ASIF – ASI Supported Irradiation Facility evolution

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www.asi.it

Outline

I. ASIF framework

II. ASIF program objectives

III. ASIF facilities capabilities description

IV. ASIF gateway

V. New opportunities, perspectives

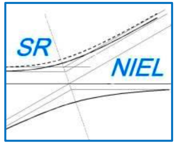
ASIF framework

In 2015 ASI initiated the coordination of a number of italian irradiation test facilities to enable their utilization for space applications.

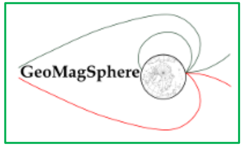
ASIF framework allows:

- the use of irradiation facilities for characterization, qualification and test activities
- to evaluate the contribution of galactic cosmic ions to space radiation environment
- to assess qualifications of devices related to SEE, TID and TNID for space missions using test beams data.

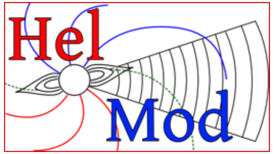
Within ASIF are available dedicated tools to the space radiation environment:



Nuclear and electronic stopping powers: TID and TNID doses, and SEE estimates



Geomagnetic processes and particle transport



Galactic Cosmic Rays heliospheric transport

ASIF framework
Cumulative doses and SEE rate are provided by

The solar energetic charged particles induce both ionizing (TID) and non-ionizing (NIEL or TNID) cumulative doses in the sensitive components used in satellite subsystems and instrumentation.

The deposited TID and TNID doses due to Galactic Comic Rays are usually expected to be less relevant. However, GCRs are a major source of SEEs, single-event effects in devices sensitive to this type of radiation damage.

ASIF program objectives

- ASIF program aims to maintain an **interactive coordinated set** of the Italian irradiation facilities, throughout the national territory, serving the national and international space communities. At national level industrial and institutional/research assets and centers in the field of EEE components need to be coordinated, supported and represented at international level.
  - Use of irradiation facilities for characterization and test activities through the ASIF gateway

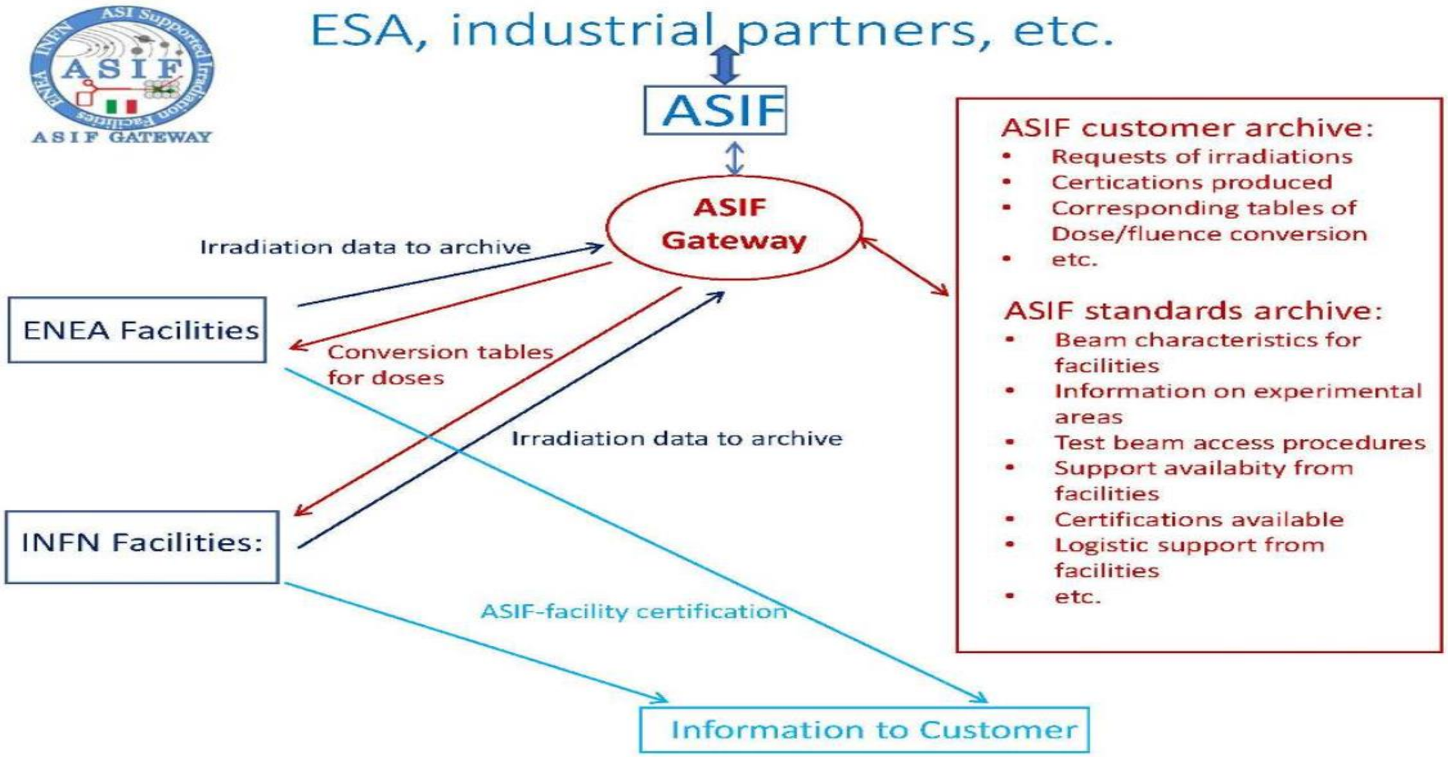
    www.asif.asi.it; www.asifgateway.asi.it;

