IFMIF-DONES ESPAÑA

High-Power Target Technology for Deuteron-Induced Medical Radioisotope Production at IFMIF-DONES

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[4] National Laboratory for Magnetic Confinement Fusion, CIEMAT, Madrid, Spain

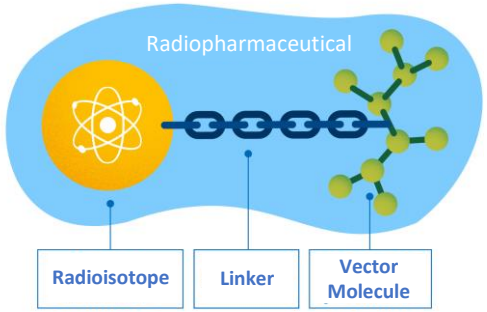
*melopez@ugr.es

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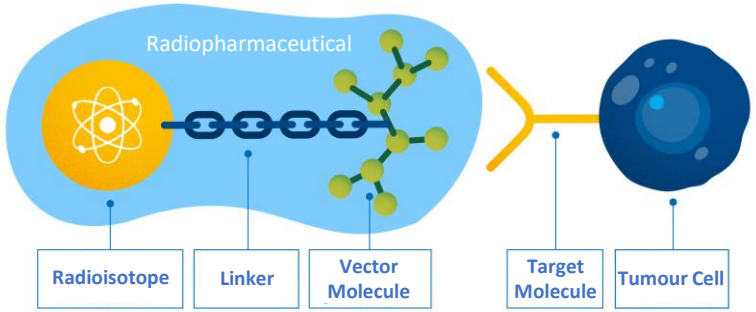
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1. The rise of radiopharmaceuticals in Nuclear Medicine
2. Radioisotope Production at IFMIF-DONES
   - Why is it necessary?
   - Radioisotope production with deuterons at R026
   - First prototype of high-power target technology
   - ^{165}Er and ^{177}Lu medical radioisotopes with deuterons at R026
   - Radioisotope production with neutrons inside Test Cell
3. Conclusions and outlook

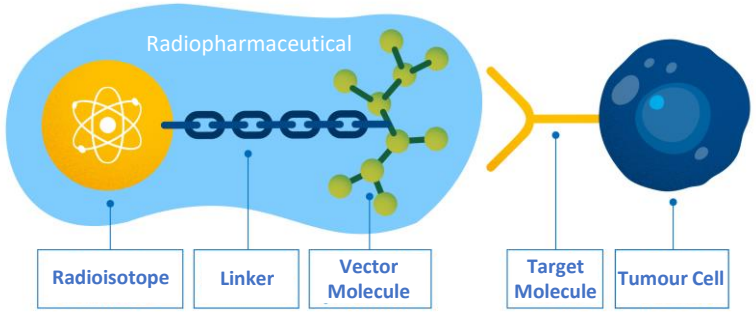
1. The rise of radiopharmaceuticals in Nuclear Medicine



1. The rise of radiopharmaceuticals in Nuclear Medicine

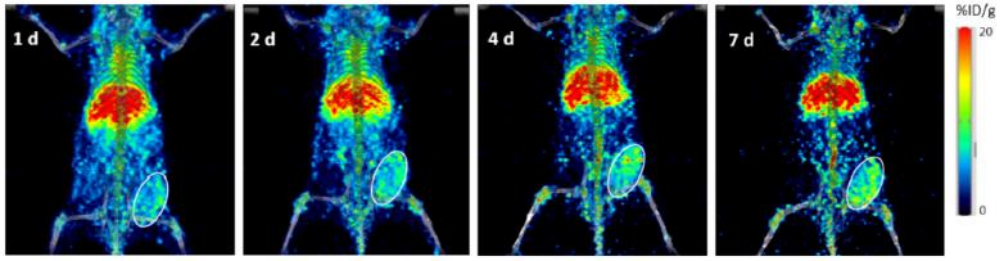


1. The rise of radiopharmaceuticals in Nuclear Medicine



Diagnostic
~85%
(^{99}Mo; ^{89}Zr; ^{18}F)

Therapy
(^{131}I; ^{90}Y; ^{165}Er)

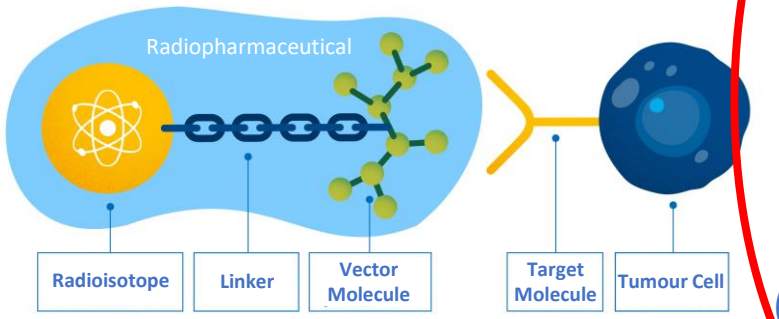


[^{89}Zr]Zr-Df-LEM2/15



IHQ image corresponding to DNA double-strand break damage as measured by γH2AX-positive cells compared to both the control group, [177Lu]Lu-DOTA-LEM2/15 single-dose and [^{177}Lu]Lu-DOTA-LEM2/15 3-dose. https://doi.org/10.1016/j.nucmedbio.2024.108930

1. The rise of radiopharmaceuticals in Nuclear Medicine



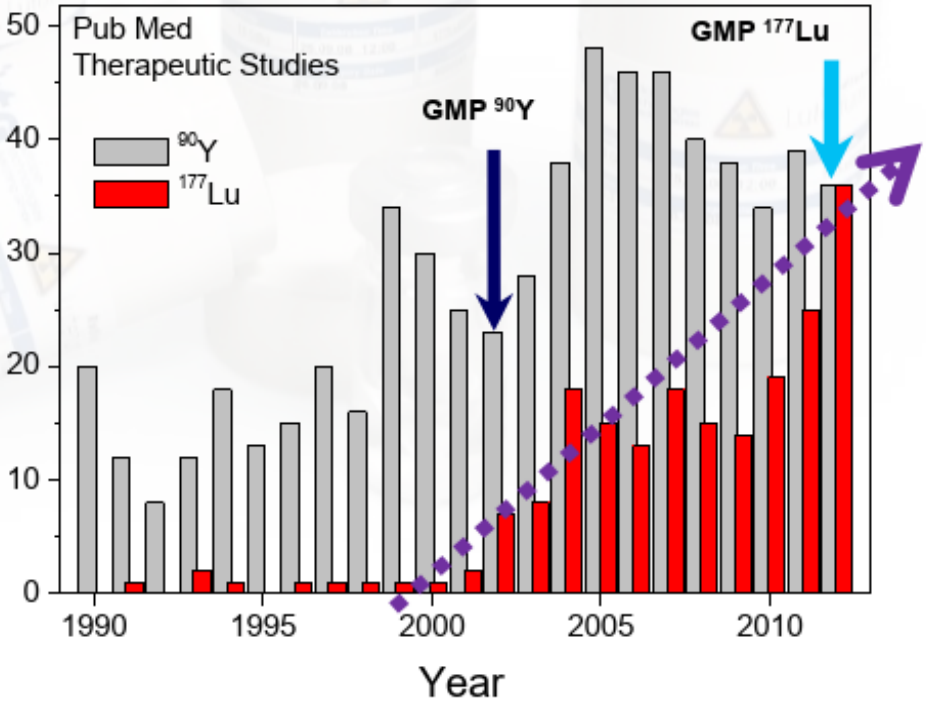
Diagnostic
~85%
(^{99}Mo; ^{89}Zr; ^{18}F)

Therapy
(^{131}I; ^{90}Y; ^{165}Er)

Theranostic
^{177}Lu !!

Number of scientific publications vs time:

Therapeutic applications of ^{90}Y and ^{177}Lu



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2. Radioisotope Production at IFMIF-DONES

Why is it necessary?

According to the **IAEA, more medical isotope facilities are needed** to guarantee supply in the face of growing demand.

