Italian National Agency for New Technologies, Energy and Sustainable Economic Development

IRradiation Effects on HTS for Fusion
12-16 November 2023
Arona, Italy

The Calliope Gamma Irradiation Facility

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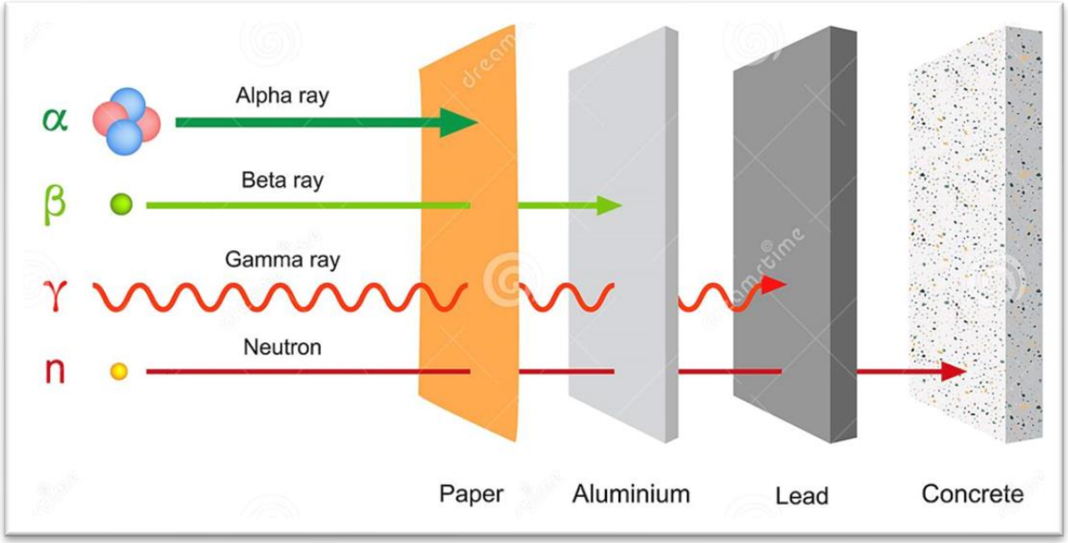
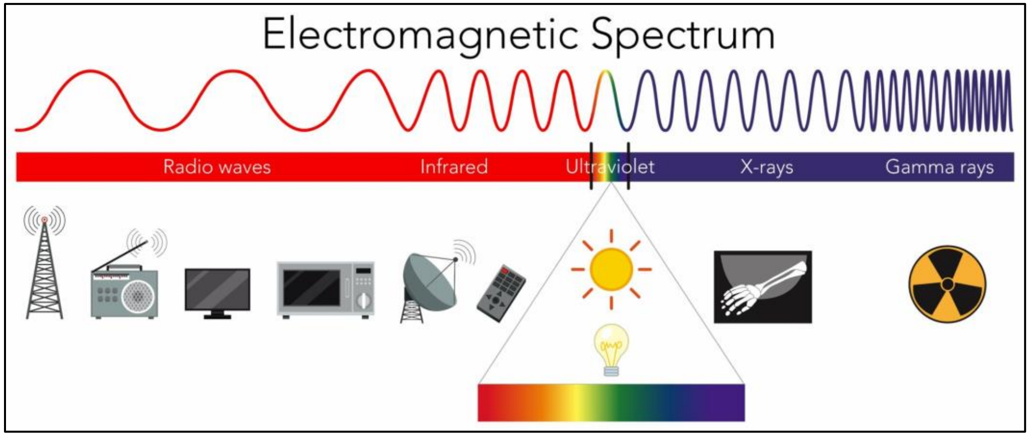
Gamma interaction with matter

high penetrating power

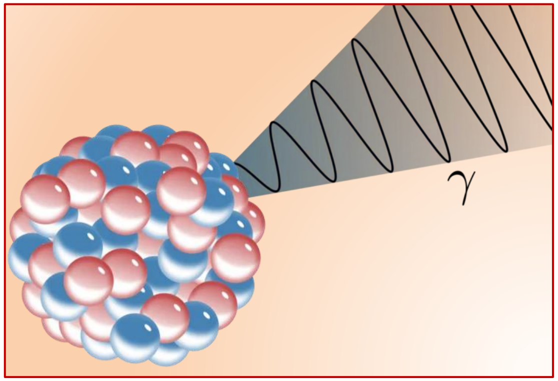




Sources of gamma rays

- Radioactive decays
- Secondary cosmic rays
- Astronomic objects (neutron stars, pulsars, supernovae, black holes)
- Lightning strikes
- Nuclear fission
- Nuclear fusion
- High-energy physics experiments
- ....

Gamma interaction with matter

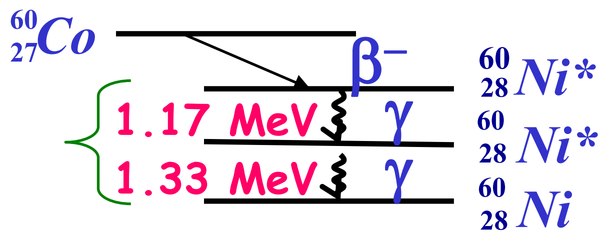


Gamma emission from **daughter nuclei** in **excited state** after alpha and beta decay or spontaneous fission.

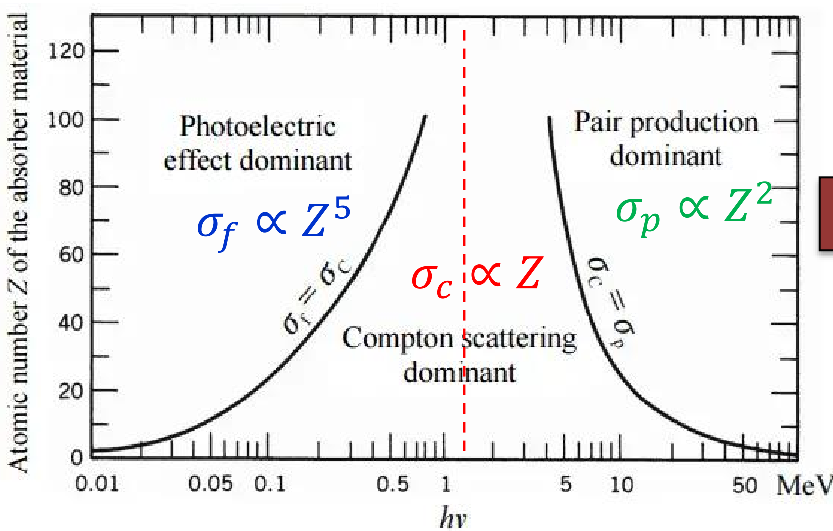
Production: $^{59}_{27}\mathrm{Co} + n \rightarrow {}^{60}_{27}\mathrm{Co}$

