CENTRO FERMI
MUSEO STORICO DELLA FISICA E CENTRO STUDI E RICERCHE ENRICO FERMI

Sistemi intrinsecamente sicuri - SIS

Project Leader: *Giovanni Ricco*
Project Coordinator: *Marco Ripani*

Participants:
Fabio Panza: CF grant from 01/10/2017 to 30/09/2019
Mikhail Osipenko
Gianni Ricco
Marco Ripani
Paolo Saracco

Place of Work & Collaborations:
INFN Genova unit

Roma, December 2018 - PTA

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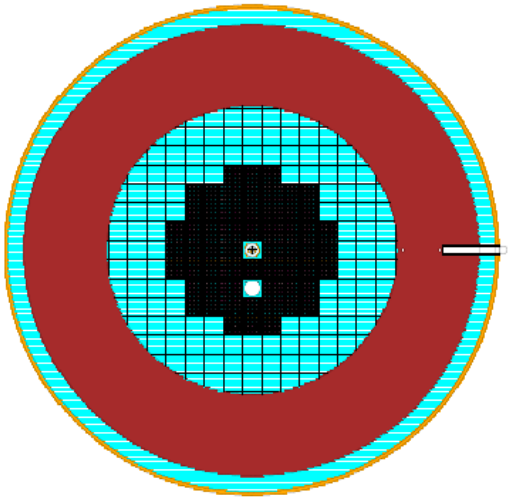
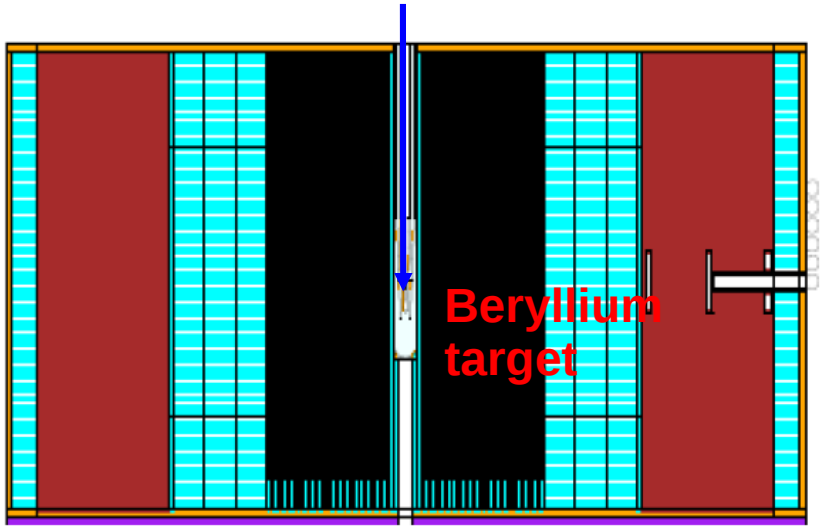
Project main goals and results achieved in 2018

Milestone 1: simulations of physics and engineering ADS aspects (100 % completed)
Milestone 2: comprehensive publication on ADS irradiation facility for fast and slow neutrons submitted to EPJ-plus (100% completed)





Thermal power P=565 kW
k_{eff} = 0.974

- **Fast core** based on MOX (U-Pu) fuel and solid Lead matrix
- **Reflector** surrounding the core made by **composite lead-graphite-lead** structure
- **Cooling** of core through **water** pipes

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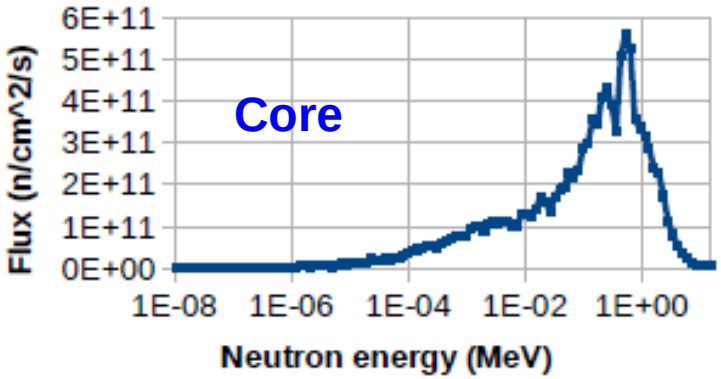