NUCLEAR MEDICINE EUROPE
the industry association

COMMUNICATION FROM NMEU TO EU OBSERVATORY FOR THE SUPPLY OF MEDICAL RADIOISOTOPES

Global Mo-99 and I-131 Production Impacted by Delay of Two Reactors Restarting from Scheduled Maintenance

Brussels, 20 October 2022

Nuclear Medicine Europe advises the nuclear medicine community that periodic Mo-99 and I-131 supply disruptions are being experienced at the current time and are likely to increase through the first week of November due to delays of two research reactors which irradiate targets for producing these radioisotopes in returning to service from planned outages.



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Published online 23 October 2008 | Nature | doi:10.1038/news.2008.1186

News

Europe's isotope shortage will continue into 2009

Hospitals forced to use substitute procedures for medical scans.

Paula Gould

Stories by subject
- Health and medicine
- Technology
- Physics

Stories by keywords
- Europe
- Isotope
- Medical
- Shortage
- Radioisotope
- Medical imaging
- Hospital
- Reactor closure
- Petten

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A Europe-wide shortage of medical isotopes will continue for at least three months while a Dutch nuclear reactor is repaired. Governments and regulators are now bending their rules concerning the use and transport of radioactive materials so that patients can still undergo diagnostic tests during the supply crisis.

The High Flux Reactor in Petten has been out of action since the end of August (see 'Isotope shortage could delay cancer treatment') after tiny bubbles of gas were found escaping from a pipe into the reactor's cooling system during a routine maintenance inspection. Although the cause of the leak has now been traced

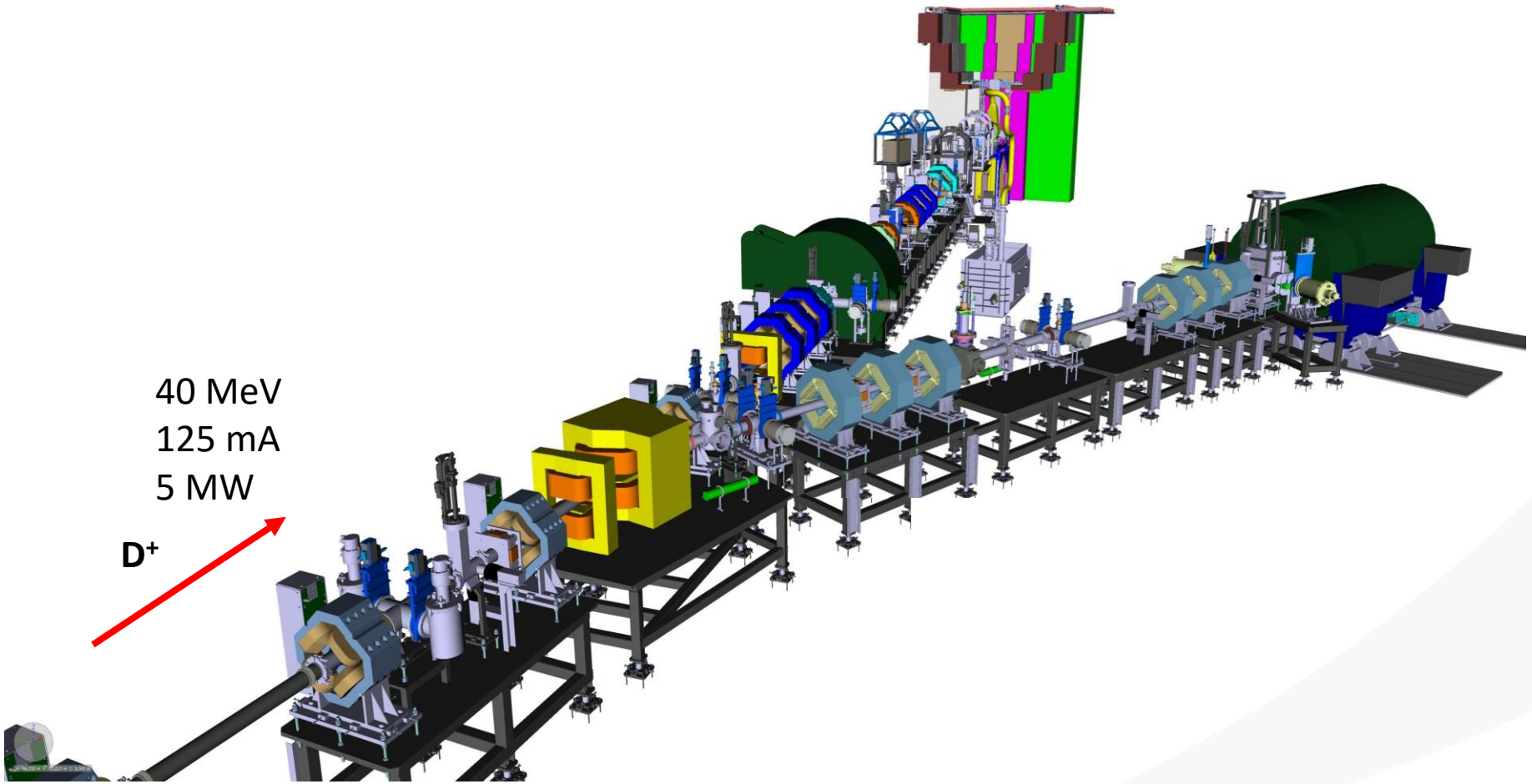
The High Flux Reactor in Petten, the Netherlands, is facing an extended shut-down. NRG

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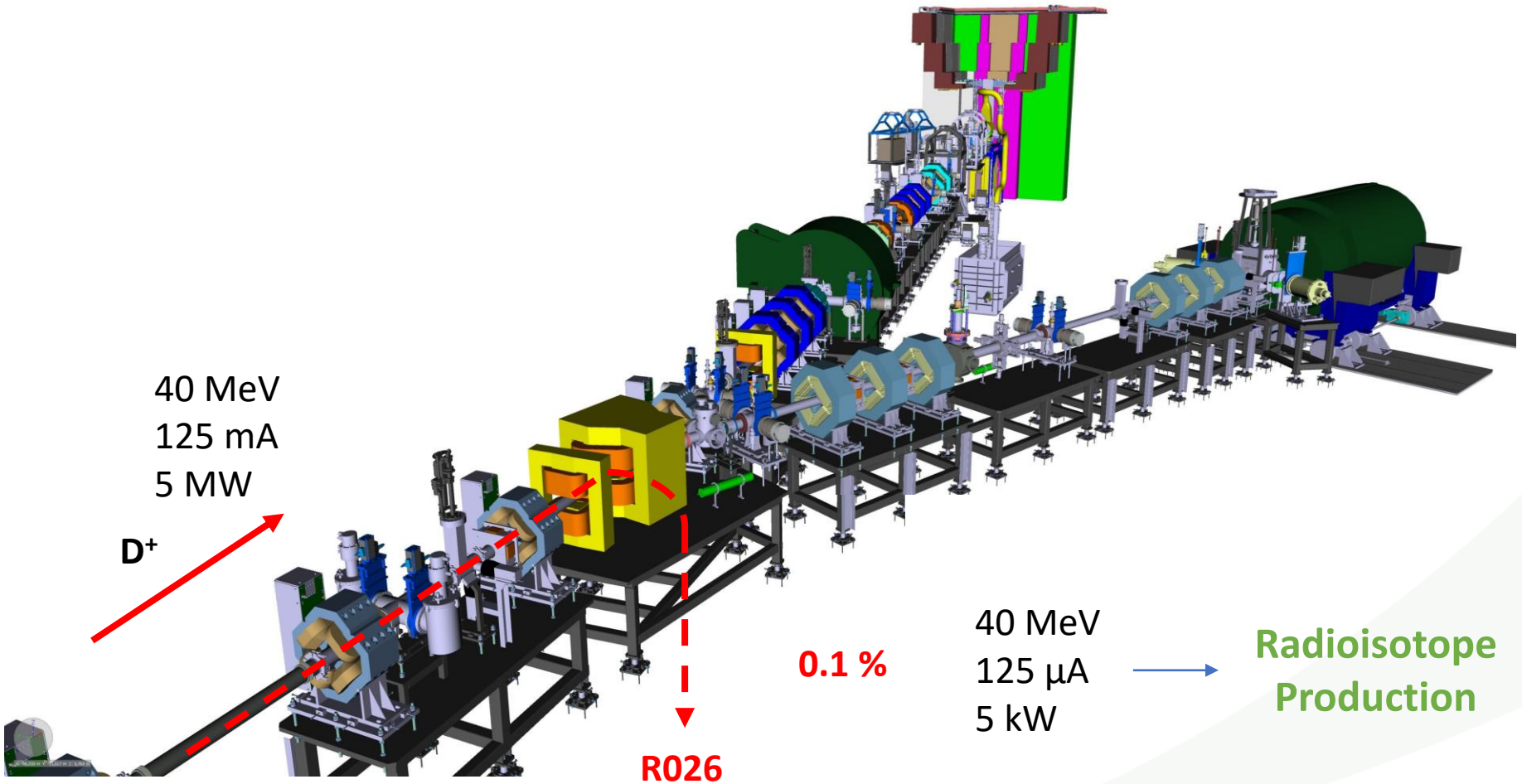
2. Radioisotope Production at IFMIF-DONES