to make available facilities with a recognized standard within ESA-ESCC qualification framework for national and international public and private users

to grow the knowledge of the space radiation environment (radiation damage, simulation and modelling tools, EEE supply chain)

To develop and validate new test configurations and protocols

ASIF – coordinated network



ASIF capabilities description

Phase 1 (2017-2019)

- Selection of facilities
- Standardization of the facilities and operating procedures
- Dosimetry

Phase 2 (2022-2024)

- Number facilities increase
- Standardization, dosimetry
- Interactive portal implementation (ASIF gateway)

http://www.asif.asi.it/

Milano Bicocca University (Physics Dept.)

The ASIF gateway website provides:

- comprehensive technical information about the different facilities
- beam time booking tools

ASIF – Access to Irradiation Facilities

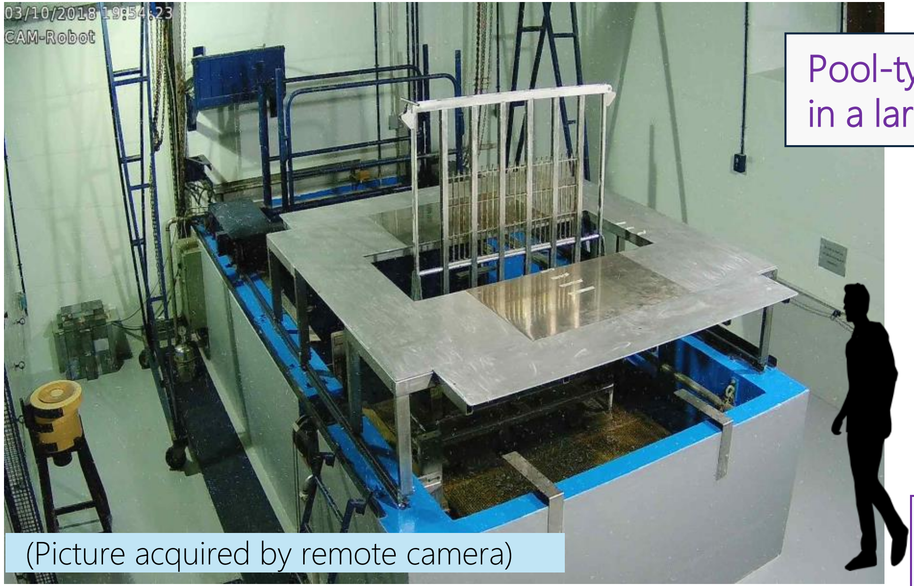
ASI-ENEA and ASI-INFN established the coordination of a structured infrastructure of Irradiation and Test Facilities currently including:

