# ESA update on European radiation facilities

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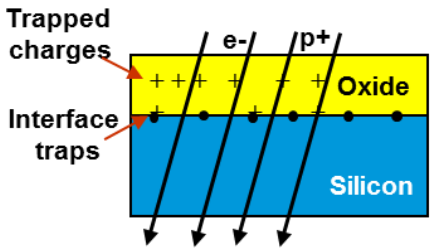
Radiation Hardness Assurance & Component Analysis Section (TEC-QEC)
Directorate of Technology, Engineering and Quality (D/TEC)

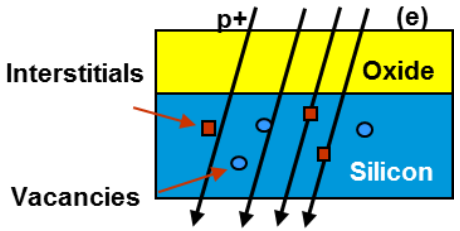
# Ionising radiation effects on EEE components

## Effect on the component



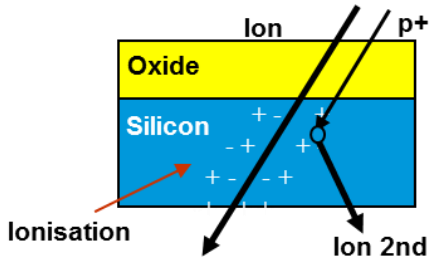

### Total Ionising Dose

Electron-hole pairs generation in semiconductor oxides




### Displacement Damage

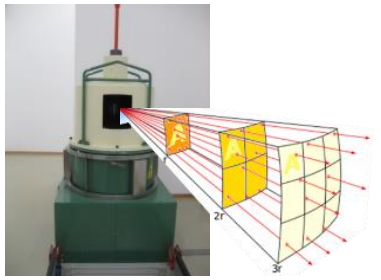
Lattice Displacement Damage caused by energetic particles




### Single event effects

Ion deposits significant charge within device that directly affects its operation

## Type of test

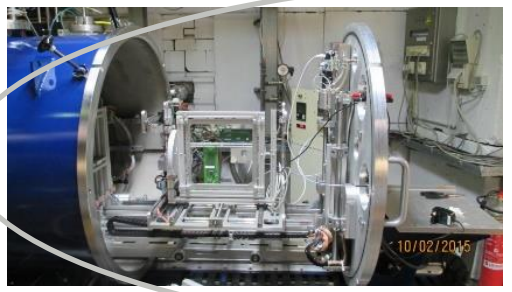


### Total Ionising Dose

Co-60 gamma ray irradiation

### Displacement Damage

High energy protons (10-200MeV)




### Single event effects

High energy ions

# Radiation test activities

ESA in house capabilities:

Co-60

Cf-252

SPA/TPA Laser

Decapping/

Delidding

RHA Engineering

External facilities

- UCL (B)
- GANIL (FR)
- CERN/CH
- LNS (I)
- RADEF (FI)
- PSI (CH)
- HPTC (NL)
- KVI (NL)
- GSI (D)

# Facilities and beam developments

One of the first CASE system used (1981).

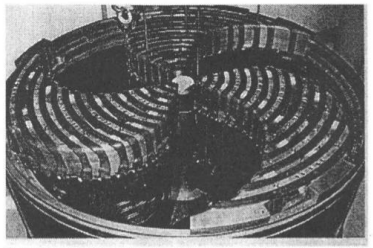


Fig 8 : One of the magnetic poles of the superconducting cyclotron AGOR (Orsay-Gröningen).

….. The Agor Cyclotron (on the left) , 40 years later

PSI

UCL – new ECRIS source

RADEF

**1991**

first Radiation and its Effects on Components and Systems (RADECS) Conference

**1992**

Heavy ion beams

GANIL (FR)

**1996**

Proton Beam

KVI (NL)

**2012**

ECSS-Q-ST-60-15C – Radiation hardness assurance – EEE components

**2020**

Heavy ions beam maintenance and upgrade -

ongoing

KVI (NL)


**1992**

Proton Irradiation Facility (PIF) at the Paul Scherrer Institut, Villigen, Switzerland protons 30–250 MeV.

**1996**

Protons and Heavy ions

UCL (BE)

Cyclotron, Université Catholique de Louvain

**2005**

Protons and Heavy ions 9,3 MeV/n 10 MeV/n

RADEF (FI)

RADiation Effects Facility at Jyväskylä, Finland

**2018**

Heavy ions

**22 MeV/n**

RADEF (FI)