Radioisotope production with **deuterons at R026**



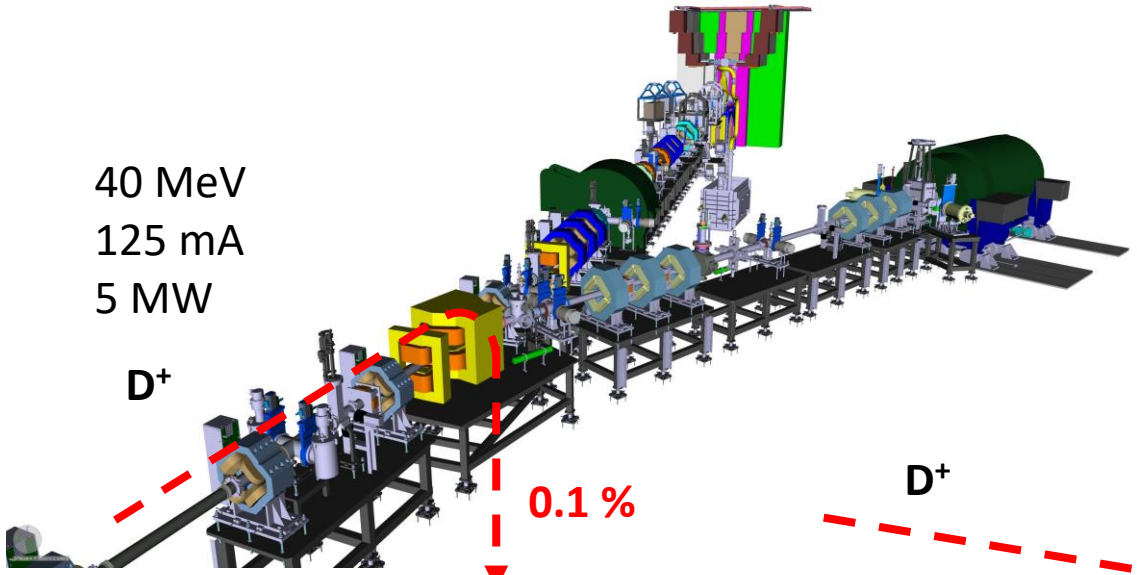
2. Radioisotope Production at IFMIF-DONES

Radioisotope production with **deuterons at R026**



2. Radioisotope Production at IFMIF-DONES

First prototype of high-power target technology



40 MeV
125 mA
5 MW

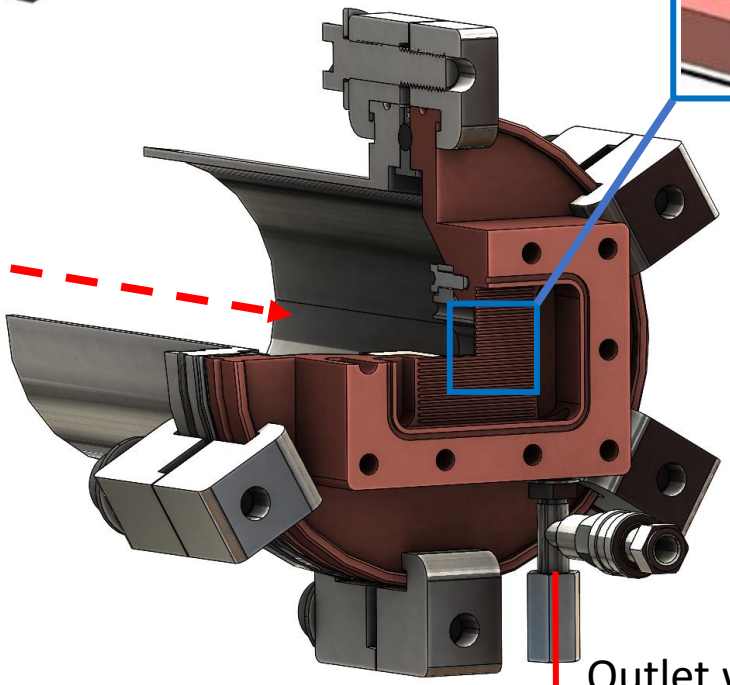
D^+

0.1 %

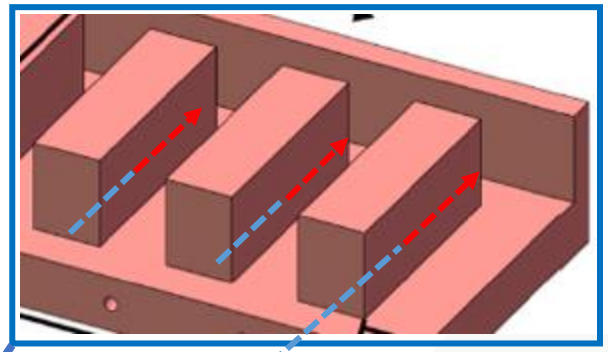
R026

D^+

40 MeV
125 µA
5 kW
1 kW/cm²



Cooling system by cutting-sweeping.

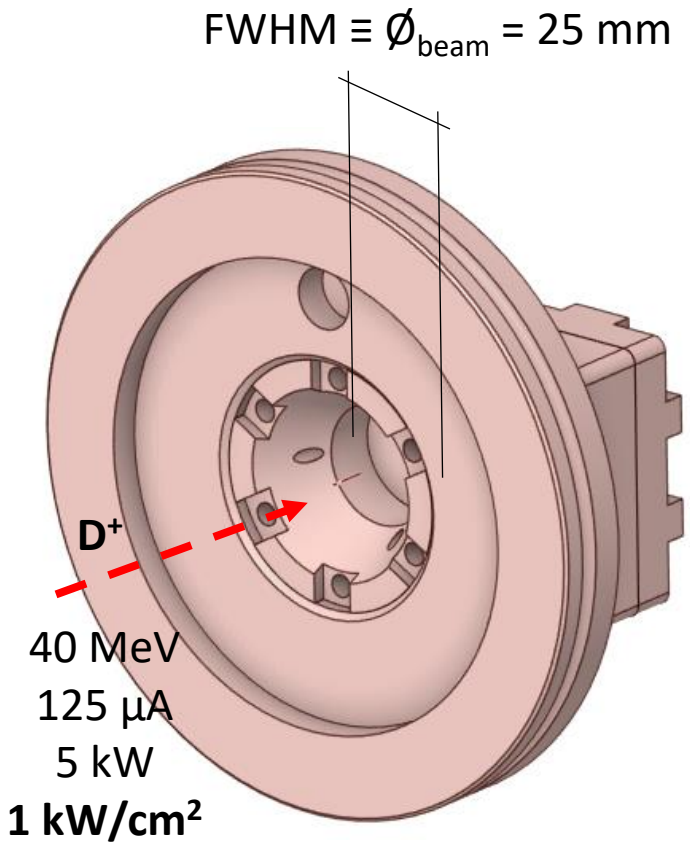


Water direction

Outlet water

2. Radioisotope Production at IFMIF-DONES

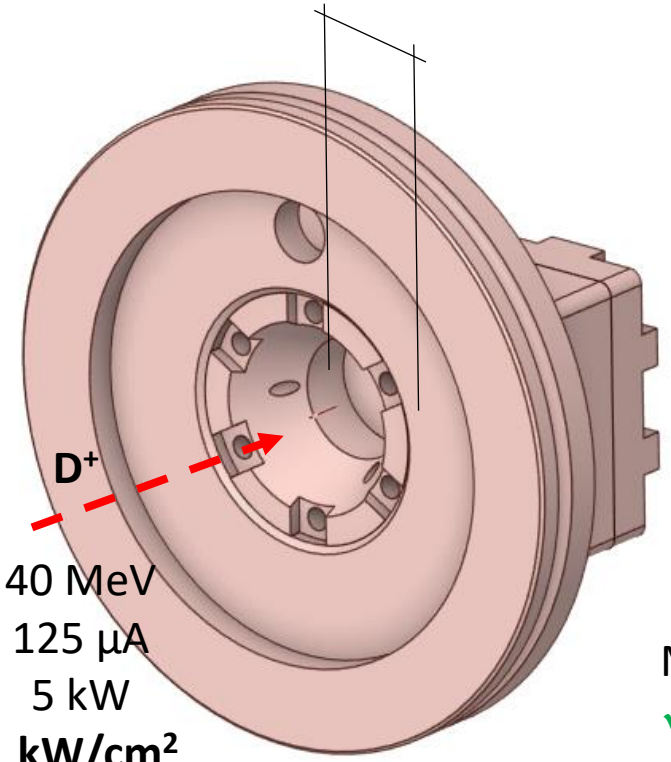
First prototype of high-power target technology - Thermal Simulations