Decay: $^{60}_{27}\mathrm{Co} \rightarrow {}^{60}_{28}\mathrm{Ni}^{*} + e^{-} + \bar{\nu}_e$

$$^{60}_{28}\mathrm{Ni}^{*} \rightarrow 2\,{}^{60}_{28}\mathrm{Ni} + 2\gamma$$



- Mean energy: 1.25 MeV
- Half life ≈ 5 years



excitation

ionization

No radioactivity induced in the irradiated materials

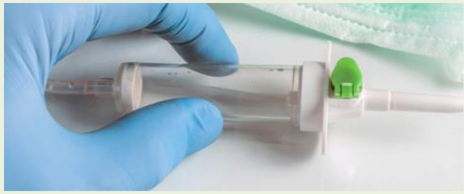
Gamma rays and matter: processing

1

Production/processing

Polymerization

Sterilization



Food irradiation

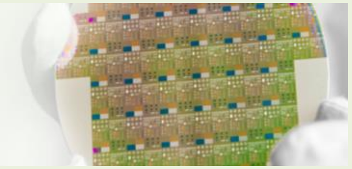
Exposition to radiation

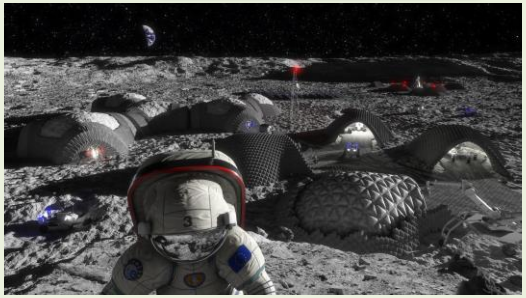
2

Radiation hardness

Lifetime prevision

Reliability





Irradiation plant

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Characterization laboratory

ENEA overview

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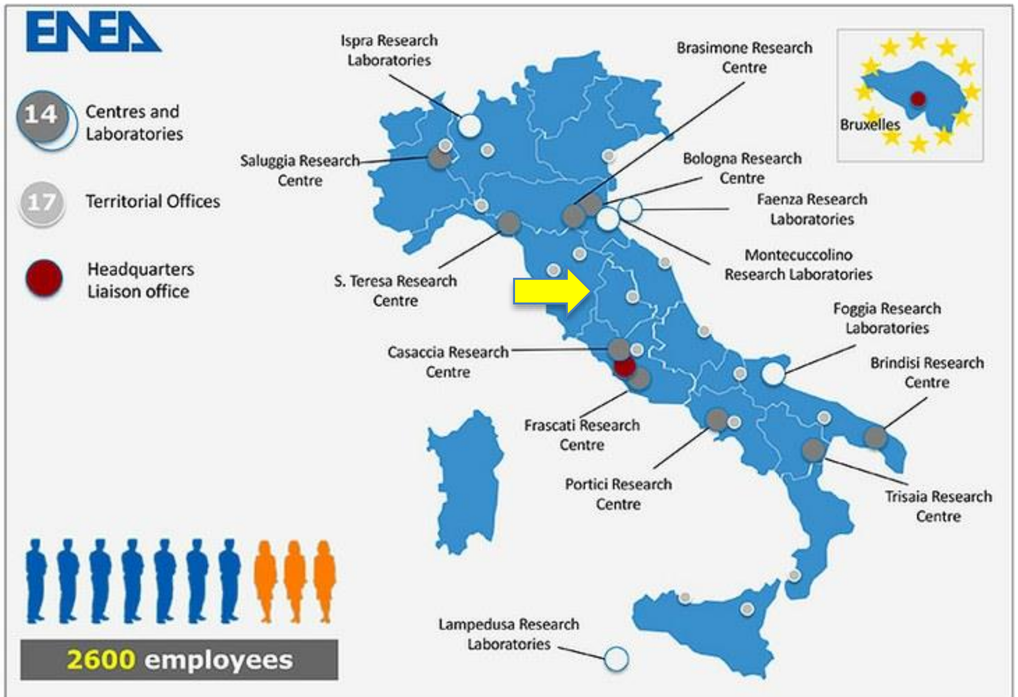
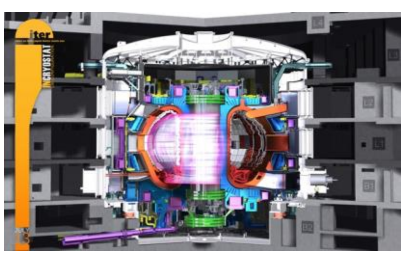


Energy efficiency

Environment and sustainability

Energy technologies and renewable energy sources

Nuclear technologies, safety and security



Calliope irradiation facility

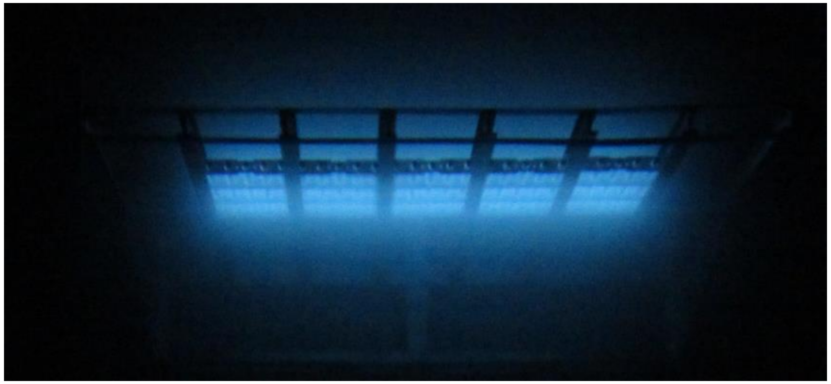
@ ENEA Casaccia Research Center (Rome)

(Picture acquired by remote camera)

- Pool-type irradiation facility.
- 25 bars of ^{60}Co (last recharge in 2018)
- Large volume irradiation cell ($7.0 \times 6.0 \times 3.9$ m^3)
- Maximum allowed activity: $3.7 \cdot 10^{15}$ Bq.
- Maximum dose rate: 6.3 kGy/h (Oct 2023)

- Irradiation and dosimetric certification.
- ISO 9001 (by 2023) and ISO 17025 (by 2024) quality management.

