ENEA R&D activities in the field of nuclear technologies

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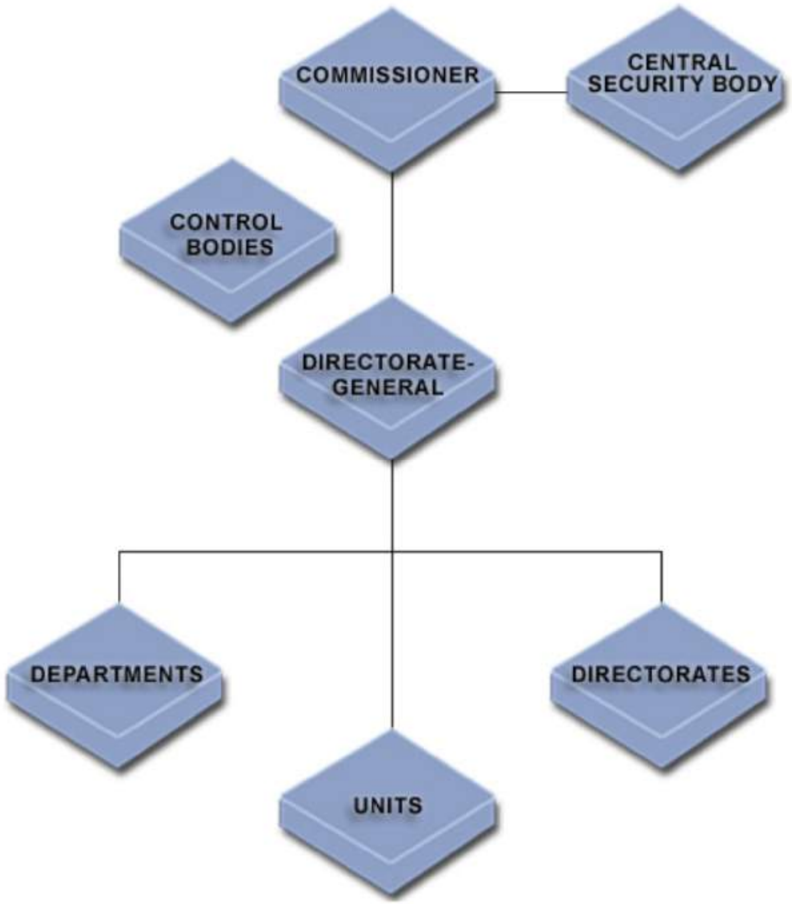
ENEA, C.R. Casaccia

ENEA Organization

ENEA is the Italian National Agency for New Technologies, Energy and Sustainable Economic Development.

It has around 2700 staff employees distributed in its 9 research centers all over the national territory.

The Agency's activities are mainly focused on **Energy Efficiency**, **Renewable Energy** Sources, **Nuclear Energy**, **Climate** and the **Environment**, **Safety** and **Health**, **New Technologies**, Electric System Research.



ENEA Departments

Energy Technologies

Fusion and Technology for Nuclear Safety and Security

Sustainable Territorial and Production Systems

- ✓ Plasma Physics
- ✓ Fusion Technology
- ✓ Experimental Engineering
- ✓ Technology, Facilities and Materials for Nuclear Fission
- ✓ Nuclear Safety, Sustainability and Security
- ✓ Technology Applications for Security, Health and Heritage
- ✓ National Institute of Ionizing Radiation Metrology

Mission

Conducts experimental activities and technological development, with technologies, facilities and laboratories based on:

- nuclear safety,
- R&D supporting new generation of nuclear reactors,
- closure of sustainable and non-proliferative nuclear fuel cycle

Main activities

- ✓ technical/scientific and institutional **support** for the **decommissioning** of the nuclear installations and the **realization** of a national superficial and geological **waste repository**
- ✓ **studies**, **designs**, **develops**, qualifies and certified methods, processes, components and systems related to nuclear installation of the **nuclear fuel cycle**
- ✓ proposes and participates in collaborative agreements with other Research Institutes and Universities, Technical and Scientific Support Organizations **(TSO)** European and international, for joint activities in the field of fission and security to support the industry and the national safety authority

Main activities

Is the manager of the **Integrated National Service** for collection and management of radioactive waste and orphan sources

Operates, at the Casaccia Research Center in Rome, the two main national research reactors, **TRIGA-RC1** and **RSV TAPIRO**

Operates an authorized laboratory for the radiological **characterization of nuclear materials**

Staff

The staff employed in the Division counts **75 units** distributed in five ENEA Research Centers:

Casaccia (Rome)

Trisaia (Matera)

Frascati (Rome)

Saluggia (Varese)

Santa Teresa (La Spezia)

TRIGA and TAPIRO neutron field characteristics

TRIGA RC-1
1 MW

TAPIRO
5 kW

1.E-02 1.E-01 1.E+00 1.E+01 1.E+02 1.E+03 1.E+04 1.E+05 1.E+06 1.E+07 1.E+08

E (eV)

