TRITIUM: A quasi-real time tritium in water monitor for NPPs

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Dublin-9/10/2023

Tritium and Nuclear Energy

- Tritium is one of the most abundantly produced radioisotopes in nuclear facilities (NPPs, research facilities).
- Tritium is produced abundantly in the nuclear reactor cooling water system of NPPs by deuterium neutron capture and it is finally released to the environment.
- Sudden increase in the tritium release level of NPPs could indicate a malfunctioning of the reactor.
- The development of safeguards able to provide tritium levels in quasi-real time is crucial.

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Tritium Properties and Radiological Hazards

Tritium is measured routinely in Spain in all the points of the Network of Sampling Stations (Red de Estaciones de Muestreo, REM).

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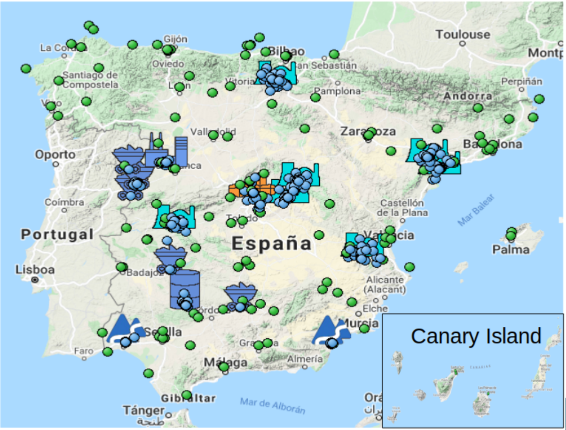
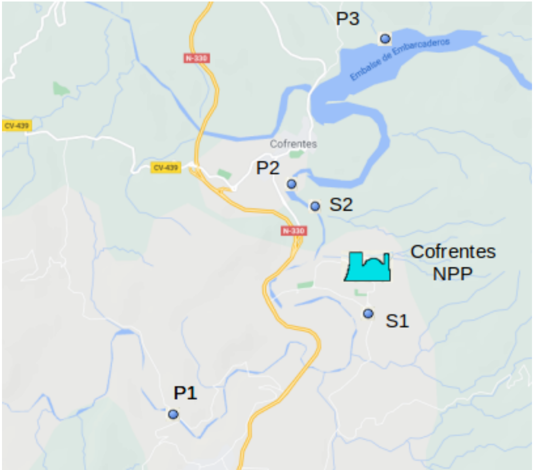
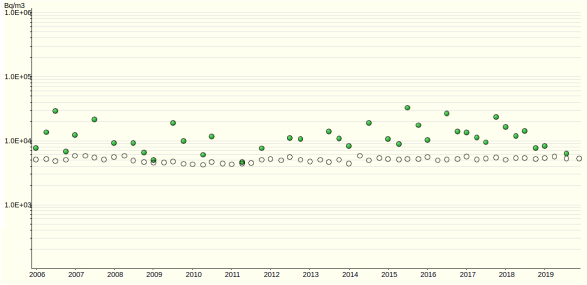


Points of measurement



- REM (Network of Samplig Stations) data of the point P2, 1 km downstream from the Cofrentes NPP (Valencia, Spain)[1].



- All measurements are below the legal limit in Spain (100 Bq/L).
- The maximum level of tritium measured is 32 Bq/L.

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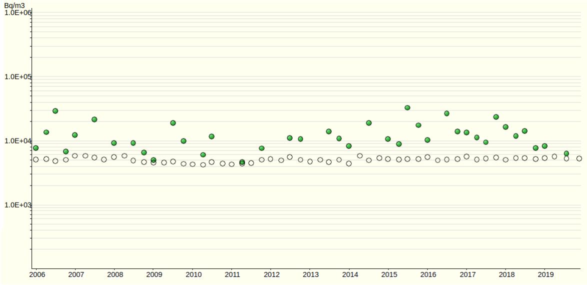

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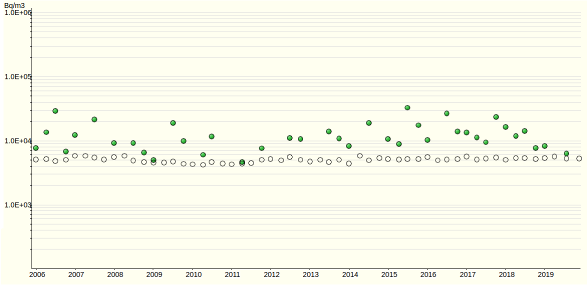