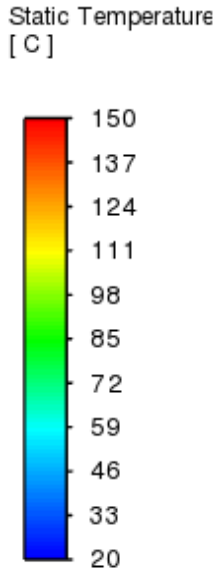
2. Radioisotope Production at IFMIF-DONES

First prototype of high-power target technology - Thermal Simulations

FWHM ≡ $Ø_{beam}$ = 25 mm

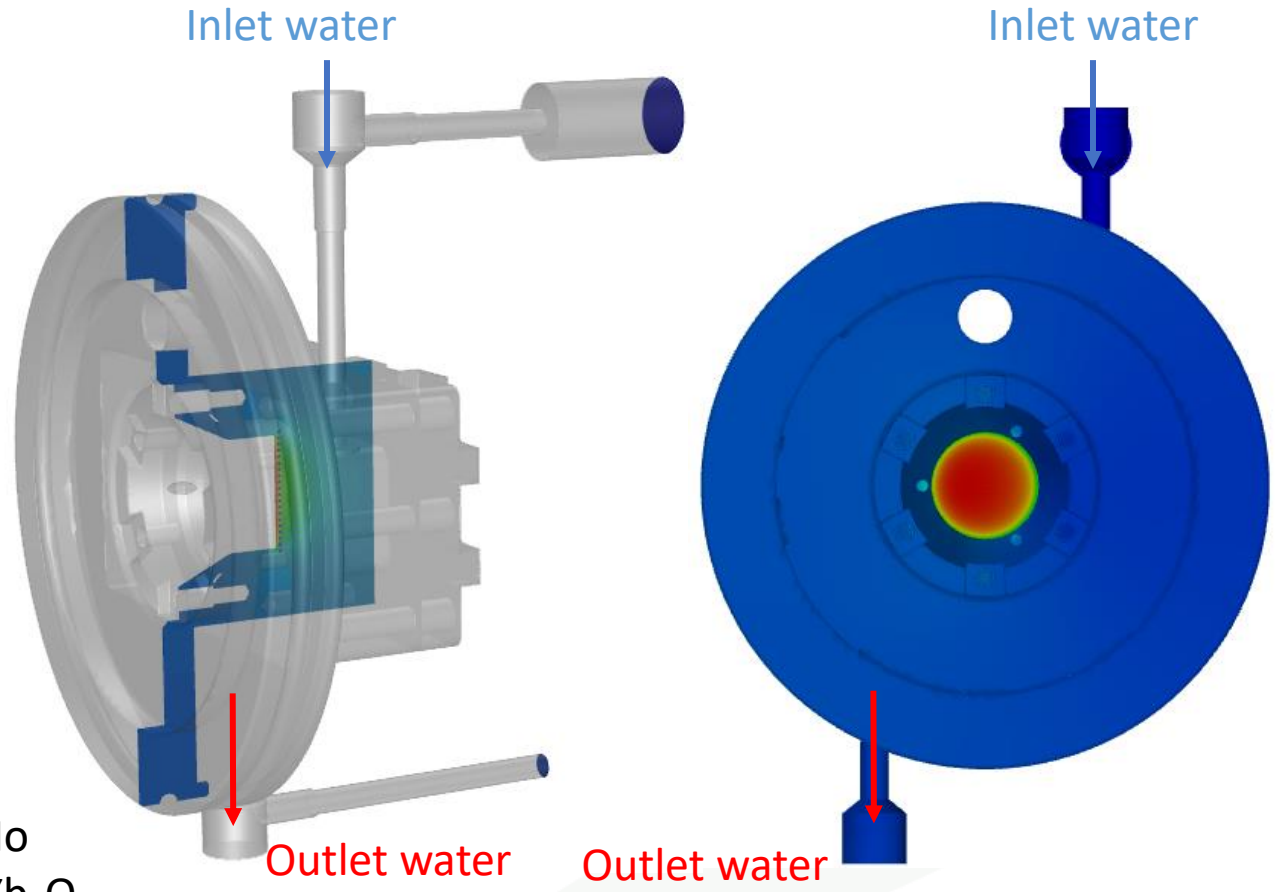


40 MeV
125 µA
5 kW
1 kW/cm²



Melting point:

- ✓ 1085 ºC → Cu
- ✓ 1461 ºC → ^{nat}Ho
- ✓ 2355 ºC → $^{176}Yb_2O_3$

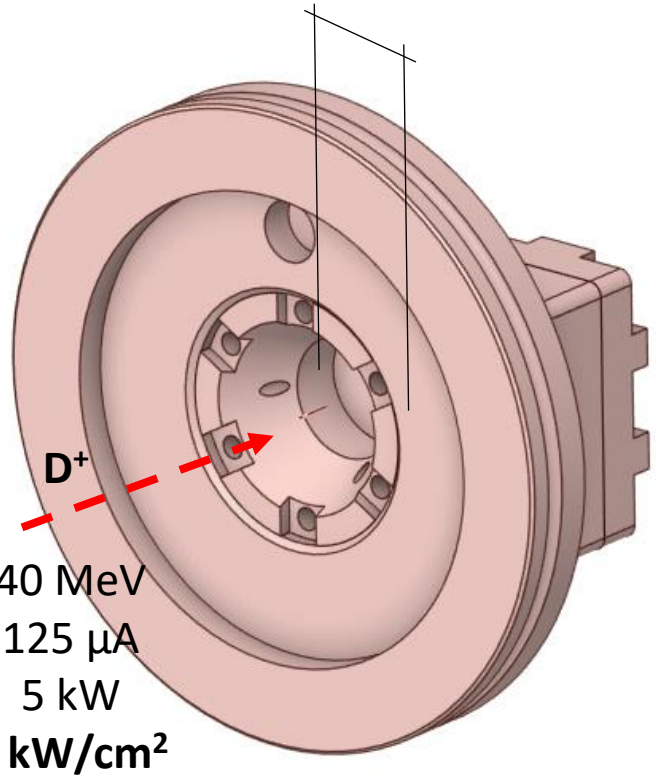


Flow Simulation with ANSYS tools.