$$\phi_{max} \approx 10^{13}\ n \cdot cm^{-2} \cdot s^{-1}$$

$$\phi_{max} \approx 10^{12}\ n \cdot cm^{-2} \cdot s^{-1}$$

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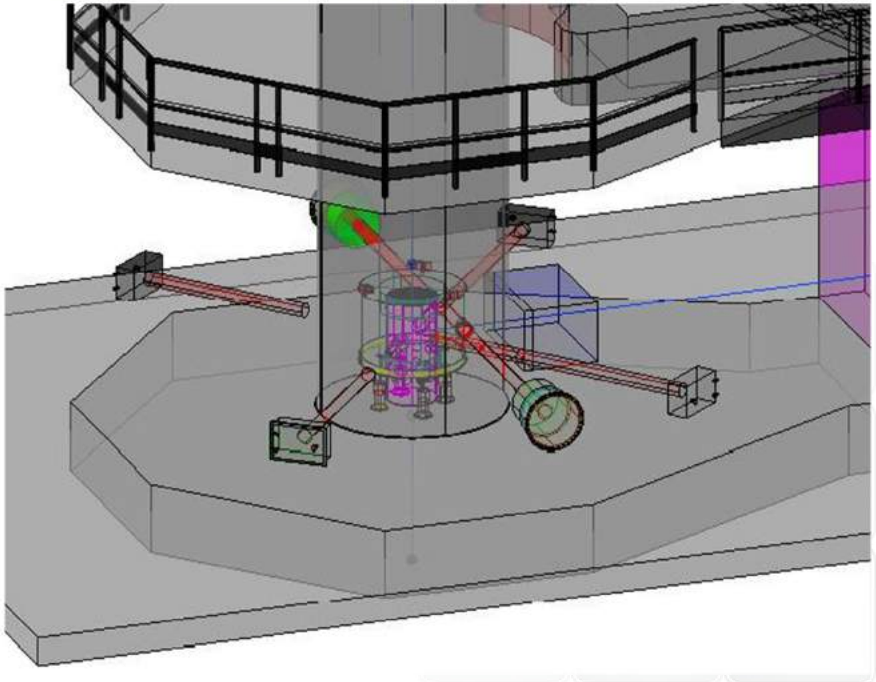
TRIGA RC -1 Reactor

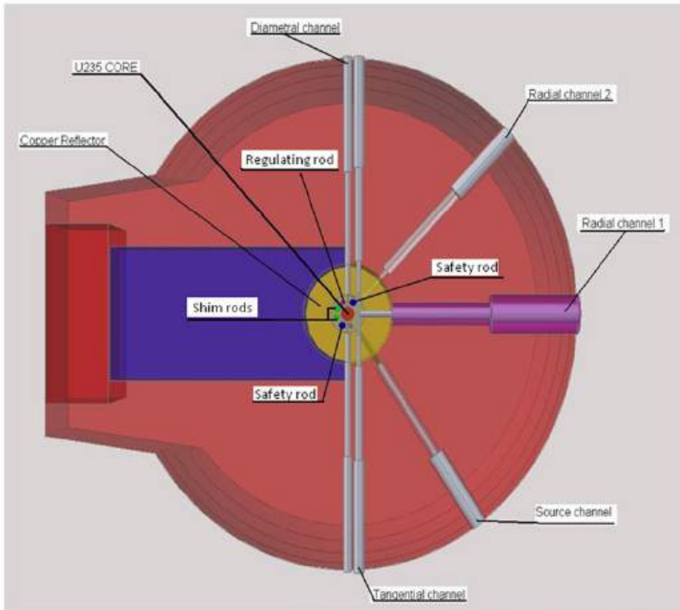
- The TRIGA RC-1 nuclear research reactor (Training research isotopes general atomic reactor Casaccia 1) is a source of thermal neutrons.
- TRIGA RC-1 was built in 1960 in its first version with 100 kW power as part of the US Atom for Peace initiative. In 1967 its power was upgraded to 1 MW based on the ENEA staff design.



- The reactor's main features are:
  - Maximum power: 1 MW;
  - Maximum neutron flux: 2.7×10^{13} n·cm^{-2}·s^{-1};
  - Core cooling by natural convection;
  - Several irradiation facilities.

TAPIRO Fast Neutrons Source Reactor

- The TAPIRO nuclear reactor is a fast neutrons source and its design is based on the Argonne Fast Source Reactor — Idaho Falls.
- TAPIRO was built in the 1960s and its first criticality was on April 1971.
- TAPIRO is able to provide a family of neutron spectra of extremely variable hardness (about pure fission spectrum near the core centre).



- The reactor's main features are:

➢ Maximum power 5 kW;

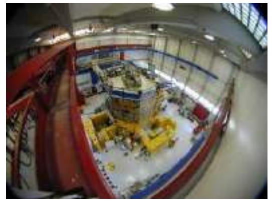
➢ Maximum neutron flux: 4×10^{12} n·cm^{-2}·s^{-1};

➢ Core cooling by forced He;

➢ Several irradiation facilities.

Reactors ongoing or planned activities

- TRIGA



  - ✓ Participation to the EDEN EU FP7 Project
  - ✓ Neutron Activation Analysis
  - ✓ Radioisotopes for Medical Applications (feasibility studies Molybdenum-99 production via (n,γ) in collaboration with TRIGA 250 kW Pavia)
  - ✓ Non Destructive Testing on site, production of gamma emitters
  - ✓ Neutron irradiation damage: support to Italian Spatial Agency and European Spatial Agency
  - ✓ Neutron Diffraction (in collaboration with TRIGA 250 kW Pavia)

- TAPIRO
  - ✓ Radiation effects damage on detectors to be used in the ITER Radial Neutron Chamber (Contract with F4E)
  - ✓ Innovative detectors calibration and performances (Contract with INFN)
  - ✓ Minor Actinides capture cross sections integral measurements (in collaboration with CEA under NEA umbrella)
  - ✓ Neutron irradiation damage: support to Italian Spatial Agency and European Spatial Agency

We plan and realize nuclear systems

Currently working on:

- **Fission generation IV**
- **IFMIF (International Fusion Material Irradiation Facility)**

planning

- **Hybrid Fusion-Fission Reactors**
- **Research reactors**

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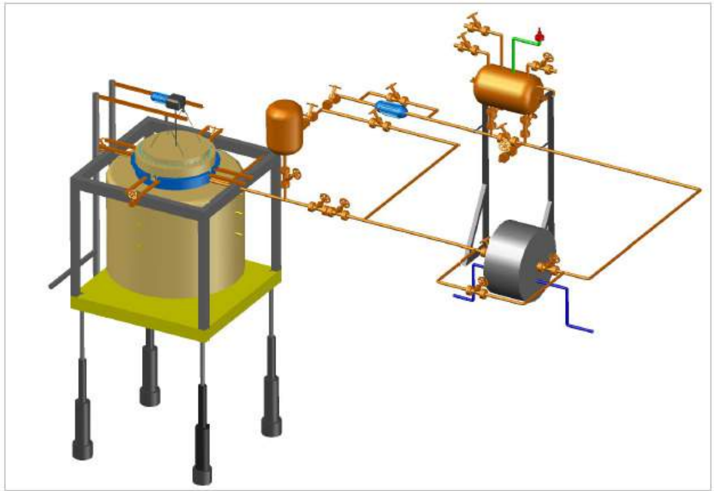
Sodium Fast Reactor