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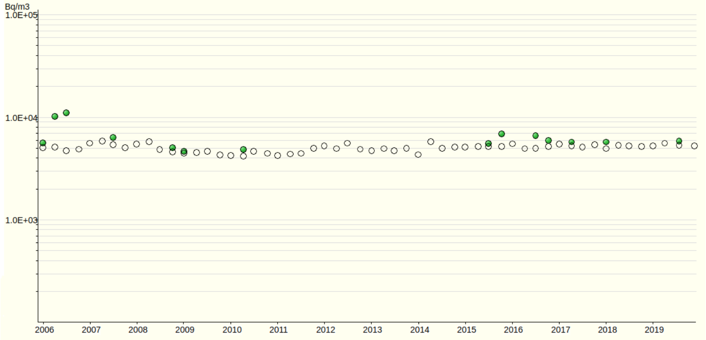

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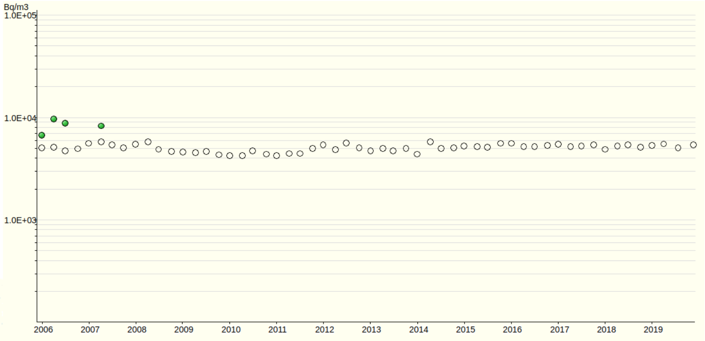
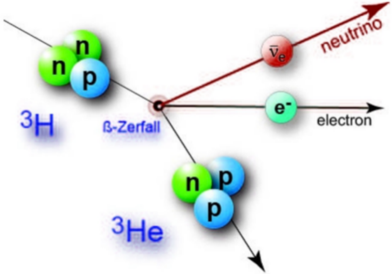
- REM data of the point P1, 6 km upstream from the Cofrentes NPP (Valencia, Spain).



Tritium Properties and Radiological Hazards

- Tritium is the only radioactive isotope of hydrogen present in the environment.
- It is a β^- emitter ($T_{1/2} = 12{,}32$ years) and decays exclusively to the ground state of the $^3_2\mathrm{He}$ isotope.

$$^3_1\mathrm{H} \rightarrow {}^3\mathrm{He} + e^- + \overline{\nu}_e$$



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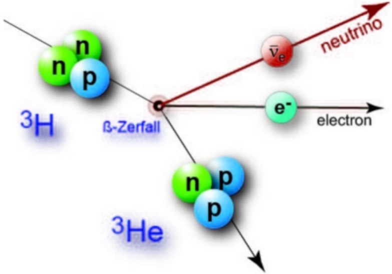

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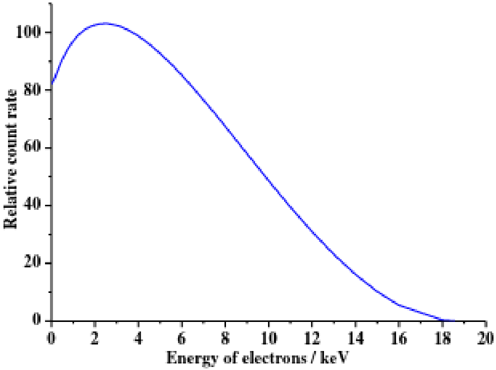

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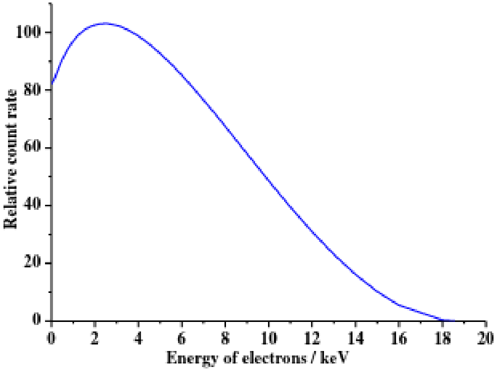

