GENeuSIS: a novel concept of test bed facility for diagnostics and critical components of ITER

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This work has been carried out within the framework of the EUROfusion Consortium, funded by the European Union via the Euratom Research and Training Programme (Grant Agreement No 101052200 — EUROfusion). Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Commission. Neither the European Union nor the European Commission can be held responsible for them.

Introduction

- Diagnostics, electronics and other critical systems installed in ITER will be exposed to complex neutron and gamma radiation fields
- Accurate knowledge of the radiation field and its characterization is fundamental to:
  - ✓ Ensure sufficient protection & demonstrate reliability of diagnostics, electronics and critical systems
  - ✓ Design and in-situ calibration of neutron diagnostic systems by ensuring the requested accuracy
- The radiation field has a *large variability in space, energy, angle & time* across ITER plasma operations and several responses/effects depends on the energy spectra distribution
- The existing neutron facilities are not able to reproduce the complexity and variability of the energy spectra in the locations where the systems are located in ITER

GENeuSIS project

GENeuSIS project

A Novel concept of neutron test bed facility

GENeuSIS

General
Experimental
Neutron
Systems
Irradiation
Station

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**

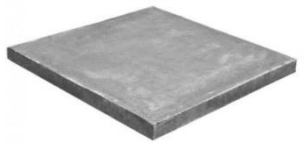
Recent studies focused to reproduce some ITER relevant neutron energy spectra using the 14 MeV neutrons produced at the **Frascati Neutron Generator (FNG)**.

R. Villari ITPA Diagnostics -43rd ITPA Diagnostics May 2023, Eindhoven

GENeuSIS 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**

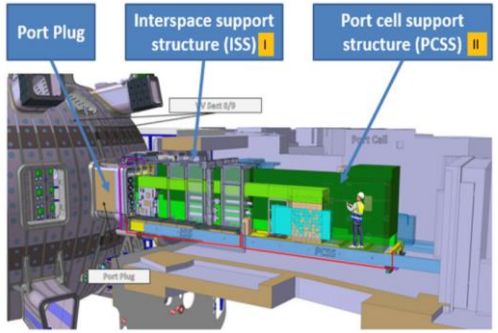
The replacement/substitution of bricks/layers to reproduce various neutron spectra. Housing for gamma sources to reproduce various gamma spectra

- **Customizable**

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

- **Multi-purpose**

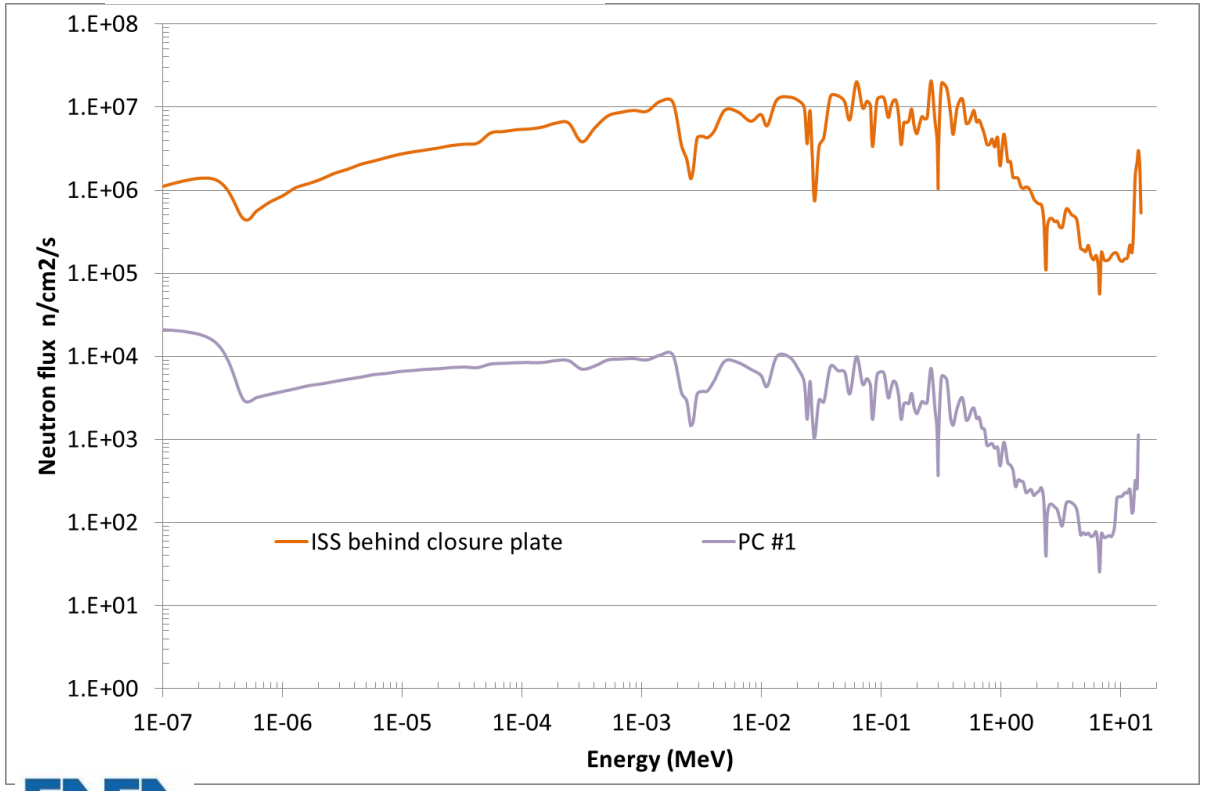
ITER Diagnostics EP#12 spectra for GENeuSIS



