ITALIAN NATIONAL AGENCY FOR NEW TECHNOLOGIES, ENERGY AND SUSTAINABLE ECONOMIC DEVELOPMENT

SATIF-16
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...lding aspects of Accelerators, Targets and Irradiation Facilities

FNG
FRASCATI NEUTRON GENERATOR

The Frascati Neutron Generator (FNG): capabilities and applications for radiation testing on electronic devices

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Contributors list

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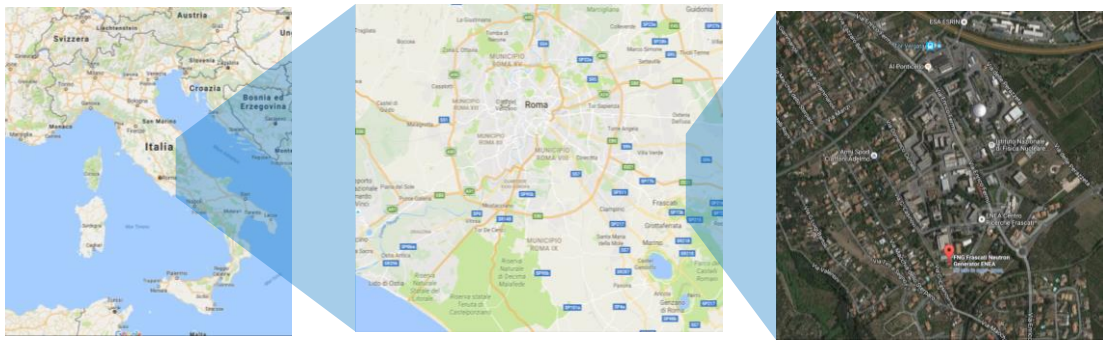
Summary

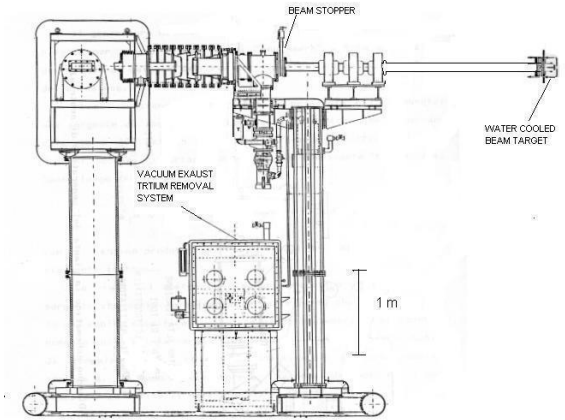
- The Frascati Neutron Generator
- Activities at the Frascati Neutron Generator
- Radiation Effects on electronics
- RADNEXT project
- ASIF program
- GENeuSIS project
- Conclusions

The Frascati Neutron Generator

- The Frascati Neutron Generator (FNG) is a medium intensity neutron source designed to **perform neutronics experiment in support of the EU Fusion community**
- It **started its operations in 1992** and has been continuously improved and upgraded in time
- **Numerous experiments** have been performed during the last 30 years: neutronincs benchmark experiments, nuclear data validation, irradiation of electronic devices, materials activation experiments
- FNG is located in Frascati (Rome) within the **ENEA Frascati research centre**