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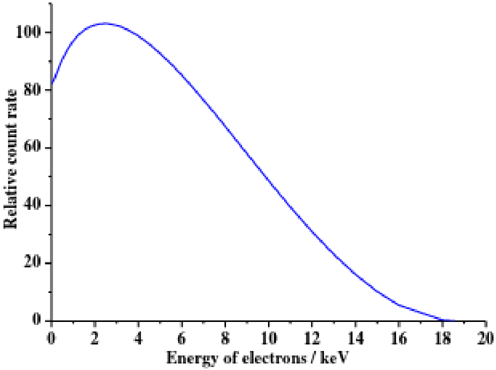

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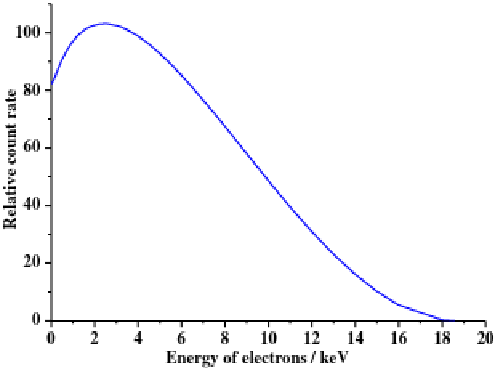

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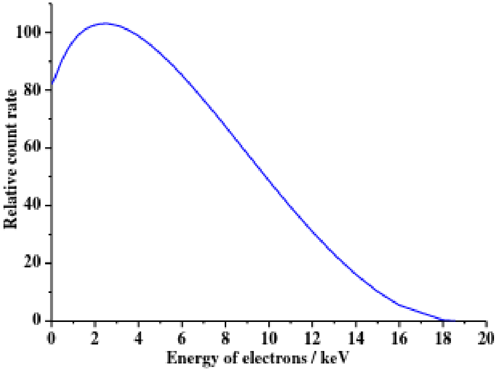

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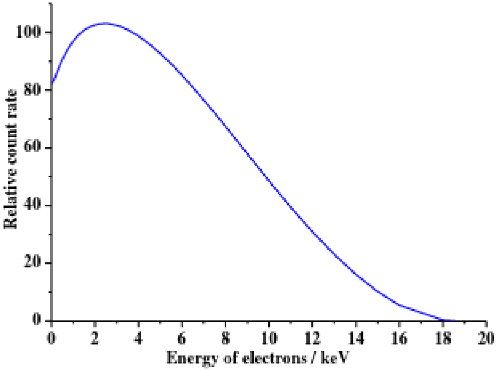

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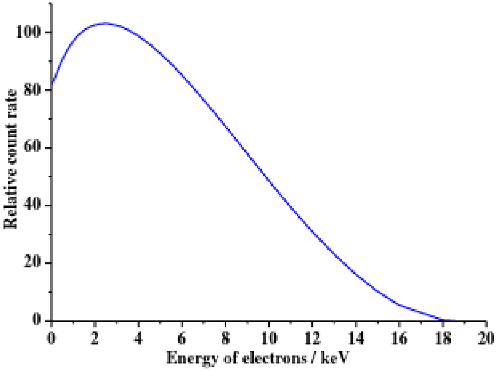

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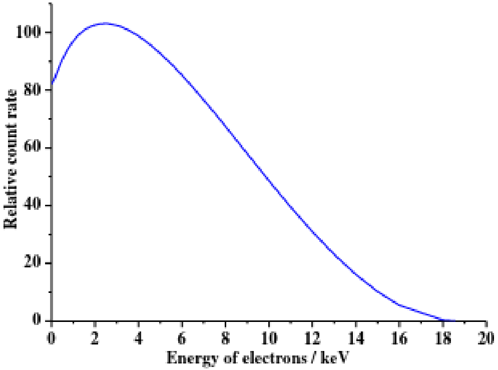

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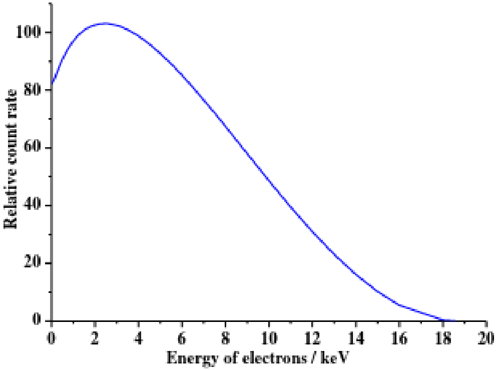

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Tritium Properties and Radiological Hazards

- Tritium is naturally produced through the interaction of cosmic rays with elements of the upper atmosphere (oxygen, nitrogen, etc.).
- Tritium concentration in environmental water (excluding anthropogenic radioactive sources) is $1 - 4$ Bq/L[2].
- Tritium concentration in rivers around an European NPP is usually around $1 - 10$ Bq/L and even $20 - 50$ Bq/L at the water discharge place.