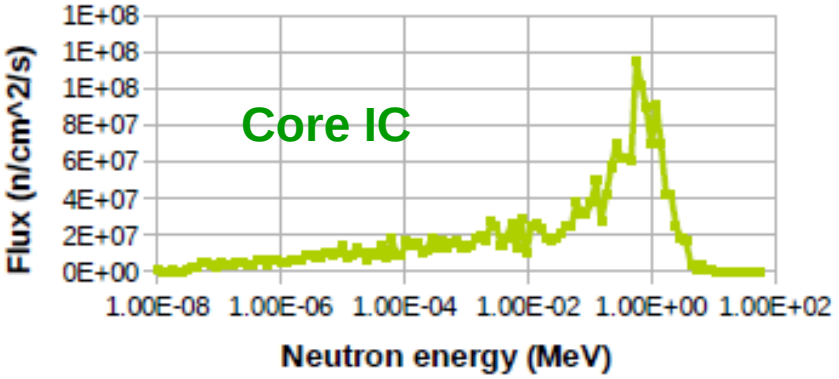

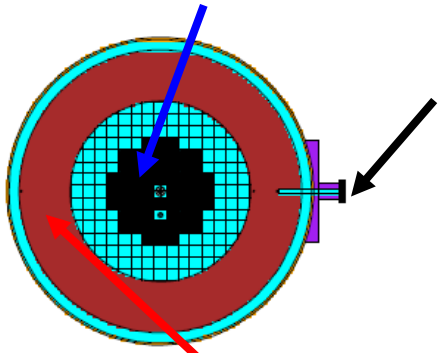

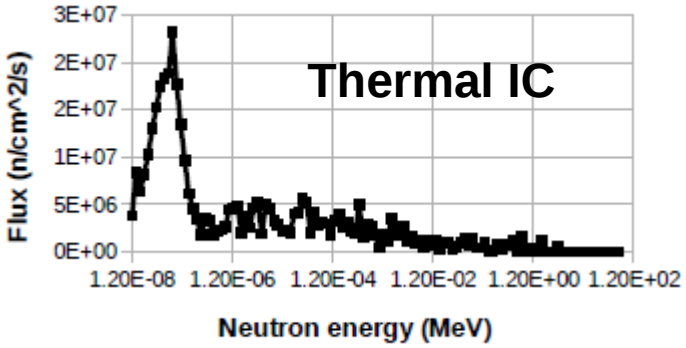

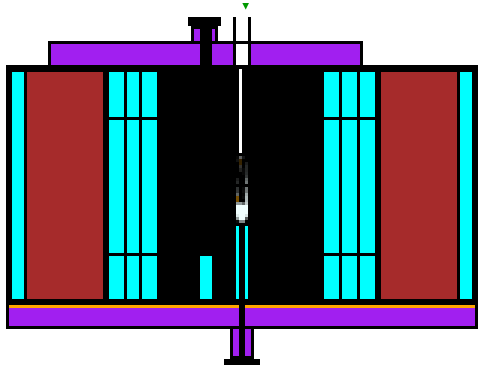

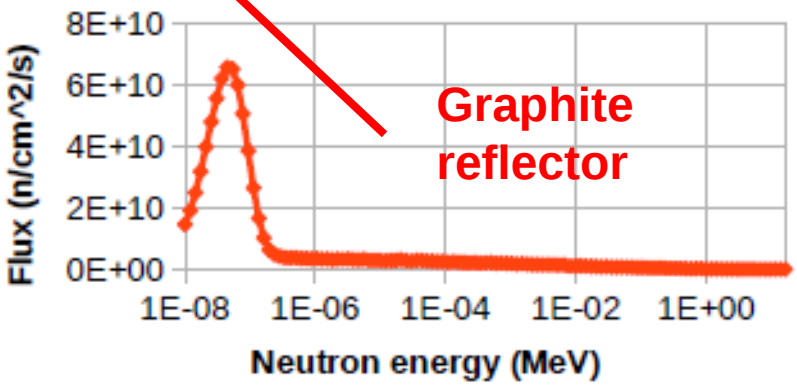

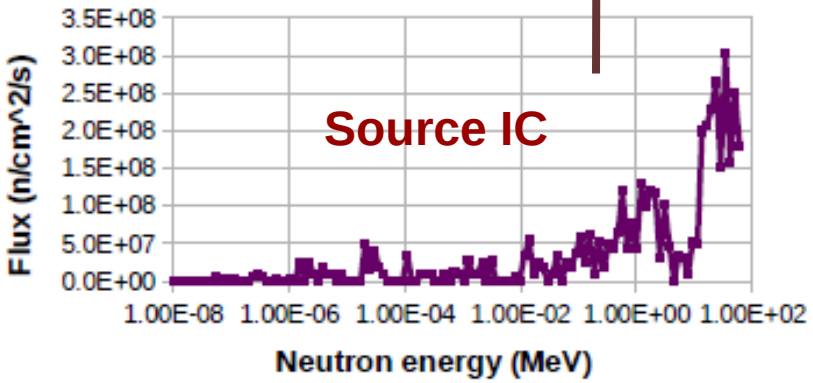

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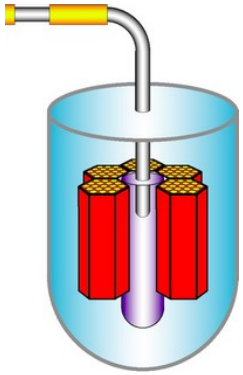
Milestone 3: study on fusion-fission hybrid systems (100% completed)

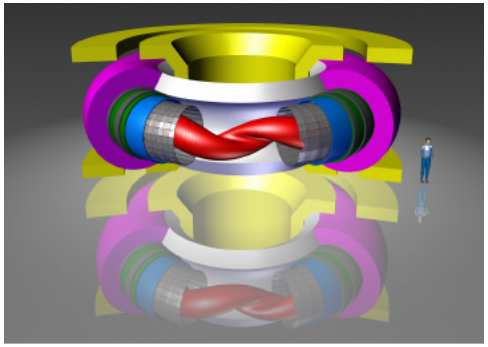
Hybrid system general concepts



Fission reactors

Advantages:
- High power level
- Carbon free
- Used and known technology
- Continuos operation mode

