Analysis of capabilities of the collimated neutron beam facility at IFMIF-DONES

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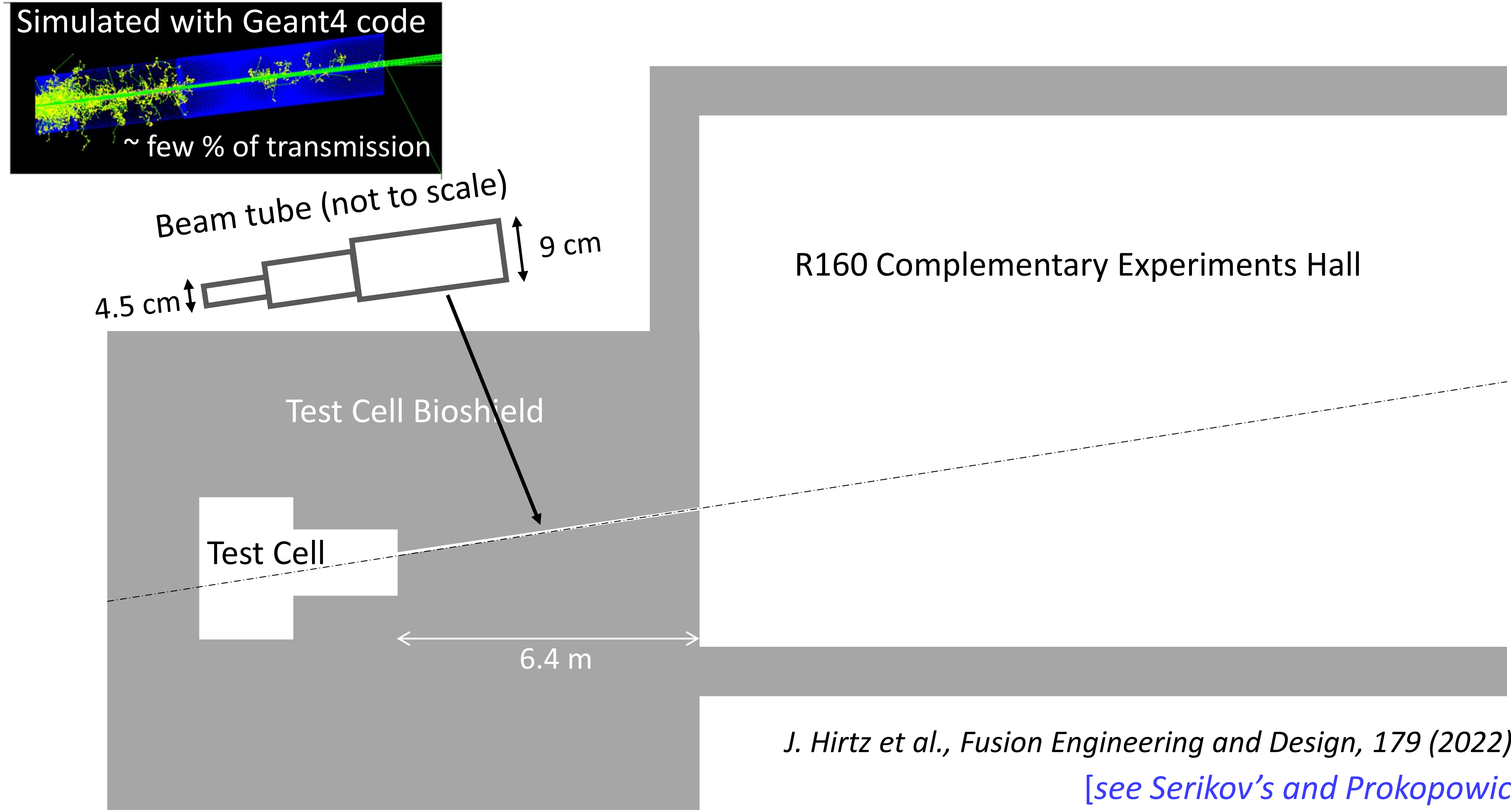
First IFMIF-DONES Users Workshop – 26-27 September 2022