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Tritium Properties and Radiological Hazards

- Excessive releases of tritium into the environment is one of the first indicators of anomalous operation of a NPP.
- Most NPP accidents can be prevented by monitoring tritium levels released.
- The exposure to high levels of tritium can be external and internal:
  - The radiological hazard from external exposure is low since tritium electrons have a low penetration in matter ($\approx 5\ \mu$m).
  - Internal exposure to tritium by ingestion or inhalation produces typical detriment due to radiation exposure.
- The current limit for tritium activity in drinking water in the European Union is 100 Bq/L[3].

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- Tritium is measured routinely with Liquid Scintillation Counters (LSC) with accuracy of $\sim 1 \mathrm{Bq/L}$.
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Tritium detection

- To detect the tritium level in water in quasi-real time would provide a crucial information.
- This level should be measured with an accuracy enough to fulfill with the present legislation requirements.
- The problem is particularly important for NPPs placed in the border of countries sharing a common river with waters employed for agriculture and human drinking.

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Tritium Detection State-of-the-Art

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- There were several attempts in the past but with too high Minimum Detected Activity (MDA):

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- Their objective is to prevent negative effects of ionizing radiation on people and environment while allowing beneficial activities (The justification, the ALARA principle and dose limitation).

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- $GL(Bq/L) = \frac{RDL}{DCF \cdot q}$
- $DCF = 1{,}8 \cdot 10^{-11}$ Sv/Bq
- $q = 730$ L/year

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Country/Agency	GL (Bq/L)
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WHO	10 000
Switzerland	10 000
Canada	7 000
Russia	7 700
Australia	76 103
Finland	30 000
United States	740
European Union	100

Tabla: Legal limits of tritium in drinking water established in several countries.

The TRITIUM Project

- **Title:** *Design, construction and commissioning of automatic stations for quasi-real time monitoring of low radioactive levels of tritium in water.*
- Funded by the Interreg SUDOE program of the EEC in the 2016 call (under contract SOE1/P4/E0214) and some local GVA grants after 2020.
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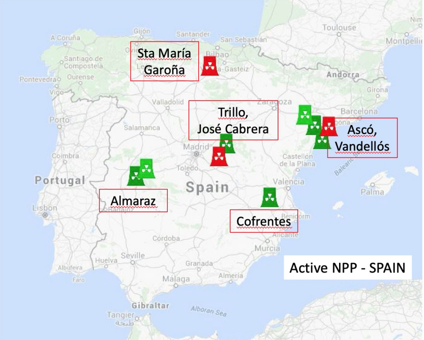

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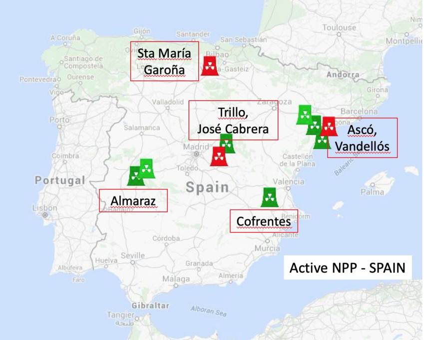

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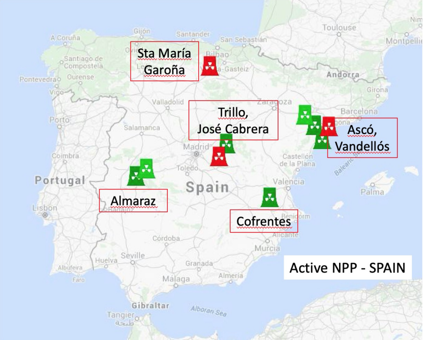

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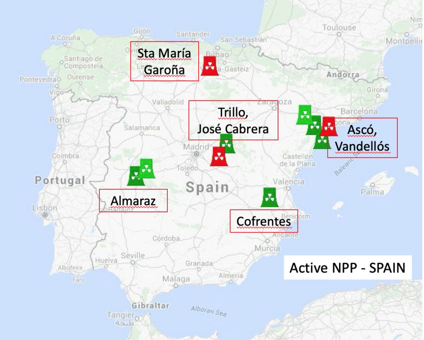