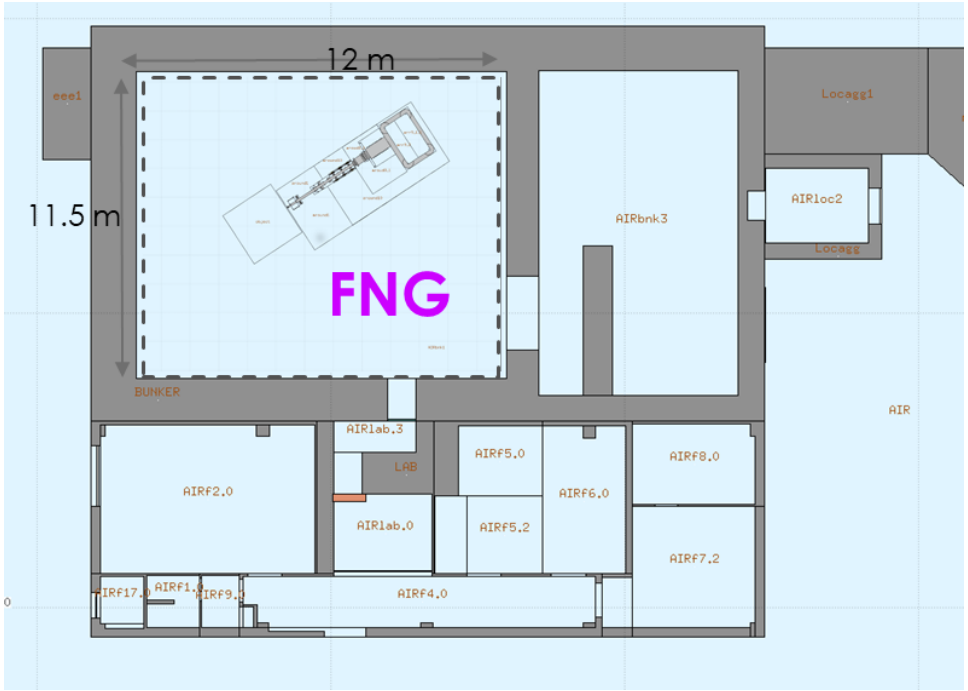
The Frascati neutron generator: main characteristics



	D- T Mode	D – D Mode
Max neutron yield	$1x10^{11}$ n/s	$1x10^{9}$ n/s
Max neutron flux → volume	$5x10^{9}$ n/cm^2/s – 1 cm^3	$5x10^{7}$ n/cm^2/s – 1 cm^3
Max irradiation volume → flux	~1 cm^3	~1 cm^3
Max irradiation time - targets	50 hours (1 target)	Continuous
Average utilization (year)	> 150 hours/years	
Free time available for irradiation	200 hours/years	
Maximum achievable fluence	$5x10^{15}$ on a 1 cm^3 sample	$5x10^{13}$ on a 1 cm^3 sample

- FNG is a **linear electrostatic accelerator with 270 keV and up to 1 mA D+ ions** are accelerated to hit:
  - **tritiated target**, producing **14 MeV neutrons** via the nuclear fusion reaction D(T,n)α
  - **deuterated target**, producing **2.45 MeV neutrons**, via the nuclear fusion reactions D(D,n) ^{3}He (D self-implantation)
- The **maximum available neutron flux** on small samples placed close to the target **is 5x10^9 n/(cm^{2}s)** (D-T), **5x10^7 n/(cm^{2}s)** (D-D)
- The **spatial distribution** of neutrons emitted by the target is **almost isotropic**

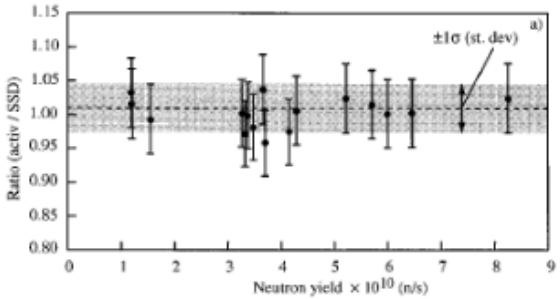
The Frascati Neutron Generator: bunker hall

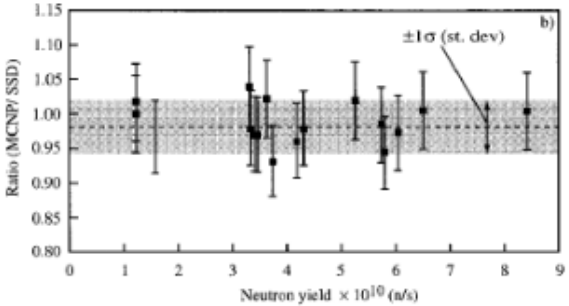


- FNG is housed in a **large shielded hall** (11.5 x 12 m^2 wide and 9 m high)
- The target is **more than 4 m far from walls**, floor and ceiling.
- The large hall **reduces to a very low level the background of moderated/thermalized neutrons** due to the reflection from the walls
- **Target holder is designed to reduce spectrum contamination** due to neutron scattering