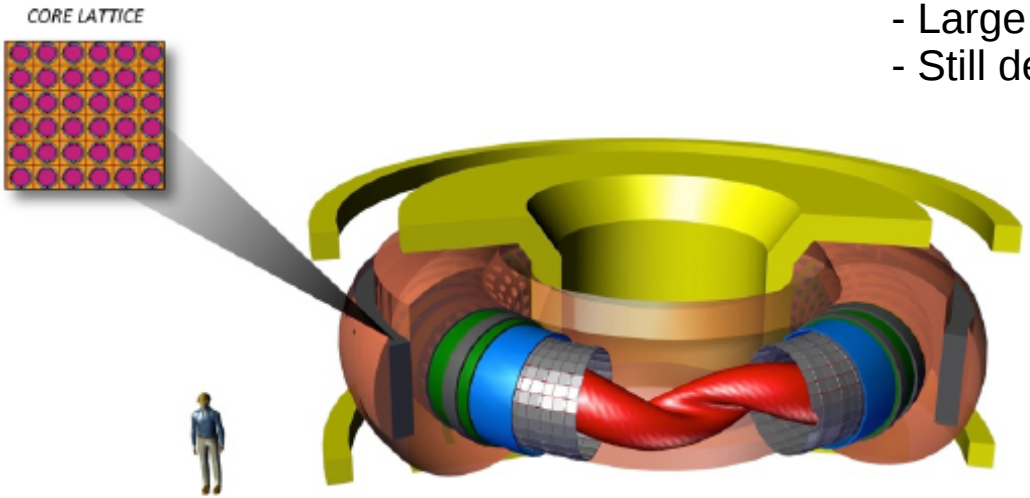
Disadvantages:
- Instability (critical reactors)
- Radioactive waste production



Fusion reactors

Advantages:
- High safety level
- Medium power level
- Carbon free
- Short lived activation product

Disadvantages:
- Pulsed operation mode
- Difficulties in tritium production
- Large dimension and costs
- Still developing technology



Fusion-fission hybrid system is a coupling between a fusion reactor, mainly acting as a neutron source and as well as less demanding power source, and a sub-critical fission reactor acting as a fusion power amplifier (FDS). Compared with fusion reactors, this system has higher power output, comparable safety level and smaller dimensions.

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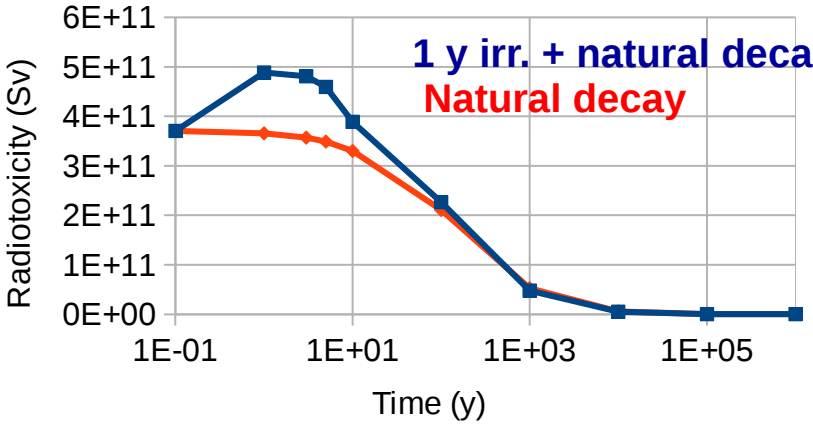
A fusion-fission hybrid reactor model for research and applications based on RF fusion machine

P_{fus} = 0.14 GW

P_{fiss} =1.25 Gw

K_{eff} = 0.973

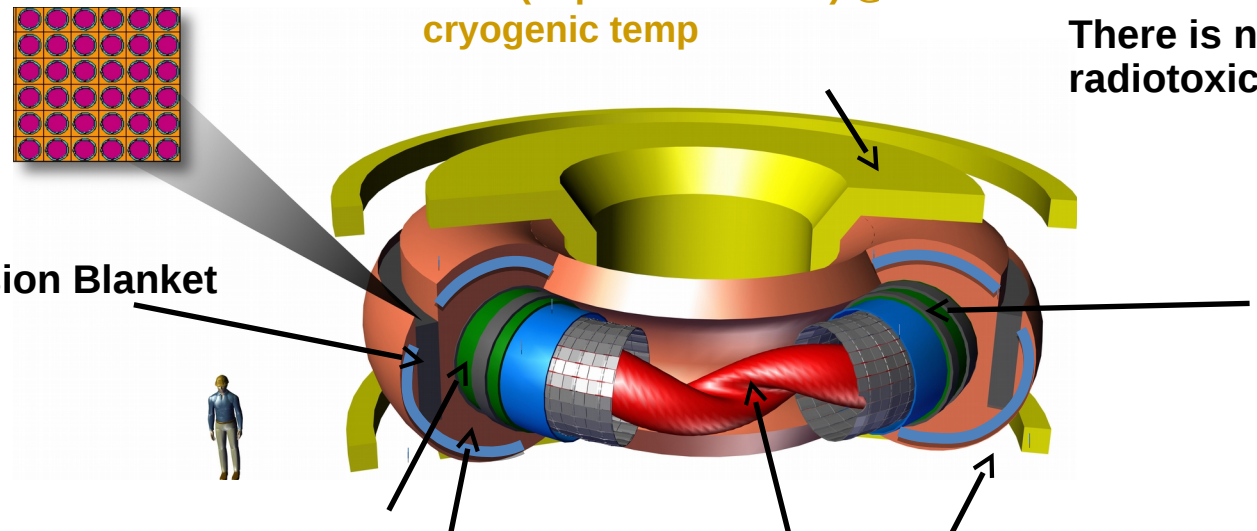
$P_{tot} = P_{fus}$ (10%) + P_{fiss} (90%)=
= 0.14 GW+1.25 GW=1.39 GW