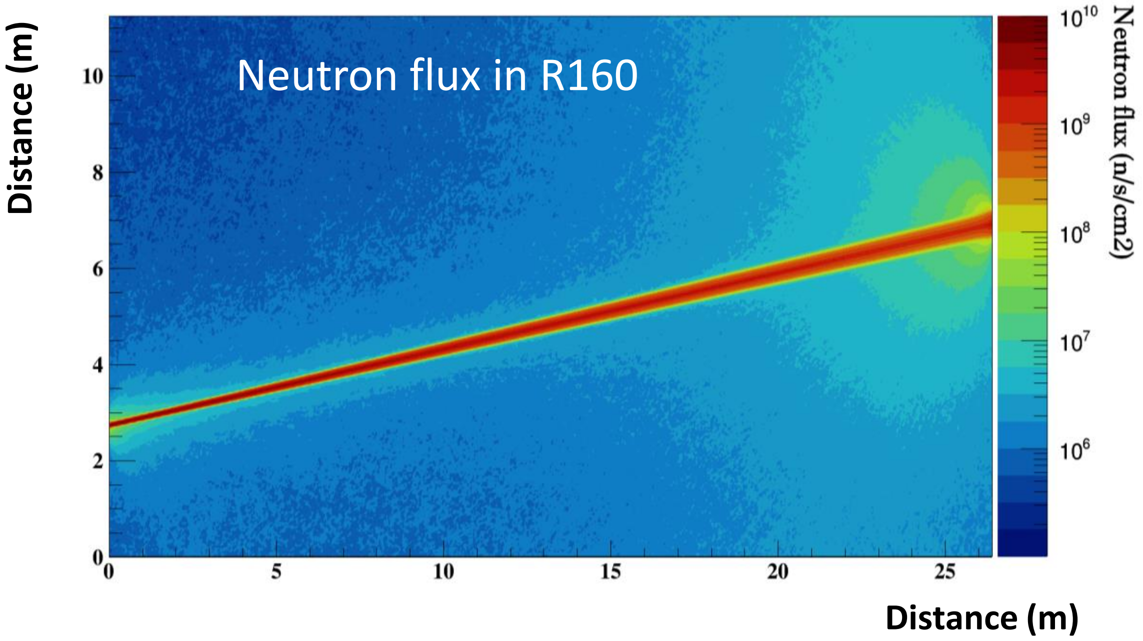
Collimated Neutron Beam Line

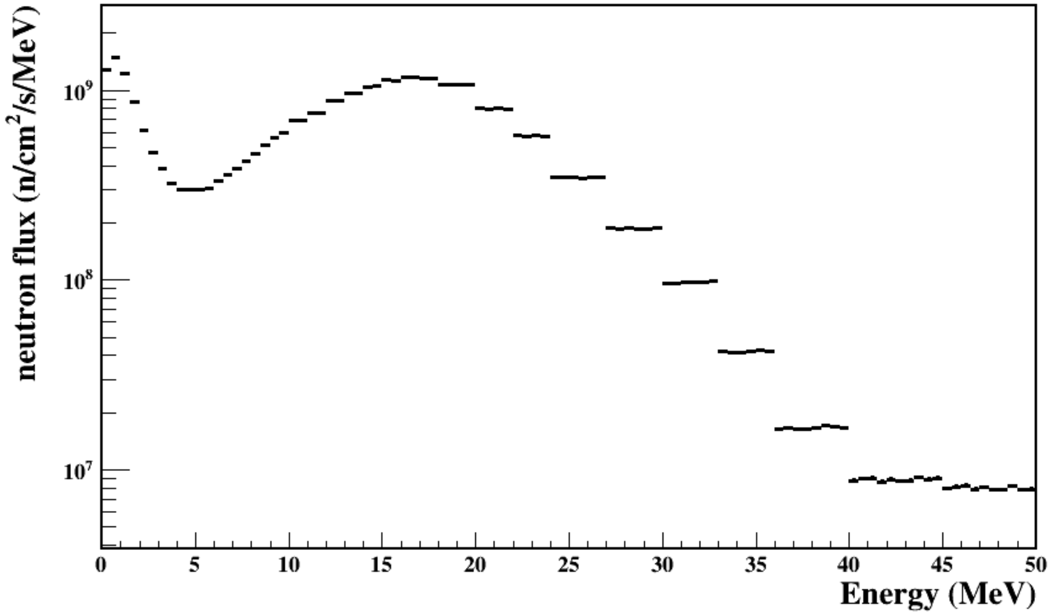


J. Hirtz et al., Fusion Engineering and Design, 179 (2022) 113133

[see Serikov's and Prokopowicz's talk]

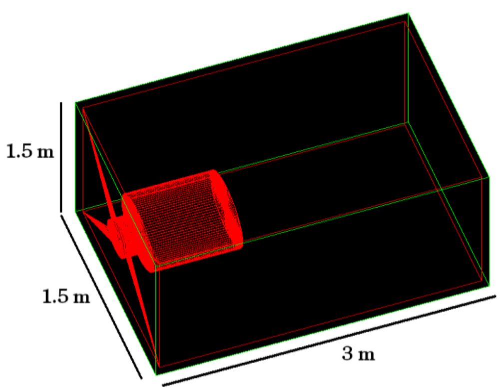
Collimated unmoderated neutron beam

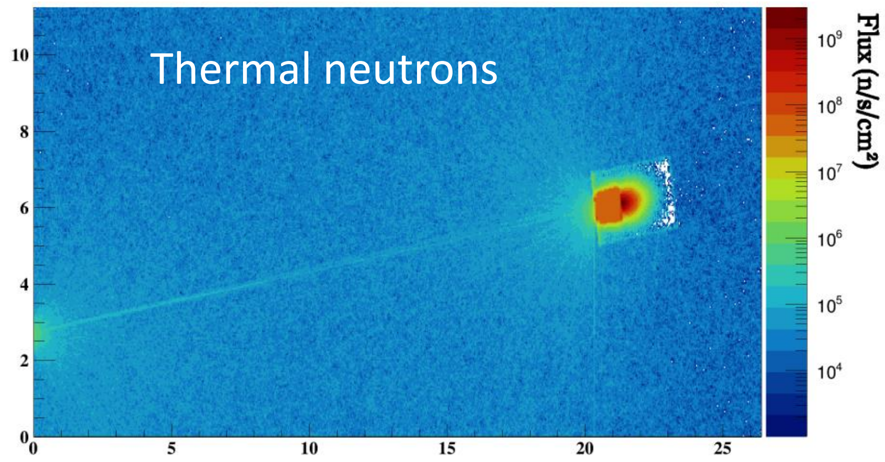


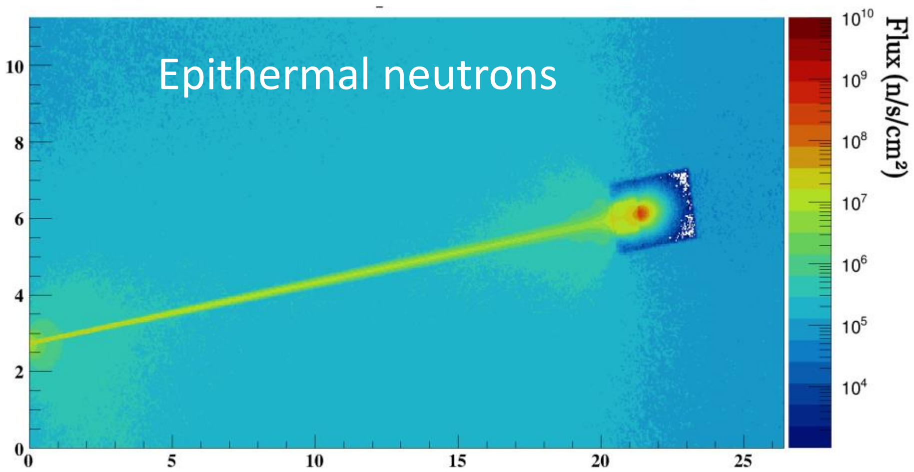


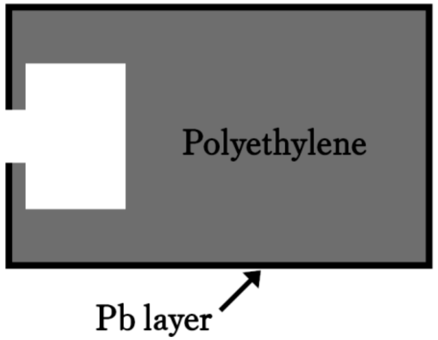
- High-flux (~2. 10^{10} n/cm^2/s at nominal operation 125 mA deuteron beam)
- Covering a large energy range
- Collimated neutron beam (~98% of the neutrons with θ < 1°)