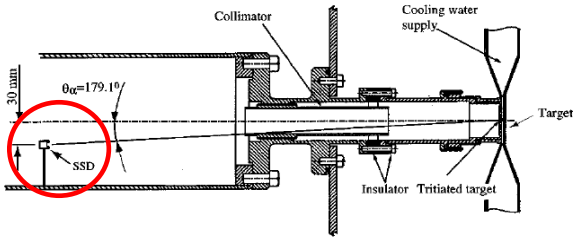
14 MeV Neutron flux measurement at FNG

- Precise, real-time flux measurement is mandatory to perform cross section measurements (physical and SEEs), detector characterization and Monte Carlo benchmark experiments
- **On-line monitoring** exploits **associated α-particle** detection by a Silicon Surface barrier Detector (SSD) placed in the vacuum pipe



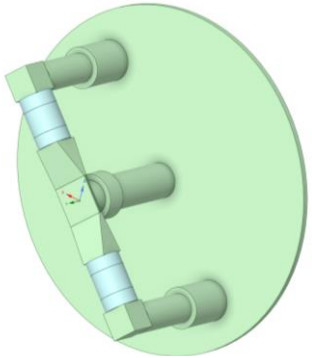


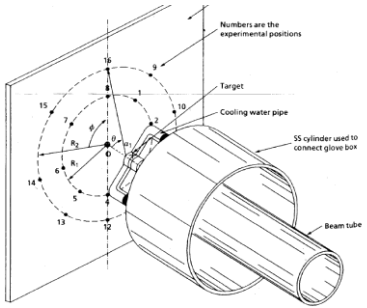
ISO 9001 certified calibration

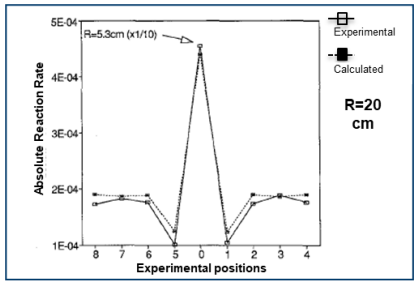


MCNP Model of FNG target and neutron source

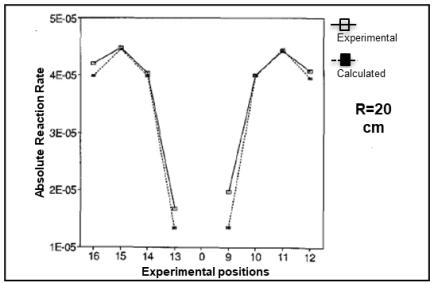
- A Monte Carlo model of the FNG target, including bunker hall, has been developed using **MCNP**
- The **neutron source has also been developed to completely describe the neutron emission**
- Characterization campaigns were performed to check the **reliability of the MCNP DT neutron source routine in 1992-1993**, and repeated in 2005 in collaboration with JAERI (now QST)
- Fission Chambers have been used to characterize the neutron emission around the source, and collected data have been compared with the MCNP model



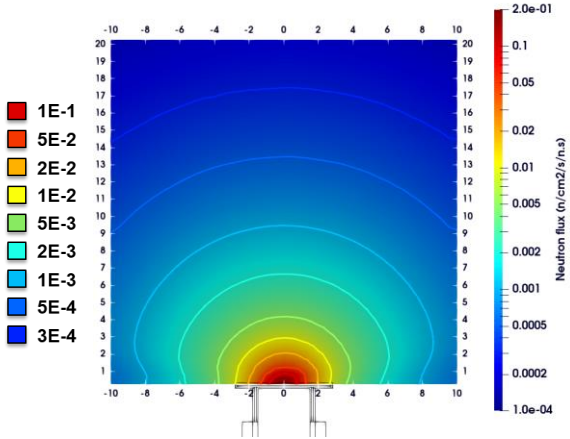




Experimental and calculated results for ^{238}U fission at R1=20 cm and for the central position at R0=5.3 cm