There is no long-term penalty in radiotoxicity after energy production

Core Lattice containing repreocessed Pu/MA fuel

Central solenoid and equi coils (superconductive) @ cryogenic temp



Fission Blanket

Copper toroidal field coils @ room temperature

Steel vacuum vessel acs as supporting structure

Plasma D-T fusion 14 MeV neutrons

Lead

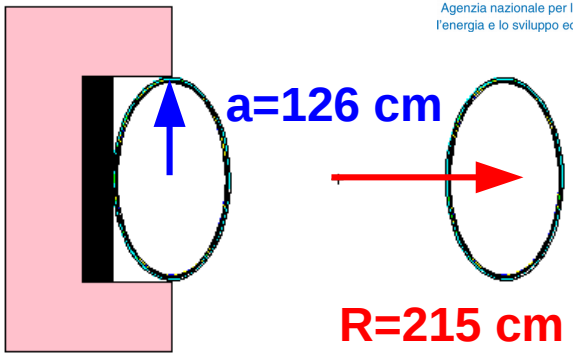
Tritium Breeding Blanket

Tritium consumption 21 g/day is completely balanced by tritium production in the Pb/Li blanket

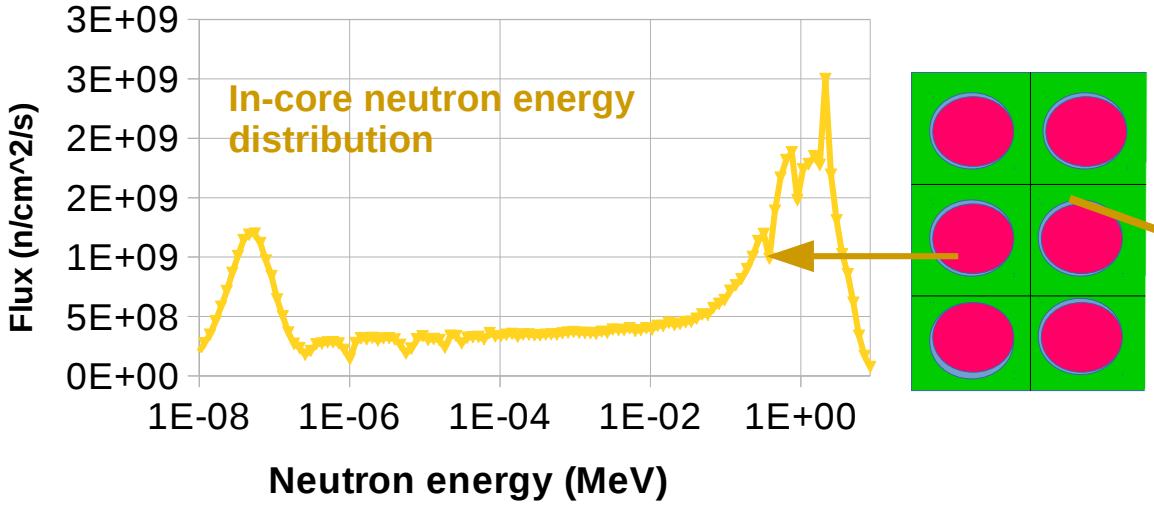
Sistemi intrinsecamente sicuri - SIS

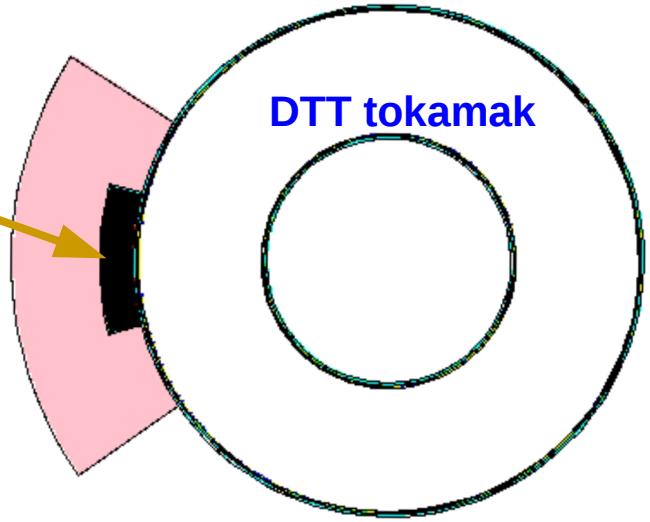
Simple FFH pilot experiment model based on DTT machine