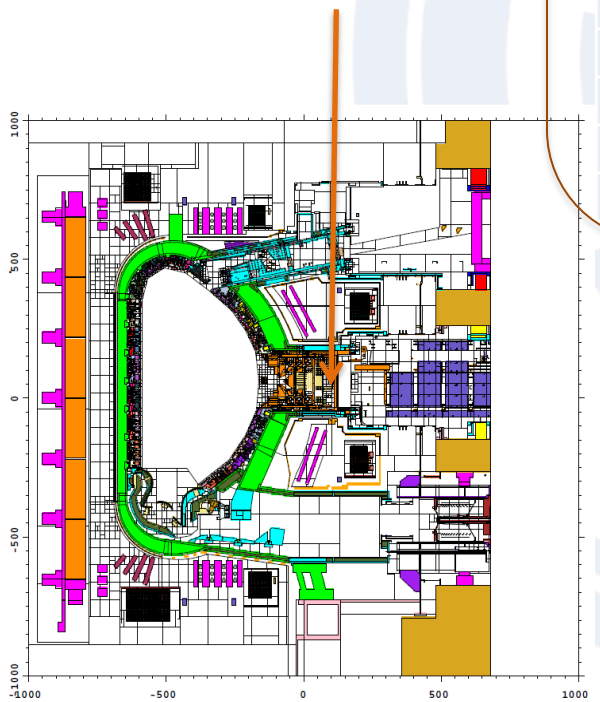
- PI: diagnostics
- PC: electronics

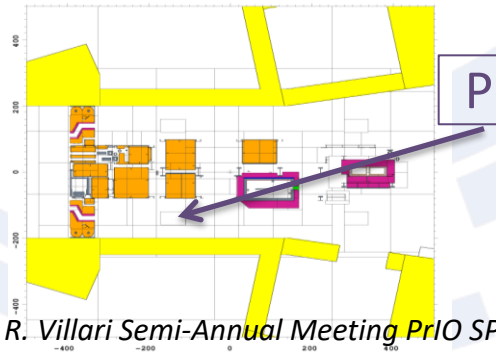
Location	N flux @ 500 MW (n/cm²/s)
PI-ISS behind Closure plate	7.62×10^8
PC#1	5.61×10^5

E_{min} (MeV)	E_{max} (MeV)	PI % E	PC % E
1E-11	1E-07	0.1	4.1
1E-07	1E-06	0.4	4.6
1E-06	1E-05	1.9	8.1
1E-05	1E-04	4.3	11.8
1E-04	1E-03	8.5	15.3
1E-03	1E-02	11.0	14.3
1E-02	1E-01	26.7	20.7
1E-01	1	41.9	19.2
1	5	3.6	1.3
5	10	0.3	0.2
10	20	1.4	0.7



PI- behind closure plate



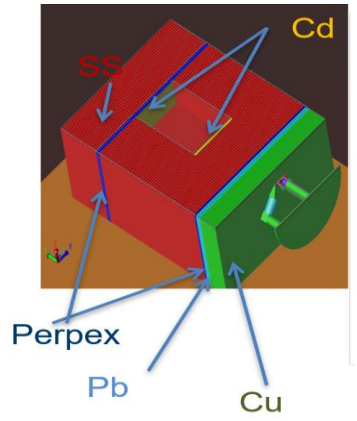


PC #1

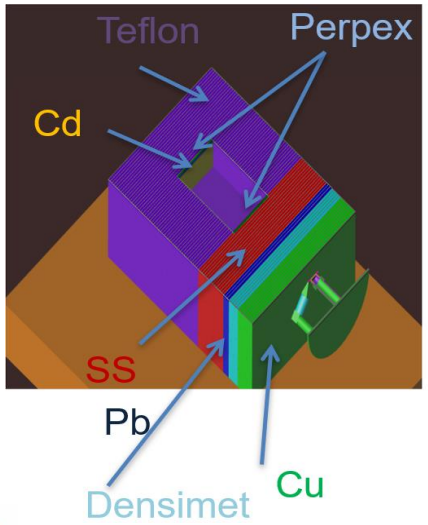
R. Villari Semi-Annual Meeting PrIO SP5, July 2024