Experimental and calculated results for ^{238}U fission at R2=40 cm



FNG Quality assurance process

- Administrative and Experimental Activities recorded in a Relational database (MariaDB) and elaborated by a home-made software (**Diogene**) installed in a secure NAS system
- List of individual user accesses
- List of users, typology, total access days, total dose
- Records of all the administrative steps
- Every FNG Shot is recorded in the database through an experiment id, progressive shot number, Start, Stop, neutron yield

Reference Metrological Chain for FNG calibration

ENEA INMRI

U=2.7%

NPL National Physical Laboratory

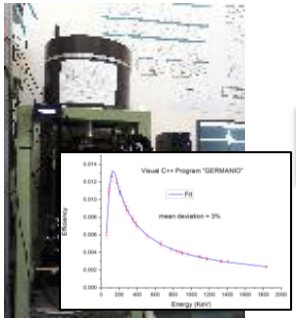
U < 1%

Eckert & Ziegler
Contributing to saving lives

U < 3%

Certificated point sources

Calibration of HPGE detector



U=3%

Use of acrtivation foils for FNG calibration

Total Uncertainty
(neutron yield)
3.1%

Activities at the Frascati Neutron Generator

- **Benchmark experiments** for validation of neutronics codes and nuclear data
- **Development of new detectors** (e.g. optical fiber detectors, GS20)
- **Detectors calibration**
- **Radiation induced effects on electronics**
- **Efficiency** of dosimeters
- **Irradiation of biological samples** (for dosimetry and radiation effects in hostile environments for living organisms as space)

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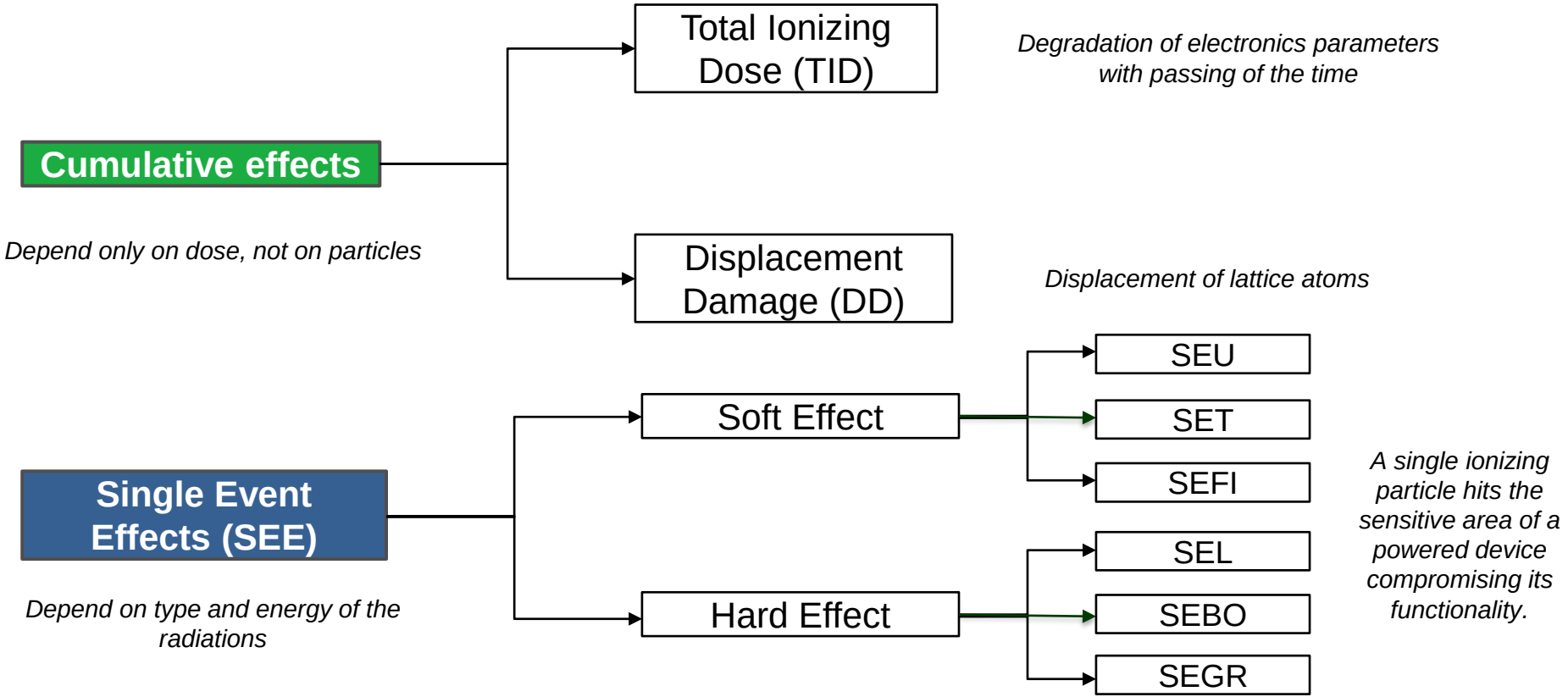
Radiation effects on electronics in a nutshell