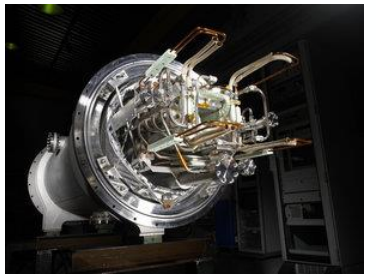
**2022**

Heavy ions

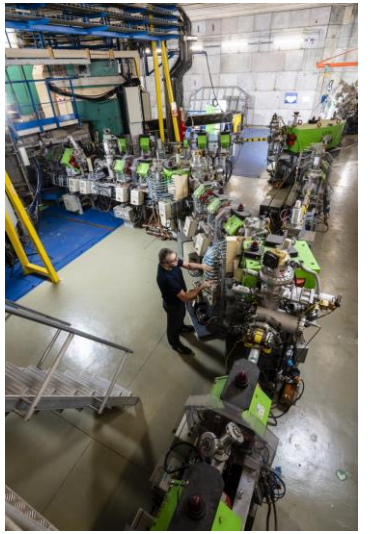
**Chimera Beam commissioning**

150 - 700MeV/n

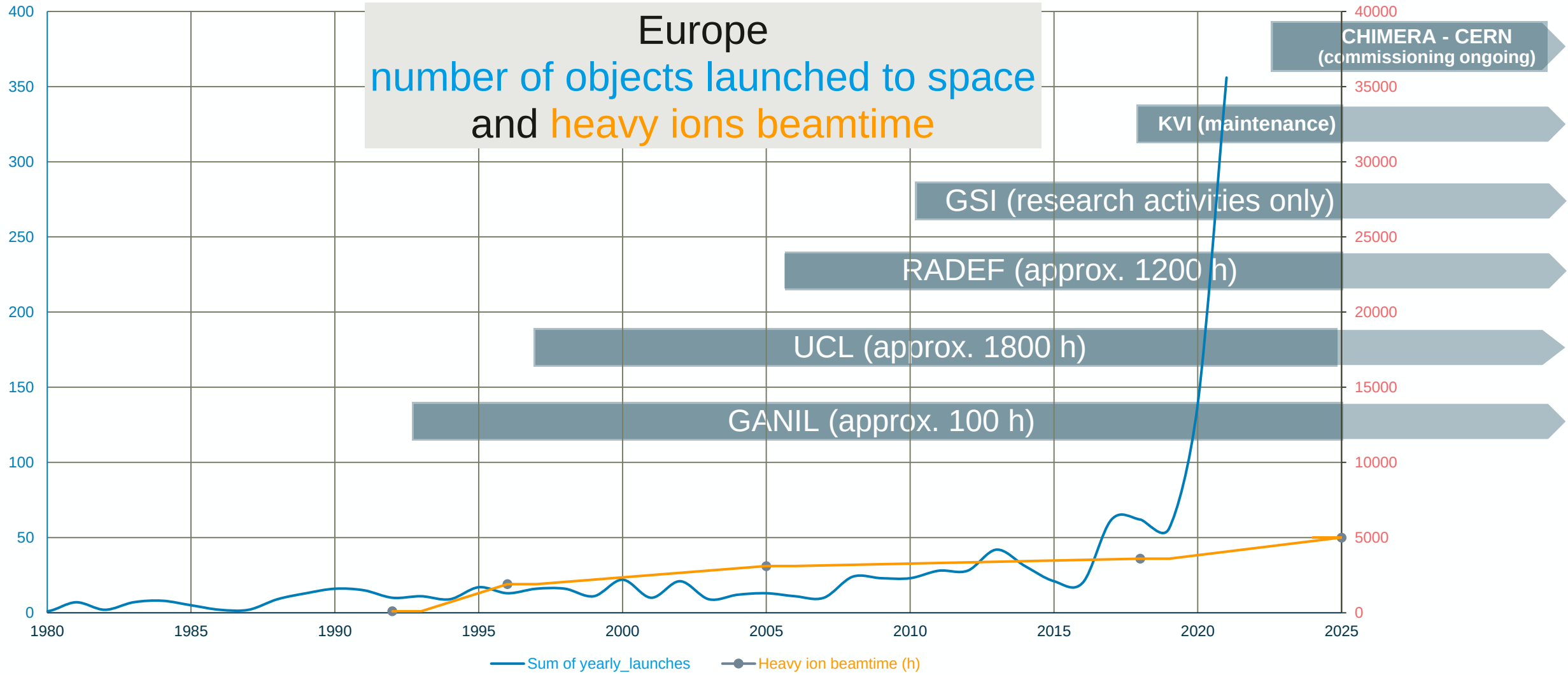
CHIMERA-CERN (CH)



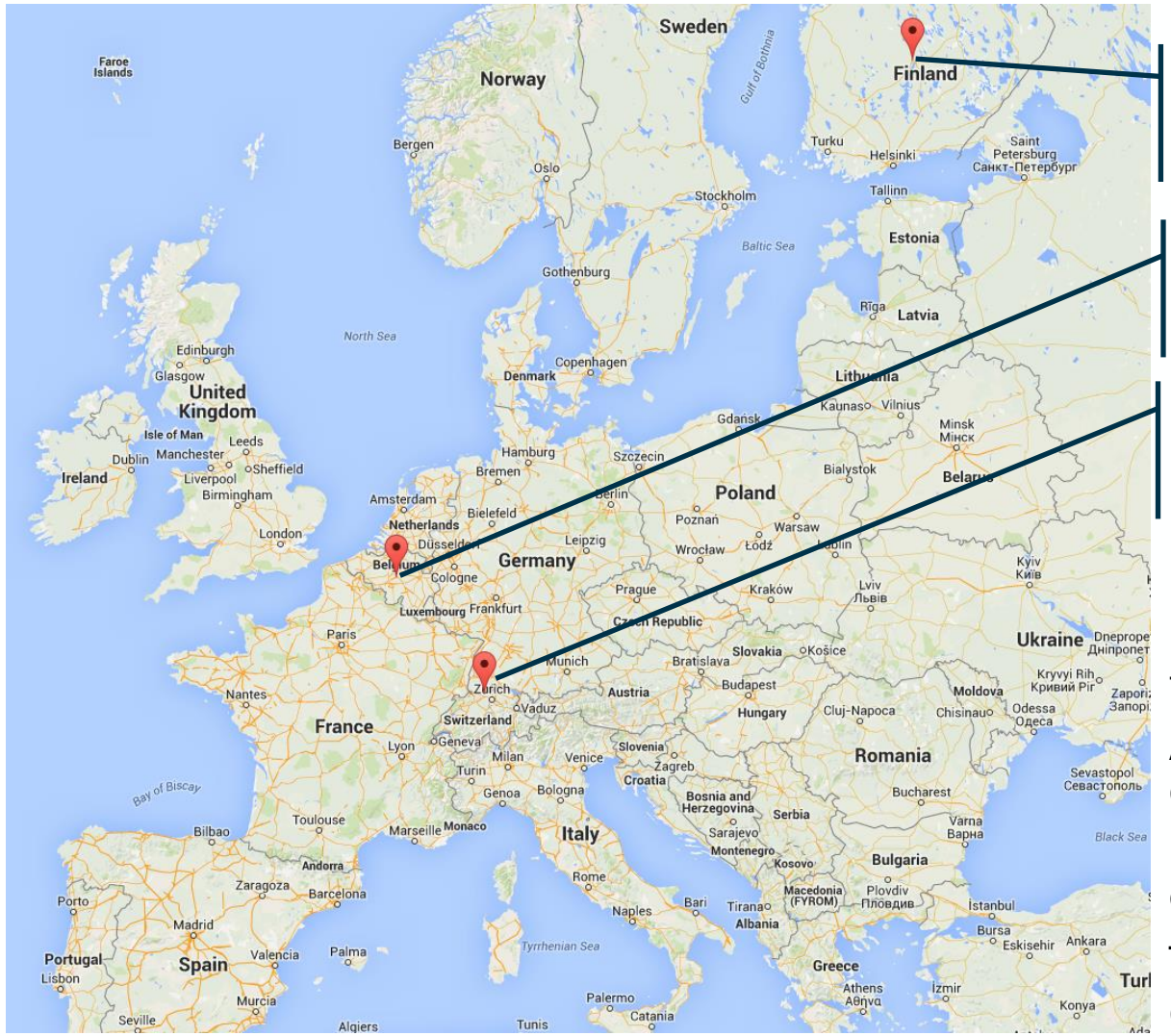
Superconducting magnet for SIS100 particle accelerator