- ENEA – Calliope, **^{60}Co gamma facility photon irradiation at Casaccia Centre**
- ENEA – FNG, **Frascati Neutron Generator, (14MeV and 2.5MeV)**
- ENEA – TRIGA, **RC-1 neutron reactor at Casaccia,** for high intensity thermal and fast neutrons
- ENEA – TAPIRO, **fast neutron reactor at Casaccia,** high intensity fast neutron reactor
- ENEA – TOP-IMPLART plant, **at Frascati, protons** 3-7 MeV (vertical out); 35 – 55 MeV (horizontal out)
- ENEA – REX–TECHEA accelerator, **at Frascati, electron source,** REX (2.4-5.0 MeV); TECHEA (up to 3 MeV)
- INFN – LNS, for high energy **heavy ions** up to 80MeV / n, **Catania**
- INFN – TIFPA, **Trento Institute for Fundamental Physics and Application,** 70 to 228 MeV prontons
- INFN – LNF/BTF – **High energy electrons** (around 150-500 MeV), Frascati, Rome
- INFN – LNL – **Irradiation with protons** (10-28 MeV), **ions** (LET up to 180 MeVxcm^2/mg), **photons**

* *Detailed information on ASIF facility infrastructure is available at asif.asi.it and asifgateway.asi.it websites*

ENEA Calliope

ENEA irradiation facilities - Calliope (gamma source, Co-60; Casaccia R. C.)



(Picture acquired by remote camera)

Pool-type irradiation facility equipped with a ^{60}Co gamma source in a large volume (7×6×3.9 m^3) shielded cell

Mean energy: 1.25 MeV

Cherenkov effect around the 25 source rods in the plane rack (active area: 41 cm x 75 cm)

Activities (research & qualification):
Space, Nuclear, High Energy Physics, environment, radiobiology, CH, medicine…

ENEA Calliope

ENEA irradiation facilities - Calliope (gamma source, Co-60; Casaccia R. C.)

Maximum allowed activity:
3.7×10^{15} Bq (100 kCi)

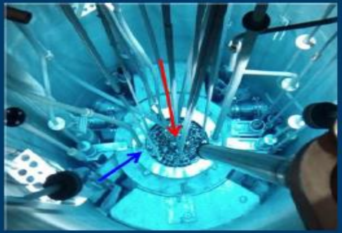
maximum dose rate (April 2024):
6.1 kGy/h

- Irradiation tests at different dose rates, atmospheric and temperature conditions and under bias.
- Online tests and remote acquisition.
- Dosimetric and characterization labs.
- Irradiation and dosimetric certifications.
- Simulation of the gamma field by Fluka/MCNP code (irradiation cell and irradiated samples).
- ISO 9001 and ISO 17025 (by 2024)

ENEA TRIGA RC-1

ENEA irradiation facilities - research reactor (thermal neutrons, Casaccia R. C.)

Thermal pool reactor, based on the TRIGA MARK II design by General Atomic.

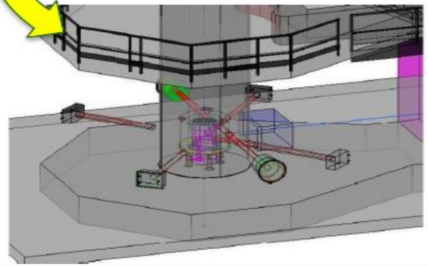


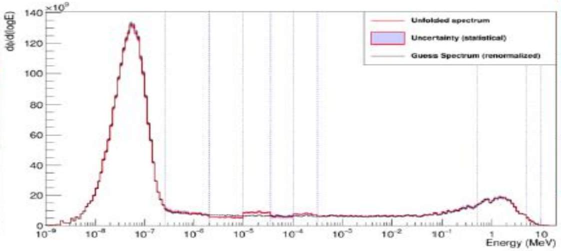
Central irradiation channel and Lazy Susan

Core:

- **111 elements** (standard TRIGA fuel element, enriched at **20% in ^{235}U**) in aluminum vessel 7 meters deep, filled with demineralized water (moderating, cooling and shielding).
- maximum thermal power of **1 MW**.

Several in-core and ex-core experimental channels (neutron and gamma field)





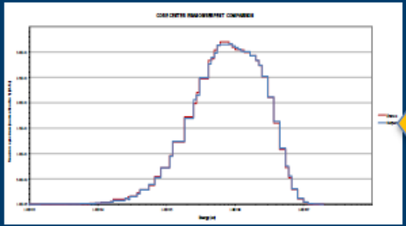
Neutron spectrum at the Lazy Susan

Channel description	Neutron flux ($ncm^{-2}s^{-1}$)
Lazy Susan	$2.00\ 10^{12}$
Pneumatic transfer system(rabbit)	$1.25\ 10^{13}$
Central channel	$2.68\ 10^{13}$
Thermal column collimator	$\sim 1\ 10^{6}$
Tangential piercing channel	$\sim 1\ 10^{8}$

ENEA TAPIRO

ENEA irradiation facilities - TAPIRO research reactor (fast neutrons, Casaccia R. C.)