2. Radioisotope Production at IFMIF-DONES

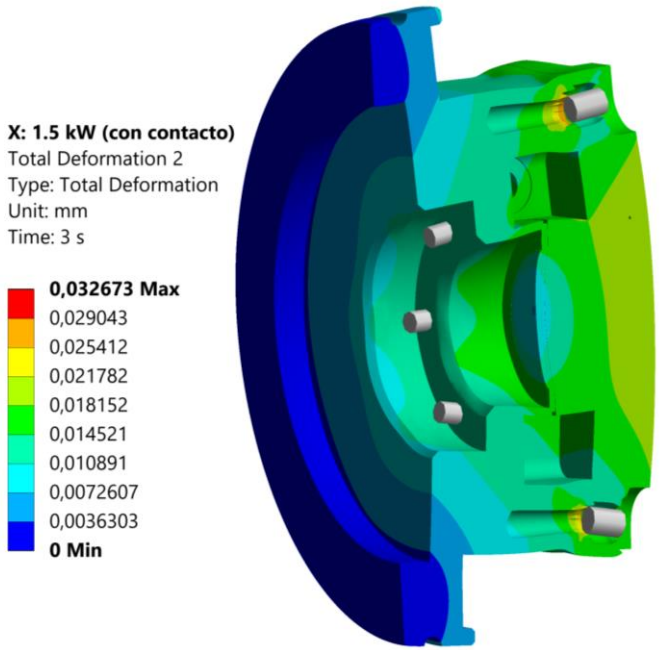
First prototype of high-power target technology - Mechanical Simulations

FWHM ≡ $Ø_{beam}$ = 25 mm

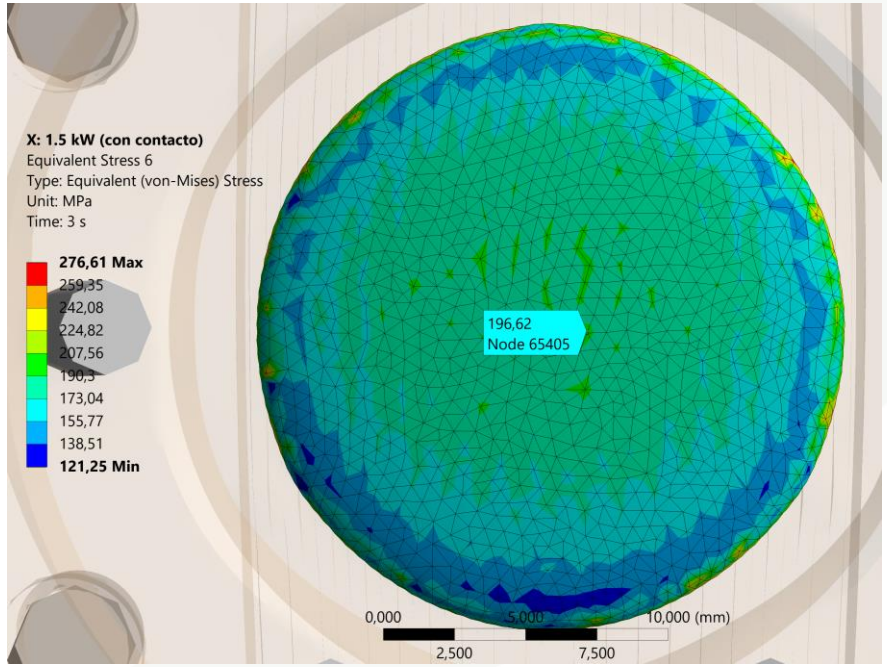


40 MeV
125 µA
5 kW
1 kW/cm²

Maximum stress: 196 MPa



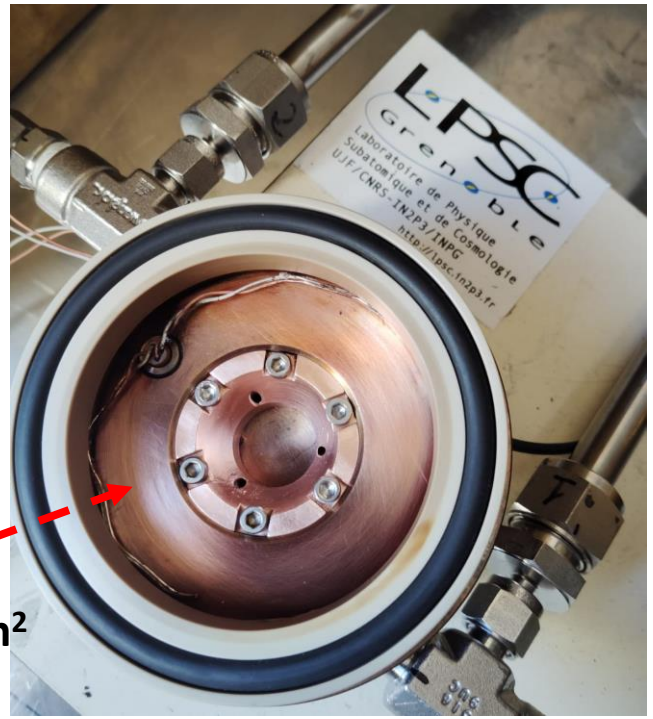
- ✓ Yield strength: 218 Mpa
- ✓ Tensile strength: 244 MPa

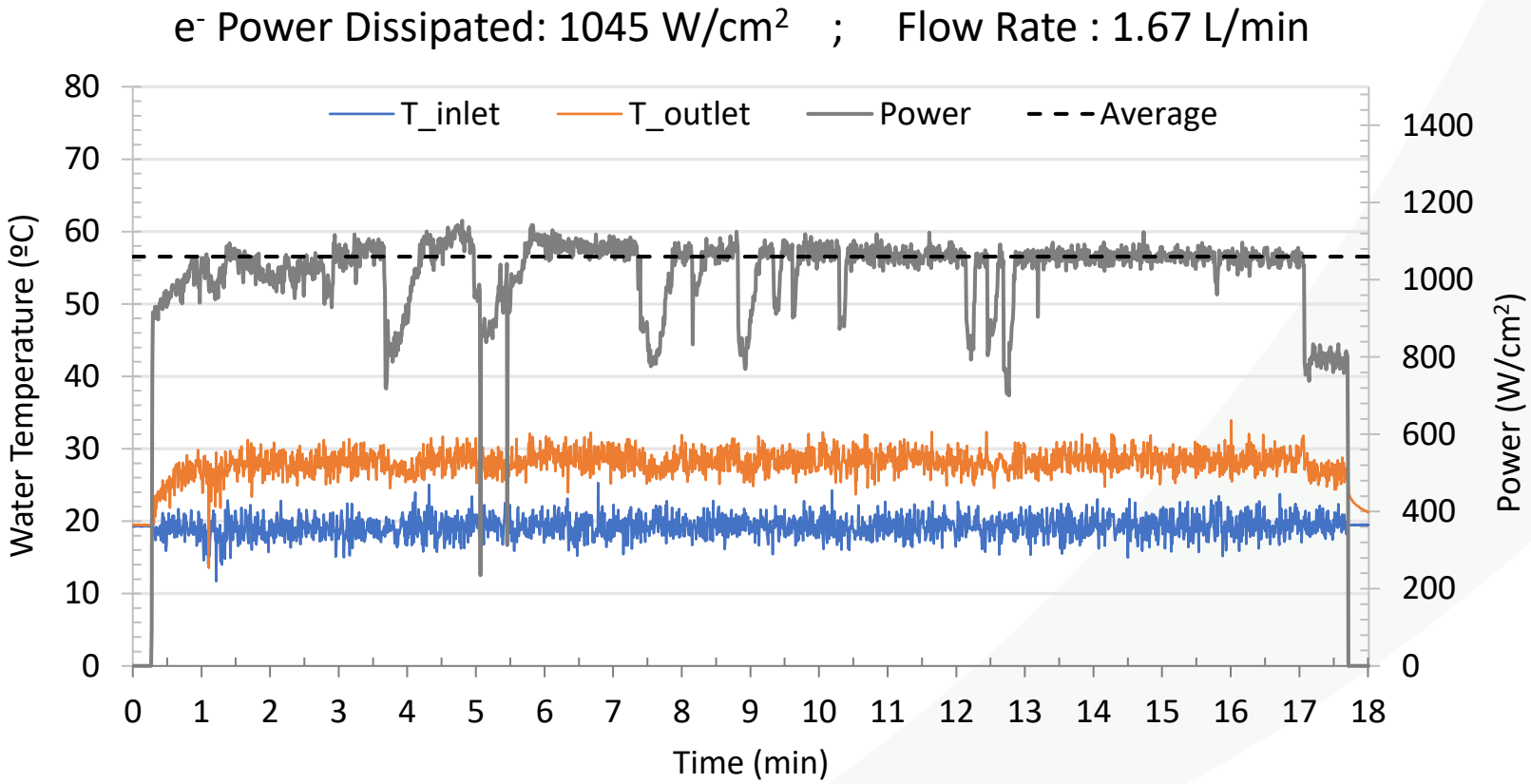


Structural Simulation with ANSYS tools.