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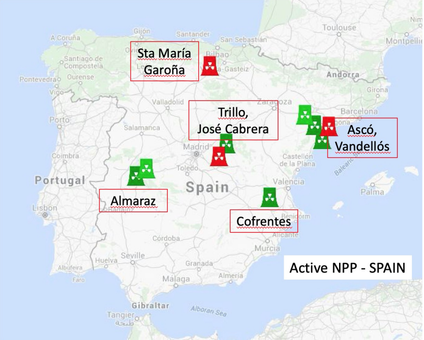

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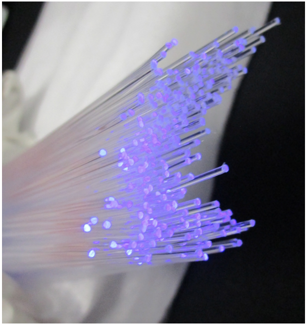

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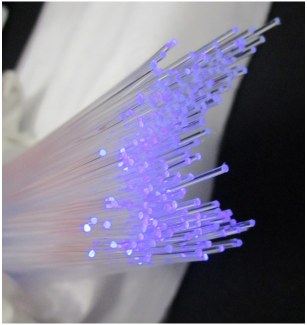

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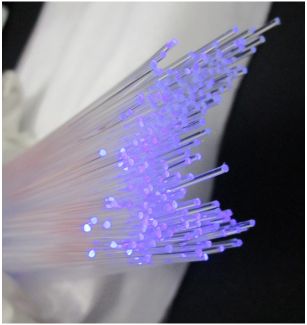

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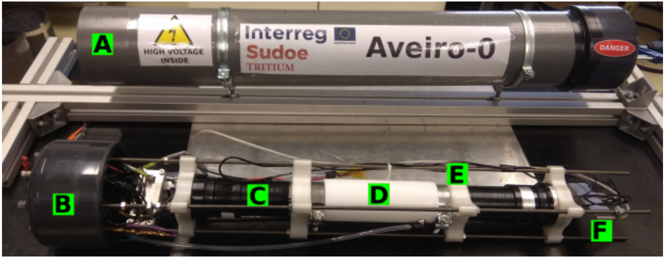
TRITIUM-Aveiro prototype

- Design:
  - 360 scintillating fibres ($\phi = 2$ mm).
  - PTFE vessel:
    - Two PMMA windows (10 mm).
  - Two PMTs (Hamamatsu $R2154 - 022"$).
  - $A = 30$ kBq/L.



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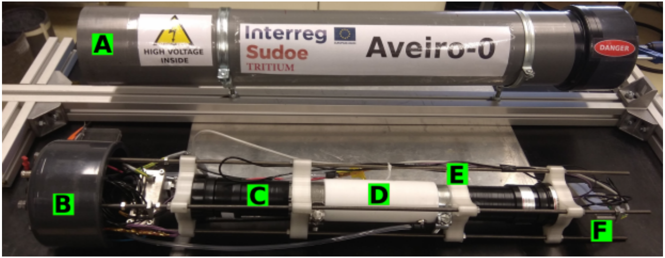

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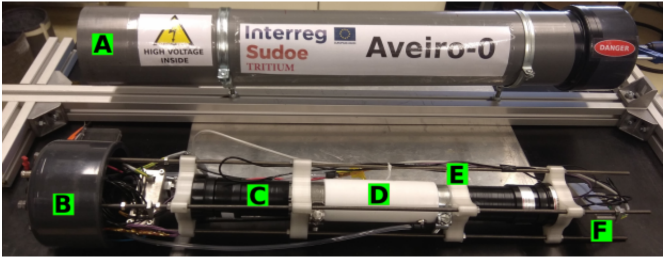

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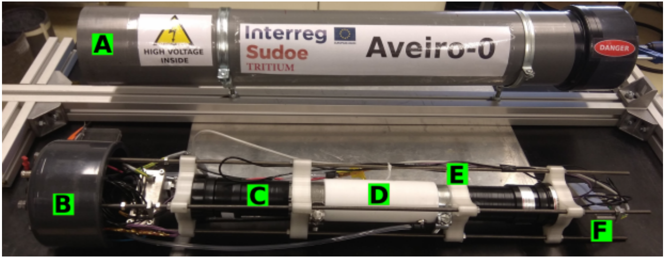