Calliope irradiation facility



Control room system

Cherenkov radiation in the water.
Active rack area: 41 cm x 75 cm.

Irradiation tests and procedures

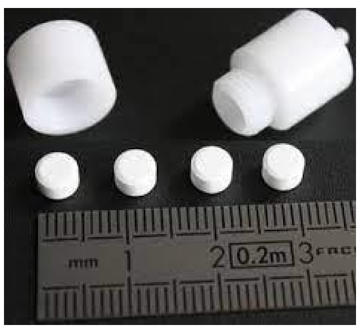
- **Different dose rates: distance from the source and use of lead shield and castles from 0 to 6.3 kGy/h.**
- **Different atmospheric and temperature conditions.**
- **Experimental dosimetric characterization.**
- **Simulation of the gamma field by Fluka/MCNP code.**

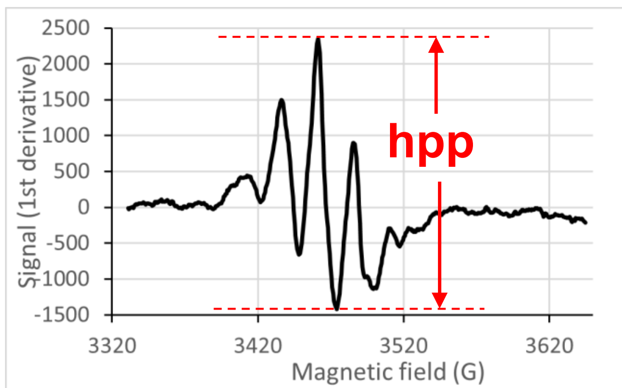
Dosimetric laboratory

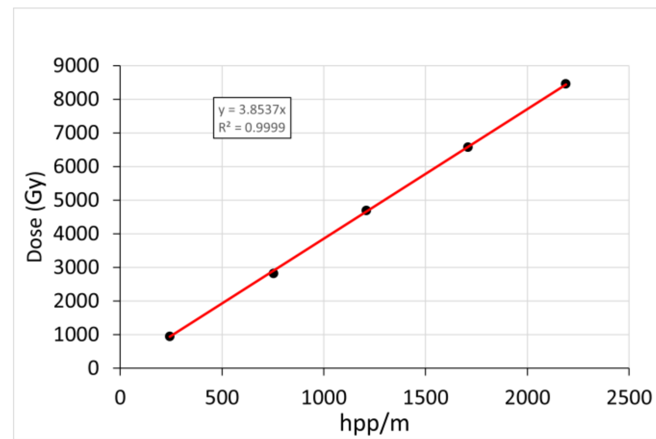
Dosimetric systems

- ❖ **Fricke dosimeter** (20-200 Gy)
  Optical transmittance
  Absolute dosimeter

- ❖ **Alanine - EPR dosimeter** (50 Gy-150 kGy)



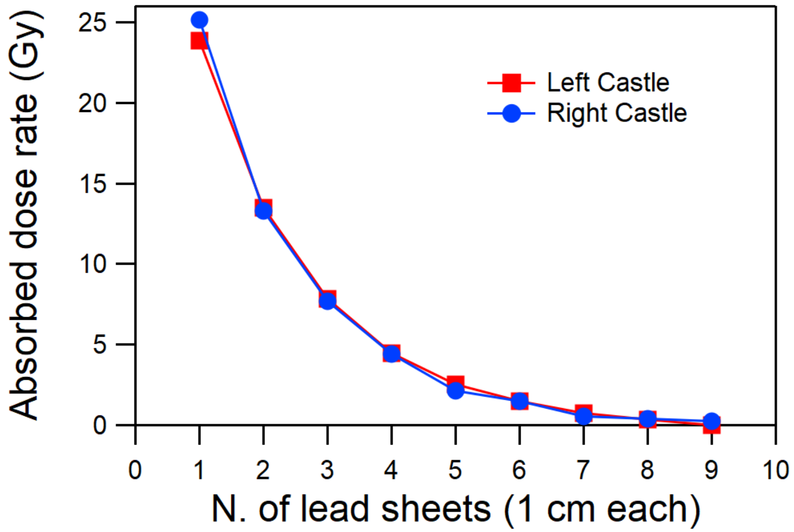




- ❖ **Red-Perspex (5-40 kGy), radiochromic** (1 kGy-3 MGy)
- ❖ **Thermo Luminescent Dosimeter (TLD)** (1 mGy-100 Gy)
- ❖ **Real-time SiC diode** (0,1 – 10 kGy/h)