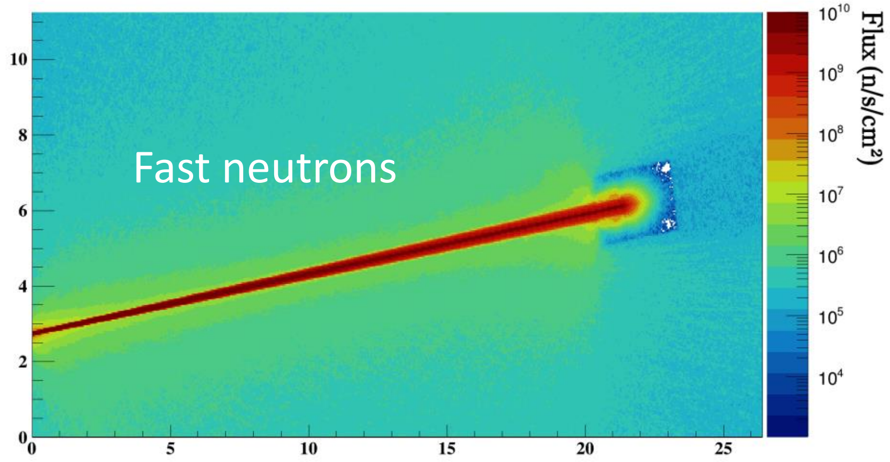
Expected ambient doses in the hall with a beam dump