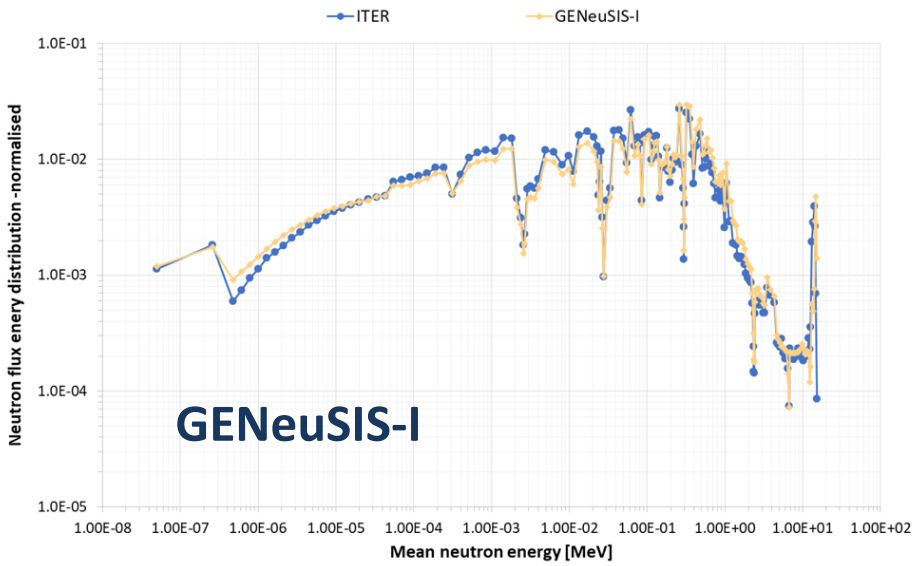
GENeuSIS design to replicate ITER Port Interspace & Port Cell

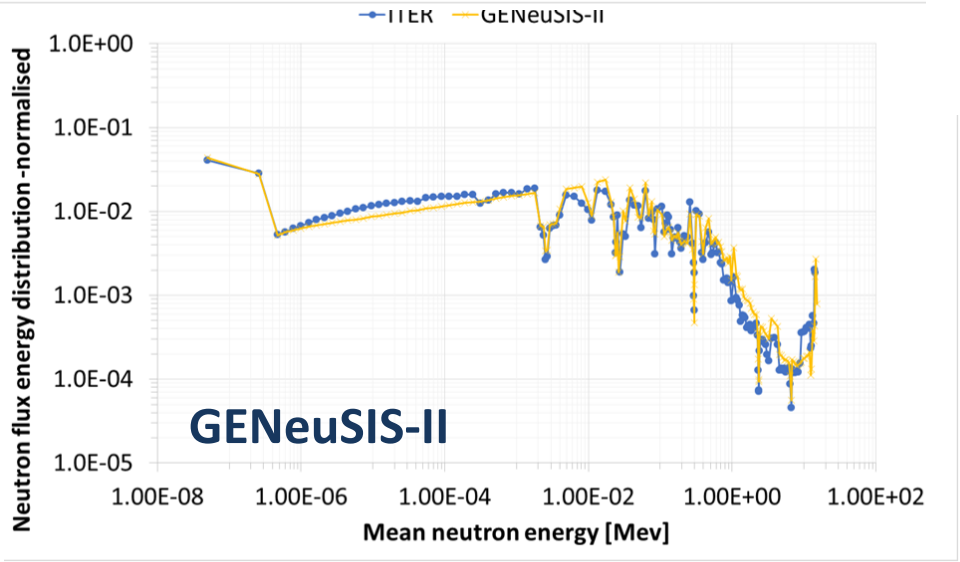
Port Interspace (GENeuSIS-I)