# Europe
## number of objects launched to space
## and heavy ions beamtime



# Radiation facilities




**RADEF, JYFL**
Jyväskylä,
Finland

*Heavy ions, protons, electrons*

**UCL**
Louvain-la-Neuve
Belgium

*Heavy ions, protons*

**PSI**
Villigen
Switzerland

*Protons, electrons*

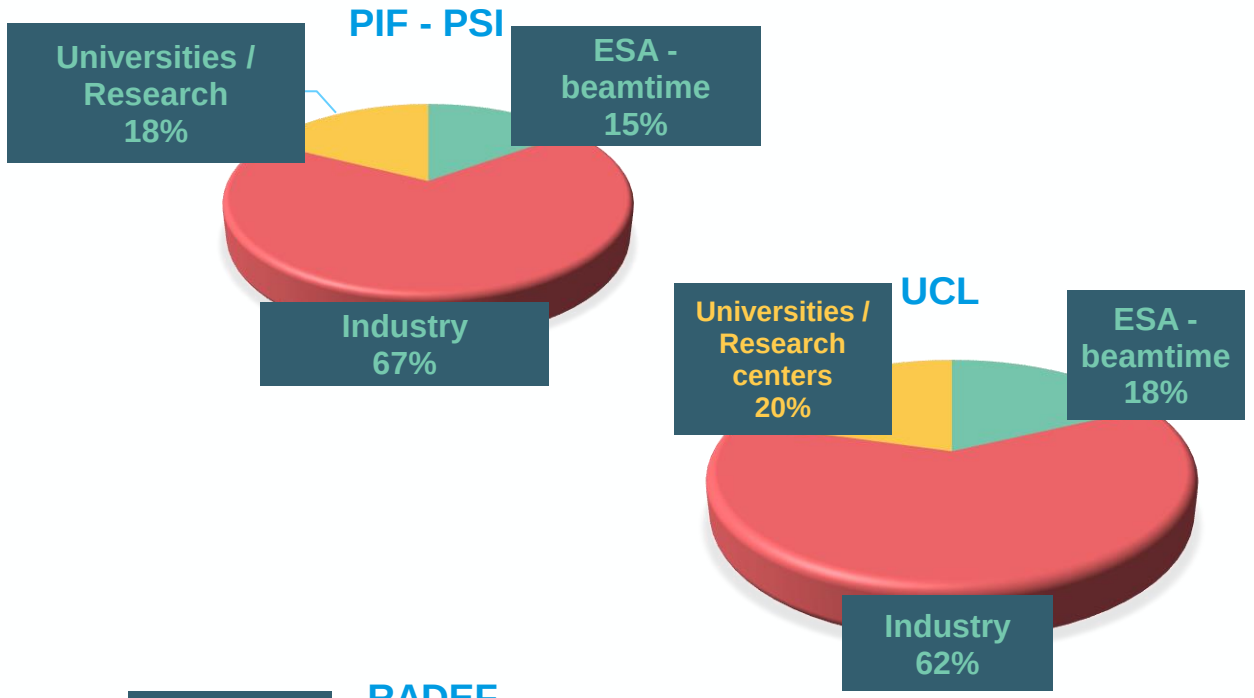
ESA has been collaborating with the three external test facilities for more than 25-years.

Aiming at continuous improvement of the quality of the beam, dosimetry and testing infrastructure

( Stable flux and energy levels, high particle selectivity, accurate dosimetry, electrical/optical interfaces for cabling…)

The support from the TRP/TDE programme has been crucial for the success of this collaboration

# External facilities for EEE RHA tests

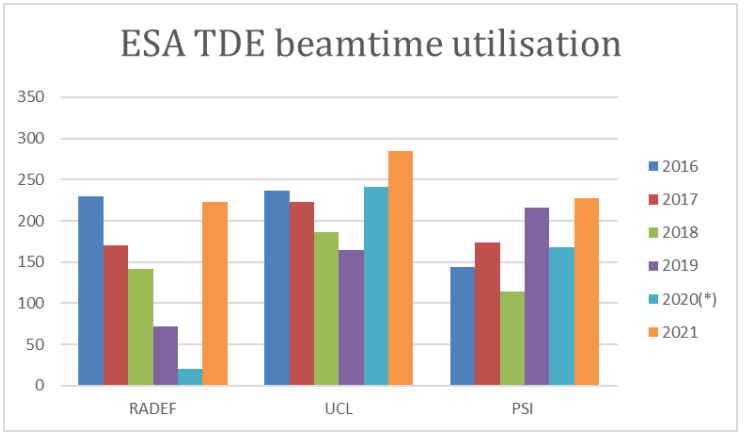


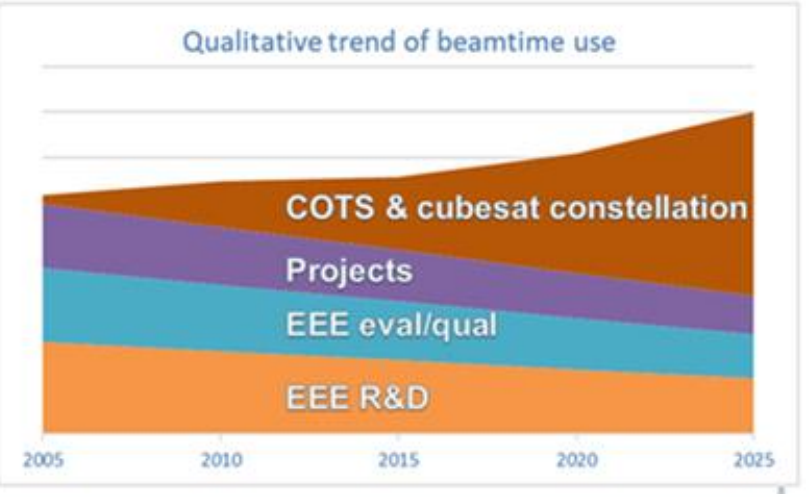

Beamtime is scarce
and precious
(and test campaign expensive):
test campaign shall be planned carefully in advance

Is recommended to request beamtime approx 6 months in advance – consider proper time and budget allocation

This has the drawback that booking (too) much in advance
- before drafting the test plan
- before procurement,
- before starting developing boards