Lead castles

Low dose rate (LDR) irradiation tests



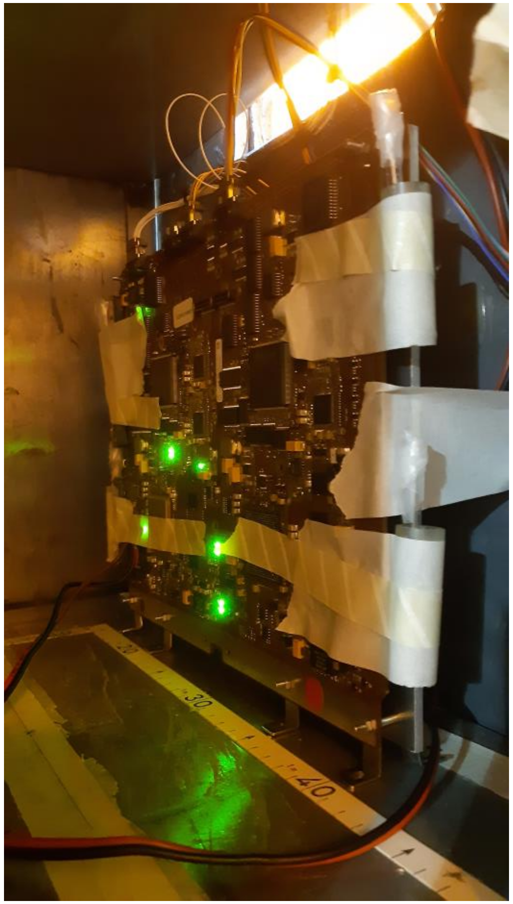
Internal dimensions: 45x35x33(H) cm^3

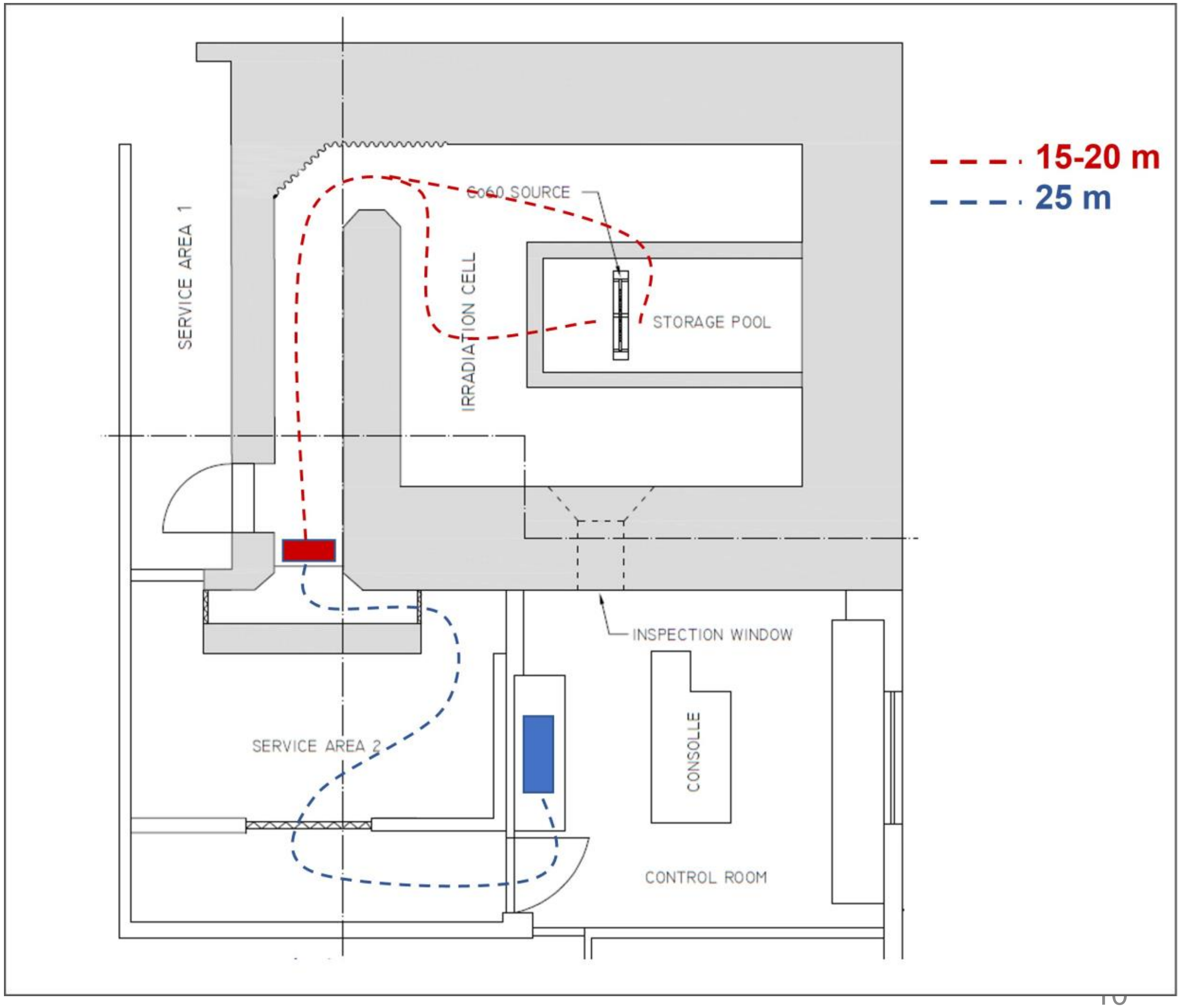
Modular lead castles:

- Variable thickness of the front wall (facing the gamma source)
- 1-cm thick Pb sheets composing the front wall
- The other walls are 3 cm thick Pb panels (fixed) to shield secondary radiation
- Opening on the rear wall for the use of cables and wires.

On-line irradiations

Irradiation of biased devices and/or remote control



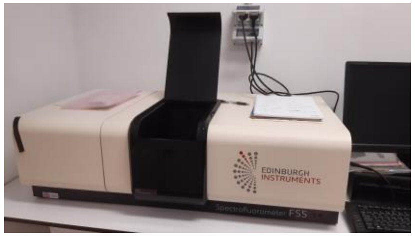


Characterization laboratory

Optical, spectroscopic and spectrometric characterization

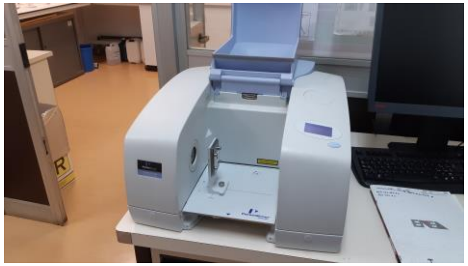
- ❖ Raman microscope
  785 nm laser source.
  + Confocal optical microscope

- ❖ UV-VIS spectrophotometer
  Range: 190-2500 nm
  Integrating sphere



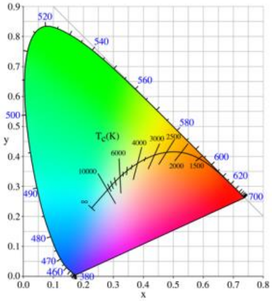
- ❖ Spectrofluorometer
  Excitation (230-1100 nm)
  Emission (300-1100 nm)

- ❖ FTIR/FTIR-ATR spectrophotometer
  Range: 400-7000 nm
  Integrating sphere



- ❖ EPR spectrometer
  X band ~9 GHz

- ❖ Colorimeter



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Processing laboratory

Thermal annealing and accelerated ageing test

❖ Climatic chamber:
temperature range: -75°C/+180°C
humidity range: 10 - 98 %
UV lamp (220 - 630 nm)

❖ Furnace
(T max = 1200°C)
Electronic components processed in biased conditions

Qualifications and research lines

Principal activities at ^{60}Co Calliope facility

Qualification tests

- ✓ Materials, electronic devices, optical components in harsh radiation environments

Applications:

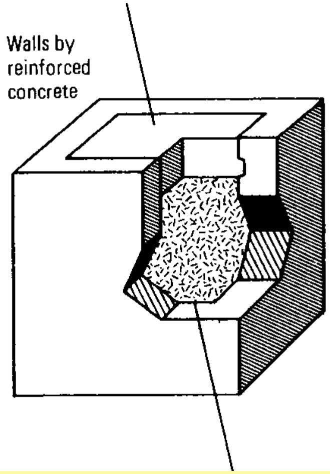
- ❖ Aerospace
- ❖ Nuclear plants (fission and fusion)
- ❖ High-energy-physics experiments.