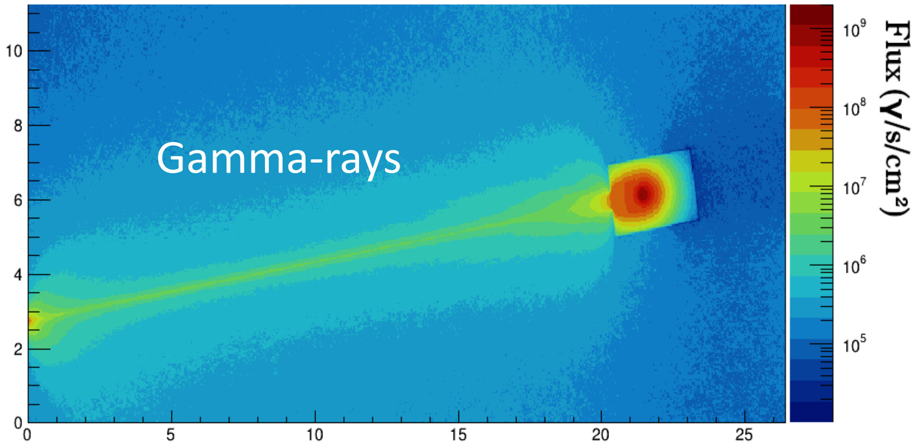






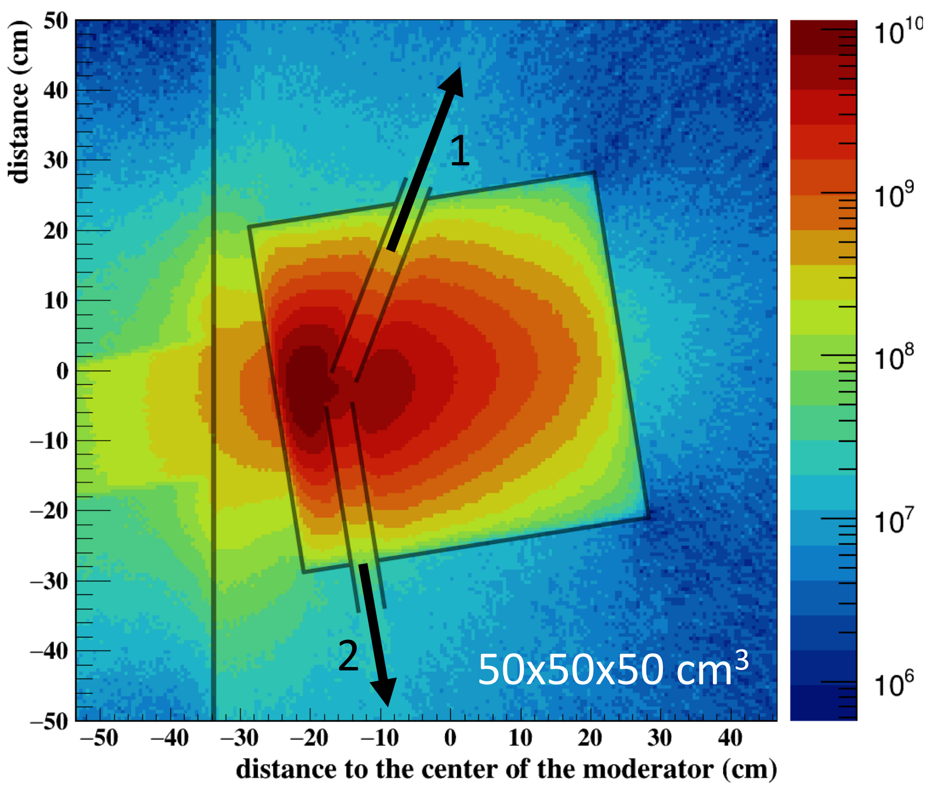


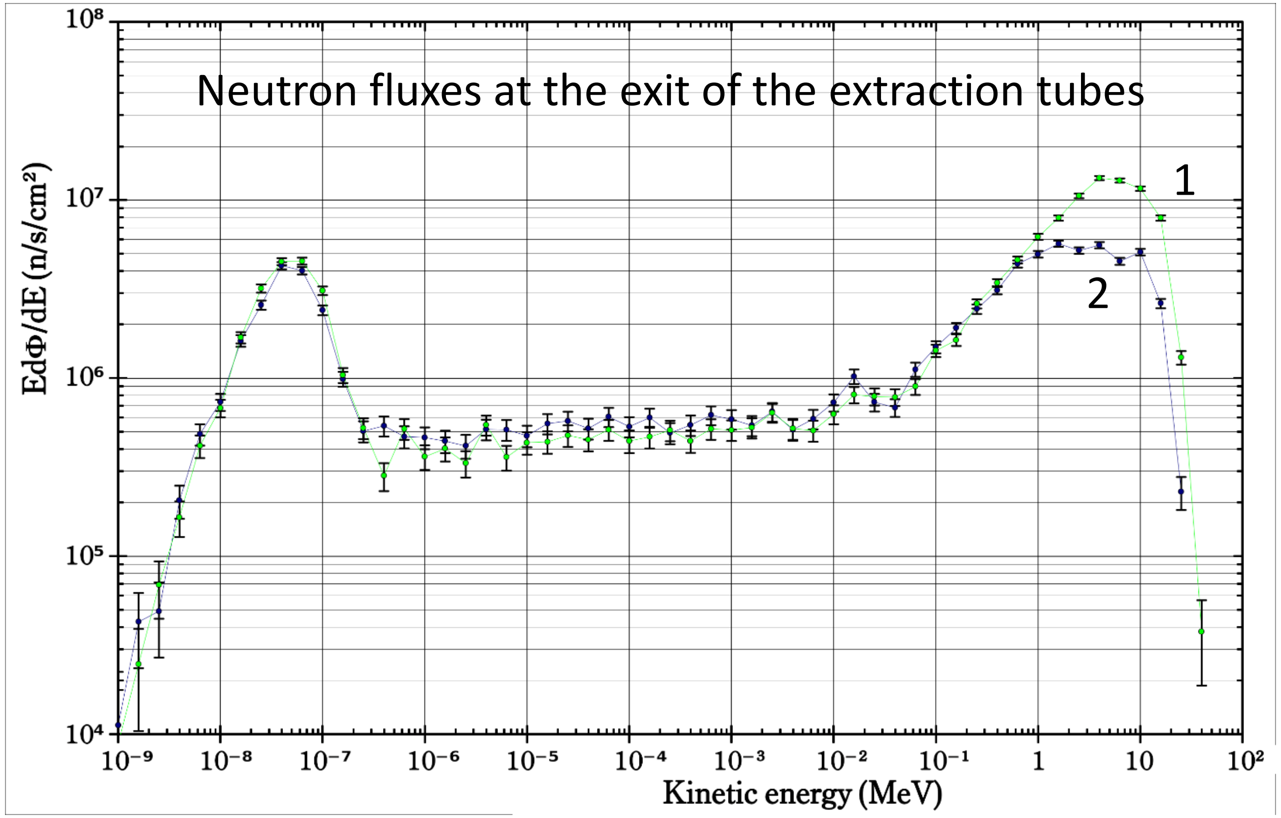




- Ambient doses: ~10^5 neutrons/cm^2/s and 10^6 γ-rays/cm^2/s
- Further shieldings will be needed

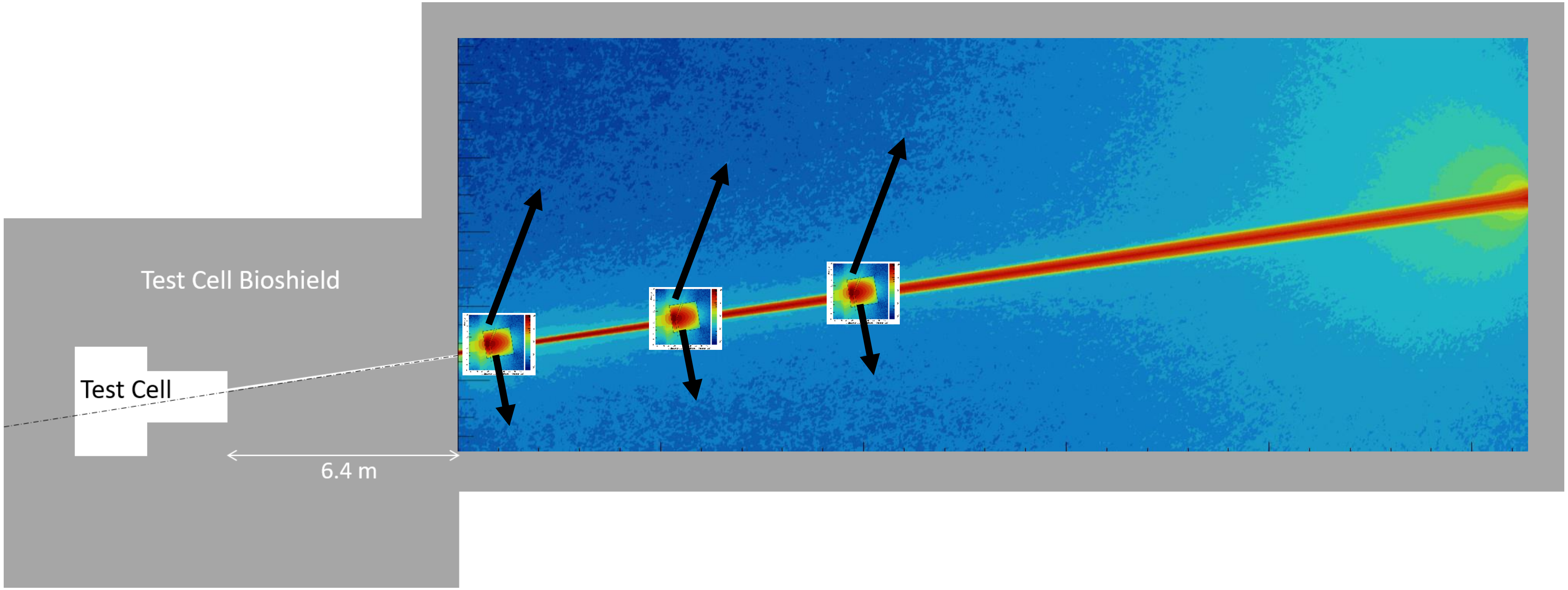
Moderated neutrons





- At the exit of the tubes, the thermal neutron flux is ~ 10^7 n/cm^2/s below 400 meV but with a large fast neutron contamination (~ 7 10^7 n/cm^2/s)
- Offer the possibility to put moderators in cascade

Fishbone configuration



IFMIF-DONES performances for neutron uses

DONES Preparatory Phase	Title of this document: Report on the complementary experiments with neutrons Author(s) & (affiliation):			Project 870186 (DONES-PreP)
X Deliverable / Managt. Rept.	Repository Code:	Reviewer(s):	Date:	Approved by: Ángel Ibarra (CIEMAT)
Agenda / Techn. Rept.				
Minutes / Other(specify)	Version:2.0			Date:

DELIVERABLE INFORMATION

Deliverable ID: D8.1-1	Title of the deliverable Dx.y-z: Other complementary experiments using neutrons				
Task number	Task Responsible person Name	e-mail	Work Package	WP Leader Name	e-mail
WP8.1	A. Letourneau	aletourneau@cea.fr	WP8	A. Maj	Adam.maj@ifj.edu.pl

Executive Summary

The potentialities of the IFMIF-DONES facility to complement its principal purpose – the irradiation of fusion materials - by other experiments that would open the facility to other communities is addressed in this work. It concerns a pre-design study based on simulations to evaluate the performances of the IFMIF-DONES for most of the neutron applications.

The case of reference chosen in this work was a beam line between the Test Cell and room R160 of conical shape, with an entrance diameter of 4.5 cm and an exit diameter of 9 cm, and aligned on the deuteron beam axis. Such geometry follows the natural dispersion of the neutrons in the Test Cell and is the best suited to maximize the neutron flux in R160. Using this geometry, we have shown that a well collimated neutron beam can be obtained in R160 with an intensity of about 2.10^{10} n/cm²/s (for an entrance flux of 1.10^{12} n/cm²/s) with a majority of fast neutrons. Such high neutron flux is interesting for isotope production and experiments where secondary particles have to be produced. Unfortunately, the absence of time structure in the deuteron beam does not allow for the time-of-flight technique and most of the experiments for nuclear physics have no interest. We have studied the possibility to add neutron moderators either in the Test Cell bio shield or in R160 in order to produce thermal or cold neutron beams needed for many applications of neutrons. Based on the pre-design simulations, we have shown that the facility could have the potentialities of a medium-flux facility for most of the neutron applications. Of course, it has to be confirmed with dedicated and optimized simulations of conceptual instruments.