⇒ may lead to several reschedules / cancellations

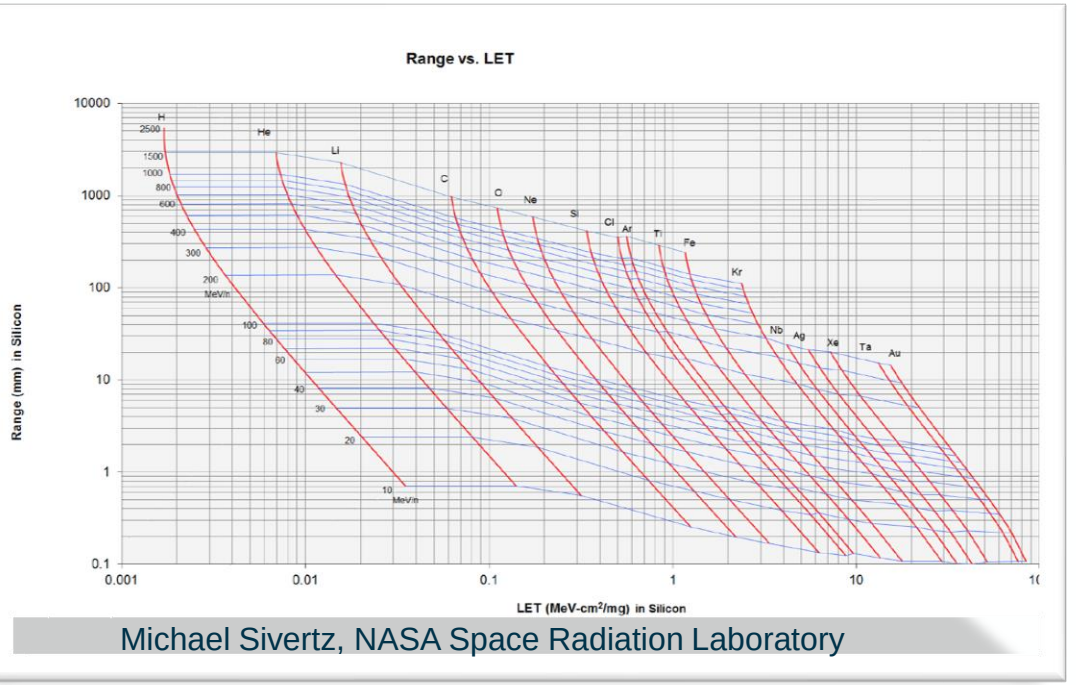


# Heavy ion beams used for SEE tests

| Facility | Ion | Beam energy [MeV] | Range [µm Si] | LET at surface [MeV/(mg/cm²)] |
|---|---|---|---|---|
| UCL HIF Louvain la Neuve Belgium | C | 131 | 269.3 | 1.3 |
| | Ne | 238 | 202 | 3.3 |
| | Al | 250 | 131.2 | 5.7 |
| | Ar | 353 | 114 | 9.9 |
| | Cr | 505 | 105.5 | 16.1 |
| | Ni | 582 | 100.5 | 20.4 |
| | Kr | 769 | 94.2 | 32.4 |
| | Rh | 957 | 87.3 | 46.1 |
| | Xe | 995 | 73.1 | 62.5 |
| RADEF 9.3 Mev/n Jyvaskyla Finland | N | 139 | 202 | 1.87 |
| | Ne | 186 | 146 | 3.63 |
| | Ar | 372 | 118 | 10.1 |
| | Fe | 523 | 97 | 18.6 |
| | Kr | 768 | 97 | 32.2 |
| | Xe | 1217 | 89 | 60 |
| RADEF 16MeV/n Jyvaskyla Finland | O | 284 | 481 | 1.52 |
| | Ne | 328 | 360 | 2.3 |
| | Ar | 657 | 264 | 7.2 |
| | Fe | 941 | 214 | 13.3 |
| | Kr | 1358 | 185 | 24.5 |
| | Xe | 2059 | 157 | 48.5 |
| RADEF 22MeV/n Jyvaskyla | O | 374 | 770 | 1.2 |
| | Fe | 1230 | 315 | 11.3 |
| | Kr | 1714 | 257 | 20.5 |
| GANIL | Ar | 972 | 113 | 5.4 |
| | Kr | 5160 | 27 | 11 |
| | Xe | 6450 | 35 | 26.5 |
| | Pb | 6032 | 64 | 72.7 |
| KVI 30MeV/n Groningen Netherlands | *O* | *454* | *1200* | *1* |
| | *Ne* | *554* | *885* | *1.5* |
| | *Ar* | *1056* | *550* | *5.2* |
| | *Kr* | *1732* | *305* | *19.5* |
| | *Xe* | *2683* | *213* | *44* |
| GSI 1GeV/n 200MeV/n Germany | *U* | *100* | *1780* | *40.57* |
| | *U* | *200* | *4750* | *28.02* |
| | *U* | *230* | *5890* | *25.94* |
| | *U* | *350* | *11210* | *21.07* |
| | *U* | *1000* | *51000* | *44* |

Maintain and improve the current availability and complementarity
Of beamlines to cover space industry and R&D testing requirements




Michael Sivertz, NASA Space Radiation Laboratory

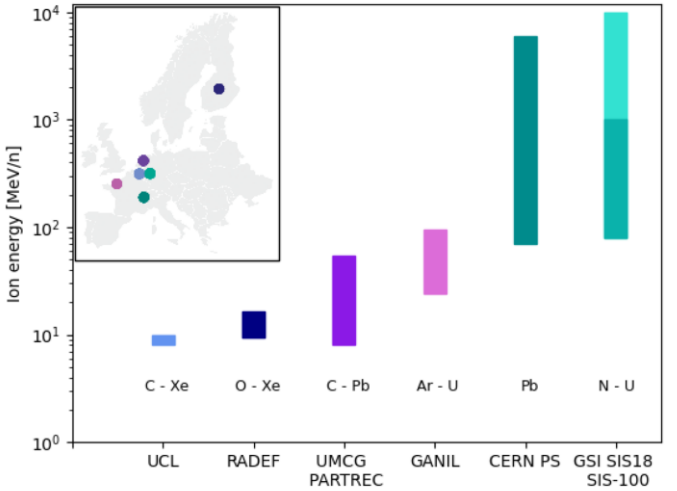



Figure 3.: Overview of the European ion infrastructure capacity after HEARTS

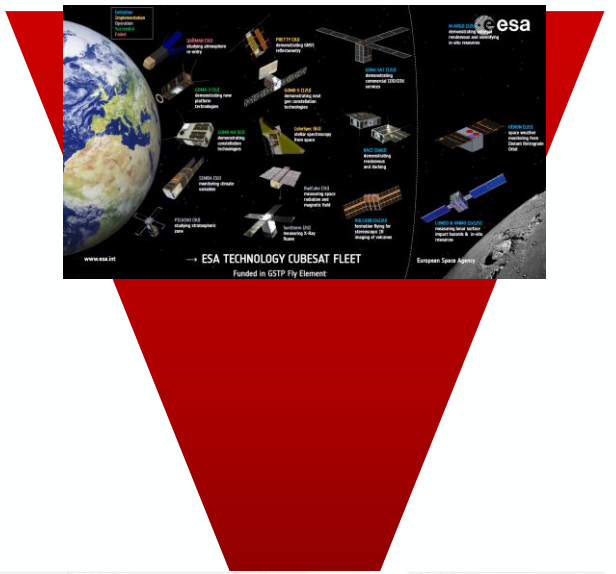
# RHA and SEE test requirement tailoring to mission risk

| | |
|---|---|
| Standard Energy | <10 MeV/n |
| High Energy | 10 MeV/n - 100 MeV/n |
| Very High Energy | 100 MeV/n – 5 GeV/n |
| Ultra High Energy | 5-150 GeV/n |