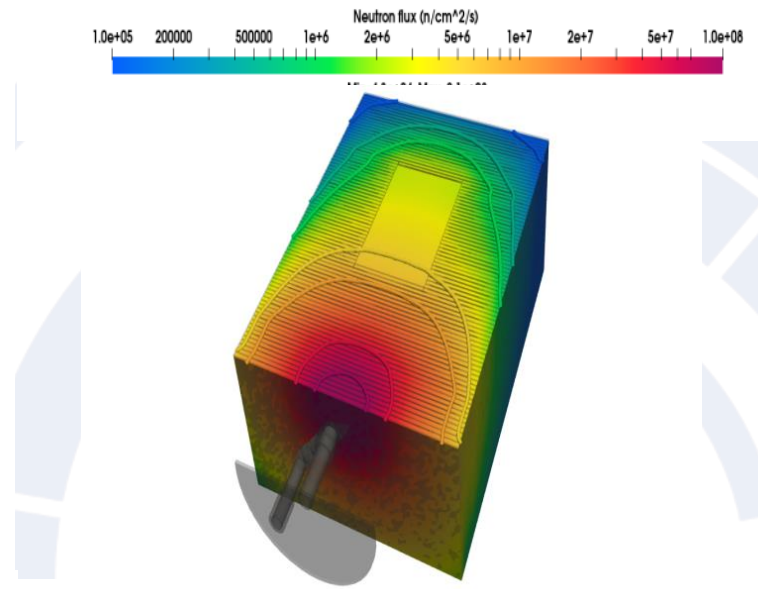


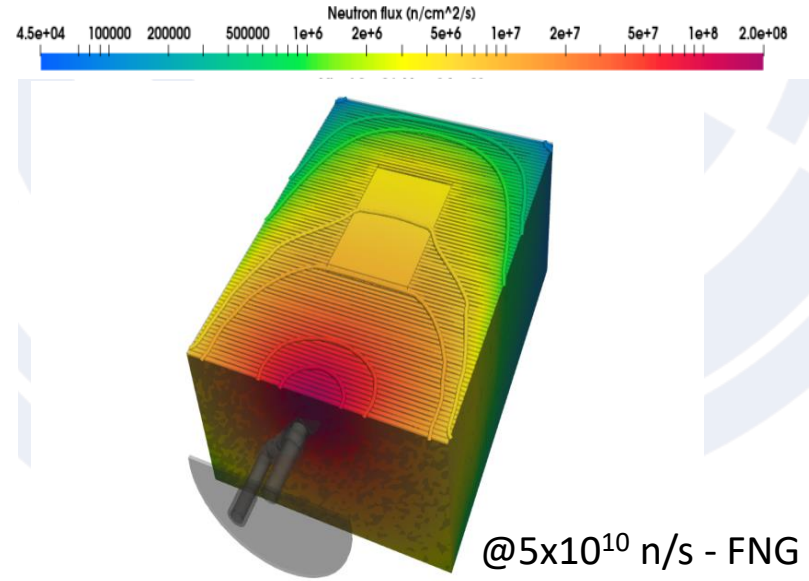
Port Cell (GENeuSIS-II)