- Plan and set up of an experimental device to assess the efficacy, during off normal events, of one of the safety systems (DHR) foreseen for ASTRID (Advanced Sodium Technological Reactor for Industrial Demonstration)
- CEA Contribution 1 M€

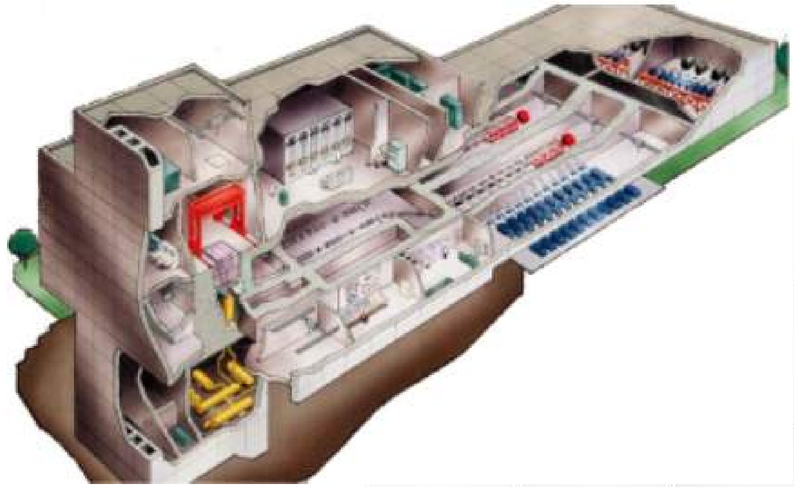


IFMIF

International Fusion Material Irradiation Facility

IFMIF is a facility projected for research on material behavior under high-energy (14 MeV), fusion relevant, neutron irradiation;

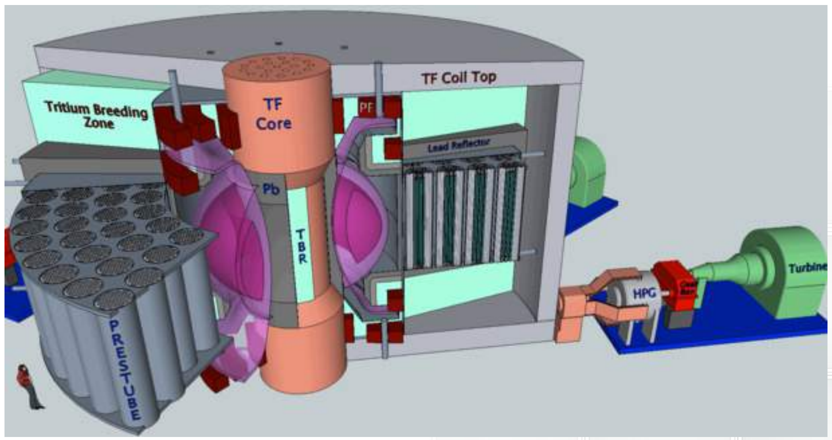
- The laboratory contributes to the conceptual revision and to the technical requirements for the realization of the facility;
- Activity in the framework of a EUROFUSION contract in collaboration with CIEMAT



Hybrids

Fusion-Fission hybrids reactors

- Contributes to the analysis of conceptual requirements for the definition of a road map towards the realization of a reactor prototype
- Proposes, studies and contributes to the experimental activities for the enhancement of the basic knowledge



Italian Research Reactor Modeling

- Reactor dynamics simulation for process analysis during normal and off normal events

- TRIGA Casaccia: done
- TRIGA Pavia: in progress
- Tapiro: foreseen

PROVA SPERIMENTALE 19-10-2010 CON SCRAM AUTOMATICO

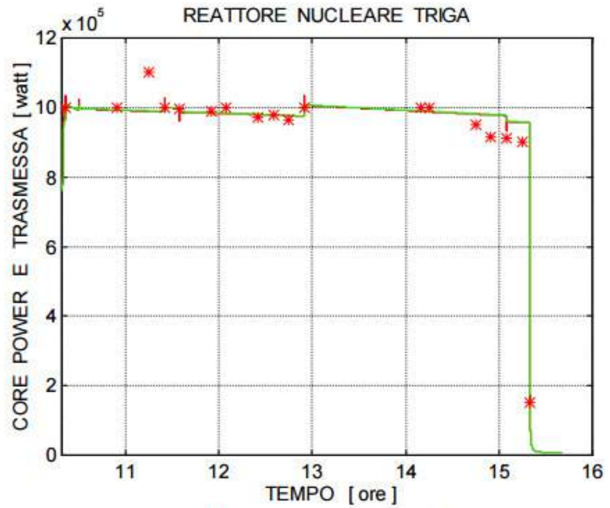


Figura 3-13 Potenze prodotta e ceduta all'acqua

*** = valori sperimentali**

Laboratory for Nuclear Material Characterization and Waste Management

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Radioactive waste characterization
Non Destructive Assays

SRWGA (Sea Radioactive Waste Gamma Analyser):
System for the characterization of materials containing γ-emitting radionuclides.

It implements different measuring techniques that allow the reconstruction of the radionuclides activity distribution and density distribution in drums containing radioactive materials:

- Open Geometry
- Angular Scanning
- Segmented Gamma Scanning
- Low resolution Emission & Transmission Tomography.

Anti-Compton System
Due to the minimization of the Compton background, this instrument is used to detect radioactive materials in extremely low concentrations (activation analysis and forensic science).

Radioactive waste characterization Destructive Assays

α Spettrometry
Detection of α–emitters activity located in potentially contaminated samples

ICP-MS Spectrometer
The mass spectrometry allows, through the light-matter interaction, the elemental analysis in unknown samples with extremely high sensitivity (ppb e ppt).

Liquid Scintillation Counting
Detection of b-emitters activity in samples after dissolution by means of chemical & physical treatments

Radioactive waste characterization
Portable instrumentation

InSpector 1000

SSNC - Small Samples
Neutron Counters

ISOCS – In Situ Object
Counting System

RAMAN Spectroscopy

LB123P Berthold
Plutonium Monitor

Active EU Projects

CArbon-14 Source Term - "CAST" (Fission FP; 2013-2016)
Collaborative Project aiming to develop understanding of the generation and release of ^{14}C from radioactive waste materials under conditions relevant to waste packaging and disposal to underground geological disposal facilities.