This status would place IFMIF-DONES as an important element in the global strategy on neutron sources in Europe.

Comments

Indicate here: shortcomings, deviations, need for future update

Record of modifications

Version	Date	Modification	Approved by
2.0		Added new studies in section 5	

DONES-PreP deliverable: **D8.1-1** Page 1 of 55

White Neutron Source

Radioisotope production

Neutron Activation Analysis

Neutron Scattering experiments

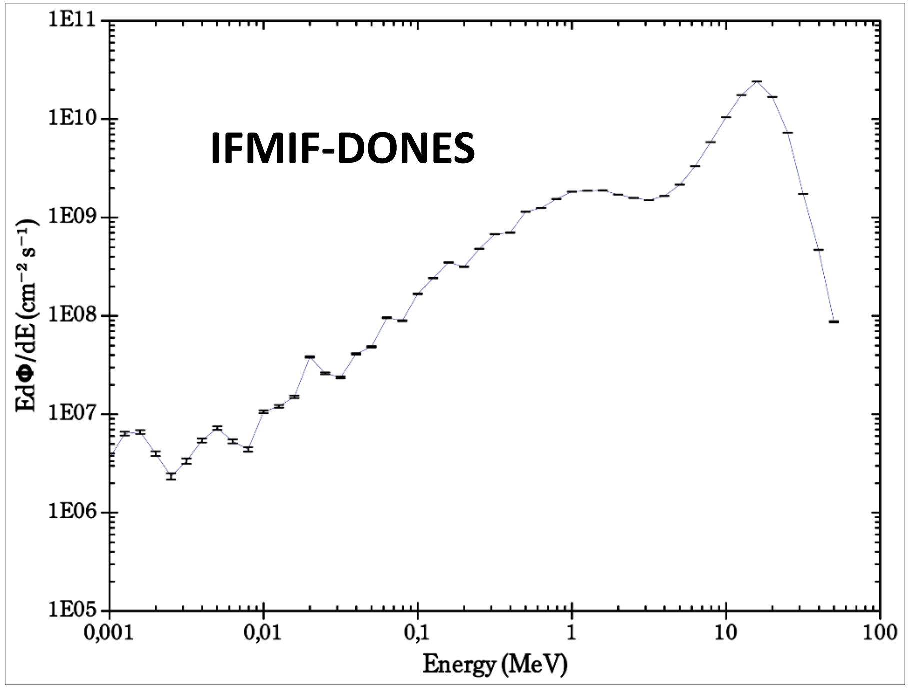
Neutron Imaging

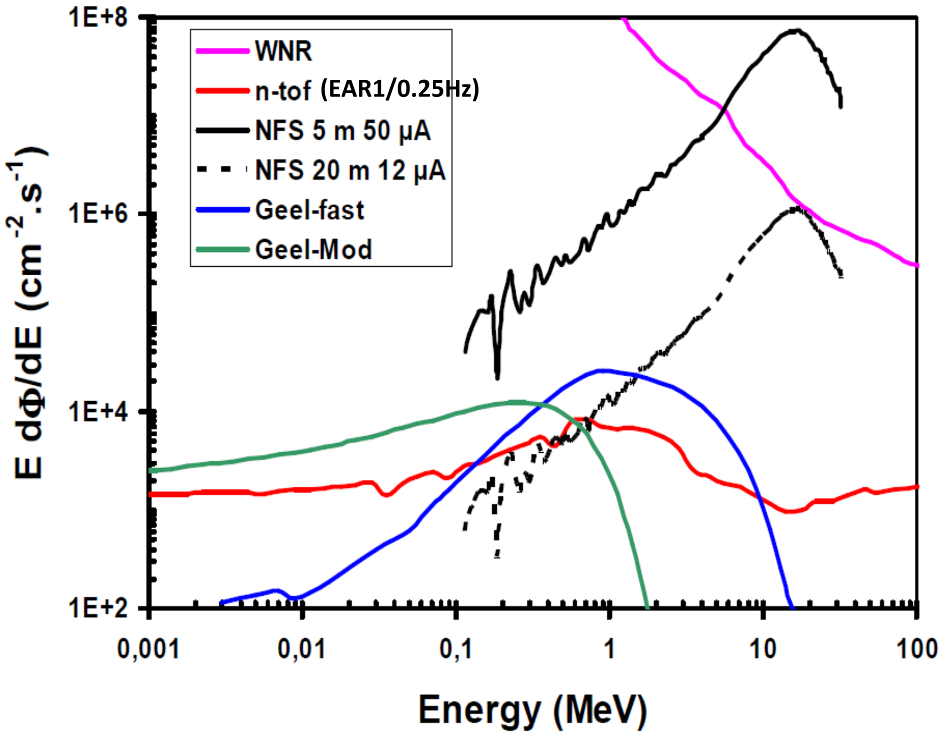
Neutron therapy

Doping of materials

Unmoderated neutron beam

- Nuclear cross section measurements (n,n'), (n,f), (n,lcp), fission studies
- Neutron irradiation, material doping
- Radioactive isotope production



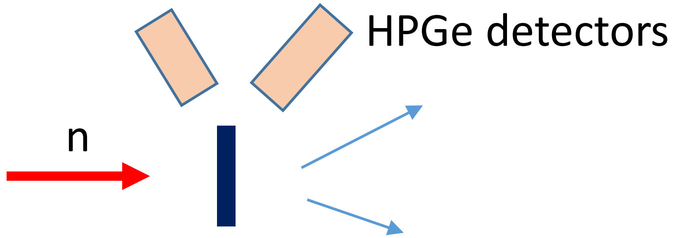


- ➢ IFMIF-DONES has higher neutron flux thanTOF facilities
- ➢ No TOF technique to select neutron energy → TOF beam line [see Cano Ott's talk]
- ➢ High flux for radioisotope production by (n,x) reaction