Spent fuel fuel, R=0.45 cm, h=262 cm
Fuel zircalloy cladding thickness 0.068 cm
Graphite reflector 100 cm/139 cm
Water coolant
Core thickness 35 cm
Core length 150 cm (30 degrees)
k_{eff} = 0.86
P_{fus}=10 kW
P_{tot}=30 kW



D-D fusion
2.5 MeV neutrons





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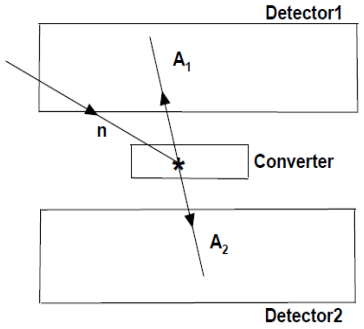
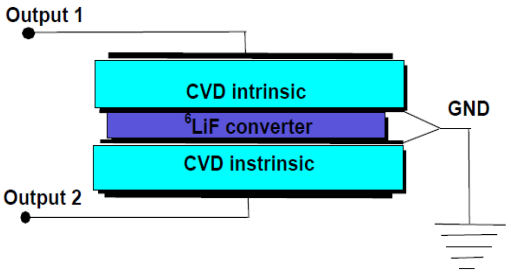
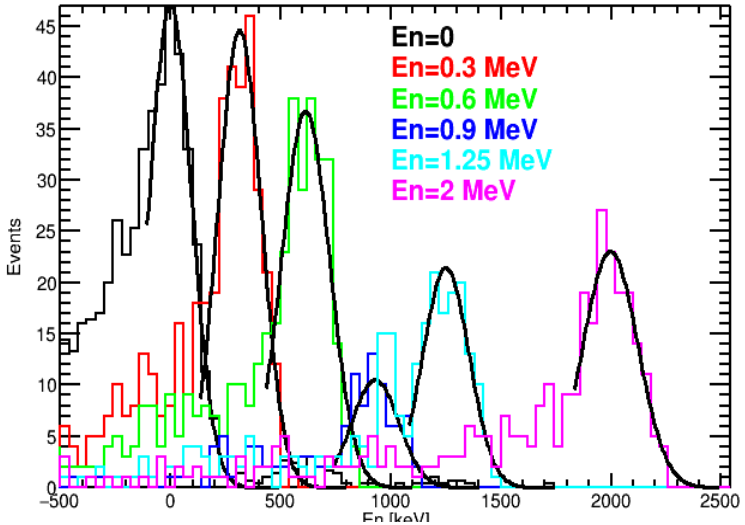
Milestone 4: development of new instrumentation for neutron monitoring based on diamond detectors (100% completed)

Neutron energy < ~ 6 MeV, exothermic reaction (Q = 4.7 MeV):

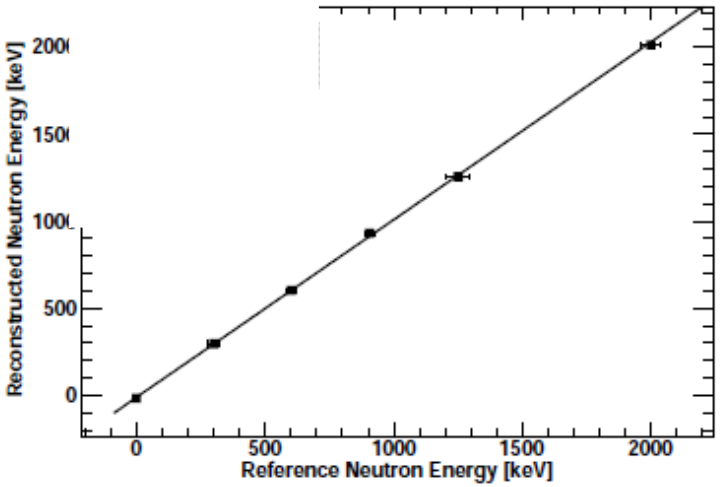
$n + {}^{6}Li \rightarrow t\,(2.73MeV) + \alpha\,(2.06MeV)$







- Experiment at PTB (Braunschweig) with certified mono-chromatic neutron source
- five beam energies + thermal calibration: 0-2 MeV
- reference energy reconstruction within 20 keV
- absolute neutron efficiency knowledge within 5%
- Resolution about 100 keV excluding energy loss tail at l.h.s. of distribution.



