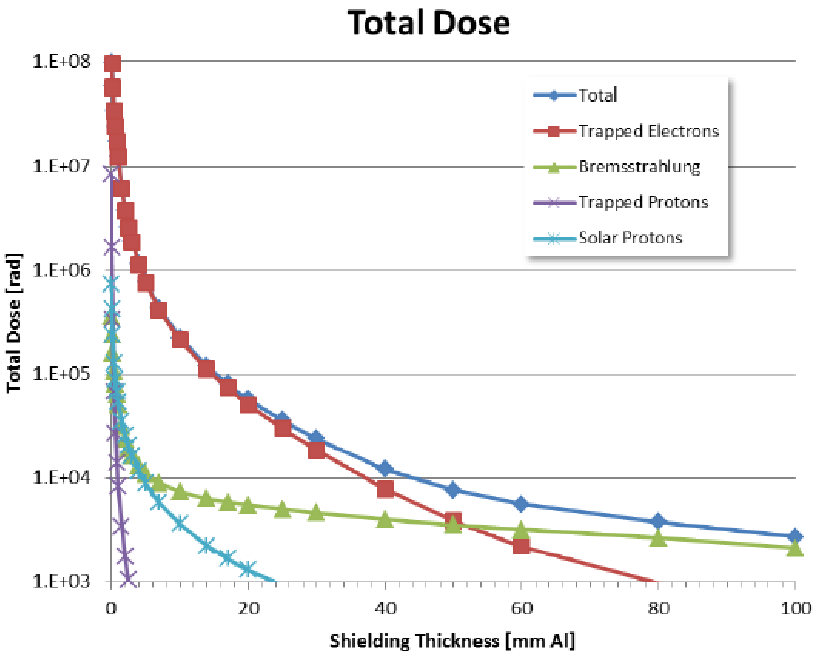
- Trapped electrons in the Jovian environment will dominate the overall mission displacement damage



E.g. for 20 mm Al shielding, the 10 MeV proton equivalent fluence from electrons for DD is ~$6 \cdot 10^{11}$ cm^{-2} and clearly dominates the total contribution

JUICE environment specification, JS-14-09 (2015)

TID in Jovian environment



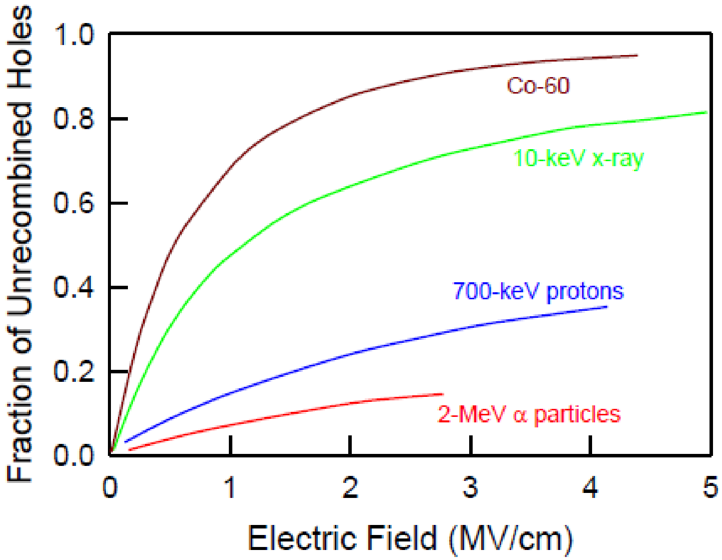
- Trapped electrons are expected to clearly dominate the TID
- Unlike in the case of the Earth trapped electron belts, due to the larger energies, shielding is less efficient
- Almost **1 kGy** for 20 mm Al shielding (design baseline)

JUICE environment specification, JS-14-09 (2015)

^{60}Co TID tests for EEE components in Jupiter

- ^{60}Co is traditionally used to characterize electronic component TID performance
- In general, it represents a worst-case condition with respect to radiation environment due to the larger fraction of unrecombined holes/electrons

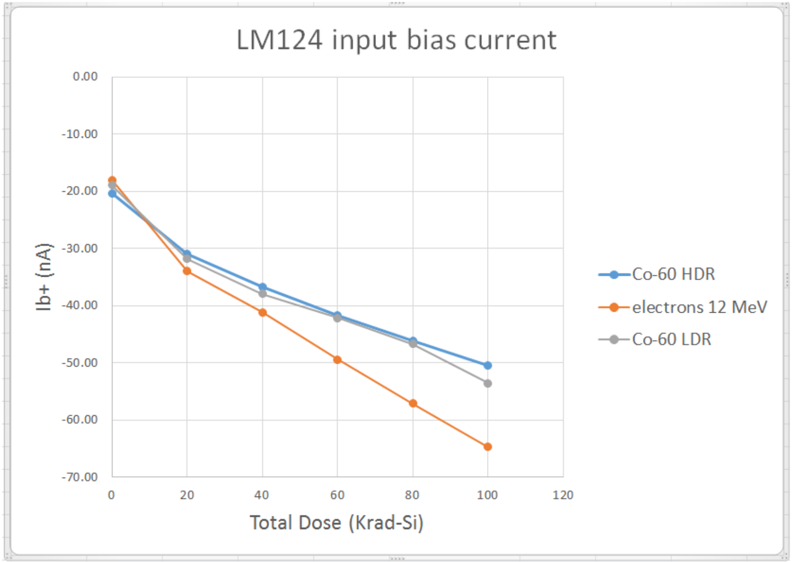
Input from A. Zadeh (TEC-QEC, ESA)