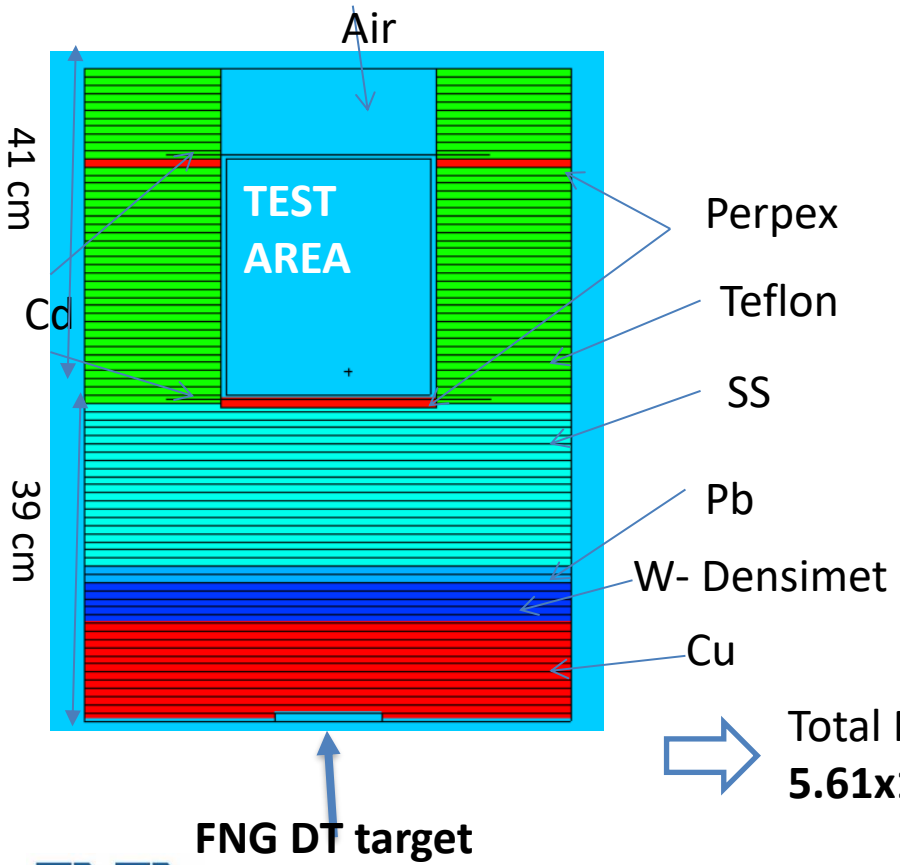
@5x10^{10} n/s - FNG

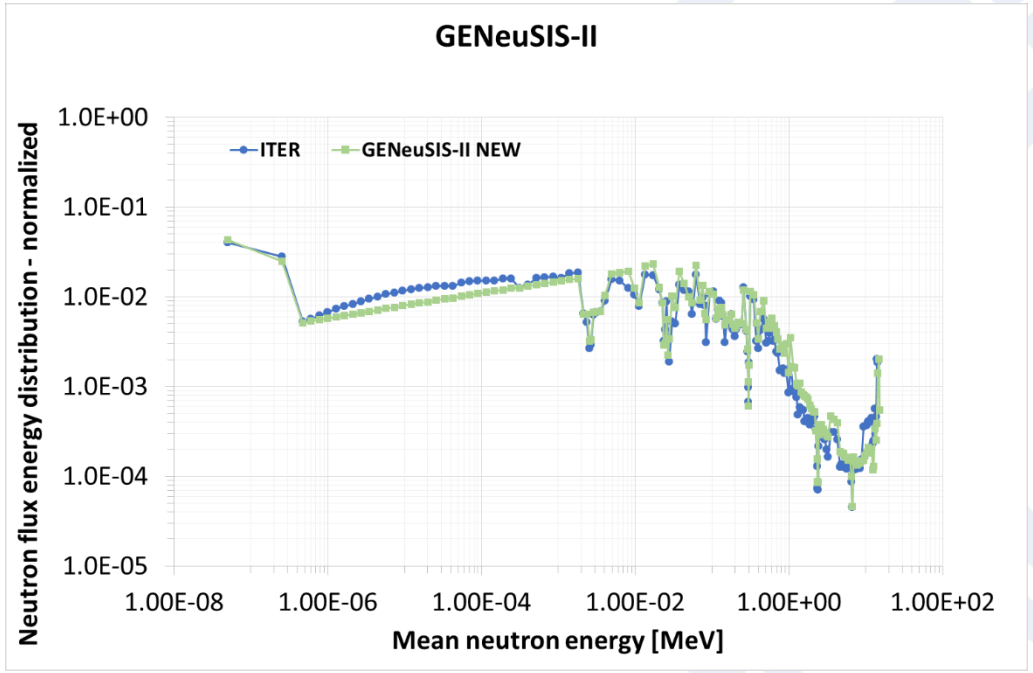
R. Villari ITPA Diagnostics -44th ITPA Diagnostics Nov 2023, Cadarache

Optimization of GENeuSIS-II design

- Reduced dimension, weight & cost
- Enabled the electronics installation & cables connection

Assembly 45x80x47 cm3, wt. 1 ton





Average ratio
1.01 σ 0.25

Emin (MeV)	Emax (MeV)	N flux normalised GENeuSIS/ ITER
1E-11	1E-07	1.07
1E-07	1E-06	0.97
1E-06	1E-05	0.78
1E-05	1E-04	0.74
1E-04	1E-03	0.78
1E-03	1E-02	1.11
1E-02	1E-01	1.14
1E-01	1	1.15
1	5	1.61
5	10	0.93
10	20	0.85

Total Neutron flux in Test cavity: 2.9×10^{-5} n/cm^2/source

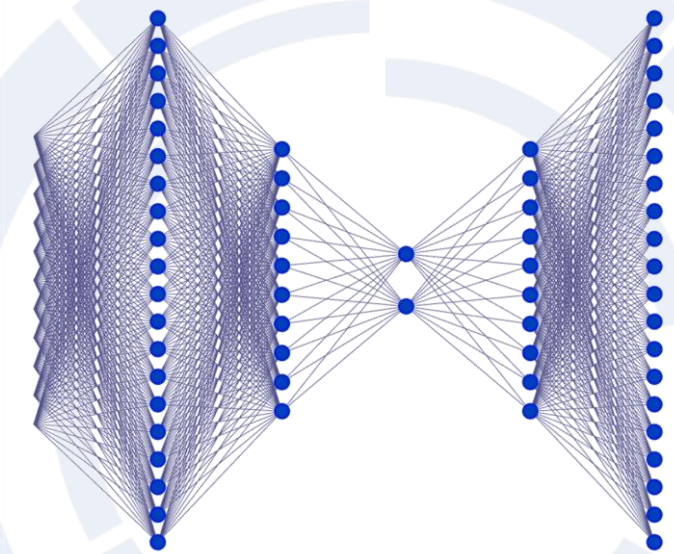
5.61×10^5 n/cm^2/s same N flux of ITER Port Cell @ FNG DT intensity ~2×10^{10} n/s

Next steps

- ✓ **Engineering design**
- ✓ **Procurement of materials**

GENeuSIS AI: Machine learning development

The simulations made during the design phase of GENeuSIS-I and GENeuSIS-II allowed the generation of a database used for training a **supervised machine learning model, based on Neural Networks.**



speed up the pre-analysis (from weeks to one day) and select the best combination of materials able to reproduce any further neutron (/gamma) energy spectra.