Main partners: FZJ, NDA, ANDRA, CEA, SCK-CEN
ENEA EU Funding: about 180 k€

End-user driven DEmo for cbrNe – "EDEN" (Security FP; 2013-2016)
The project will leverage the added-value of tools and systems from previous R&D efforts and improve CBRNE resilience through their adaptation and integration. The concept of the EDEN project is to provide a "toolbox of toolboxes" EDEN Store to give stakeholders access to interoperable capabilities they deem important, or affordable, from a certified set of applications.

Main partners: BAE Systems Ltd, ASTRIUM SAS, Cbrne Ltd.
ENEA EU Funding: about 1600 k€.

The Interministerial Committee for Economic Planning in 1980, approved the establishment of a limited company between CNEN (now ENEA) and Agip Nucleare (stake purchased by SOGIN in 2004), named NUCLECO for the low and medium activity radioactive waste management.

Later on CIPE assigns additional tasks in the sector of low and medium activity radioactive wastes produced to guarantee the collection, storage and management.

In 1986 ENEA approved the establishment of an «Integrated Service» for the management of low and intermediate radioactive wastes generated by external operators.

D.Lgs. 52/2007 Implementation of the Directive 2003/122/CE EURATOM on the control of the High Activity Sealed radioactive Sources and orphan sources.

- Art. 2, «Integrated Service»: technical operative tool able to take charge of all the phases of the management cycle of the disused source.
- Art. 12, Training and information on orphan sources
- Art.14, «The Prefect prepares action plans for the implementation of safety in the case in which orphan or suspected sources are found»: ENEA role as consultant and technical assistant.
- Art. 17, The Integrated Service guarantees all the phases of the management cycle of the disused sources like the preparation for shipment, the transport, eventually the conditioning and the temporary storage: **ENEA** is the **Manager** and **Sogin** is the **Operator**.

High Activity sources

Orphan Sources Emersion

Findings in metallic scraps for metallurgy, extra U.E. military or medical surplus etc.

Through the subsidiary company **NUCLECO**:

- Management of radioactive waste
- Collection of radioactive wastes produced by plants and Hot Labs at Casaccia Research Centre (about 10 mc per year)
- Facilities for the treatment of solid and liquid wastes (ICS 42 and ITLD22 Plants)

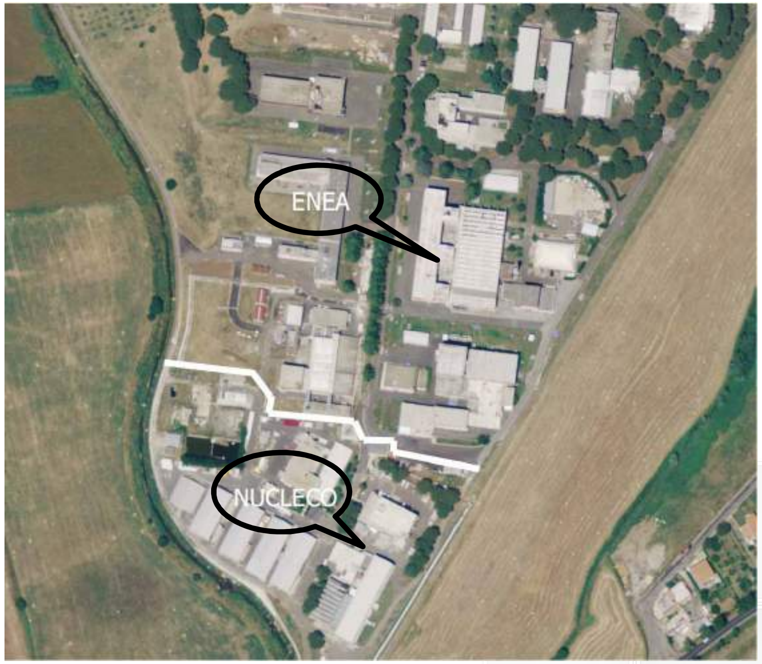
Through its **Characterization Laboratory**:

- Management of the Integrated Service
- Consultancy and specialist technical assistance, training and information on Orphan Sources
- Characterization of radioactive waste