Fission fragment production with unmoderated beam

- Fission and neutron-rich isotope studies
- Radioactive isotope production

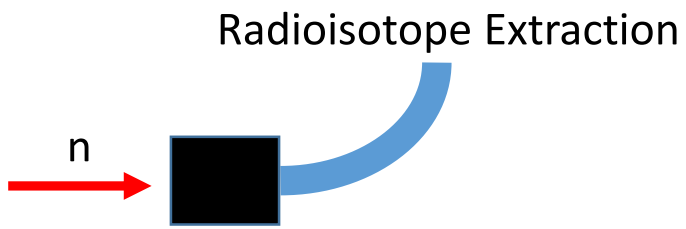
Neutron-rich isotope studies



Thin (150μg/cm^2) fissile target: ~ 10^5 f/s

FIPPS@ILL

Neutron-rich isotope production

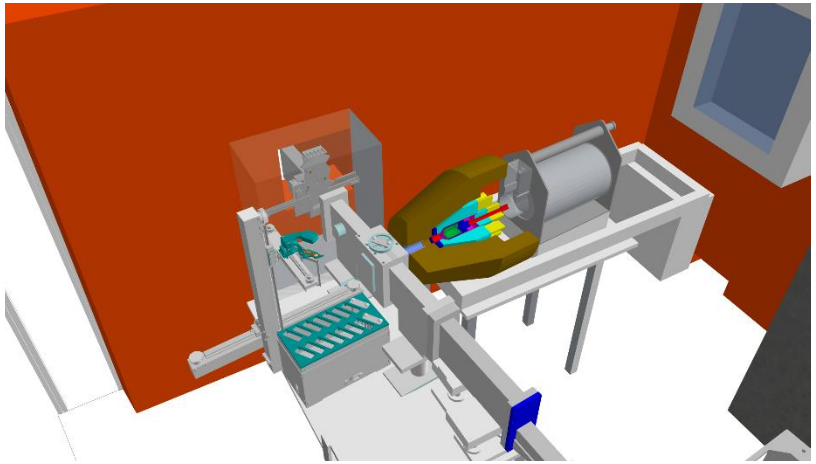


High density UCx target (2 kg): ~10^{10} f/s

Shine company

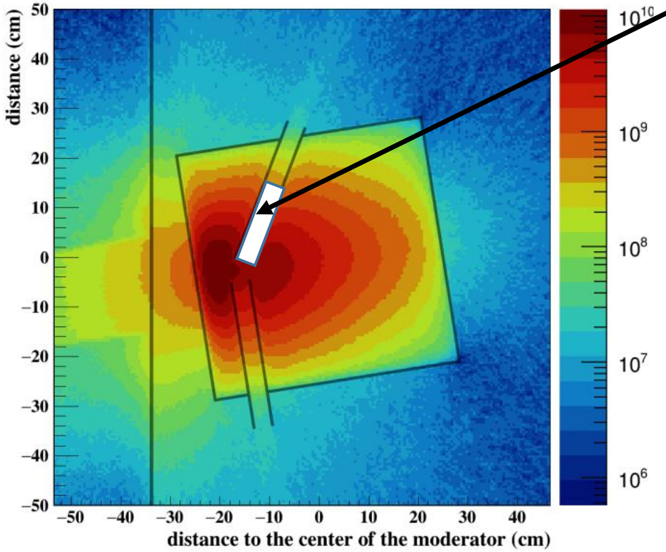
Neutron Activation Analysis

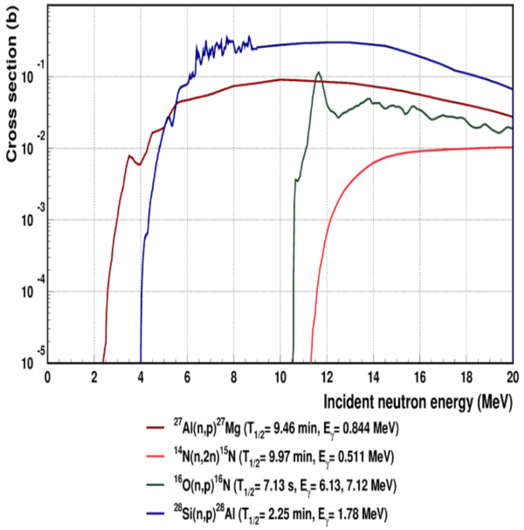
- Non-destructive method to determine the elemental composition of materials
  - with thermal Neutrons (NAA and Prompt Gamma AA)
  - with Fast Neutrons (FNAA and FPGAA).
- Neutron flux is a key ingredient:
  - ~$10^{12\text{-}14}$ n/cm^2/s for NAA ; ~10^8 n/cm^2/s for PGAA,
  - ~10^8 n/cm^2/s for FNAA



PGAA station @Budapest Neutron Center

Irradiated sample to be analyzed





Fast Neutron Activation Analysis

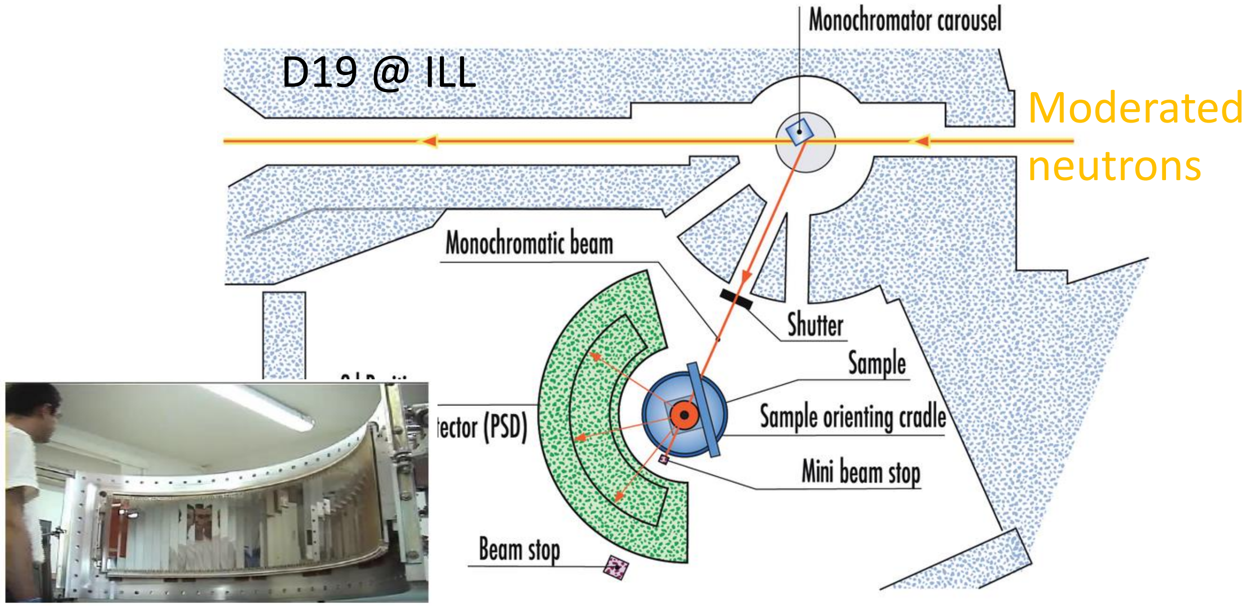
➢ The IFMIF-DONES has the advantage to provide both thermal and fast neutrons and is competitive for FNNA and PGAA