#	Material
1	SS
2	Pb
3	Perspex
4	Cd
5	Cu
6	Densimet
7	Teflon
8	B4C
9	Air

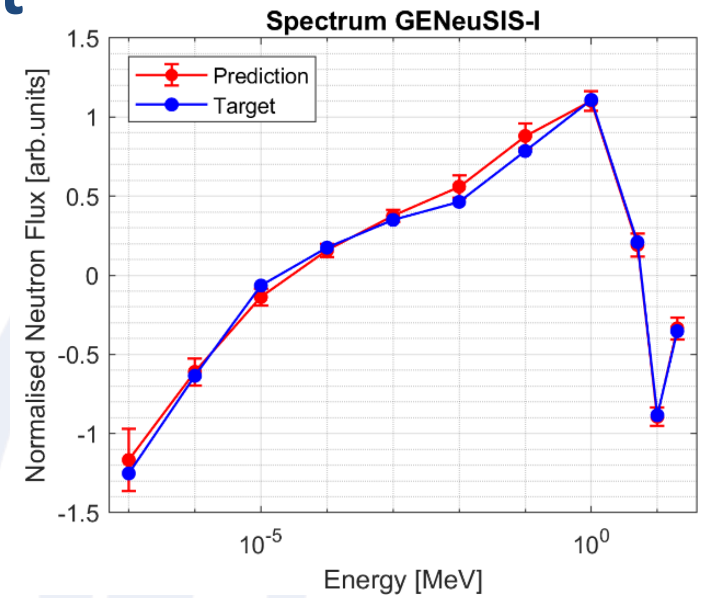
- First step: **database** generation → **matrix based** instead of string based
- Second step: materials → fluxes
- Third step: Variational AutoEncoder (VAE)
- Fourth step: fluxes → materials

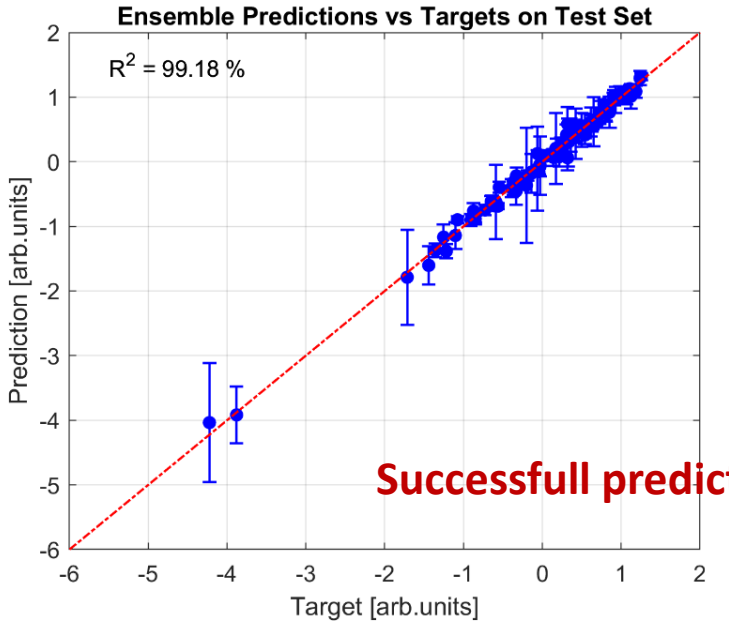
GENeuSIS AI: Machine learning development

- **Materials → Fluxes**

  - MATLAB code
  - Division in training set and test set (90% - 10%)
  - Initialization of Fully Connected Neural Network [10 5 2 5 10]
  - Bottleneck technique to avoid overfitting
  - Ensemble made of 30 Neural Network (NN)