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SIS: list of publications

Papers on international reviews

1) G. Lomonaco, W. Borreani, M. Bruzzone, D, Chersola, G. Firpo, M. Osipenko, M. Palmero, F. Panza, M. Ripani, P. Saracco, C. M. Viberti, “Initial thermal-hydraulic assessment by OpenFOAM and FLUENT of a subcritical irradiation facility” Thermal Science and Engineering Progress, 2018 pag. 447 vol. 6C

2) S. Dulla, P. Ravetto, P. Saracco “The time eigenvalue spectrum for nuclear reactors in multi-group diffusion theory”, European Physical Journal Plus, 2018, pag 290 vol. 133

3) Fabio Panza, Walter Borreani, Gabriele Firpo, Guglielmo Lomonaco, Mikhail Osipenko, Marco Palmero, Giovanni Ricco, Marco Ripani, Paolo Saracco, Carlo Maria Viberti “An ADS irradiation facility for fast and slow neutrons” submitted to The European Physical Journal Plus

4) Chiara Bustreo, Piero Agostinetti; Paolo Bettini; Riccardo Casagrande; Roberto Cavazzana; Dominique Franck Escande; Fabio Panza; Roberto Piovan; Maria Ester Puiatti; Giovanni Ricco; Marco Ripani; Marco Valisa; Giuseppe Zollino; Matteo Zuin “RFP based Fusion-Fission Hybrid reactor model for nuclear applications” submitted to Fusion Engineering and Design

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SIS: list of publications

Conferences & meetings (2)

5) C. Bustreo, P. Bettini, R.Casagrande, R.Cavazzana, D.Escande, M. Osipenko, F.Panza, R.Piovan, M.E.Puiatti, G.Ricco, M.Ripani, M.Valisa, G.Zollino, M. Zuin "RFP based Fusion-Fission Hybrid reactor model for nuclear applications" 30th edition of the Symposium on Fusion Technology (SOFT 2018)

6) F.Panza, P. Bettini, C. Bustreo, R.Casagrande, R.Cavazzana, D.Escande, M. Osipenko, R.Piovan, M.E.Puiatti, G.Ricco, M.Ripani, M.Valisa, G.Zollino, M. Zuin "A fusion-fission hybrid reactor model for research and applications", 104° Congresso Nazionale Societa' Italiana di Fisica

7) F. Panza, G. Ricco, M. Ripani, M. Osipenko, M. Ciotti, I. Balog, F. P. Orsitto "Simple FFH pilot experiment model based on DTT-like machine", 3rd International Conference on Fusion Neutron Sources and Subcritical Fission Systems

8) R. Piovan, P. Agostinetti, P. Bettini, C. Bustreo, R. Cavazzana, D.F. Escande, M. Osipenko, F. Panza, M.E. Puiatti, G. Ricco, M. Ripani, M. Valisa, G. Zollino, M. Zuin "Preliminary integrated design of a RFP fusion core and a hybrid reactor blanket " 3rd International Conference on Fusion Neutron Sources and Subcritical Fission Systems

9) M. Carta, M. Salvatores, F. P. Orsitto, T. Burgio, V. Fabrizio, L. Falconi, M. Palomba, F. Panza "The experimental validation of the Fusion-Fission concept using a 'tokamak fusion blanket' coupled with a standard fission system", 3rd International Conference on Fusion Neutron Sources and Subcritical Fission Systems

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SIS: list of publications

Conferences & meetings

10) M. Osipenko, M. Ripani,P. Saracco, F. Panza, G. Lomonaco, D. Trucchi, M. Girolami, G. Verona-Rinati, F. Pompili,, M. Pillon, M. Angelone, R. Cardarelli "Compact neutron spectrometer for ADS characterization", 3rd Meeting IAEA CRP ADS 10-14 December 2018 Budapest

11) P. Saracco et al. Study of heterogeneity (reflector) effects on kinetic parameters (lifetime), 3rd Meeting IAEA CRP ADS 10-14 December 2018 Budapest

12) P. Saracco et al. "Reformulation of the multipoint method and definition of parameters", 3rd Meeting IAEA CRP ADS 10-14 December 2018 Budapest

13) P. Saracco et al. "Investigation of methods for the experimental and computational determination of integral parameters (e.g., the effective delayed-neutron fraction and prompt generation time)", 3rd Meeting IAEA CRP ADS 10-14 December 2018 Budapest

14) P. Saracco et al. "Development of methods for the mitigation of spatial and spectral effects (combination of the signals of local detectors", 3rd Meeting IAEA CRP ADS 10-14 December 2018 Budapest

14) P. Saracco et al. "Study of a source oscillation method for experimental estimation of integral parameters", 3rd Meeting IAEA CRP ADS 10-14 December 2018 Budapest
15) P. Saracco et al. "Study of effects of models on the estimation of the effective mean prompt generation time", 3rd Meeting IAEA CRP ADS 10-14 December 2018 Budapest

Sistemi intrinsecamente sicuri - SIS

Milestones 2019

1. Completion of studies for pilot experiment on fusion-fission hybrid concepts

2. Completion of studies on fusion-fission hybrid based on RFP fusion machine and publication of a paper

3. Extension of studies on hybrid fusion-fission system based on RFP fusion machine, considering alternative fuels among which the possibility to use spent fuel)