FNG for radiation testing of electronic components

Considering characteristics of the generator it represents a unique facility to test electronic devices under neutron irradiation. Wide range of application can be tested at FNG:

- Nuclear instrumentation
- Avionics
- Fusion research
- Aerospace
- Particles accelerators

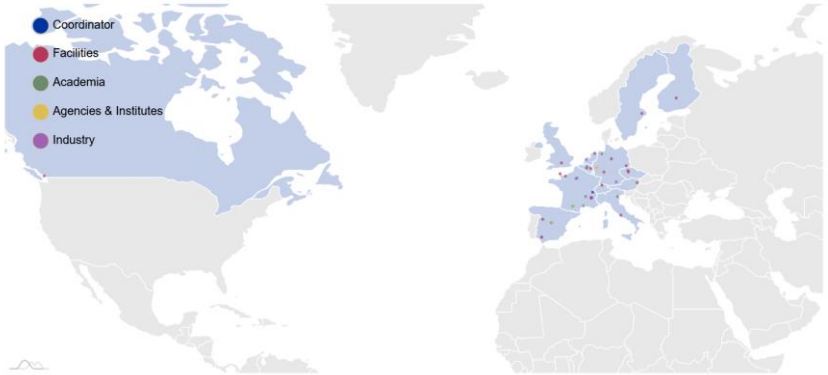
Presently **FNG is involved several projects** regarding the investigation of radiation effects on electronic devices:

- **RADNEXT** *(RADiation facility Network for the EXploration of effects for indusTry and research)*
- **ASIF** *(ASI supported radiation facility program)*
- **GENeuSIS ENEA project** *(General Experimental Neutron System Irradiation Station)*

The RADNEXT project

RADiation facility Network for the EXploration of effects for indusTry and research

RADNEXT is an **H2020 INFRAIA-02-2020** infrastructure project, led by CERN, with the objective **of creating a network of facilities and related irradiation methodology for responding to the emerging needs of electronics component and system irradiation**; as well as **combining different irradiation and simulation techniques** for optimizing the radiation hardness assurance for systems, focusing on the related risk assessment.



- 22 irradiation facilities
- 8 Academia centers
- 4 agencies
- 5 industries

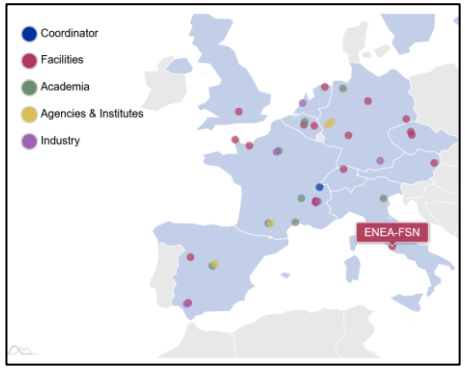
Partner and associates

- 6 irradiation facilities
- 9 Academia centers
- 3 agencies
- 24 industries

Supporters

Reference to the project ➡ R. G. Alía et al., "Heavy Ion Energy Deposition and SEE intercomparison within the RADNEXT irradiation facility network", in *IEEE Transactions on Nuclear Science*, doi: 10.1109/TNS.2023.3260309 .