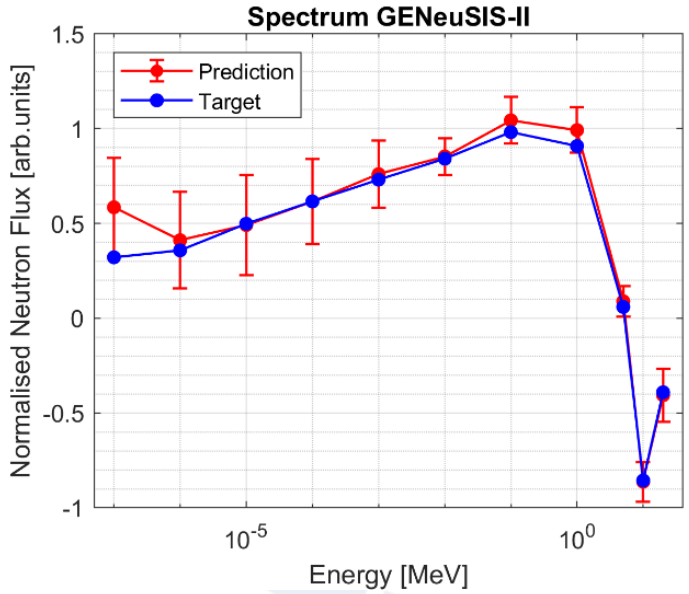
GENeuSIS-I AI





Successfull predictions

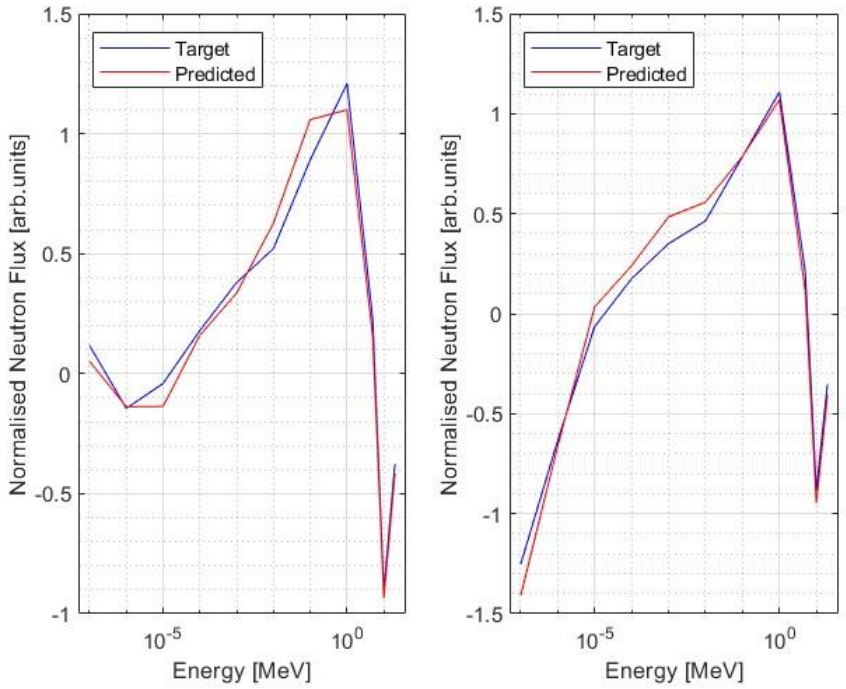
GENeuSIS-II AI



GENeuSIS AI: Machine learning development

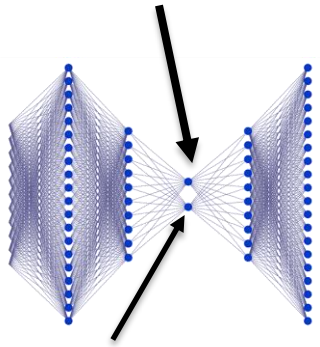
- **VAE: Variational AutoEncoder**

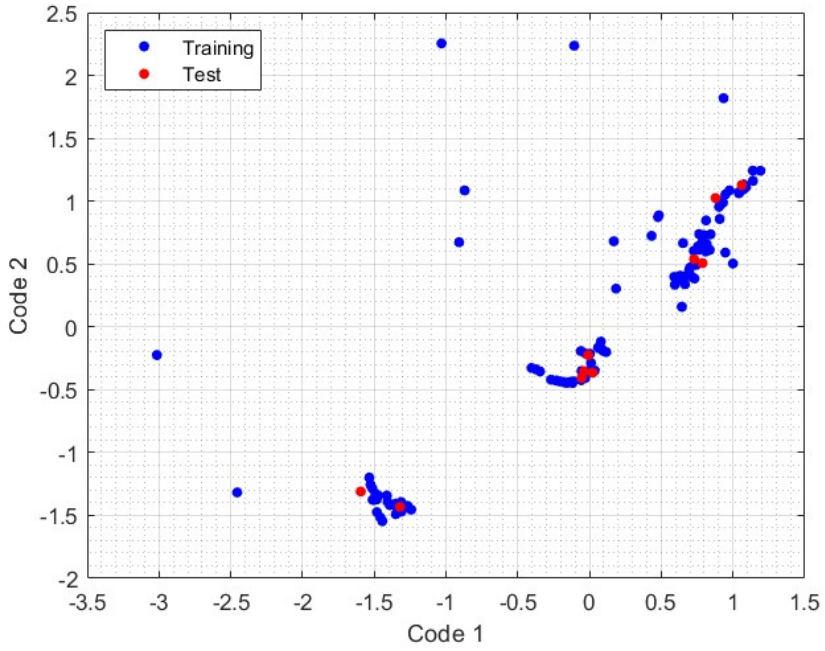
  - It allows the generation of new data similar to the input data
  - Use an explicit likelihood-based approach, ensuring that the generated data follows a probabilistic model