After F. B. McLean and T. R. Oldham, HDL Technical Report, No. HDL-TR-2129 (1987) and M. R. Shaneyfelt, et al., (1991)

^{60}Co TID tests for EEE components in Jupiter

- For the LM124, the data indicates **increased electron irradiation induced parameter degradation** compared to ^{60}Co tests.
  - Electron 12MeV at ~6.7rad/s. HSM (Portugal)
  - Electron >10MeV at RADEF (Finland).
  - ^{60}Co gamma at ~6.7rad/s. CTN (Portugal)
  - ^{60}Co gamma at ~0.08rad/s. ESTEC (The Netherlands)



Input from A. Zadeh (TEC-QEC, ESA)

Outline

Facilities: CLINAC@RADEF

- Example of medical linac accelerator
- CLINAC electron accelerator installed at RADEF facility
- Aimed to be used for irradiation studies of semiconductor materials and devices
- Extraction energies from 6 to **20 MeV**
- Maximum dose rate: 600 Gy/h
- Pulse distance of 5.5 ms (RF frequency of 180 Hz), pulse width of 5 um
- Dosimetry: ionization chamber, 2D array detector (PTW Octavius)

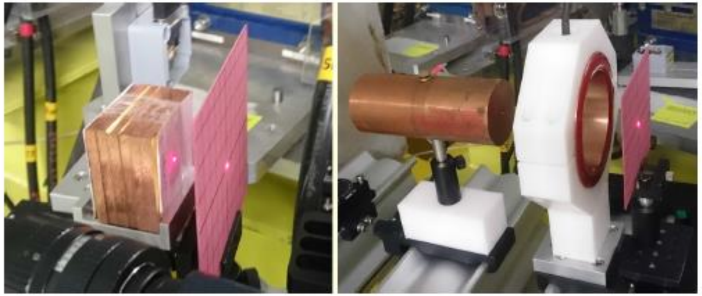
Facilities: piM1 beam line@PSI

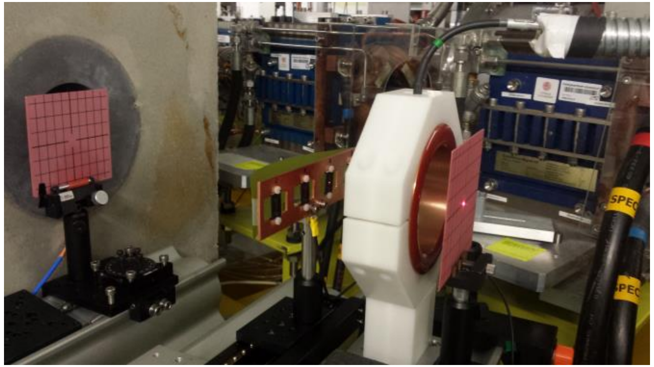
- Secondary particles produced on thick carbon target from energetic proton beam
- Selection of particle charge/momentum and guides to test areas
- Electron flux/energies ranging from $1.5 \cdot 10^3$ e/cm^2/s at 20 MeV to $2 \cdot 10^6$ e/cm^2/s at 345 MeV
- Beam contamination with heavier particles (protons, pions) above 115 MeV/c

Figure 2. Experimental arrangement in the piM1 area.

Facilities: VESPER@CALIFES

- Developments in beam line, optics, instrumentation and dosimetry for radiation testing
- **200 MeV** electrons, with a large range of possible intensities
- First external test campaign: Flash memories from University of Padova/ESA
- More information in next presentation (*“VESPER status and outlook”, Maris Tali*)





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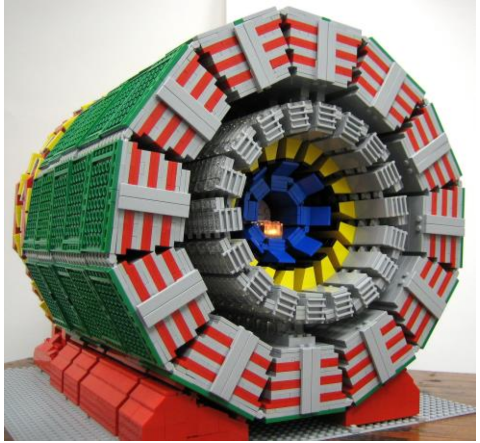
Example of test request for VESPER

- SEE tests from ESA and CNES (e.g. deep sub-micron CMOS technology)
- Study the degradation of triple junction solar cells for space applications
  - Electron energy between 75 and 200 MeV
  - Fluence between 10^{12} and 10^{15} e/cm^2

Possible interest from HEP community

- Electronics for detectors: possible use of high intensity electron beam for high dose applications (though effects such as e.g. high dose rate would need to be analysed)
- Electromagnetic calorimetry: radiation effects in scintillating materials
- Testing and calibrating dosimeter samples and radiation monitors



Input from F. Ravotti (CERN EP-DT-DD)

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Summary

- Trapped electrons will dominate the DD and TID in the Jovian environment
- Therefore, it is important to evaluate whether standard test approaches (e.g. protons for DD, ^{60}Co for TID) are representative of the high energy electron induced damage in state-of-the-art technologies
- The availability of a **200 MeV electron** radiation facility is a **key asset** for performing such a study, as medical linacs used for radiation effects testing typically have energies one order of magnitude below