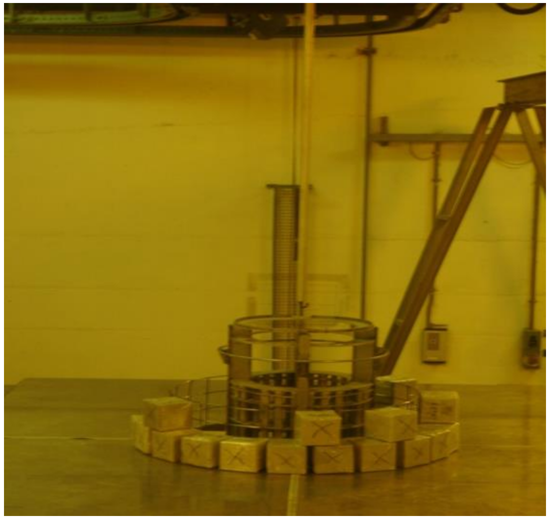
Experimental research

- ✓ Chemical, physical and biological effects of ionizing radiation
- ➢ Materials' science
- ➢ Nuclear science
- ➢ Experimental particle physics (detectors)
- ➢ Cultural Heritage (elimination of biodeteriogens)
- ➢ Agriculture, control of pests

Qualification test: Nuclear applications

Radiation damage of concrete matrices for nuclear waste treatment





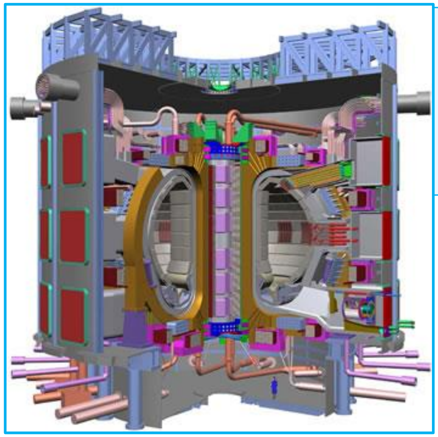
(previous cylindrical rack configuration)

Waste form pre-qualification for "*low and intermediate level waste*"(LILW)

According to Waste form Technical Position (United States Nuclear Regulatory Commission) absorbed dose 10E+6 Gy corresponding to a period of 300 years.

Qualification test: Nuclear application

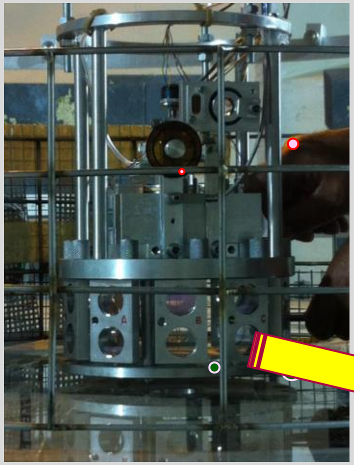
Radiation damage for fusion components



ITER

International Thermonuclear Experimental Reactor Project

Fusion for Energy

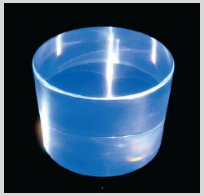


piezo-motor

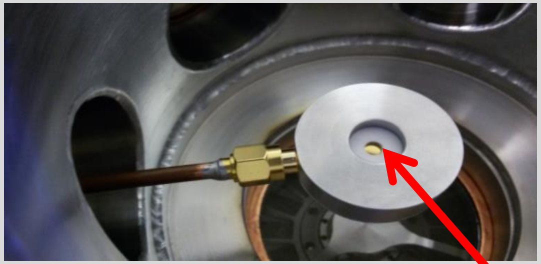
IVVS actuating components
(dose = 4 MGy)

optical components

Radial Neutron Camera scintillators



Plastic (neutron and gamma)



Synthetic diamond

Qualification test: Space

Irradiation tests on electronic components and devices for SPACE

Space radiation

- ★ Ionization and displacement damage (surface/bulk)
- ★ dose rate effects
- ★ T effects on damage mechanisms

^{60}Co

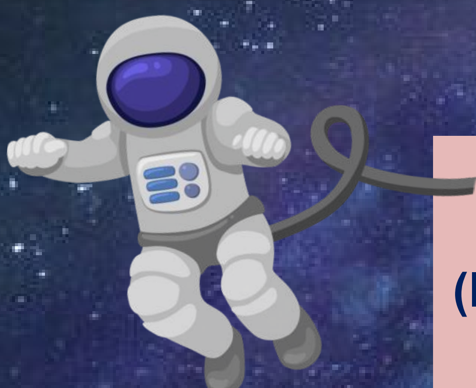
γ

Ionization damage due to space radiation

Total ionizing dose

Specifications:
- ESA/SCC 22900 (5)
- MIL-STD 883

Standard and low dose rate windows

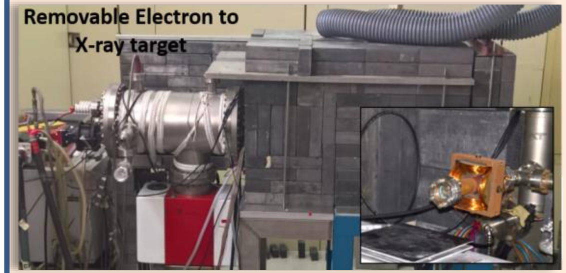


The Calliope facility is part of the ASIF Programme (Italian Space Agency Supported Irradiation Facility) and indicated by the European Space Agency ESA for space irradiation tests.