New fluxes generated with VAE: similar but not equal to the initial ones

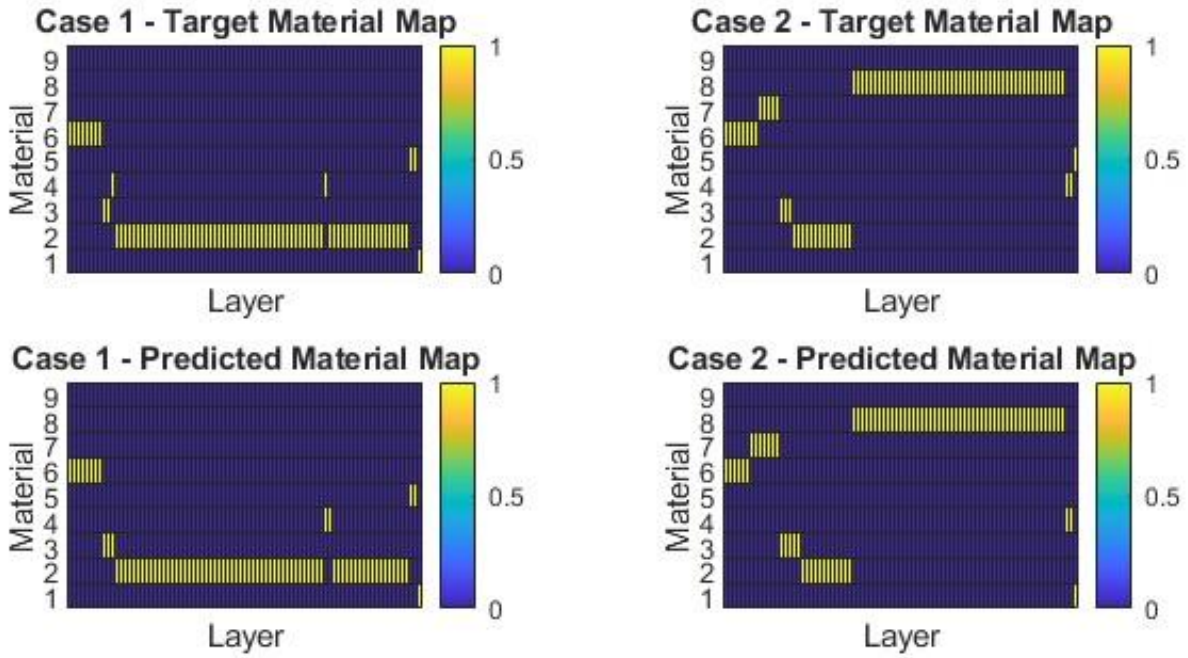
If the test points (red) exhibit a significant distance from the training points (blue),
the flux deviates substantially from the reference database



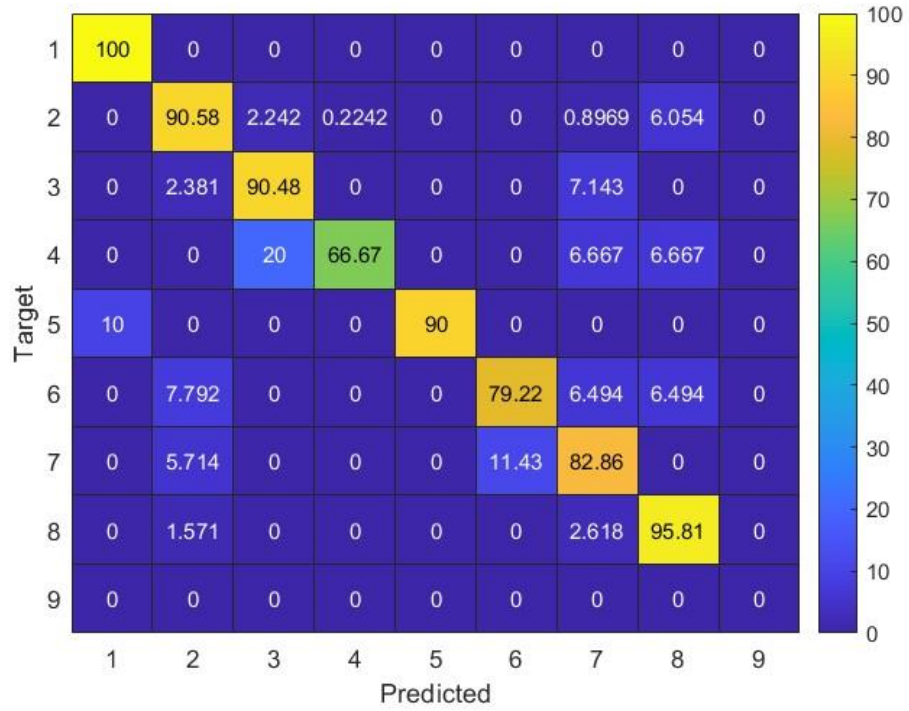


GENeuSIS AI: Machine learning development

- **Fluxes → Materials**



Confusion Matrix: how accurately the model's predictions correspond to the true classifications



Next steps

- ✓ GENeuSIS-III: sample spectrum
- ✓ Targeted MCNP simulations to **increase the database**

THANK YOU

Appendix

- **Fluxes → Materials**