Neutron scattering / Neutron imaging

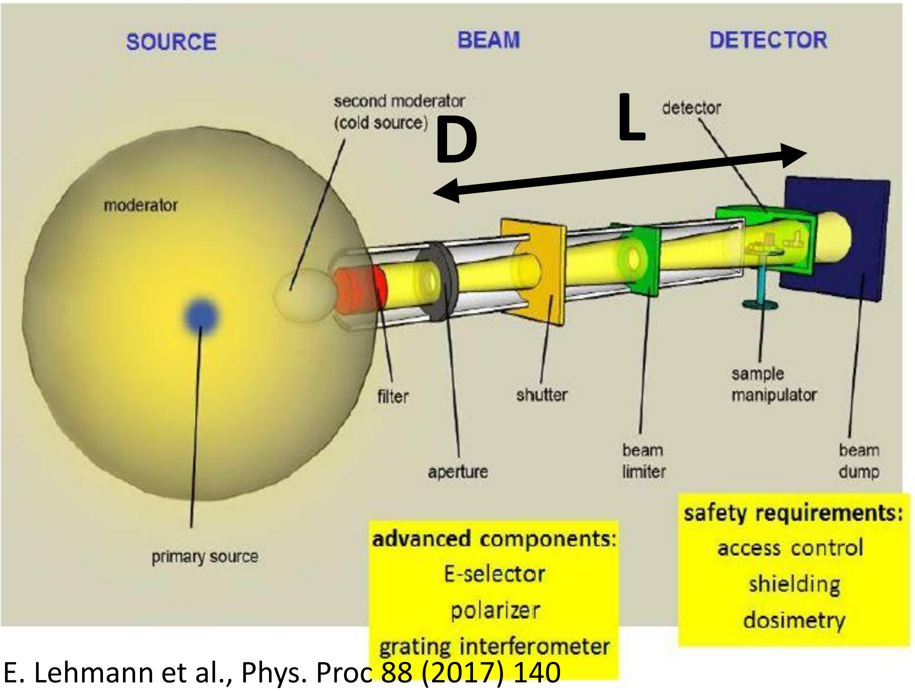
- Widely use in chemistry, magnetism, soft matter, biological molecules, industrial applications…
- Key parameters for the neutron beam on the target:

  - flux : **~ 10^4 and 10^8 n/cm/s/Å**
  - wavelength resolution -> divergence **below 3°**

  - flux: 10^6 – 10^7 n/cm^2/s
  - divergence and beam size: **100 < L/D < 400**
  - thermal and fast neutrons