4. Prepare paper on diamond sandwich detector characterization at PTB Braunschweig

Sistemi intrinsecamente sicuri - SIS

ENEA and RFX consortium invitation letters to continue the collaboration on FFHS

ENEA

AGENZIA NAZIONALE PER LE NUOVE TECNOLOGIE, L'ENERGIA E LO SVILUPPO ECONOMICO SOSTENIBILE

Divisione FSN-FISS
Divisione Tecnologie, Impianti e Materiali per la Fissione Nucleare
Il Responsabile

Casaccia, 14/12/2018

Prot. ENEA/2018/69330/FSN-FISS

CENTRO FERMI
Museo Storico della Fisica e Centro Studi e Ricerche Enrico Fermi
Piazza del Viminale 1

00184 Roma (Italy)

Oggetto: proseguimento collaborazione per progetto reattori ibridi Centro Fermi-ENEA-INFN

La collaborazione tra Centro Fermi, ENEA ed INFN sul progetto riguardante i reattori ibridi fusione-fissione, iniziata nel 2018, ha avuto come oggetto lo studio preliminare di un esperimento pilota basato sui reattori ibridi fusione-fissione. Questo tipo di reattore è composto da una macchina a fusione che assume la funzione primaria di generare neutroni, per cui la potenza richiesta non è elevata, successivamente utilizzati dal blanket di fissione che produce la maggior parte della potenza generata dal sistema. Questo aspetto è sicuramente interessante anche dal punto di vista della realizzazione di macchine a fusione, considerando che in questo caso le caratteristiche non devono essere portate al limite. Dal punto di vista fissione, questi sistemi potrebbero fornire indicazioni interessanti sugli aspetti dell'accoppiamento dei due sistemi, nonché sull'incenerimento delle scorie nucleari.

Come primo schema di esperimento pilota, è stata studiata una configurazione che parte dal tokamak progettato per la facility DTT (Divertor Tokamak Test facility), che induce reazioni di fusione deuterio-deuterio con l'emissione di circa 10^{16} neutroni al secondo. Sono quindi state disegnate tre possibili soluzioni di bassa potenza basate su diversi tipi di combustibile, materiali e raffreddamento, pensate per mantenere una relativa semplicità costruttiva e dimensioni contenute. Si prevede che la suddetta attività possa proseguire sia per ottimizzare le possibili configurazioni fra le molte possibili di accoppiamento fusione-fissione, sia per studiare scenari di funzionamento di reattori a fissione sottocritici e gli effetti di iniezione di criticità mediante una sorgente esterna, scenario che si prevede possa essere ottenuto sperimentalmente utilizzando il reattore Triga presente presso il centro Enea di Casaccia.

Si ritiene quindi opportuna la prosecuzione di questa collaborazione, sia per permettere la continuazione dell'attuale studio, considerando eventualmente anche altri modelli, sia per progettare un reale esperimento qualora a livello internazionale si verificasse un interesse in tal senso.

Con i migliori saluti

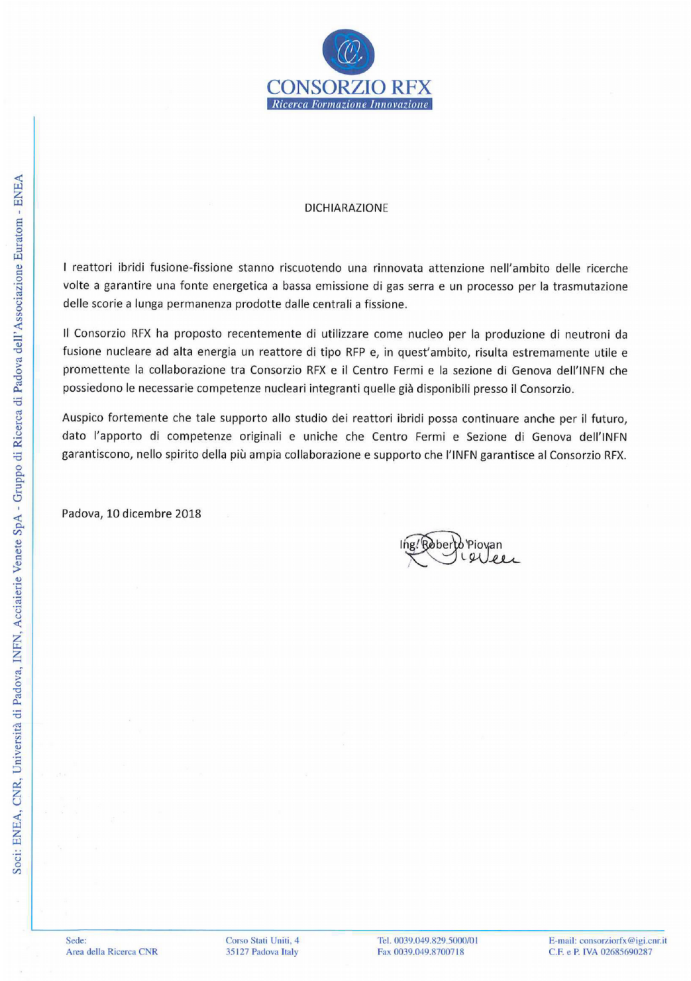
ENEA
DIPARTIMENTO FUSIONE E TECNOLOGIE PER LA SICUREZZA NUCLEARE
Divisione Tecnologie, Impianti e Materiali per la Fissione Nucleare
Il Responsabile