2. Radioisotope Production at IFMIF-DONES

First prototype of high-power target technology - Proof of Concept: LPSC (Grenoble, France)

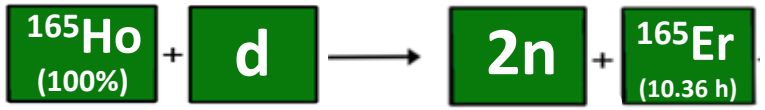




✓ The actual manufactured device has withstood irradiation tests based on equivalent power per unit area.

2. Radioisotope Production at IFMIF-DONES

^{165}Er and ^{177}Lu medical radioisotopes with deuterons at R026



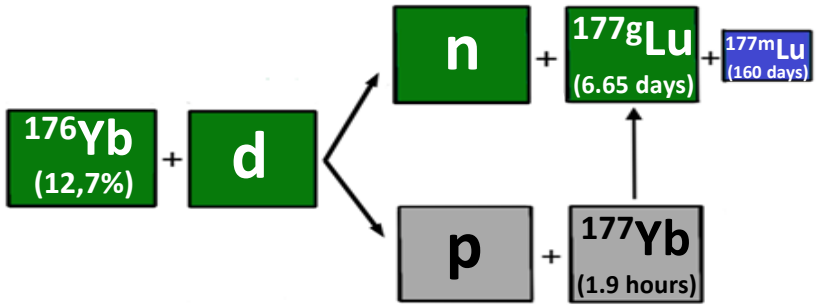
Therapeutic Radioisotope

Reaction	Energy Range (MeV)	Irradiation /Cooling Time (hours)	Activity (GBq)	Molar Activity (TBq/mmol)
^{165}Ho(d,2n)^{165} Metallic Ho	18 - 11.7	30/10	165	8040

- ✓ Radioisotope purity > 99.9 %
- ✓ Isotopic purity > 70 %
- ✓ Medical application (MA ~ 37 – 130 TBq/mmol)

I. Da Silva et al. (2021) https://doi.org/10.3390/molecules26247513

Direct Route "Carrier added"



Theranostic Radioisotope

Indirect Route "Carrier free"

Reaction	Energy Range (MeV)	Irradiation /Cooling Time (days)	Activity (GBq)	Specific Activity (GBq/mg)
^{176}Yb(d,x)^{177}Lu $^{176}Yb_2O_3$ powers (99.6%)	12 – 5	7/2	25	1100

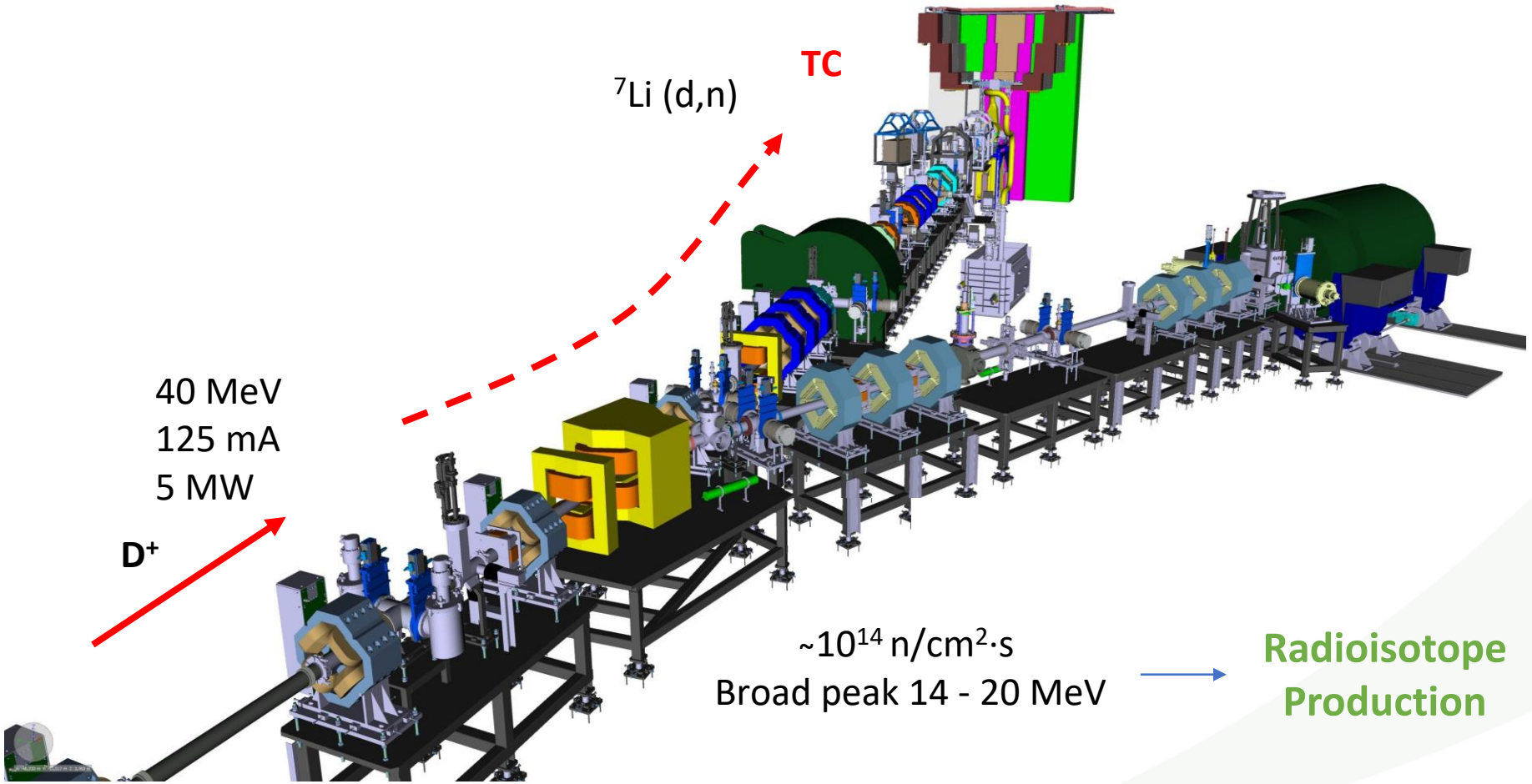
- ✓ Quality similar to nuclear reactors (c.a. route)
- ✗ Significantly lower yields for clinical
- ✓ Quantities accepted for preclinical studies

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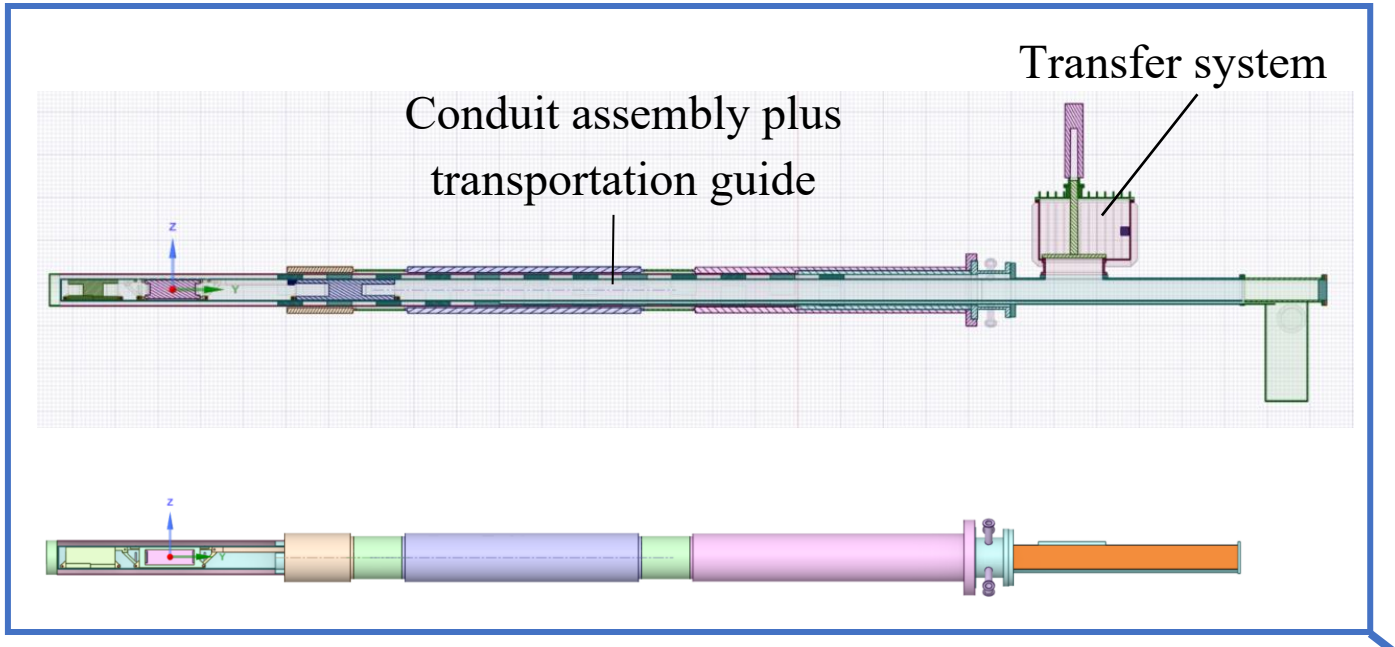
2. Radioisotope Production at IFMIF-DONES