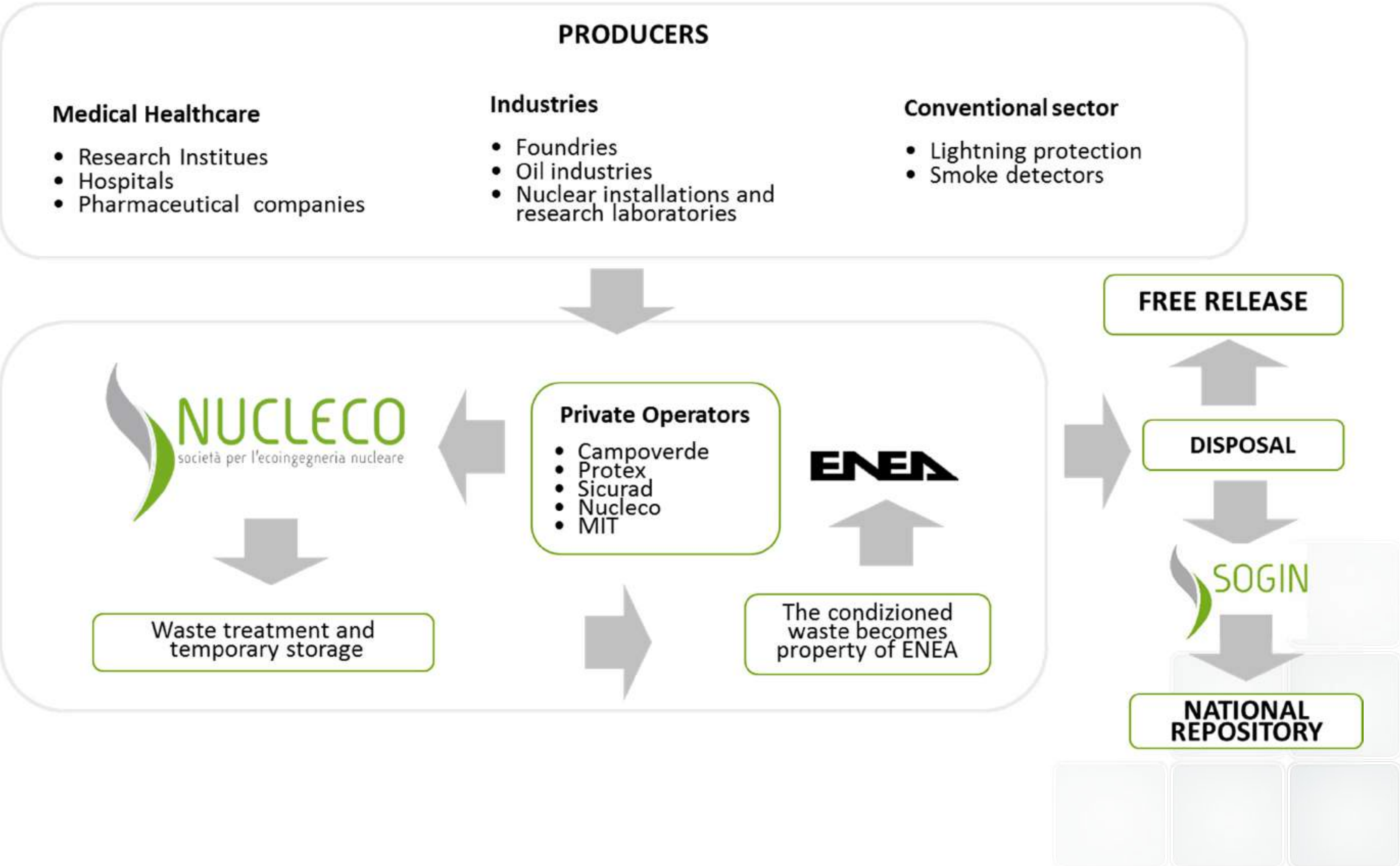
NUCLECO

Commercial and operative aspects: **NUCLECO**

- collection
- transport to Casaccia
- characterization
- treatment
- conditioning
- temporary storage



Management of the Integrated Service for the collection of Industrial and Healthcare Radioactive Wastes



Experimental techniques at the FNG-Lab and related Instrumentation & Tools

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- Activation technique
- X- and γ-ray spectroscopy
- Dosimetry (TLDs, neutrons)
- β-γ coincidence detection system

- Two HPGe detectors calibrated for γ-ray spectroscopy (recently inter-compared with National Institute of Metrology of Ionizing Radiation-**INMRI** of **ENEA**).
- Several types of TLD detectors (LiF, GR-206, GR-207, TLD-300) → γ and n dose separation
- GM tubes & Ionization Chambers for γ-dose measurements
- Two Fission Chamber detectors (U-238 and U-235)
- Scintillators (NE-213, NaI, CsI.)
- Large CsI detectors (Well-type) + Beta counter for both Pulse Height Spectra and and **β-γ** coincidence counting → absolute activity.
- Single crystal and polycrystalline diamond detectors for thermal and fast neutrons
- Codes for neutron spectrum unfolding (SAND-II, STAY-SL).
- New facility for diamond growth (starting in a few months)

An example of FNG activities

- **Benchmark experiments for ITER**: Stainless steel bulk shielding, Nuclear heating, Shut down dose rate;
- **Activation experiments on fusion relevant materials**: SS-316 (IG), F82H, MANET, EUROFER, Fe, Cu, V & V-alloys, SiC, W, Al, Cr, Pb;
- Design oriented benchmark experiments in support of ITER nuclear design
- **Experiments for validation of EFF / EAF nuclear data libraries and for Advanced Materials**;

Other not fusion related activities

- **Chip irradiation**: **NUCLETUDE** (France) used FNG to irradiate components for **AIRBUS**
- **Radiation hardness of detection system**: a **J-LAB** (US) team irradiated SiPM based detector readout to assess radiation hardness.
- **Oil extraction tubes: TRACERCO** (UK) irradiated double layer thick tube sections used for oil extraction to see water content by means of fast neutron induced Oxygen activtion**.**
- **Biology:** In-vivo mice irradiation to study DNA damaging.

Detector development @ ENEA

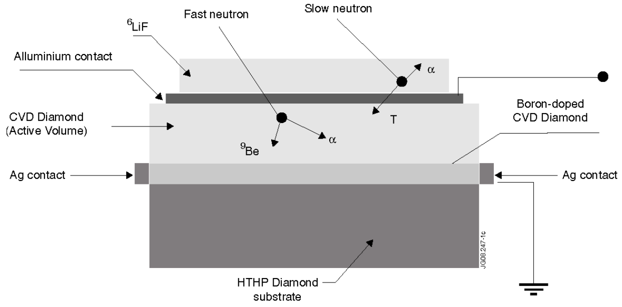
Fast Neutrons:

- ✓ Single Crystal Diamond detectors for Plasma Fusion diagnostics
- ✓ Single Crystal Diamond detectors for in-core fast fission reactor diagnostics
- ✓ Gas Electron Multipliers (GEM) for 2.5 MeV (D-D) and 14.0 MeV (D-T) neutron detection
- ✓ Self Powered Neutron detectors

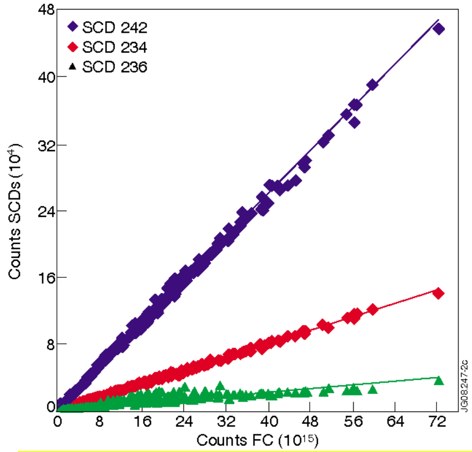
Thermal neutrons (He-free):