Fast neutron source, based on the concept of Argonne FSR, first criticality in 1971.



Core:
- fuel: U-Mo alloy (98,5% wt of U), enrichment 93.5 % ^{235}U
- maximum thermal power of 5 kW.

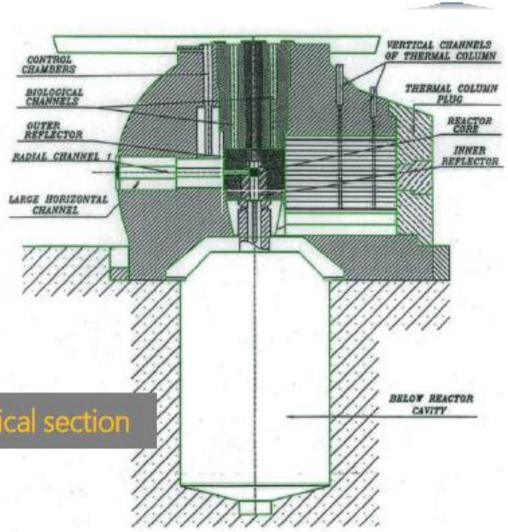
Max neutron flux: 3 10^{12} $ncm^{-2}s^{-1}$

Neutron spectrum at the diametral channel (core center)

Several channels where irradiation experiments may be performed
Experiments are prepared and placed in one of the channels selected based on sample size, required spectrum, fluence, etc

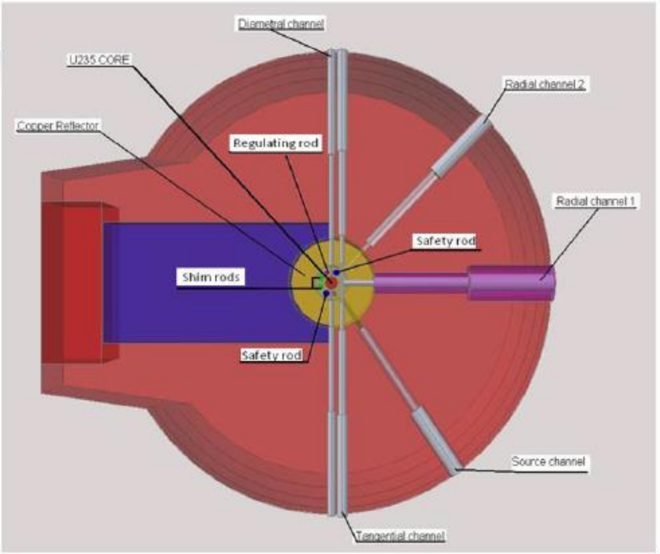
ENEA TAPIRO

ENEA irradiation facilities - TAPIRO research reactor (fast neutrons, Casaccia R. C.)



Vertical section

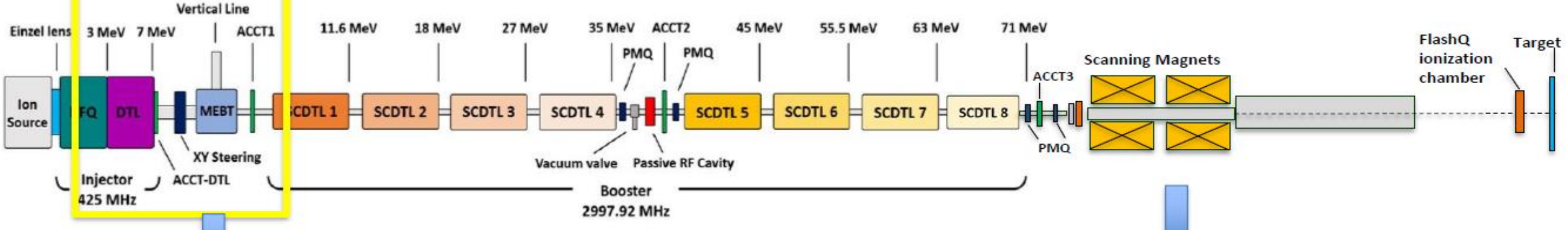
TAPIRO experimental channels



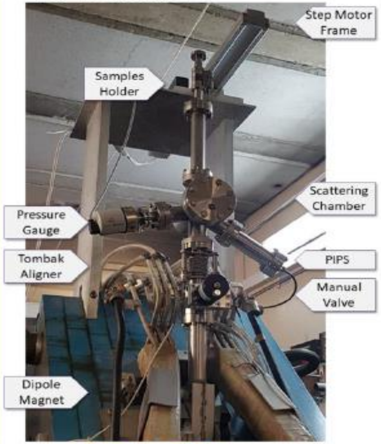
ENEA TOP-IMPLART

ENEA irradiation facilities - TOP-IMPLART proton linear accelerator (Frascati R. C.)

