RADIATION EFFECTS TESTING AT RADEF

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Finnish Satellite Workshop
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Radiation Environments

- Radiation can cause a myriad of problems in space systems
  - Single Event Effects
  - Cumulative effects
    - Total Ionizing Dose
    - Displacement Damage
- Modern technologies
  - SEEs can occur at ground level due to neutrons and even muons
RADiation Effect Facility - RADEF

- [https://www.jyu.fi/accelerator/radiation-effects-facility](https://www.jyu.fi/accelerator/radiation-effects-facility)
- Accelerator Laboratory at University of Jyväskylä (JYFL)
- First commercial irradiation tests by Daimler Benz in 1998
- ESA supported facility since 2005
  - 1/3 ESA’s external test sites
  - 1/2 Heavy ion test sites
RADEF GROUP

Ari Virtanen, professor
Arto Javanainen, senior researcher
Heikki Kettunen, laboratory engineer,
Mikko Rossi, laboratory engineer
Jukka Jaatinen, laboratory engineer
Alexandre Bosser, post doctoral researcher (30.6.2018)

Maris Tali, graduate student
(ES A-NPI project, hosted by CERN, 1.12.2015-)
Corinna Martinella, graduate student
(hosted by CERN, 1.1.2017 -)

Sascha Luedeke, graduate student
(RADS AGA EU- MSCA project, 1.10.2017 -)
Daniel Söderström, graduate student
(RADS AGA EU- MSCA project, 1.10.2017 -)
Andrea Coronetti, graduate student
(RADS AGA EU-MSCA-project 1.12.2017 -)

Jaakko Tuominen, MSc. Student
Juhani Lepistö, MSc. Student
Orvokki Eerola, MSc. Student
Davide Giurisato, MSc. Student
(ERASMUS from University of Padova)

18.1.2018

Finnish Satellite Workshpp
RADEF BEAMS

- **Heavy ions at 9.3 MeV/\( \text{amu} \) (upgrade up to 16 MeV/\( \text{amu} \) in progress)**
- **Protons**
  - 500 keV – 6 MeV (low)
  - 6 MeV – 55 MeV (high)
- **Electrons**
  - 6 /9 /12 /16 /20 MeV
  - X-rays continuous spectra:
    - 0 – 6 MeV (peak @ 1MeV)
    - 0 – 15 MeV (peak @ 2MeV)

### Table 1. 9.3 MeV/amu cocktails (M/Q=3.7, $^4\text{M/Q}=3.3$).

<table>
<thead>
<tr>
<th>Ion</th>
<th>Energy [MeV]</th>
<th>LET$^{\text{MEAS}}$ @surface [MeV/mg/cm$^2$]</th>
<th>LET$^{\text{MEAS}}$ @Bragg peak [MeV/mg/cm$^2$]</th>
<th>LET$^{\text{SRIM}}$ @surface [MeV/mg/cm$^2$]</th>
<th>Range$^{\text{SRIM}}$ [microns]</th>
<th>LET$^{\text{SRIM}}$ @Bragg peak [MeV/mg/cm$^2$]</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{15}\text{N}^{14}$</td>
<td>139</td>
<td>1.87</td>
<td>5.92 (@191 um)</td>
<td>1.83</td>
<td>202</td>
<td>5.9 (@198 um)</td>
</tr>
<tr>
<td>$^{20}\text{Ne}^{16+}$</td>
<td>186</td>
<td>3.59</td>
<td>9.41 (@138 um)</td>
<td>3.63</td>
<td>146</td>
<td>9.0 (@139 um)</td>
</tr>
<tr>
<td>$^{30}\text{Si}^{8}$</td>
<td>278</td>
<td>6.53</td>
<td>13.7 (@114 um)</td>
<td>6.40</td>
<td>130</td>
<td>14.0 (@120 um)</td>
</tr>
<tr>
<td>$^{40}\text{Ar}^{12+}$</td>
<td>372</td>
<td>10.07</td>
<td>18.9 (@100 um)</td>
<td>10.2</td>
<td>118</td>
<td>19.6 (@105 um)</td>
</tr>
<tr>
<td>$^{56}\text{Fe}^{15}$</td>
<td>523</td>
<td>18.59</td>
<td>29.7 (@75 um)</td>
<td>18.5</td>
<td>97</td>
<td>29.3 (@77 um)</td>
</tr>
<tr>
<td>$^{82}\text{Kr}^{22}$</td>
<td>768</td>
<td>31.21</td>
<td>41.7 (@68 um)</td>
<td>32.2</td>
<td>94</td>
<td>41.0 (@69 um)</td>
</tr>
<tr>
<td>$^{131}\text{Xe}^{35}$</td>
<td>1217</td>
<td>57.36</td>
<td>67.9 (@57 um)</td>
<td>60.0*</td>
<td>89*</td>
<td>69.2 (@48 um)</td>
</tr>
</tbody>
</table>
EQUIPMENT FOR TESTING