ENEA ASIF Facilities:

Irradiation facility national network for Space irradiation test

REX
Removable Electron to X-ray

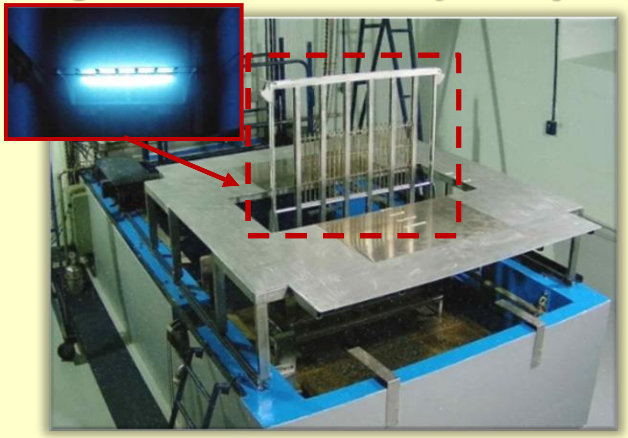


- Electron and X-ray
- 5 MeV electron linac
- Electron to photon conversion unit

TOP IMPLART
Intensity Modulated Proton Linear Accelerator for Radiotherapy

- Low energy proton (2.6 MeV - 7 MeV)
- High energy proton (35 MeV - 71 MeV)

Calliope
gamma irradiation facility



- 2 γ emitted in coincidence with 1.25 MeV mean energy
- Activity: 1.6 x 10^{15} Bq (May2022)
- Max dose rate (May 2022): 7.4 kGy/h

FNG – Frascati Neutron Generator

- 14 MeV neutron (reaction $T(d,n)^4He$);
- 2.5 MeV neutron (reaction $D(d,n)^3He$)

Triga RC-1

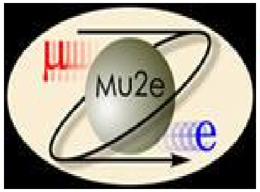
- Maximum thermal power: 1 MW;
- Maximum neutron flux: $2.7 \cdot 10^{13}$ n/cm$^2 \cdot$s

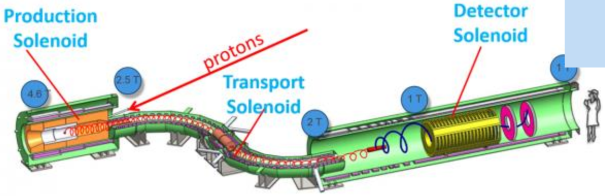
Tapiro

- Maximum power: 5 kW;
- Maximum neutron flux: $4 \cdot 10^{12}$ n/cm$^2 \cdot$s

Experimental research: High energy physics experiments

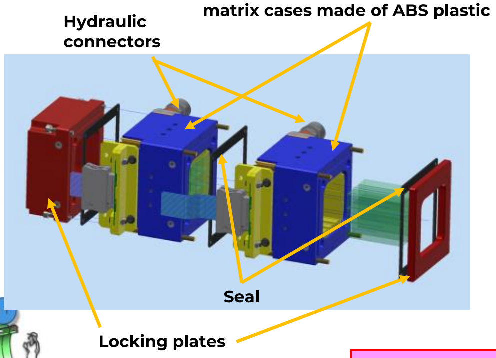
Cherenkov and scintillator detectors

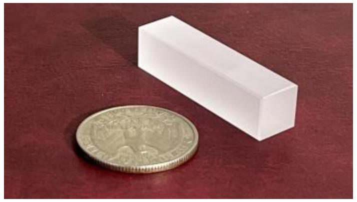




Neutrinoless decay of muon

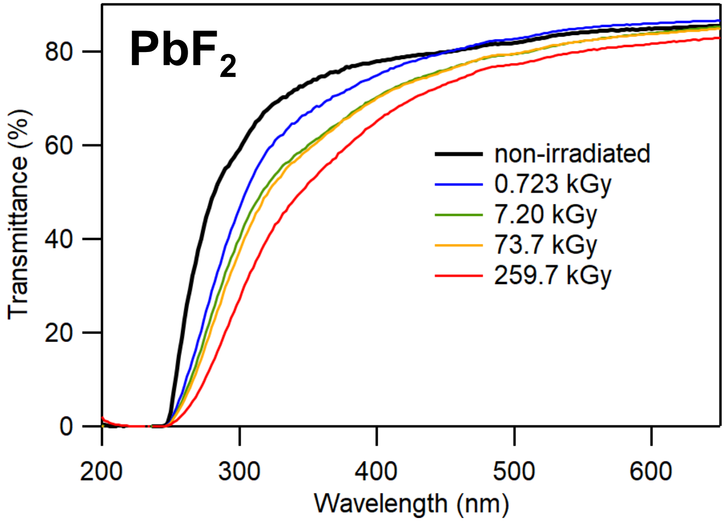
Calorimeters with Cherenkov crystals

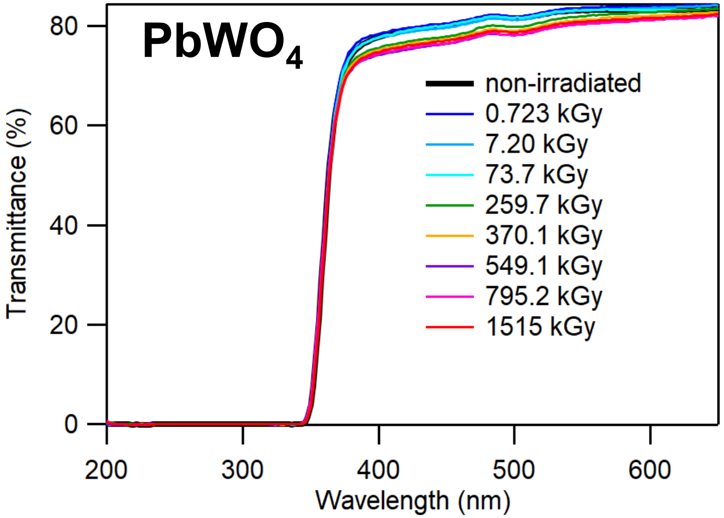




Scintillator crystals @ Calliope

- CMS @LHC CERN
- BELLE II @SuperKBK (JAP)





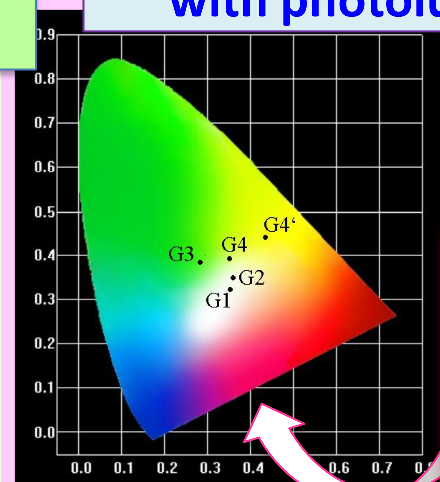
Experimental research: Glassy matrices and optical devices

1) Lenses and optical coating substrate for Space and Nuclear Plant

Rad-hard BK7 glass

G18 glass

2) Transition metal doped glassy matrices with photoluminescence properties



For production of different colored LEDs *(white)*

CIE chromaticity is tuned from yellow and green to white by adjusting glassy matrix composition and/or Cu^{+}/Mn^{2+} dopant concentration ratio.