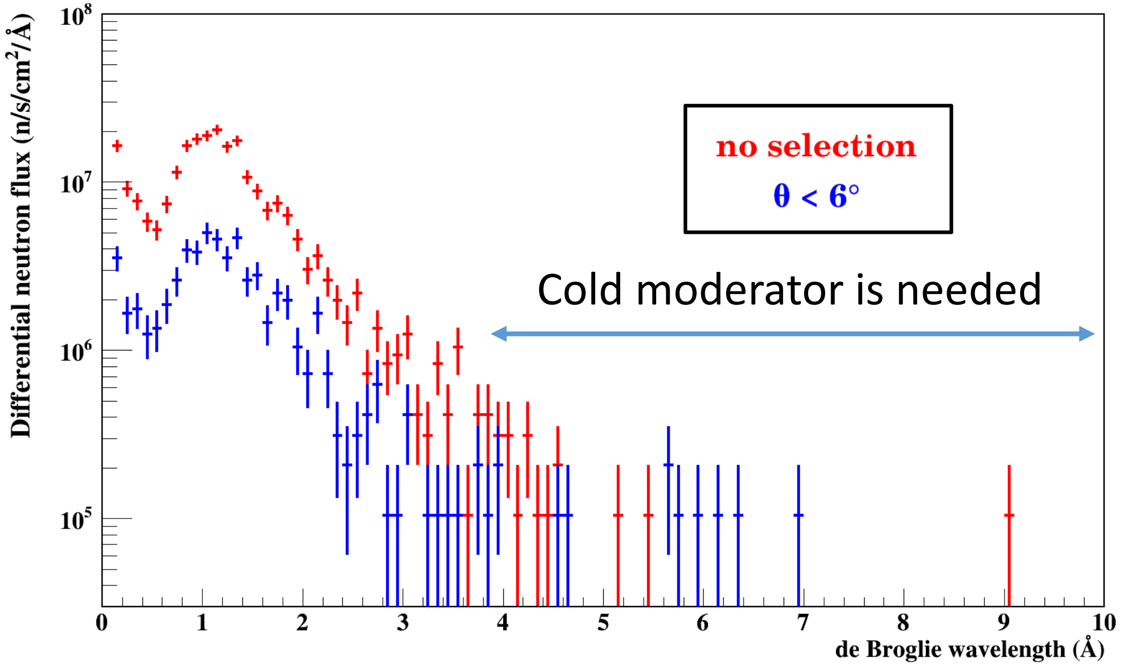
Neutron scattering instrument

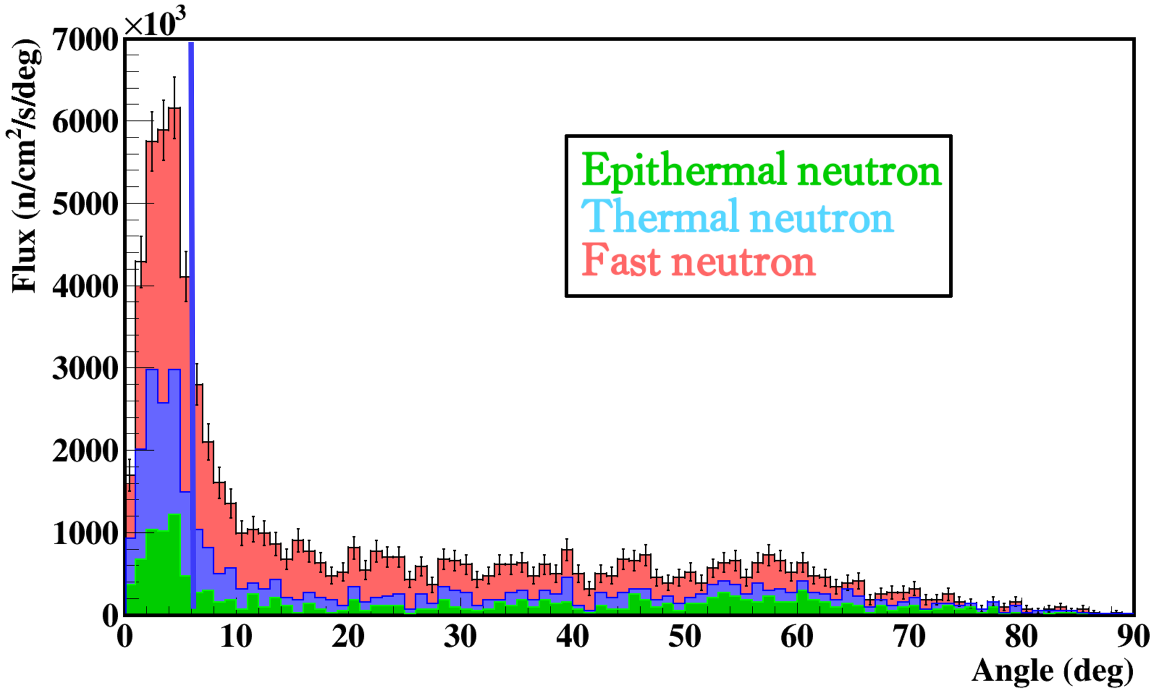


E. Lehmann et al., Phys. Proc 88 (2017) 140

Neutron imaging instrument

IFMIF-DONES performances for neutron scattering/imaging



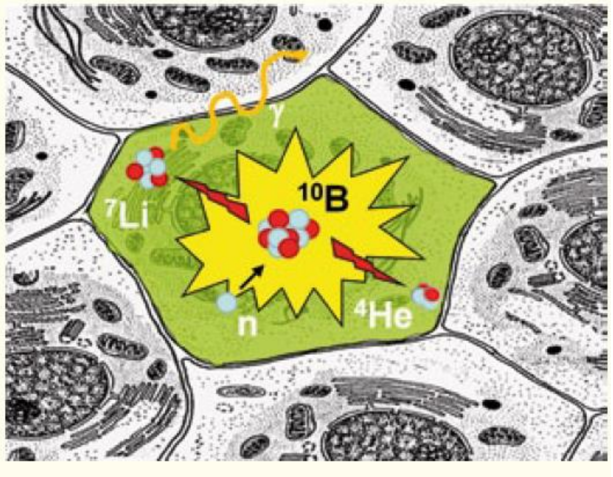


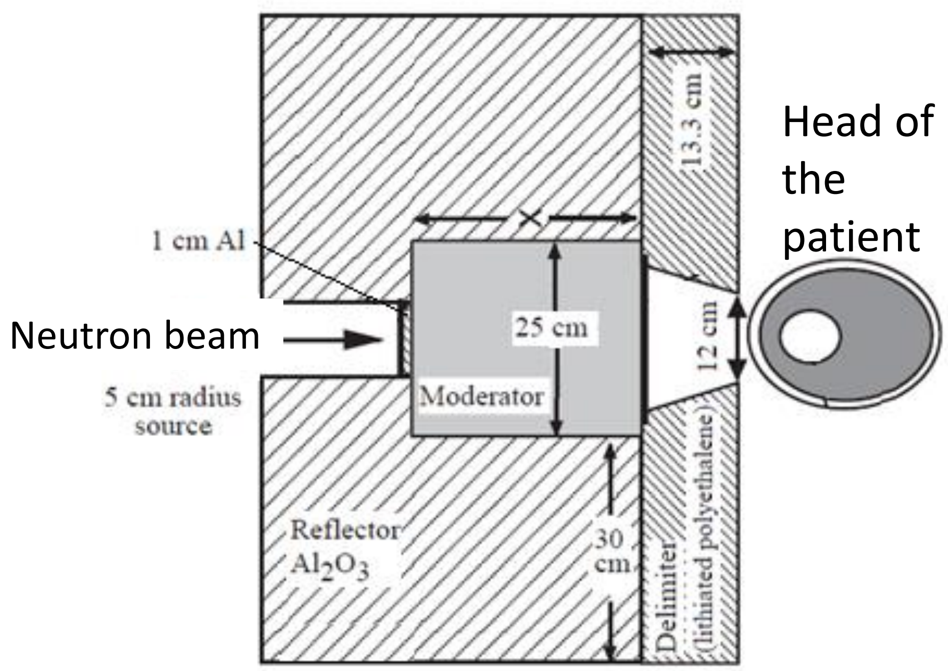
- With ~10^6 n/cm²/s/Å on the target, IFMIF-DONES is in the range of medium-scale facilities for neutron scattering
- For neutron imaging, we could expect ~ 10^4 n/cm²/s on the sample for a L/D=200 (D=30 mm and L=6 m), 4 orders of magnitude lower than state of the art imaging instruments

[see Torres-Sánchez's talk]

Boron Neutron Capture Therapy

- Mainly for brain tumors (glioblastoma)
- Moderator to produce thermal / epithermal neutrons for shallow / deep tumors





Shallow tumours

$\Phi_{th} \geq 10^9\ cm^{-2}s^{-1}$

$\Phi_{th} / \Phi_{tot} \geq 0.9$

$\dot{D}_{n\ (epi+fast)} / \Phi_{th} \leq 2\times10^{-3}\ Gy\ cm^2$

$\dot{D}_{\gamma} / \Phi_{th} \leq 2\times10^{-3}\ Gy\ cm^2$

Deep tumours

$\Phi_{epi} \geq 10^9\ cm^{-2}s^{-1}$

$\Phi_{epi} / \Phi_{th} \geq 100;\quad \Phi_{epi} / \Phi_{fast} \geq 20$

$\dot{D}_{n\ (fast)} / \Phi_{epi} \leq 2\times10^{-3}\ Gy\ cm^2$

$\dot{D}_{\gamma} / \Phi_{epi} \leq 2\times10^{-3}\ Gy\ cm^2$

➢ The neutron flux is two orders of magnitude lower than what is required for tumor treatment

Conclusions

- The collimated neutron beam allows IFMIF-DONES to be a first class facility for techniques using fast neutrons and a medium flux facility for techniques using thermal neutrons.
- Proposals are opened
- Dedicated simulations must be performed to better evaluate the real performances

IFMIF-DONES Prep Phase Report
https://idm.dones.irb.hr/op/op.ViewOnline.php?documentid=254&version=1

J. Hirtz et al., Fusion Engineering and Design, 179 (2022) 113133
https://www.sciencedirect.com/science/article/pii/S0920379622001284?via%3Dihub