Heavy ions and protons

ECR ION SOURCE

K-130 CYCLOTRON
EQUIPMENT FOR TESTING

Heavy ions and low-energy protons 0.5 – 6 MeV

High energy proton line 6 – 55 MeV
EQUIPMENT FOR TESTING

- Heavy ions and low-energy protons typically in vacuum
  - 1-2 minutes to ventilate
  - ~ 5 minutes to pump down
- Device positioning and dosimetry remotely controlled.
  - Typically ~ 2x2cm² beam area
  - X-Y and tilting
- Cabling for user’s equipment on request
- Possible to test in air (limited)
  - Sensitive volume has to be on surface
  - Faster device change
  - Limited ion range
Electron Linear Accelerator

- Recommissioned Varian Clinac® medical accelerator
- 6 /9 /12 /16 /20 MeV
- X-rays continuous spectra:
  - 0 – 6 MeV (peak @ 1 MeV)
  - 0 – 15 MeV (peak @ 2 MeV)
- Typical beam area is about 25x25 cm²
- Remote controlled from user barrack
- Cabling for user’s equipment on request
- For harsh electron environments
  - Jupiter Icy Moon Explorer mission
  - MEO satellites (e.g. navigation)
Beam time usage at RADEF facility

- in 2017
  - 45 irradiation campaigns
  - 26 individual users
  - ~1400 hours
  - ~1/4 of total beam time at JYFL

Space - ESA: 12%
Space - others: 42%
Other irradiations: 43%
Basic research (PAC): 3%
Annual revenue – last 10 years

Recent RADEF projects

- Membrane production 2012-17 1 560 k€
- ESA/GSTP 2015-18 400 k€
- CCN for ESA TRP 2016-17 840 k€
- ESA/NPI 2016-18 90 k€
- EU-MARIE-CURIE ITN 2017-20 538 k€

TOT. 3 428 k€

Incipient projects

- Membrane production
  - contract 2.2 M€/5yrs 2018->
- ESA
  - contract 600 k€/5yrs 2018->
  - Promise to space industry >2M€/5yrs
Collaborators ~70 over the years
How to apply for beam time

1\textsuperscript{st} option: Contact Heikki Kettunen (heikki.i.kettunen@jyu.fi)
- High demand → recommended months in advance
- 800 eur/hour for heavy-ions and protons
- 400 eur/hour for electrons

2\textsuperscript{nd} option: Scientific proposal to PAC
- Deadlines: March 15\textsuperscript{th} and September 15\textsuperscript{th}
- Submitted to Mikael Sandzelius (mikael.sandzelius@jyu.fi)
- Free of charge, but requires solid scientific basis
- Testing COTS for scientific Cubesat may not be sufficient ;}

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Finnish Satellite Workshop
**RADSAGA EU-MS CA-ITN**

- **RAD**iation and Reliability Challenges for Electronics used in **Space**, **Aviation**, **Ground** and **Accelerators**
- “Brings together industry, universities, laboratories and test-facilities in order to innovate and train young scientists and engineers in all aspects related to electronics exposed to radiation.”
- [https://radsaga.web.cern.ch/](https://radsaga.web.cern.ch/)
- Started 2017
- 15 PhD projects
  - 3 PhD students at RADEF
- Total budget 3.9 M€ (~ 0.5 M€ for RADEF)
- CERN as coordinator

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Other recent activities

- SkyFlash (262890 EU-FP7 Project) [http://www.skyflash.eu/](http://www.skyflash.eu/)
  - Development of a RadHard by design (RHBD) methodology for non-volatile flash memories
- R2RAM (640073, H2020-COMPET-2014 RIA)
  - Development of Radiation Hard Resistive Random-Access Memory
- Airbus D&S GmbH, sub-contract
  - Radiation tests of the PHY transceiver electronics with heavy ions and protons
- SENSROVER (Proposal H2020-MSCA-ITN-2018)
  - SENSors for RObots in Various EnviRonments
  - Very Integrated Rf Technology solution for frequency Up-conversion and amplitude-phase Operation setting dedicated to next generation Smart Antenna array systems
- Radiation effects in SiC power devices
  - Vanderbilt, NASA, Silvaco Inc., ESA, CERN, ETH, STMicroelectronics
  - Ongoing
Recent publications (~ 100 since 2012)

Conclusions

- RADEF’s activities growing steadily
  - Solid customer base (space industry and membrane production)
  - Annual total revenue about 1Meur (~ 60% space related)
  - 10-20 scientific publications annually
  - 5 PhD students

- Strong support from ESA both scientifically and economically
  - 300 keur for HIISI + 100 keur for high energy electrons
  - Continuing basic contract 600 keur for 2018-23

- International collaboration
  - ESA, NASA, JAXA, CNES, RADSA GA, Vanderbilt, Montpellier, ETH, STMicroelectronics, etc.

- Partnering in EU projects and proposals (EU-FP7 and H2020)
Thank you for your attention

Need to test your components? Welcome!
https://www.jyu.fi/accelerator/radiation-effects-facility