Modular structure (from 3 MeV to 71 MeV)



Vertical line:



beam properties

Pulse length	15 to 60 μs
Pulse repetition frequency	25 Hz
Flux per pulse	10^6 to $2{\cdot}10^7$ p/cm^2/pulse
Pristine energy from the injector	3 -7 MeV
Energy on target	1 - 6 MeV
Beam diameter on target (max.)	16 mm
Transverse homogeneity on target	± 5 %

Horizontal line:

beam properties

Pulse length	2.4 μs
Pulse repetition frequency	25 Hz
Protons per pulse (max)	4.5 10^8 p/pulse
Pristine energies on target	61 -70 MeV
Pencil beam spot size (FWHM)	17 mm
Maximum flux on a 10 x 10 cm² area	1.1E+08 p/cm²/s

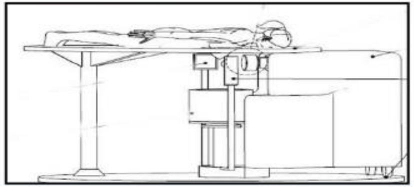
ENEA TECHEA e REX

ENEA irradiation facilities - TECHEA and REX electron linacs (electrons and X-rays, Frascati R. C.)

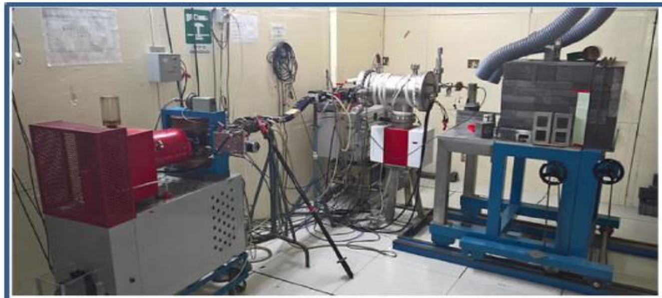
Max. energy: 3 MeV

X ray source, self shielded

TECHEA (TEChnology for HEAlth): project for treatment of breast cancers



Pulse lenght	3.5 μs
Pulse current (max)	135 mA
Electrons per pulse (max)	$2.95 \cdot 10^{12}$
Pulse Repetition Frequency	5 to 100 Hz
Average current (max)	47 μA
Electrons per second (max)	$2.9 \cdot 10^{14}$
Electron beam size at the linac exit (FWHM)	5.2 mm



REX: Removable Electron to X-ray source (Max. energy: 5 MeV)

Pulse lenght	3 μs
Pulse current (max)	150 mA
Electrons per pulse (max)	$2.95 \cdot 10^{12}$
Pulse Repetition Frequency	20 Hz
Average current (max)	9 μA
Electrons per second (max)	$5.6 \cdot 10^{13}$
Electron beam size 5 cm from the linac exit (FWHM)	20 mm

REX irradiation chamber

ENEA FNG

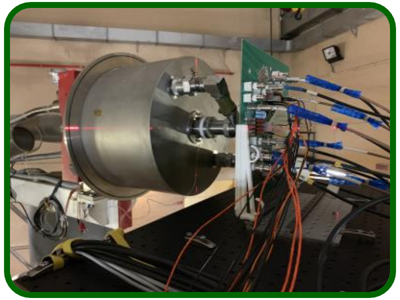
ENEA irradiation facilities – Frascati Neutron Generator (Frascati R. C.)