Selection of test method and test strategy, facility, type of beam shall be tailored and coordination of test campaign, risk of delays due to backlog and full occupation of facility is high.

| Facilities | Energy (MeV/nucleon) | Availability per year |
|---|---|---|
| PIF-PSI<br>KVI<br>Medical facilities (eg HPTC) | Protons | 3000 |
| **UCL HIF (Louvain-la- Neuve, Belgium)** | 10 MeV/n | 1200 |
| **RADEF (Jyväskylä,Finland)** | 9.3 MeV/n<br>16.3 MeV/n,<br>22 MeV/n , | 1000 |
| **KVI CART (Groningen, Netherlands)** | 30 MeV/n | 500 *maintenance until May 2023 |
| **GANIL G4 (Caen, France)** | 27 to 60MeV/n | 300 |
| **GSI SIS18 (Darmstadt, Germany)** | 50 MeV/n to 1-1.5 GeV/n | 100 *only for scientific experiments |
| **CERN CHIMERA (Geneva, Switzerland)** | 100-300MeV/nucleon | 100 |

ESA new Approach to Mission Classes
Evolution of RHA and SEE test requirements see next slide




High risk/ Low budget mission

Board level tests

New space

Complex devices

Flip chip

Stacked dies

# ESA new Approach to Mission Classes
# Evolution of RHA and SEE test requirements – in definition

## 5 Classes, 4 different sets of requirements tailored from ECSS-Q-ST-60-15

**Class V**

- < 3 M
- No TID test
- NO SEE test **except for MOSFET VDS > 200V**
- **Proton Test recommended (component or board level)**

**Class IV**

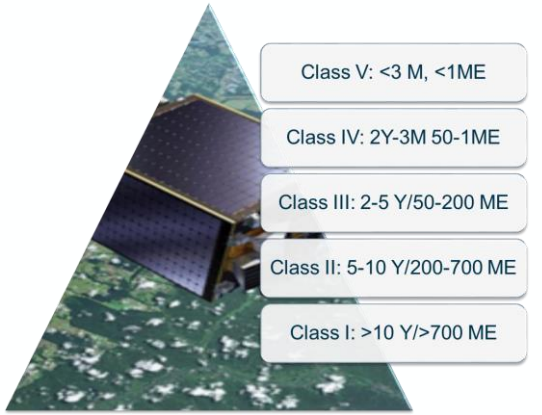
- 3M-2y
- No TID test if TIDL<5Krad
- **SEE** HI test **recommended**
- **Proton** test **required**

**Class III**

- 2y -5 y
- No TID if TIDL<5Krad
- HI at part and board level
- Proton at part and board level

**Class I & II**

- > 5 y
- ECSS-Q-ST-60-15
- ESSB-Q-008
- TID
- SEE




Guidelines for the utilization of COTS components and modules in ESA **ESA-TEC-TN-021473**
can be distributed to external parties only on a "need to know basis", and with the commitment not to distribute it to third parties without ESA consent

# Recent and ongoing activities at radiation facilities

*Since 2010*

*Heavy Ions **beam spectra assessment***

*[Radecs 2022]PIPS Diode Test Setup for Heavy Ion Beam Spectral Characterization*

T. Borel[1], A. Costantino[1], M. Muschitiello[1], H. Kettunen[2], L. Standaert[3], G. Santin[4], A. Pesce[4], V. Ferlet Cavrois[4]

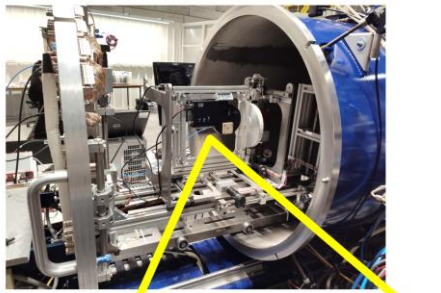
**PIPS Diode Test Setup for Heavy Ion Beam Spectral Characterization**

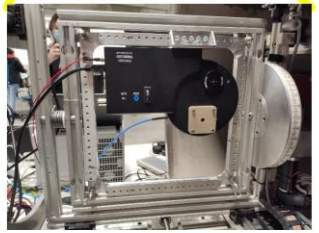
has been used systematically over the years
to monitor the quality of heavy ion beam spectra in European Facilities

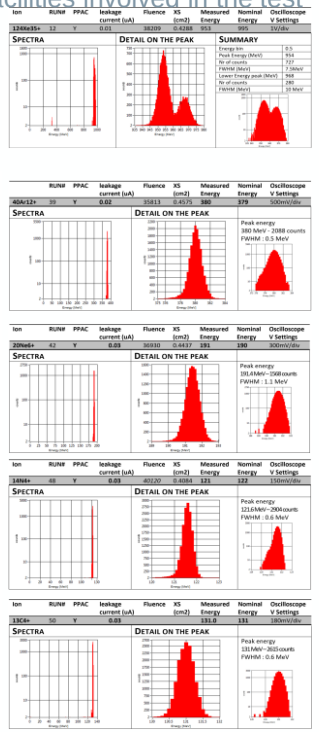
The reproducibility and accuracy of the system was confirmed by the result of cross calibration conducted on all the available ion species at the European facilities involved in the test ca

**Test Campaigns**

| Year | Facility |
|---|---|
| 2022 | UCL |
| | GANIL |
| 2021 | UCL |
| | RADEF |
| 2019 | KVI |
| | RADEF |
| | GSI |
| 2018 | CERN |
| | Radef |
| | CERN |
| 2016 | GSI |
| 2015 | KVI |
| | CERN |
| | RADEF |
| | UCL |
| 2014 | KVI |
| | RADEF |
| 2013 | GANIL |
| | RADEF |
| | UCL |
| 2012 | GANIL |
| | RADEF |
| | UCL |
| 2011 | GANIL |
| | RADEF |
| | UCL |