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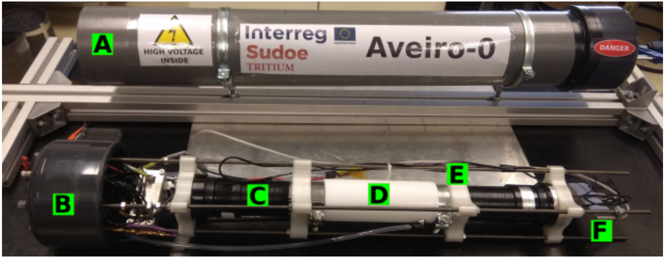

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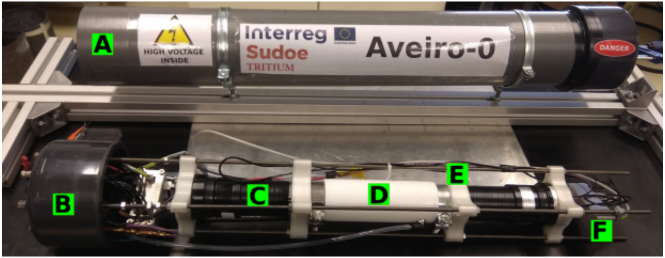

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- Design:
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TRITIUM-IFIC-2

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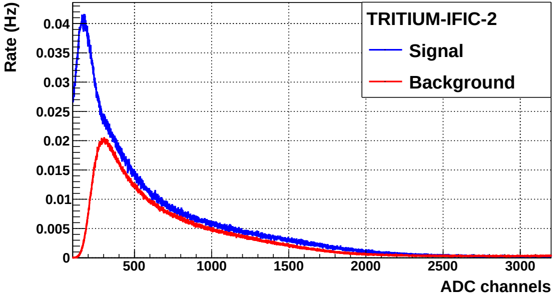

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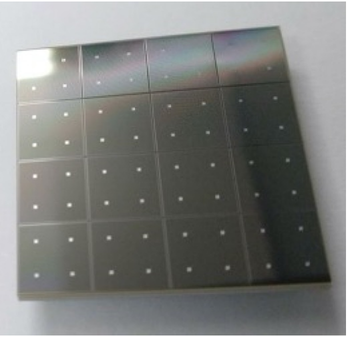

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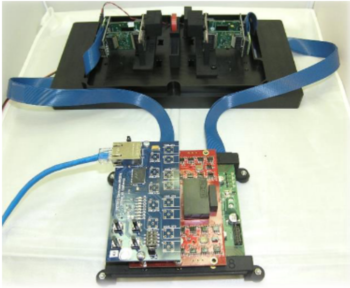

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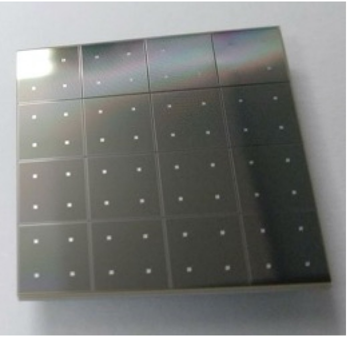

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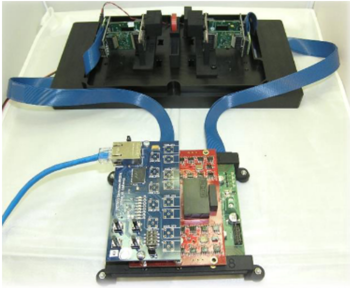

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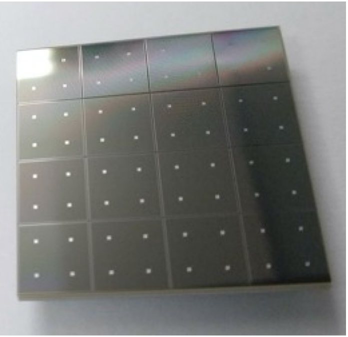

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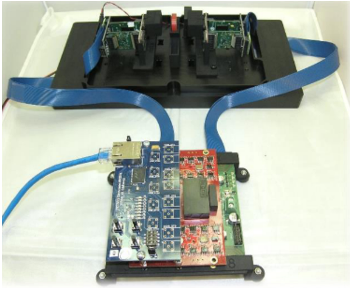