ISO 9001

Pulse operation possible	0.1 s min.
Certification	ISO 9001
Remote acquisition	Control room

in ASIF:

- standard irradiation test jig/sample holders
- new integrated system to monitor the neutron yield, fluence and spatial uniformity (HW and SW)
- intercalibration measurements with IRMM - Institute for Reference Materials and Measurements (Belgium)
- optical table and laser system for samples precise positioning
- monitoring IP cameras
- control room for users



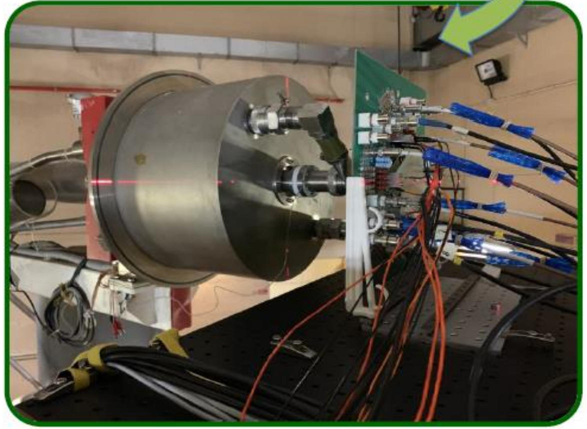
Two different operating conditions

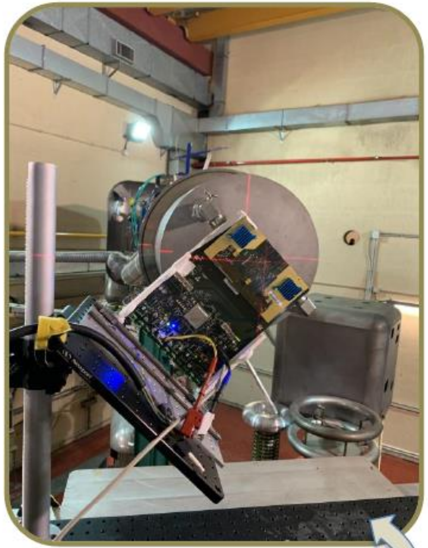
	D-T operation	D-D operation
Neutron yields (accuracy 3%)	1 10^{11} n/s max. 14 MeV	1 10^{9} n/s max. 2.5 MeV
Flux vs irradiation volume	10^7/s/(4* π*m^2)	10^5/s/(4* π*m^2)

ENEA FNG

ENEA irradiation facilities – Frascati Neutron Generator (Frascati R. C.)

Multiple DUT board for SEE test with high flux, on bias and online data acquisition from the Control Room

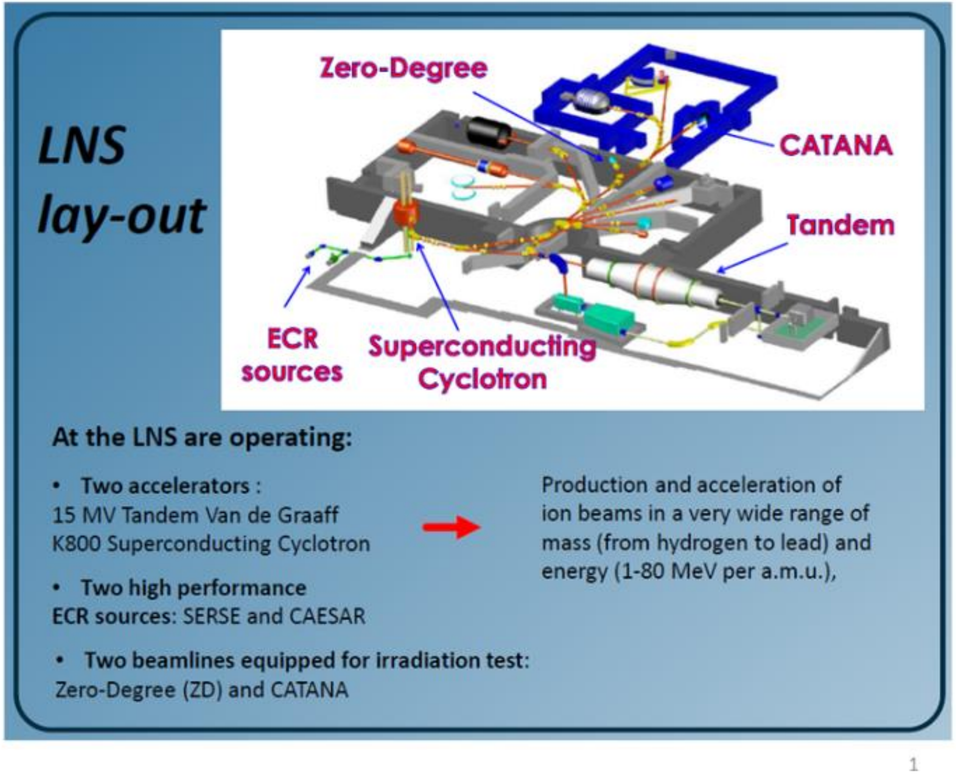




Special setup to account for target cooling beam shaping

Passive irradiation of SiPM for displacement damage test on silicon, with different fluences

INFN Laboratori Nazionali del SUD (LNS)



The **Superconducting Cyclotron** installed at LNS in combination with the available **ECR ion sources** can provide **protons** up to 80 MeV and a number of **heavy ions** beams for Single Events Effect (SEE) studies; protons and heavy ions can also be provided by the Tandem accelerator.