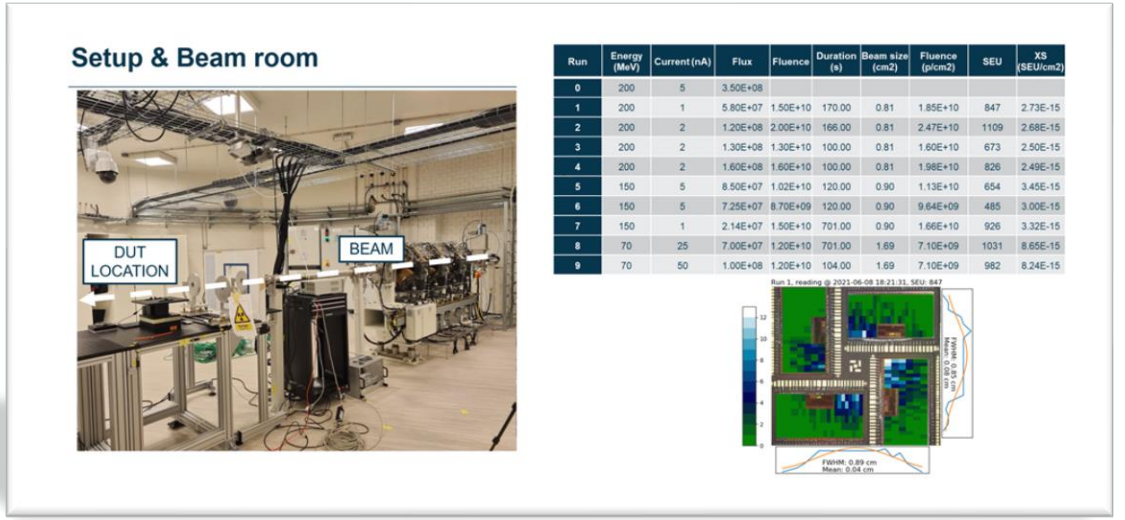
*2020-2022*

*Support to HPTC **proton beamline** for EEE tests development*

*[Radecs 2022] The HollandPTC R&D proton beam line for radiation hardness tests in space application*

M. Rovituso[1], A. Costantino[2], T. Borel[2], W. Van Burik[1], E. Schenk[1], A. Pesce[2]

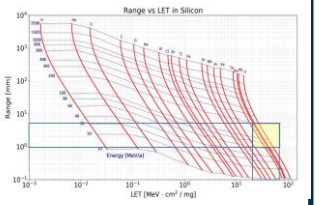
[1] HollandPTC, Netherlands, [2] ESA-ESTEC, Netherlands




| Run | Energy (MeV) | Current (nA) | Flux | Fluence | Duration (s) | Beam size (cm2) | Fluence (p/cm2) | SEU | XS (SEU/cm2) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 200 | 5 | 3.50E+08 | | | | | | |
| 1 | 200 | 1 | 5.80E+07 | 1.50E+10 | 170.00 | 0.81 | 1.85E+10 | 847 | 2.73E-15 |
| 2 | 200 | 2 | 1.20E+08 | 2.00E+10 | 166.00 | 0.81 | 2.47E+10 | 1109 | 2.68E-15 |
| 3 | 200 | 2 | 1.30E+08 | 1.30E+10 | 100.00 | 0.81 | 1.60E+10 | 673 | 2.50E-15 |
| 4 | 200 | 2 | 1.60E+08 | 1.60E+10 | 100.00 | 0.81 | 1.98E+10 | 826 | 2.49E-15 |
| 5 | 150 | 5 | 8.50E+07 | 1.02E+10 | 120.00 | 0.90 | 1.13E+10 | 654 | 3.45E-15 |
| 6 | 150 | 5 | 7.25E+07 | 8.70E+09 | 120.00 | 0.90 | 9.64E+09 | 485 | 3.00E-15 |
| 7 | 150 | 1 | 2.14E+07 | 1.50E+10 | 701.00 | 0.90 | 1.66E+10 | 926 | 3.32E-15 |
| 8 | 70 | 25 | 7.00E+07 | 1.20E+10 | 701.00 | 1.69 | 7.10E+09 | 1031 | 8.65E-15 |
| 9 | 70 | 50 | 1.00E+08 | 1.20E+10 | 104.00 | 1.69 | 7.10E+09 | 982 | 8.24E-15 |