FNG in RADNEXT



- In the frame of RADNEXT, **ENEA** is involved in the **Transnational Access program** with FNG facility for testing electronic devices under 14 and 2.45 MeV neutron irradiation.
- **FNG is involved in the project since the beginning** (2021) and, presently, **results as one of the best irradiation facility** for completed experiments, availability and reliability.
- **More than 250 hours of experiments**, including beam delivered, experimental setups and experiment preparation have been spent at FNG.

Examples of RADNEXT test done at FNG

- Neutron **test for photosensors for Crilin experiment**
- Study of **Displacement damage effects on octocouplers**
- Study of neutron irradiation on **active implanted medical devices**
- 14 MeV **neutron calibration of Fiber Optic Dosimeters**
- DVS and Environment Sensitivity Evaluation for **Radiation Vulnerability of COTS SRAMs**

The ASIF program: space radiation conditions

Radiation sources	Primary particles	Shielding	Secondary radiation
Galactic cosmic rays	87% protons 12% Helium 1% Heavy nuclei 100 MeV – 100 GeV		Neutrons Protons Electrons X-rays Gamma rays Recoil heavy nuclei
Solar particle events	92% protons 6% Helium 2% Heavy nuclei keV – 100 MeV		
Earth radiation belt	Electrons & Protons 1 MeV – 100 MeV		

Curtesy of A. Cemmi

The ASIF Program: ASI supported Irradiation facilities

The ASIF program aims to establish a coordinated network of the Italian irradiation facilities (ENEA, INFN)

- to grow the knowledge of the space radiation environment (radiation damage, simulation and modelling tools, EEE supply chain)
- Standard ESA-ESCC qualification

Private Companies
Public users

Phase I (2017-2019)

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

Phase II (2022-2025)

- **Increase the number of facilities**
- **Standardization, dosimetry**
- **Interactive portal implementation (ASIF gateway)**

Many activities for testing electronics in space environment have been performed at FNG within the ASIF program

The GENeuSIS project

GENeuSIS

General
Experimental
Neutron
Systems
Irradiation
Station

A Novel concept of neutron test bed facility

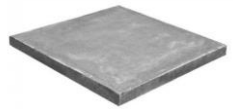
Assembly to be located in front of DT neutron generator to reproduce in a proper irradiation region the **neutron and gamma energy spectra** (with embedded gamma sources) expected in the positions in which the components/systems of interest will be installed in ITER.

- Neutron diagnostics calibration
- Test for critical diagnostics/ systems with low radiation tolerance
- **Single Event Effects study on electronics**

Recent studies focused to reproduce some ITER relevant neutron energy spectra using the 14 MeV neutrons produced at the **FNG**

Curtesy of R. Villari

The GENeuSIS project: Design requirements & features



- **Modular**

Bricks + sheets assemby

- **Combination of common materials**

SS316L, Perpex, Borated polyethilene, Lead, Tungsten, Copper, Teflon, Cd, Boron Carbide, etc...

- **Trasportable**

Easy mounting/dismounting to be used also in other similar neutron facilities.

- **Flexible**

The replacement/substitution of bricks/layers to reproduce various neutron spectra. Housing for gamma sources to reproduce various gamma spectra

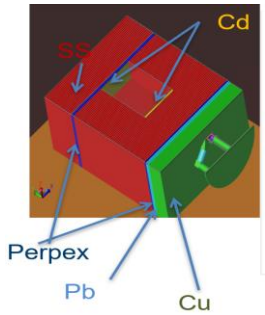
- **Customizable**

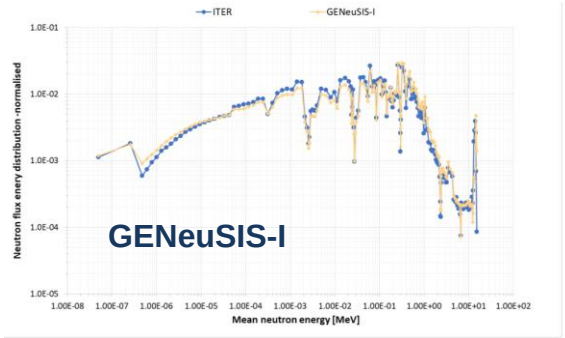
Experimental cavity (ies) adjustable and customizable to the system/component under test