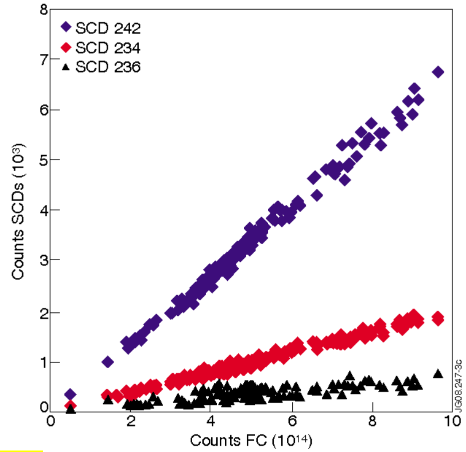
- ✓ Gas Electron Multipliers (GEM) for high-efficiency neutron detection
- ✓ Detectors based on Radiative Neutron Capture
- ✓ Single crystal neutron detectors with LiF coating
- ✓ supercondutors (Nb, NbN) neutron detectors
- ✓ Semiconductors (GaAs) (starting activity)
- ✓ Resistive Plate Chambers (RPC) (future activity)

Diamond detectors at JET



Detector configuration

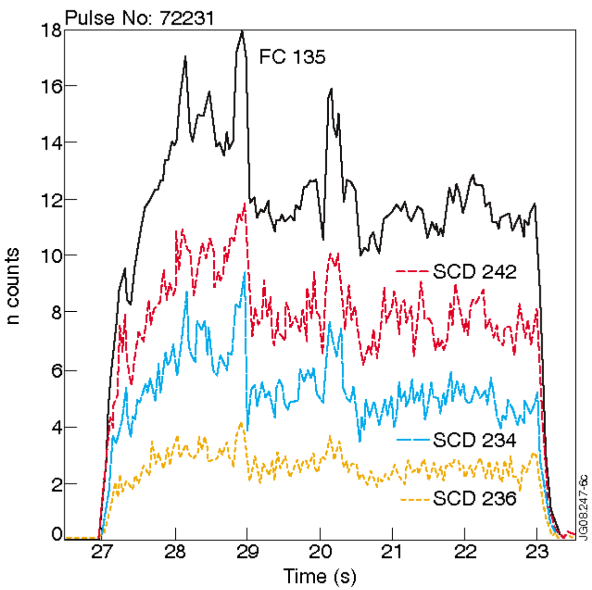


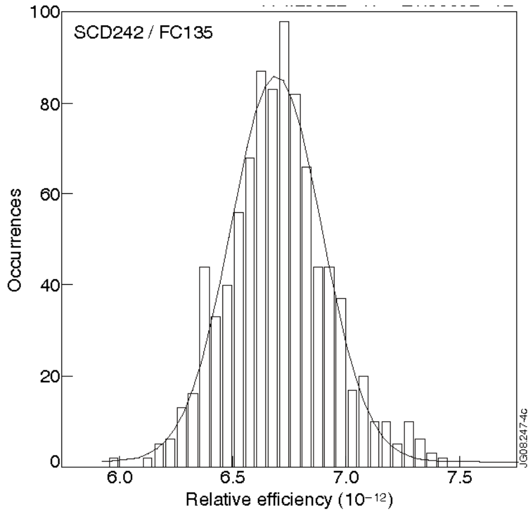


Correlation between the three diamond detectors and the FC for 900 JET shots examined.

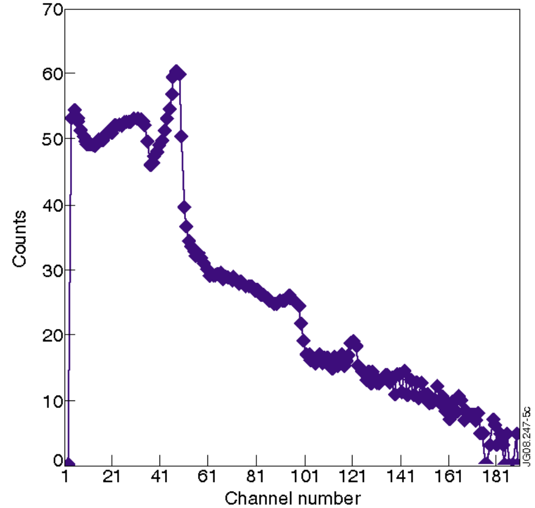
Correlation between the three diamond detectors and the FC for the shots with low total neutron yields (< 1. E15).

A typical JET Pulse No: (72331) showing the matching between the FC and the three SCD detectors (normalized counts). Pulse duration 6.2s; neutron yield = 1.109 E16.





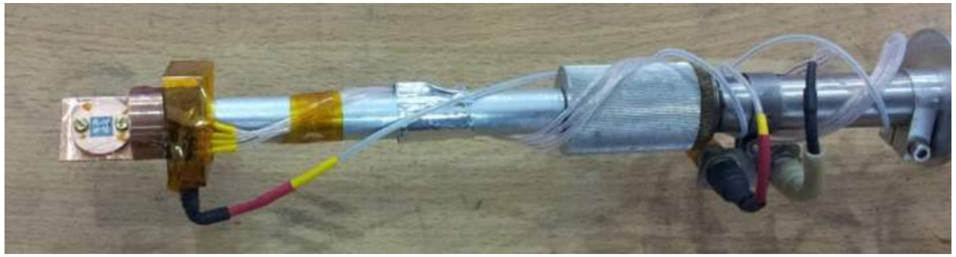
Statistical distribution of the relative efficiency (SCD242/ FC135) for all the 900 JET shots.



Sum of more than 800 JET spectra (total neutrons) as measured by SCD 234.