3) Radiochromic and photochromic glassy matrices as dosimetric systems, data memories and optical lenses

Manganese doped phoshate glasses

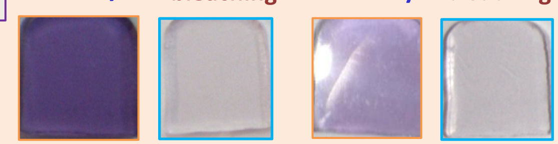
Mn^{2+} *uncolored* → Oxidation by γ irradiation → Mn^{3+} *colored*

optical properties change when exposed to gamma radiation

Glass matrix: P_2O_5; Dopant: MnO, 4 mol%

Reversible thermal bleaching

14.3 kGy	after bleaching	14.3 kGy	after bleaching



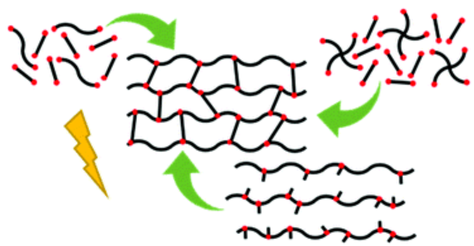
G1 G4

Experimental research: Polymeric materials

Effects of gamma radiation on polymeric materials

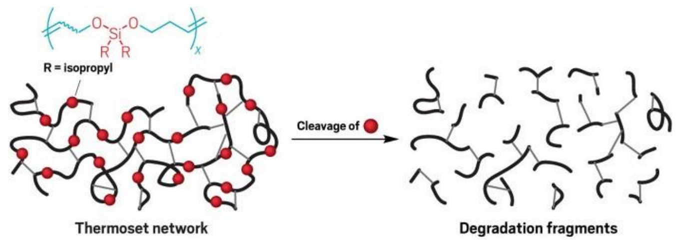
Low dose → **Cross-linking**

High dose → **Degradation**



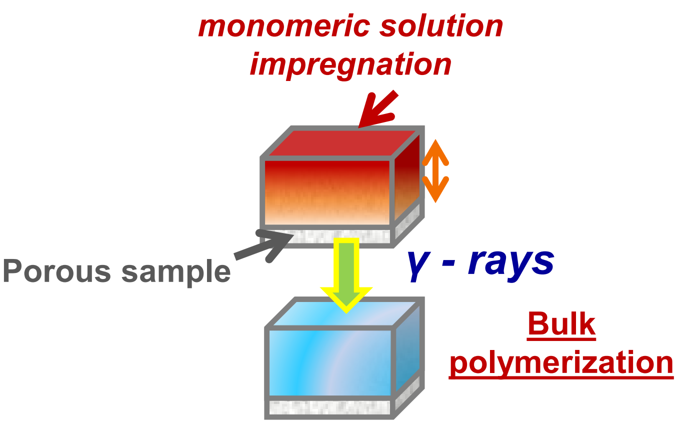
Hughes et al. Material Horizons (2019)

Influence of
- **atmospheric conditions**
- **irradiation parameters**
- **temperature**



Remmel, c&en (2020)

Embrittlement, fragmentation, change of color



Free radicals

Very active species

Post-irradiation chemical reactions with free radicals

- ❖ Cultural heritage (paper, wood, cellulose).
- ❖ Biopolymers, proteins
- ❖ Polymers of technological interest, resins

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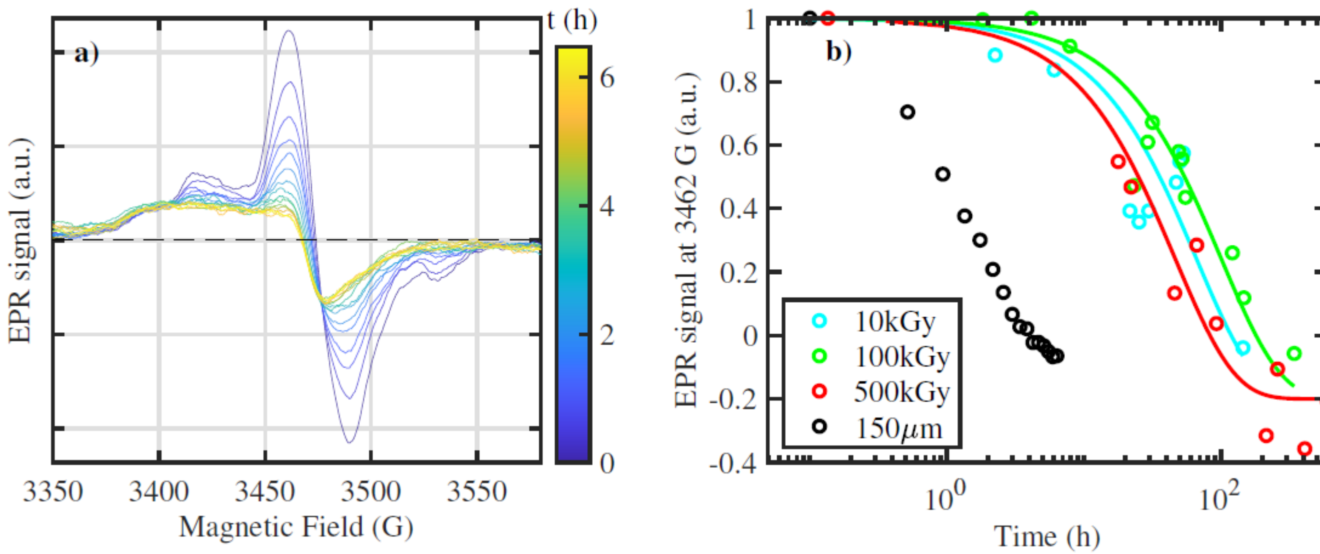
Experimental research: Adhesive epoxy resins