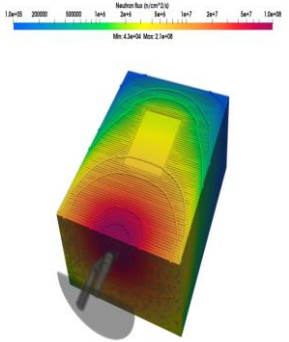
Curtesy of R. Villari

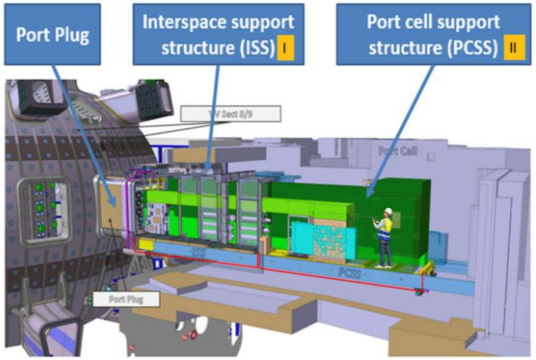
The Geneusis project

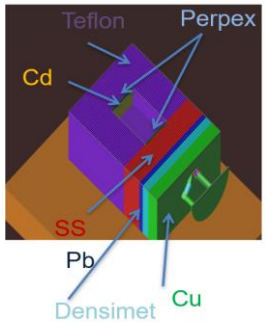
The goal is to perform at FNG specific tests aimed at **studying the response and performance of active diagnostic systems, electronics and shielding optimization under ITER relevant conditions.**

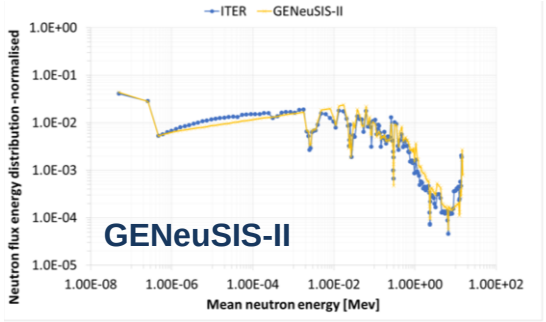


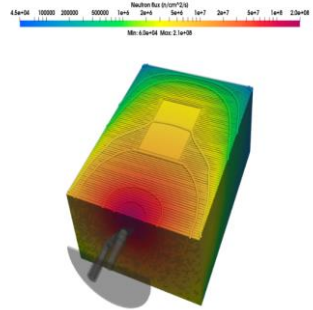












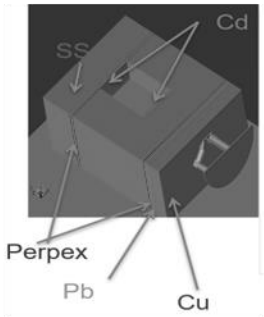
E.g., assemblies to replicate at FNG the neutron flux energy spectrum expected in a Diag Eq. Port:

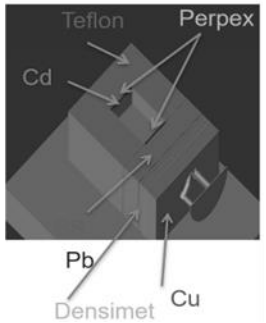
Port Interspace (GENeuSIS-I)