# Recent and ongoing activities at radiation facilities

*Since 2021-ongoing* ***CERN- CHIMERA***

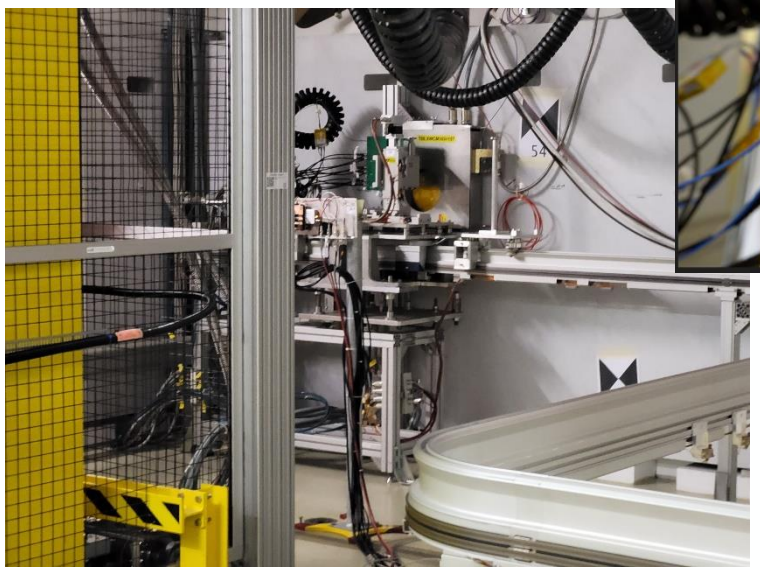



*Support to the Chimera beam development*

***High energy beam (intensity, range and LET)***

*for radiation tests of highly integrated electronic components*

*[OSIP-TDE contracts]*



*Since 2018* ***GSI (SIS18 and Microbeam)***

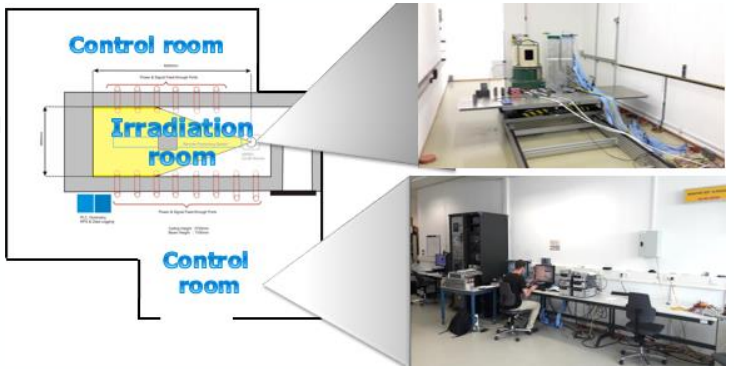
*R&D test campaigns*

*Annual ESA-FAIR Space* ***Radiation Summer School*** *(September)*

# ESTEC- TEC-QEC lab for RHA test and preparation

## Co60 Facility

80 TBq Co60 source for Total Ionising Dose tests
Dose rate window compliant with the ESCC22900 standard (from 0.01 rad/s [Si] to 3rad[Si]/s)
ISO17025 accredited dosimetry

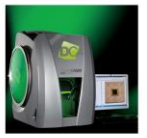



## Decapsulation systems and sample preparation

For plastic packaging
(Plasma, Laser, mechanical, acid)

Acid etcher
- Selective etching
- Material dependant
- Coarse opening
- Plastic only

Mechanical opening
- Very high precision
- Precise dimensions needed
- Plastic and metals

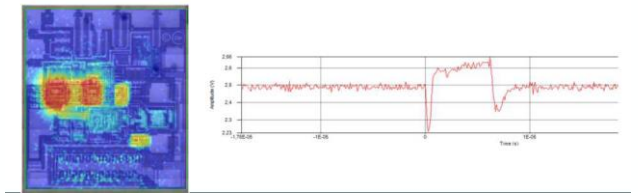


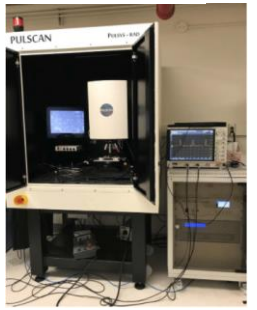
Laser
- Allows removal of plastic material
- Destructive on the die
- Plastic / Metal / Ceramic

Plasma etching
- Slow process
- Not destructive
- Safe for most structures
- Plastic Only

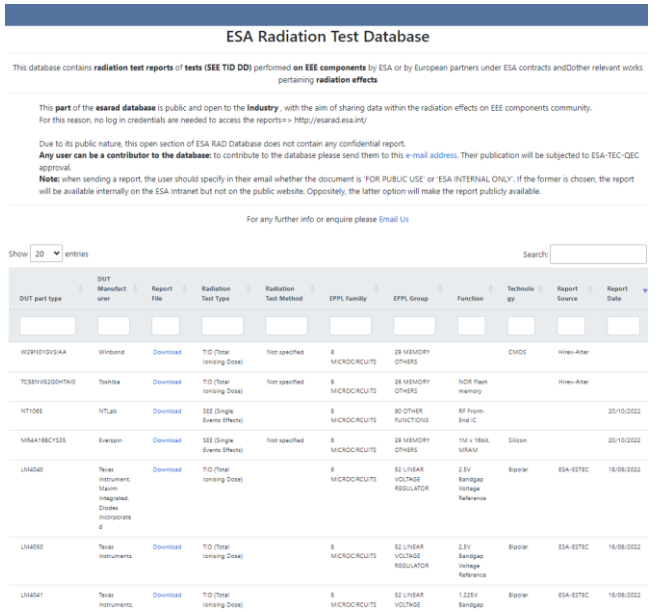
## SPA/TPA LASER

Two Photon Absorption Pulscan Laser System for SEE qualitative investigations






ESA Website for **Radiation Test data**
https://esarad.esa.int/



# Facility coordination and support future perspectives

- EEE Sovereignty plan – Technology line : Radiation Facilities

  **objective to expand the European radiation test capabilities with high energy ion beam (>22MeV/n).**

**Maintain European Facility network and collaborations**

- ESA-CERN, ESA-GSI Bilaterals
- Support to Heavy ions and Proton facilities
- Coordination for beamtime use, support to ESA projects and activities to facilitate test execution at external facilities, use of test methods and tailoring of testing metods.

- Complementarity and coordination to complement EU initiatives (RADNEXT, HEARTS)