Investigation of the gamma irradiation effects (0-500 kGy)

- Mechanical properties
- Chemical bonds (FTIR)
- Formation and recombination of free radicals (EPR)

3MTM Scotch-WeldTM EC-2216 B/A Gray (3M2216)

EPR analysis



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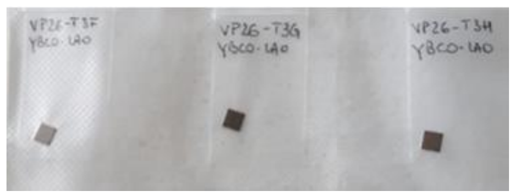
Experimental research:
Gamma irradiation of superconductors

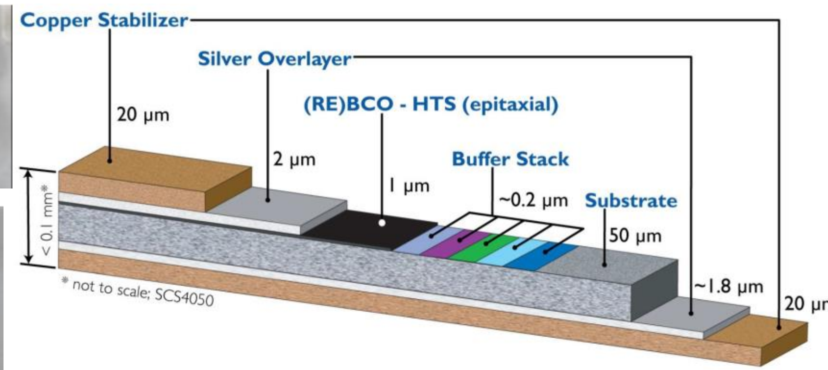
Irradiation of SC tapes and thin films for space applications

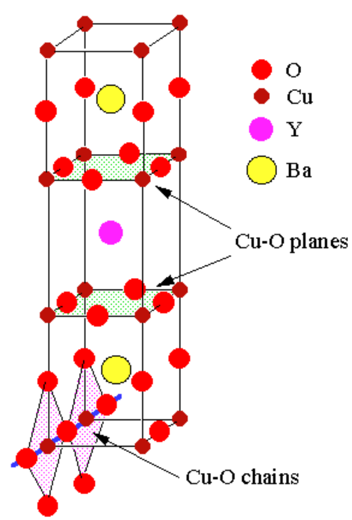
Collaboration with
ENEA FRASCATI Superconductivity Laboratory

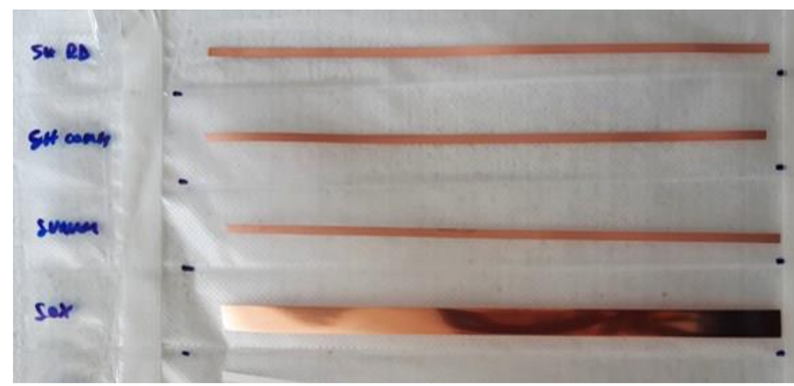
- ❖ YBCO thin films grown on LAO and STO by metalorganic decomposition (MOD).
- ❖ Commercial *RE*BCO tapes (SuNAM,SuperOx, Shanghai ST)

See oral contributions from **Valentina Pinto** this morning and **Antonio Pietropaolo** in this session.









Experimental research: Gamma irradiation of superconductors

- Effects of the gamma irradiation on HTS are strongly controversial. See presentation by **Simon Chislett-McDonald** yesterday.

Future perspectives

- Irradiation at higher absorbed dose and dose rate: simulation of the gamma radiation field in a fusion nuclear reactor.
- Irradiation in operating conditions (below T_C)
  ALERT: explosion of liquid nitrogen in gamma field

- Comparison with neutron irradiation @ Frascati Neutron Generator (**FNG**)

Calliope: the research staff

Alessia Cemmi
Director of Calliope Facility

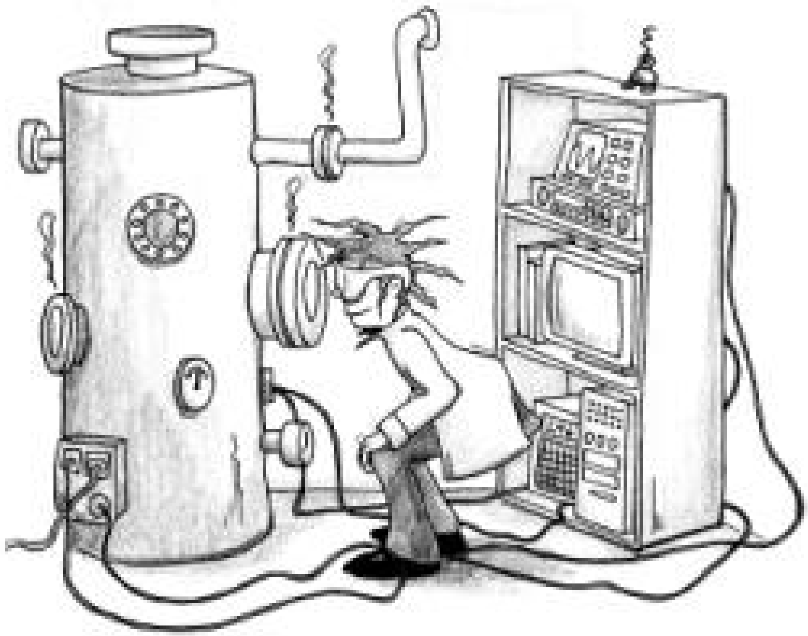
Ilaria Di Sarcina

Jessica Scifo

Giuseppe Ferrara

Adriano Verna

Rocco Carcione



Thank you for your attention!