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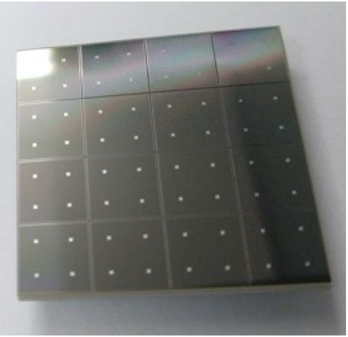

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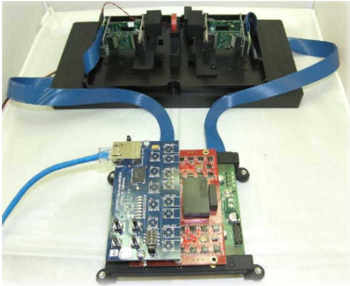

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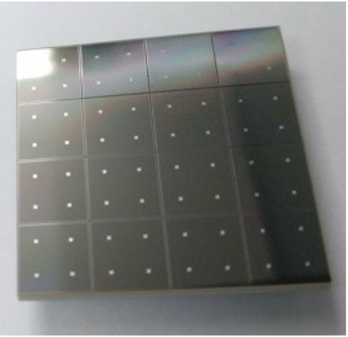

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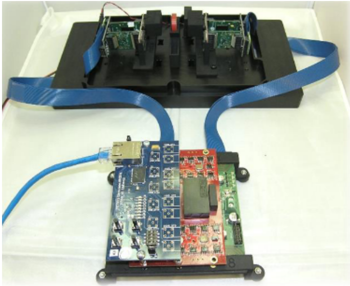

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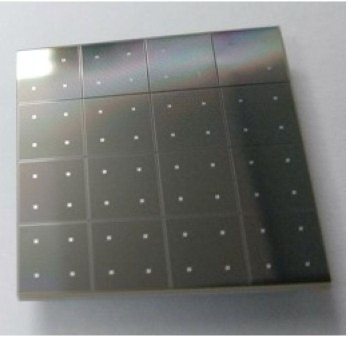

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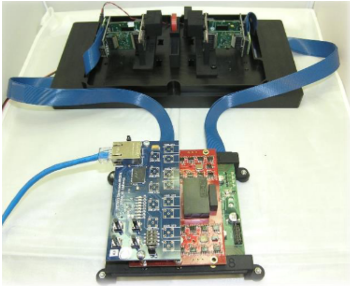

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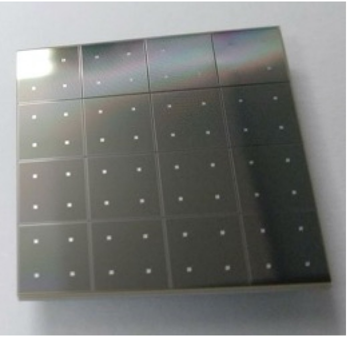

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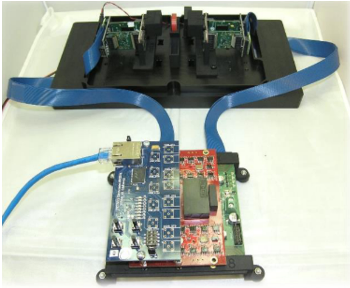

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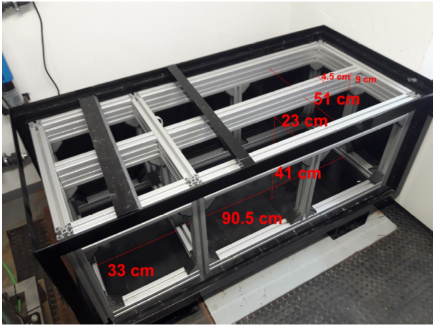
- The modules were placed inside an aluminum structure that hold the lead shield to mitigate natural radioactive background.



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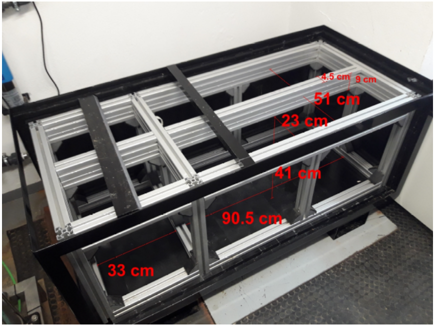