# Thank you

**Info on external facilities**

https://escies.org/webdocument/showArticle?id=921&groupid=6

e-mail: ERFbooking@esa.int

**Info on ESTEC Co60**

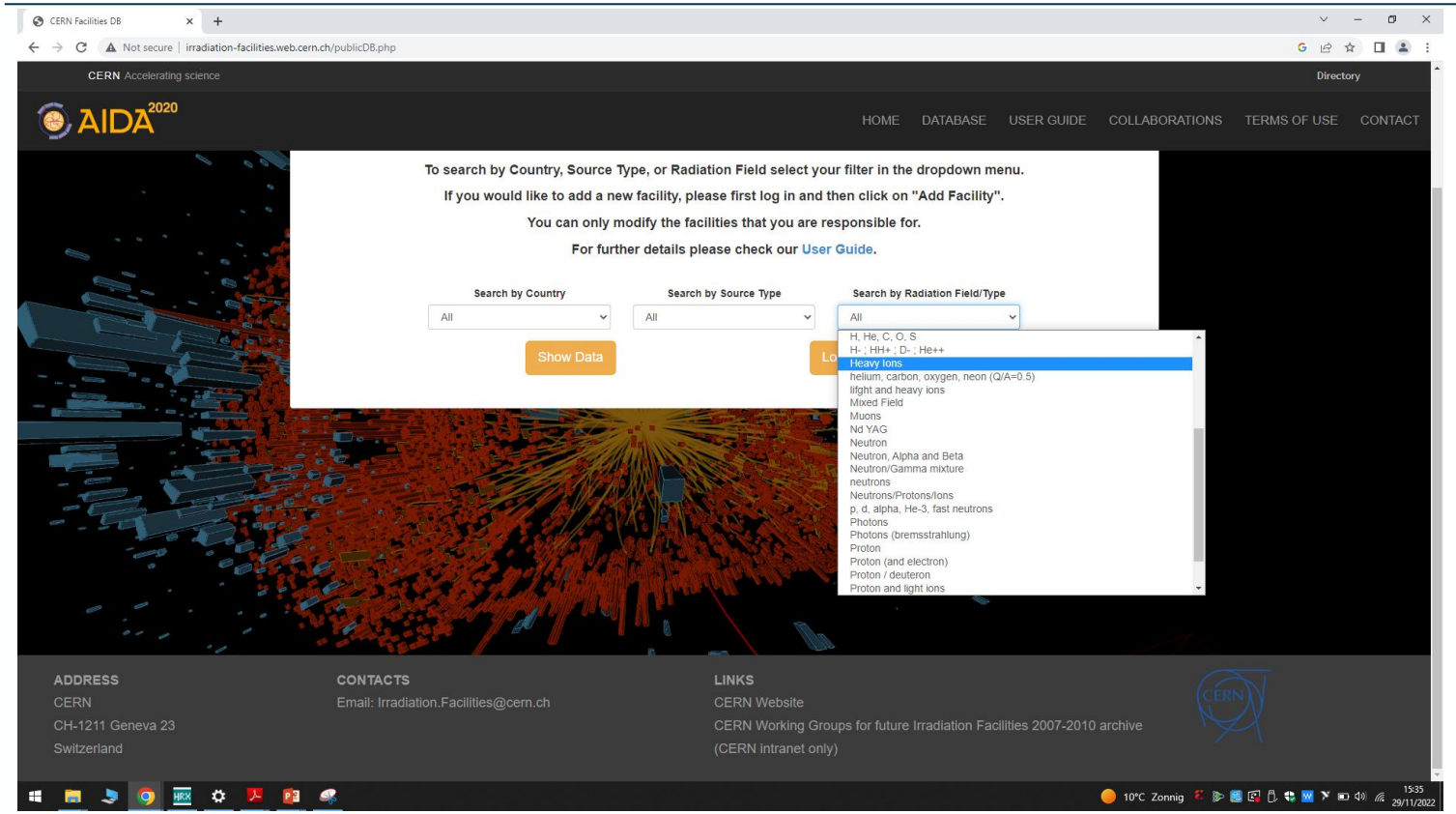
https://escies.org/webdocument/showArticle?id=251&groupid=6

e-mail: Co60.Facility.ESTEC@esa.int

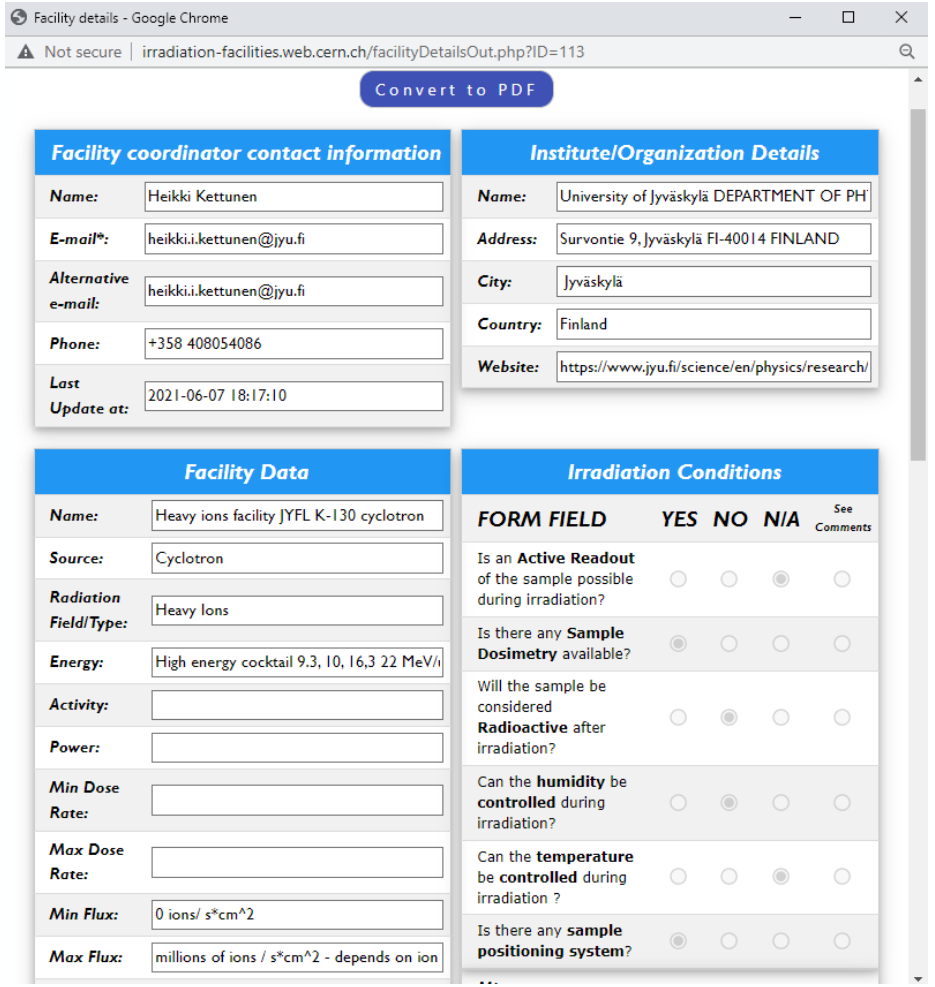
**AIDA – database of facilities worldwide**

https://irradiation-facilities.web.cern.ch/

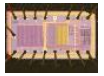
# CERN AIDA Facilities database – search




https://irradiation-facilities.web.cern.ch/



# Practical aspects

| | TID test | Proton test | SEE test |
|---|---|---|---|
| Source type | Co60 gamma rays | Proton Irradiation | Heavy Ions Irradiation |
| | Decay of radioactive source | Particle accelerator (cyclotron) | Particle accelerator (cyclotron) |
| Irradiation in | Air | Air | Vacuum / Air |
| Die exposure  | No | No | **YES** **(*)** |
| Activation of irradiated DUT?  | NO | **YES** | NO |
| Test duration  | Days / Weeks | Some hours (8 h) (cost > 1keuro/hour) | Some hours (8 h) (cost > 1keuro/hour) |
| Irradiation execution  | Irradiation 24/7 Access to the facility: office hours | Irradiation in shifts **(24/7)** Typically 8/12h | Irradiation in shifts **(24/7)** Typically 8/12h |
| How in advance to book | 1 Month | **>> 3 Months** | **>> 6 Months** |
| Beam sharing | Yes | No | No |
| Beam dimension  | From 20cm to 3m | Approx **8 cm** | Approx **3 cm** ( GSI Chimera up to 20 cm )* |
| Cable length from control to DUT | 6 m | **10-20 m** | 3m |