Divisione FSN-FISS
Divisione Tecnologie, Impianti e Materiali per la Fissione Nucleare

Centro Ricerche Casaccia
Via Anguillarese 301
00123 Santa Maria di Galeria (Roma)

Tel. +39-06-30486586
Fax +39-06-30483147
alessandro.dodaro@enea.it

Sede Legale - Lungotevere Thaon di Revel, 76 - 00196 Roma - Italia – Tel. +39-06-36271
Partita IVA 00985801000 - Codice Fiscale 01320740580 - www.enea.it



CONSORZIO RFX
Ricerca Formazione Innovazione

Soci: ENEA, CNR, Università di Padova, INFN, Acciaierie Venete SpA - Gruppo di Ricerca di Padova dell'Associazione Euratom - ENEA

DICHIARAZIONE

I reattori ibridi fusione-fissione stanno riscuotendo una rinnovata attenzione nell'ambito delle ricerche volte a garantire una fonte energetica a bassa emissione di gas serra e un processo per la trasmutazione delle scorie a lunga permanenza prodotte dalle centrali a fissione.

Il Consorzio RFX ha proposto recentemente di utilizzare come nucleo per la produzione di neutroni da fusione nucleare ad alta energia un reattore di tipo RFP e, in quest'ambito, risulta estremamente utile e promettente la collaborazione tra Consorzio RFX e il Centro Fermi e la sezione di Genova dell'INFN che possiedono le necessarie competenze nucleari integranti quelle già disponibili presso il Consorzio.

Auspico fortemente che tale supporto allo studio dei reattori ibridi possa continuare anche per il futuro, dato l'apporto di competenze originali e uniche che Centro Fermi e Sezione di Genova dell'INFN garantiscono, nello spirito della più ampia collaborazione e supporto che l'INFN garantisce al Consorzio RFX.

Padova, 10 dicembre 2018

Ing. Roberto Piovan

Sede:
Area della Ricerca CNR

Corso Stati Uniti, 4
35127 Padova Italy

Tel. 0039.049.829.5000/01
Fax 0039.049.8700718

E-mail: consorziorfx@igi.cnr.it
C.F. e P. IVA 02685690287

Roma, December 2018 - PTA

Sistemi intrinsecamente sicuri - SIS

Plan of activities 2019 - 2021

- The first study is in collaboration with ENEA and its aim is to devise a so-called pilot experiment where the fusion machine is taken from a real example of a reactor working in D-D fusion mode (e.g. the proposed DTT in Italy) and the fission blanket power is extremely low such as to make all engineering aspects like the cooling easier to realize.Within this collaboration there may be the possibility to design an experiment either at their Casaccia research center, by coupling a D-T neutron generator to one of their research reactors, or at the Frascati Neutron Generator. Within the collaboration with RFX,

- In he second study, in collaboration with RFX Consortium in Padua, Italy, we will consider the Reversed Field Pinch concept, that has the advantage of providing a higher duty cycle in terms of length of plasma pulses with respect to transients and the advantage of offering more free space as it does not have toroidal coils. In this case, the aim is to design a high power system (fusion machine working with D-T and fission blanket providing thermal power of the order of the GW), We plan to explore in particular other fuel compositions, including the possibility to recycle commercial spent fuel directly, or to insert a Thorium blanket for breeding U-233 fuel.

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Plan of activities 2019 – 2021 (2)

- If it will be possible to set up a collaboration with the group of Prof. R. Gatto at University of Rome - La Sapienza, we may take advantage of their perturbative methodology to investigate various configurations before launching Monte Carlo simulations. Indeed, their methodology allows to obtain fast estimates of various quantities of interest by varying some design parameters, thereby driving the input to the more time-consuming Monte Carlo.

- Theoretical studies on general properties of subcritical systems will continue, with the goal of obtaining a deeper insight into the non-trivial behavior of such assemblies.

- On the experimental side, we will try to solve a residual problem observed in our diamond sandwich detector. The detector has proven to be able to measure the energy of neutrons thanks to its conversion to charged ions from a Lithium film. However, the diamond response still shows a low energy tail that worsens the energy resolution and whose origin is not clear. We would like to investigate whether such tail is coming from the presence of an inactive diamond layer and what could cause such layer to form, by testing diamonds prepared with different procedures.

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Expected funding in the 3-year period:

- **Request of funding by Centro Fermi**
  - ✓ Grant: renewal of postdoc fellowship in October 2019 for a third year
  - ✓ Max 20 k€ for consumables and travel expenses per year
  - ✓ INFN provides some cofunding

- Potential external funding:

- ✓ Euratom H2020 program calls in Work Programme 2019-2020
- ✓ Project proposal on diamond detectors submitted to European call ATTRACT

- Collaborations:

- ✓ Collaboration with Consorzio RFX on fusion-fission hybrids will continue
- ✓ Collaboration with ENEA and CREATE on fusion-fission hybrids will continue
- ✓ Proposal for collaboration with Prof. R. Gatto, University of Rome La Sapienza, on deterministic calculations on fusion-fission hybrids → Prof. Gatto submitted application to become a CF research associate