Radioisotope production with **neutrons inside Test Cell**

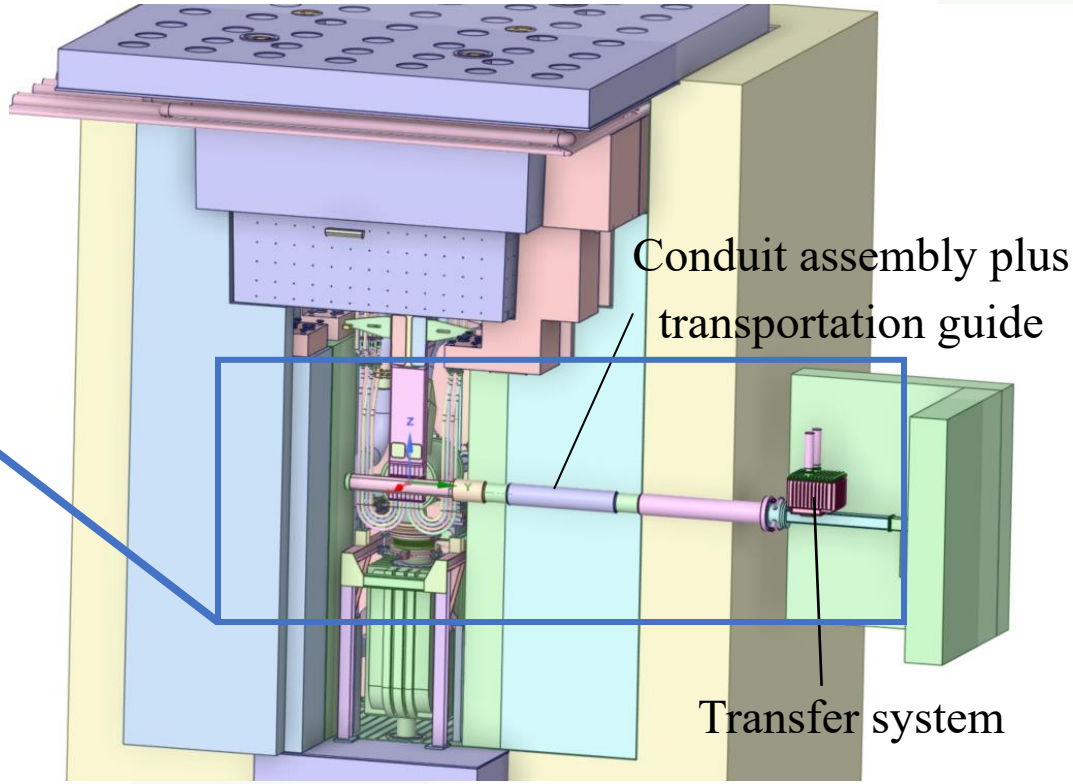


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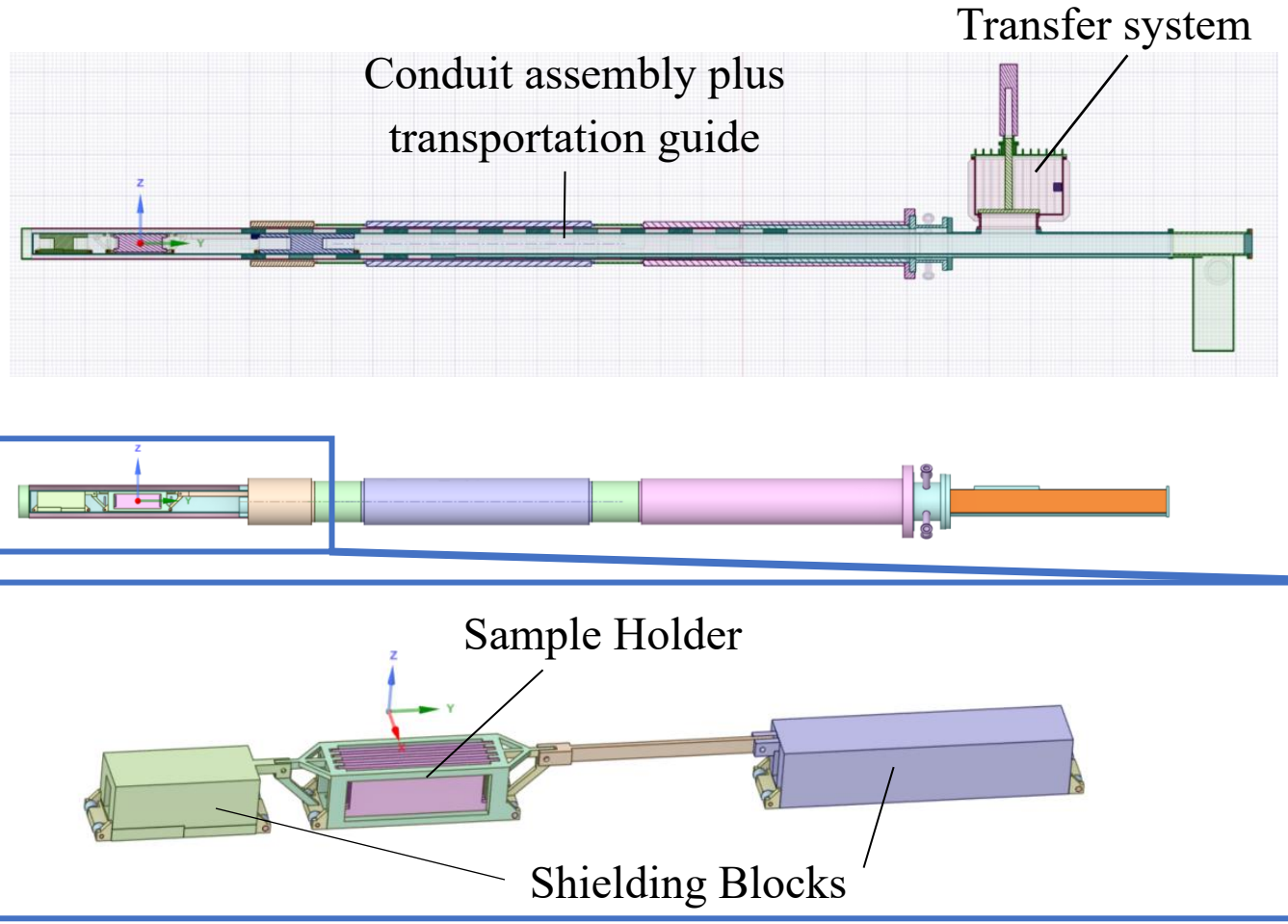