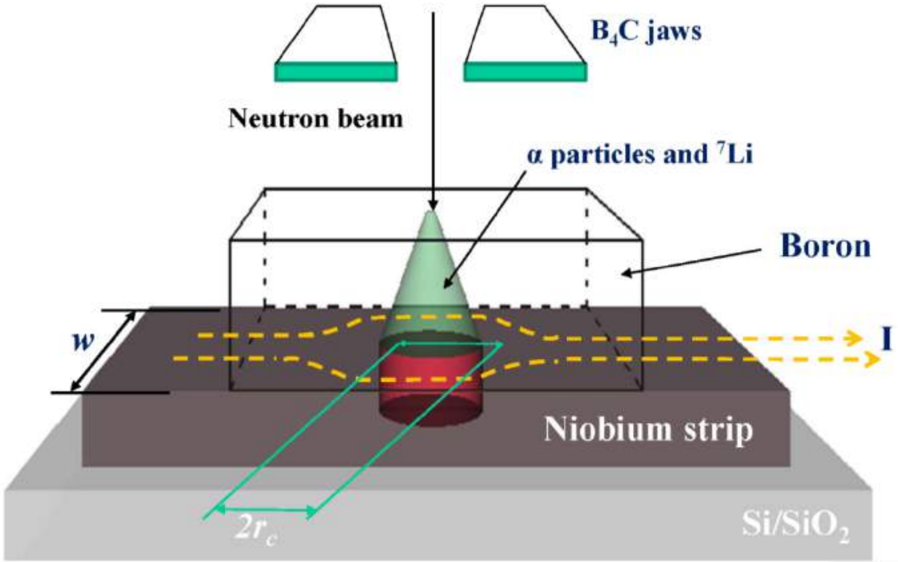
Hot-Spot Superconducting neutron detectors

Measurements performed at ISIS (INES)



Development of in-beam imaging with high-spatial resolution detection system

Presented at ECNS 2015
published on APL



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CrossMark

Hybrid superconducting neutron detectors

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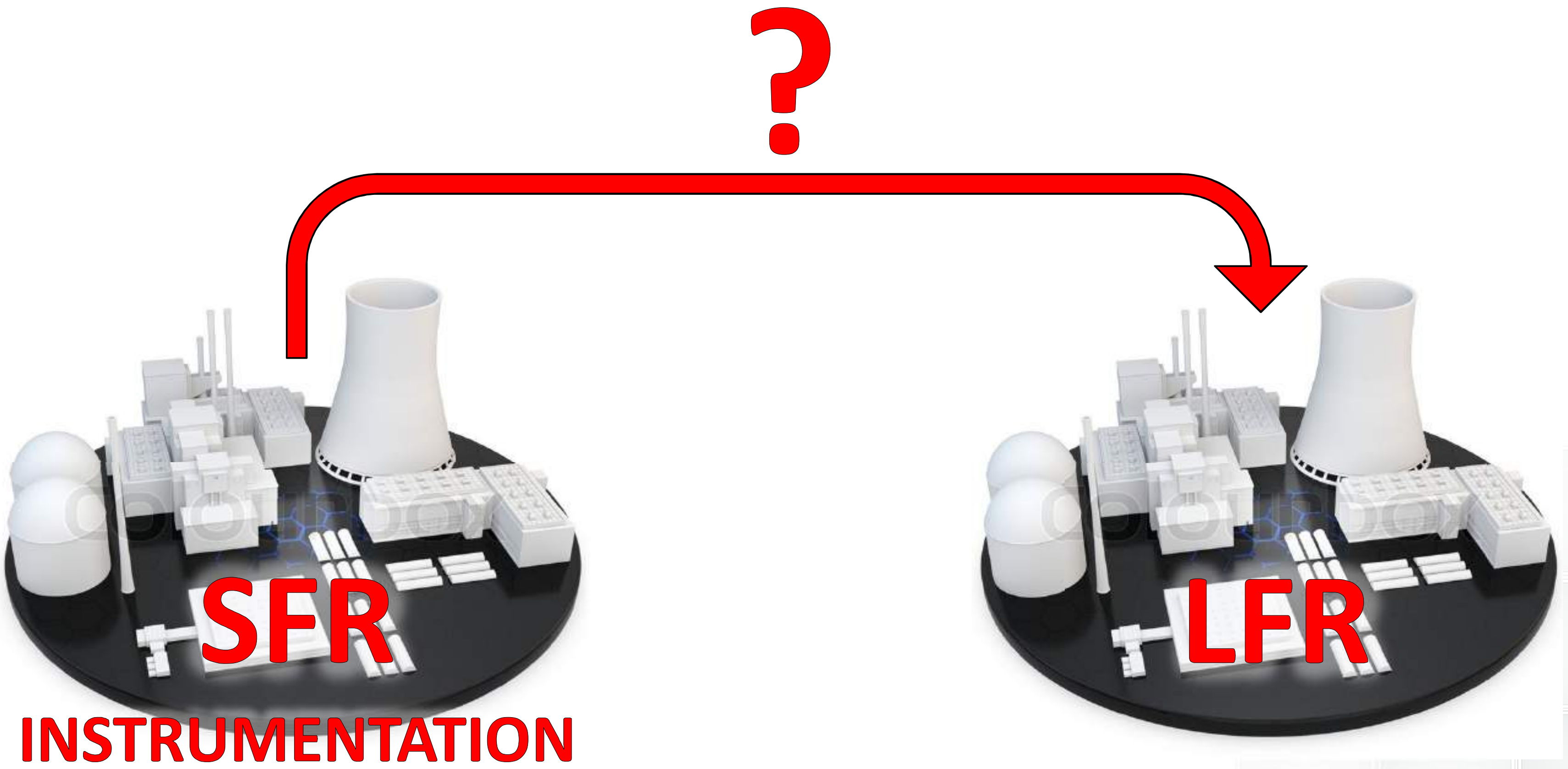
New measurements in 2016 at ISIS with a faster detector using uperfuid He

A proposal for innovative neutron detectors for harsh environments

Aim of the work:

Neutron instrumentation issues for Lead Fast Reactor oriented to the control of the plant. Neutron flux detectors used in Sodium Fast Reactor could not completely fit the needs of LFRs.



I&C OPEN ISSUES

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- What is the **best control strategy (in/out-of-core; in/out-of-vessel) for LFR? Core neutron-monitoring-needs** and **instrumentation technology**?