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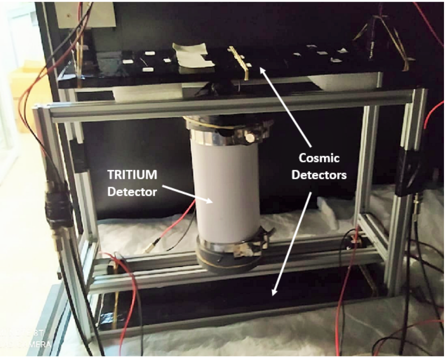
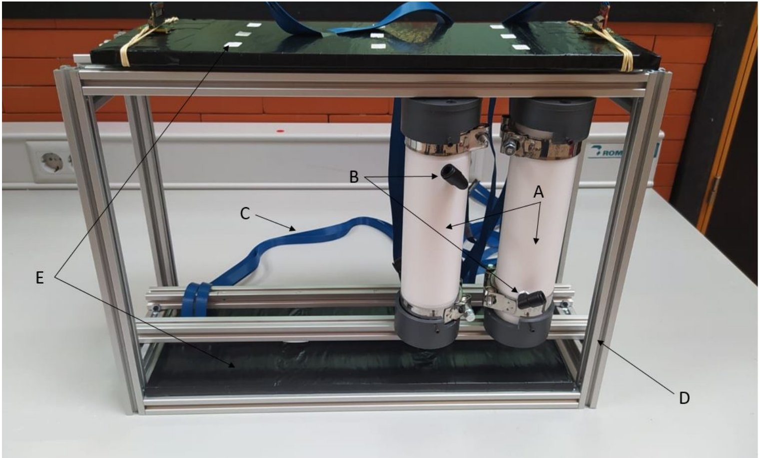


TRITIUM monitor module



Water purification system

- The water employed by the monitor has to be ultra-pure to avoid deposition in the fibres and maintenance operations.
- A water purification system was installed at the Arrocampo damm site to provide high purity water for the monitor.
- The system has gross, fine and ultra-fine osmosis filtering stages that eliminate particles larger than 1 μm and a UV system that destroys organic matter.
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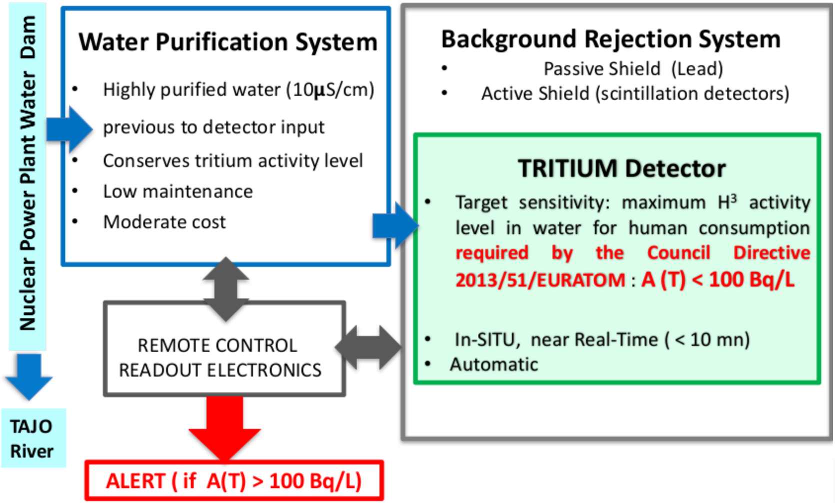
Design Principles and Components of TRITIUM monitor



Water purification system

Results and Conclusions

1. Several TRITIUM prototypes were developed with increasing sensitivity.
2. The state of the art of tritium detection was greatly surpassed with the TRITIUM-IFIC-2 prototype. An MDA of 220 Bq/L was obtained with only one module and no cosmic shielding.
3. The TRITIUM goal of 100 Bq/L is expected to be achieved, according to GEANT IV simulations, using 5 modules with an integration time of 1 h.
4. An active veto was built and characterized, obtaining a detection efficiency of 85 % for hard cosmic rays.
5. The prototype modules are currently installed at the Arrocampo dam and the signal is provided to the alert system of Extremadura Junta.

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2. The state of the art of tritium detection was greatly surpassed with the TRITIUM-IFIC-2 prototype. An MDA of 220 Bq/L was obtained with only one module and no cosmic shielding.
3. The TRITIUM goal of 100 Bq/L is expected to be achieved, according to GEANT IV simulations, using 5 modules with an integration time of 1 h.
4. An active veto was built and characterized, obtaining a detection efficiency of 85 % for hard cosmic rays.
5. The prototype modules are currently installed at the Arrocampo dam and the signal is provided to the alert system of Extremadura Junta.

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THANK YOU!