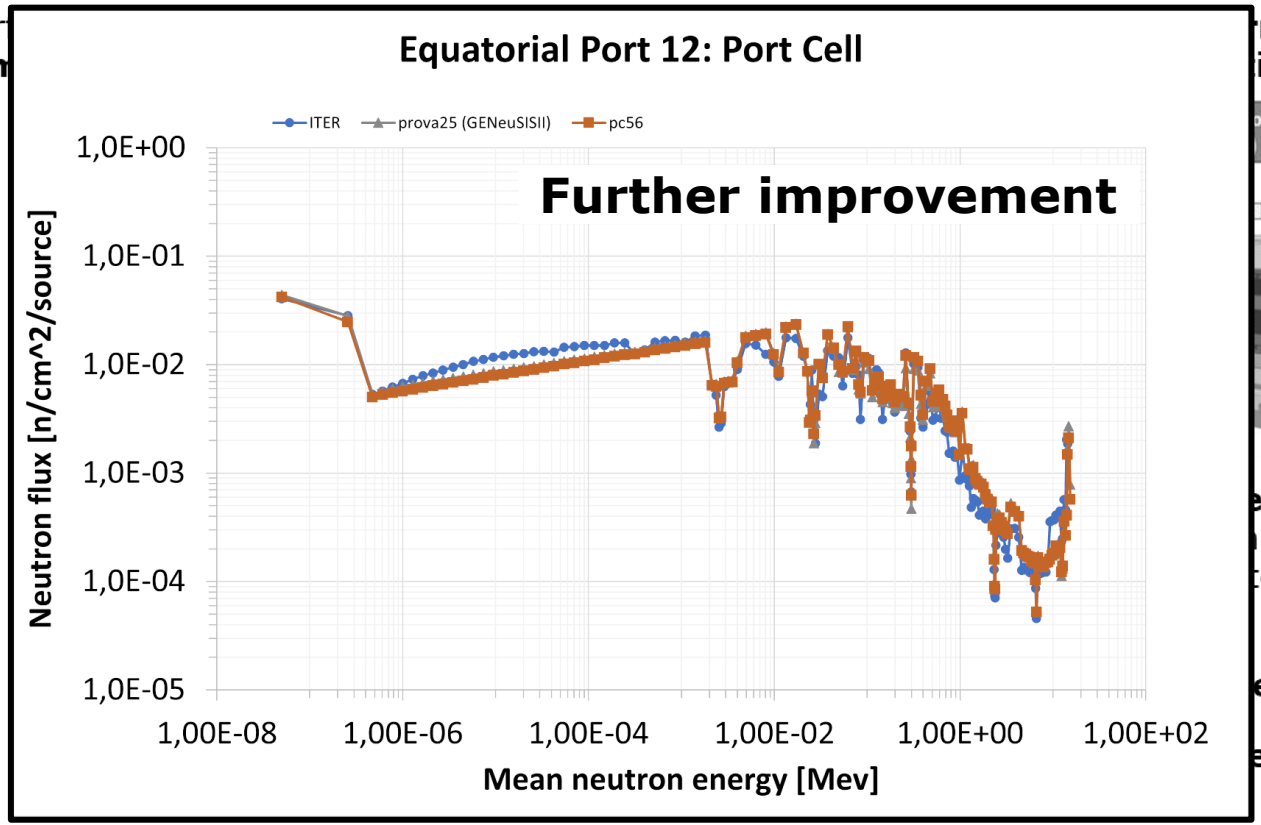
Port Cell (GENeuSIS-II)

The Geneusis project

The goal is to per
diagnostic system







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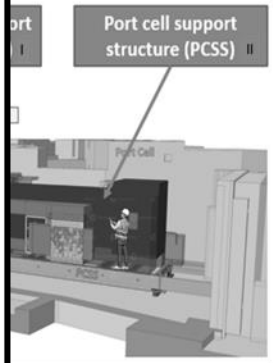

es to replicate at
flux energy
ted in a Diag Eq.

e (GENeuSIS-I)

euSIS-II)

Conclusions

- The Frascati Neutron Generator has started in the last few years an **intense activity on testing neutron induced effects on electronic devices**
- These activities cover a **wide range of application**: Nuclear Fusion, Accelerators, Spatial Manners, Nuclear Fission, Avionics, Medical applications
- FNG is involved in many **international project** such as RADNEXT and ASIF
- A **novel and innovative project called GENeuSIS** has started last year to build a modular irradiation station for testing electronics under neutron and gamma radiation
- FNG staff is **continuously improving its knowledge and equipment** on these projects by delivering hundreds of hours of beam time and collaborating with many institutions

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We look forward to facing new collaborations and exciting challenges!

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Thank you!