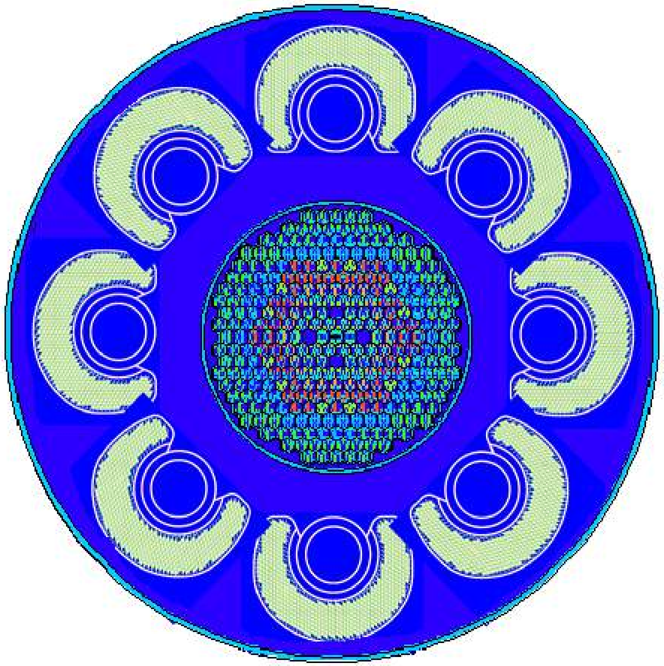
- **SFR and LFR <u>reference</u> spectra are not so different, but spectral differences must be evaluated** in the positions where instrumentation is supposed to be installed.

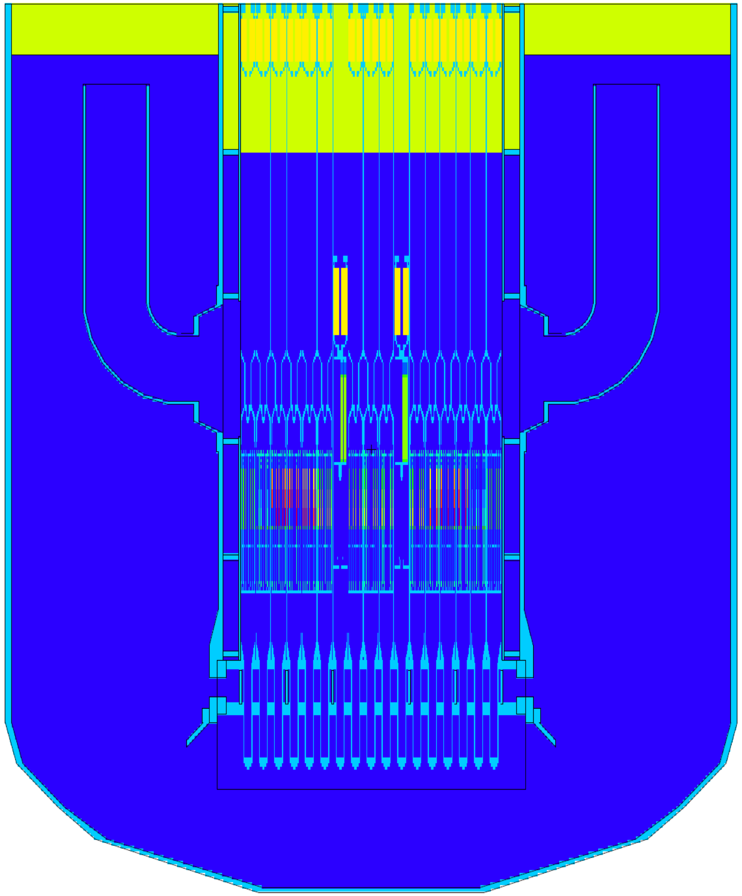
- **Instrumentation & control issues <u>may need to come in parallel with neutronics and thermal-hydraulics</u>** issues, in order to optimize the I&C instrumentation/system alongside the other customization processes on reactor design.

Reference Reactor

The LFR reactor modeled into MCNPX is based on **LEADER Project (ALFRED)**.

The MCNPX input deck now includes the 8 bayonet steam generators, having reached ~50000 lines.





Instrumentation selected for neutron flux:

- **Fission Chambers (FC)**
- ***Self* Powered Neutron Detectors (SPND)**

Instrumentation analyzed

- **Fission Chambers (FC):**
  Manufacturer: **PHOTONIS**
  - 1 CFUE32

- **Self Powered Neutron Detectors (SPNDs):**
  Manufacturer: **ThermoCoax**
  - 1 Co-type
  - 1 Pt-type

Cresco4 allowed:

- Calculation of the **neutron fluxes** at Points Of Interest (POI);
- Calculation of the **neutron spectra** at POI;
- Calculation of the **gamma background** at POI;
- Update of **detector's sensitivities to neutron** and **gamma**;
- Calculation of **detector's responses** at POI.

Results:
Photonis CFUE32 fission chamber use in ALFRED

Key points:

- CFUE32 can follow the reactor power **till 1-10% of full power**;
- Neutron fluxes corresponding to reactor power **>10% of full power burn the device too fast**;
- When reactor power **>0.1% of full power**, devices too close to the active length suffer **an excessive gamma bombardment**; such a noise has to be studied;
- **Replacement devices** has to be foreseen inside the reactor design to **insert the instrument** as close as possible to the active length at start-up and **remove** it when neutron or gamma fluxes become unsustainable.

Results:
THERMOCOAX SPND Pt-type use in ALFRED

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Key points:

- SPND **do not follow lower decades** of reactor power;
- They can monitor from **10% to 100% of full power**, according to positioning;
- **Low Burn-up rate** allow the device to **endure** for the whole irradiation campaign foreseen for the elements;
- They can be installed as a **fixed component** into fuel and reflector elements: **no replacement is needed**;
- They could **suffer some gamma noise** at installation sites within the fuel.
- **Maximum limits on burn-up** has to be investigated.

Future work

R&D on SPND is strongly suggested, in both **theoretical** and **experimental** approaches.

According to the **spectral characteristics of the neutron flux**, SPNDs for full power monitoring can be **optimized in materials** and **geometries**.

MCNPX can represent an useful **design tool** to conceive and test in simulation **innovative SPNDs**.

⇒ ***MCNPX*** *for SPND modeling has to be validated first*

⇒ *An* ***irradiation experience on SPNDs in TAPIRO*** *has been reconstructed to validate MCNPX as a design tool for SPNDs*