Two beamlines Zero-Degrees (use various ion beams) and CATANA (with proton beams) are equipped for irradiation tests. These beamlines have been upgraded to meet ESCC n. 25100 specifications related with radiation hardness testing for devices suitable for space applications.

INFN Laboratori Nazionali del SUD (LNS)

Available beams for irradiation

SEE test

Heavy Ions			
Ion	Energy *MeVA*	LET[SRIM] *MeV/(mg/cm²)*	Range[SRIM] *µm*
^{20}Ne	20	1.996	504.54
^{40}Ar	20	6.266	356.49
^{84}Kr	20	21.59	245.12
^{129}Xe	20	44.05	204.46

LET and Range values are calculated with SRIM2008

The selected ions provide, at the moment, the best compromise in reducing the time required for beam change (4-8 hours) and in providing a large range of values of LET. In in-air irradiation air is used to reduce beam energy → **Several LET points up to 60 *MeV/(mg/cm²)***

Integrated dose test

Protons	
Energy MeV	Flux ions/cm2/s
10 - 23 from Tandem 60, 80 from CS*	10^7

*Energy can be reduced by means of a stack of plastic degraders

Five irradiation runs during 2018

Ion	Energy on DUT *MeV*	Beam Time Units (BTU)
H	10 MeV*, 30 MeV	3
^{40}Ar	500	7
^{84}Kr	750	
^{129}Xe	612	

* from TANDEM accelerator

@LNS beam is reserved for irradiation testing 8 BTU per quarter (24 BTU per year).

The LNS facility is capable of providing very high ion beam energies attractive for EEE component irradiation testing

INFN Laboratori Nazionali di Frascati (BTF)

INFN Frascati beam-test facility (BTF)

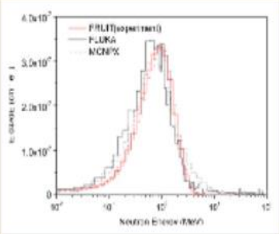
The BTF is part of the DAΦNE accelerator complex: it is composed by a dedicated transfer line, driven by a pulsed magnet, that allows to divert electrons or positrons (normally injected to the DAΦNE damping ring, and from there to the collider rings) from the end of the high intensity LINAC*, towards a dedicated experimental area.

*S-band, 2/3π TW, SLAC-type with SLED compression, thermo-ionic gun

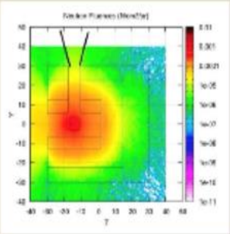
Irradiation type

Pulsed high-energy **electrons** and **positrons**

Neutrons by photoproduction on thick high-Z target

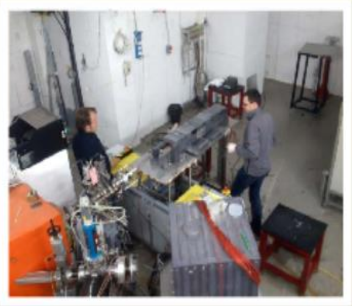


Neutron spectrum



Neutron flux @ 1 m from shield

3 10^5 n/cm2/s equivalent dose=43 mSv/h



Photons (tagged in energy), by Bremsstrahlung radiation on thin active target

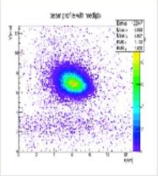
BTF is a **test and calibration facility,**
with the possibility of irradiation

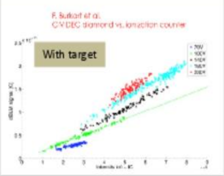
INFN Frascati beam-test facility (BTF)

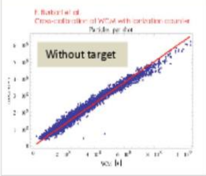
Beam parameters

The beam can be delivered in different modes: **dedicated** running or **parasitic** operation and **with** or **without** attenuating target. Different ranges of beam parameters can be achieved:

Parameter	Parasitic mode		Dedicated mode	
	With target	Without target	With target	Without target
Particle species	e^+ or e^- Selectable by user	e^+ or e^- Depending on DAFNE mode	e^+ or e^- Selectable by user	
Energy (MeV)	25–500	510	25–700 (e^-) 25–500 (e^+)	250–730 (e^-) 250–530 (e^+)
Energy spread	1% at 500 MeV	0.5%	0.5%	
Repetition rate (Hz)	Variable between 10 and 49 Depending on DAFNE mode		1–49 Selectable by user	
Pulse duration (ns)	10		1.5–40 Selectable by user	
Intensity (particles/bunch)	1–10^5	10^7–1.5 10^{10}	1–10^5	10^3–3 10^{10}
Maximum average flux	3.125 10^{10} particles/s			
Spot size (mm)	1–25 (y) × 1–55 (x)			
Divergence (mrad)	1–2			







INFN TIFPA

INFN irradiation facilities – Trento Institute for Fundamental Physics and Applications

ESS = proton degrader + 'beam analyzer'

Beam production
Isochronous cyclotron, max protons energy = 235 MeV, minimum= 70 MeV
Beam line current = 300 nA
RF frequency = 106 MHz
Typical efficiency = 55%

INFN Laboratori Nazionali di Legnaro (LNL)

INFN irradiation facilities – SIRAD

- **Protons**
  - available: from 100 keV to 6 MeV using the AN2000 accelerator and CN accelerator (***Tandem)***
  - future: 35-70 MeV at ***SPES*** (future)
- **H, D, He** at AN2000 (2 MV Van de Graaff)
- **Heavy ions** from H to Au at the ***Tandem + ALPI complex***
- **Neutrons**
  - up to 14 MeV at **CN** (available)
    - Quasi-Monochromatic beam (***QMN***)
- **TID – ^{60}Co gamma-ray source**
  - Dose rate: 10 krad(Si) in 8 hours at D= 41 cm

The SIRAD irradiation facility is located in the experimental hall 1, beam line +70°, of the Legnaro Nuclear Laboratories of INFN, in Italy.

It is dedicated "to investigate radiation effects on silicon detectors, electronic devices and systems in radiation hostile environments".

It is capable of performing measurements of:

- *Total dose effects* (as a result of ionization damage);

- *Bulk damage effects* (as a result of displacement damage);

- *Single event effects* (as a result of an energetic particle strike).

ASIF gateway

The **ASIF gateway** website provides comprehensive technical information about the different facilities, conditions of use, availability and a beam time booking tool.
Users should register in order to request irradiation time and/or related information

The registered users will have information on:

- Introduction to each facility
- Particle species and beam parameters
- Energies or spectral distribution available.
- Flux information.
- Dosimetry (dose, dose rate) or flux information.
- Energy measurement accuracy information.
- Flux measurement accuracy
- Radiation field uniformity at sample.
- Beam purity.
- Beam set-up and calibration procedure information
- Procedures required to book facility beam time (standard facility access procedure)

New opportunities, perspectives

- Qualification for space applications and entry into the ASIF network of new plants or instrumental infrastructures of ENEA and INFN Centers and Laboratories
- Supported by ASI, academic, experimental and/or industrial research activities oriented to space radiation environment, induced damages effects in space missions and radiation damage mechanisms on devices
- Inter-facility comparison experiments, collaboration with other Italian or international facilities or network
- Planning and performing test campaigns on selected families of components sensitive to radiation for the consolidation of the criteria and the validation of the procedures and methodologies used for each type of test (DB ASI components population)
- Promotion of three-year, master's and post-graduate doctoral theses
- Maximize the use of ASIF services in national, EU and international projects

Conclusions

- As the ASIF comprehensive infrastructure of facilities becomes available to space community, users can get access to the full set of particles needed for space qualification of devices with respect to TID, TNID and SEE induced radiation damages
- Enhancement of the national contribution and competitiveness, enabling future space exploration mission with public and private national and international partners
- Improvement of European irradiation testing facilities to ensure compliance to rapidly evolving EEE component technologies
- Facilitate the access of the users to appropriate facility for their interests and applications
- Continuous effort in standardization and technical improvement
- Increase of knowledge on components, devices, materials, biological systems and human in harsh space radiation environment

Thank you for your attention

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