Radioisotope Production Device (RIPD)
integrate in the Test Cell

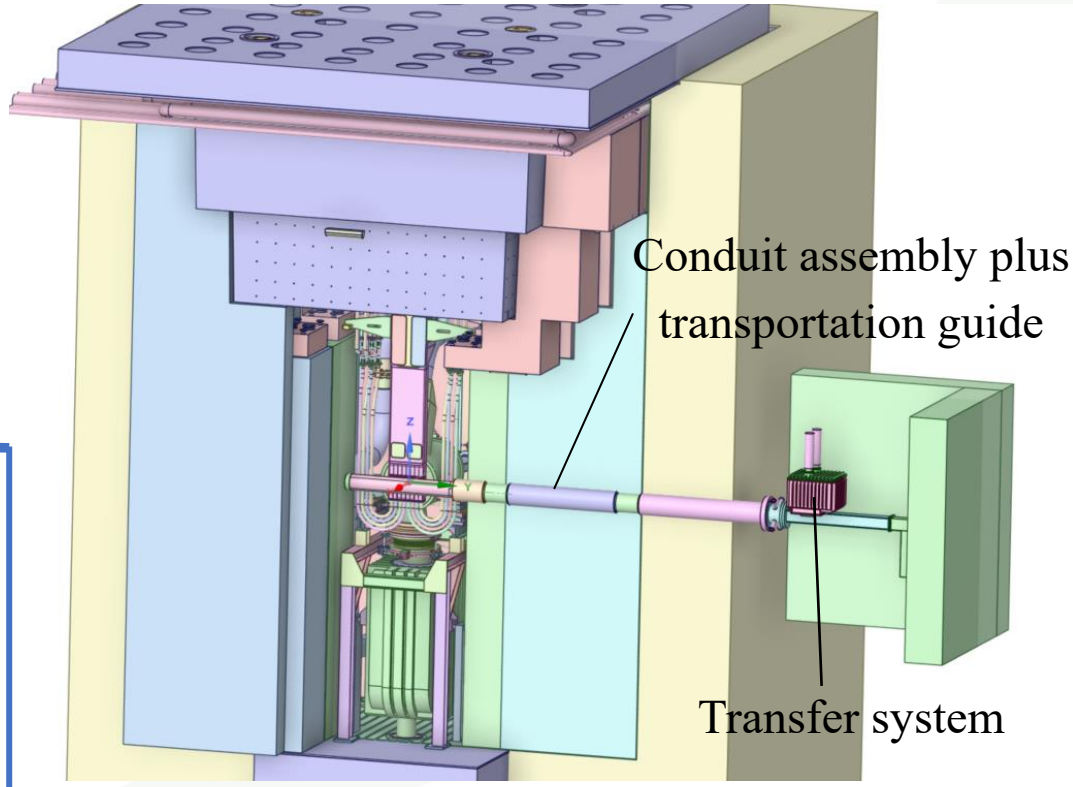


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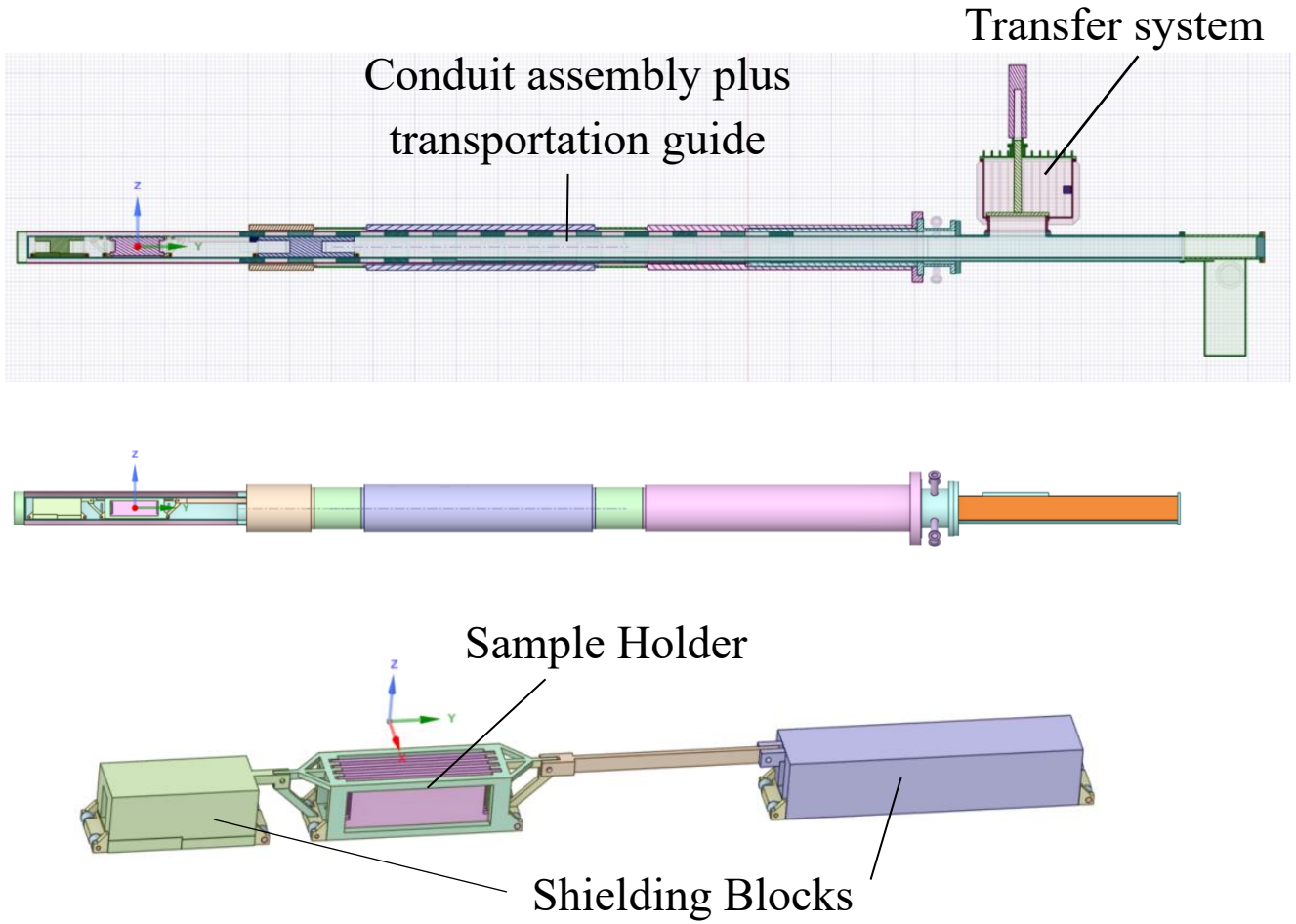


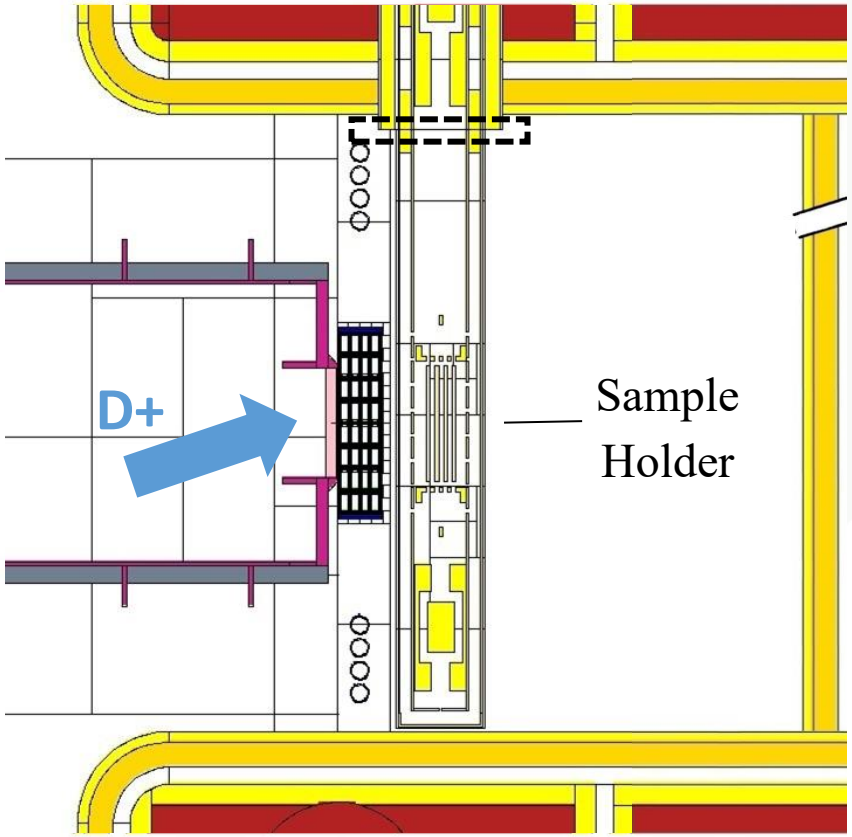
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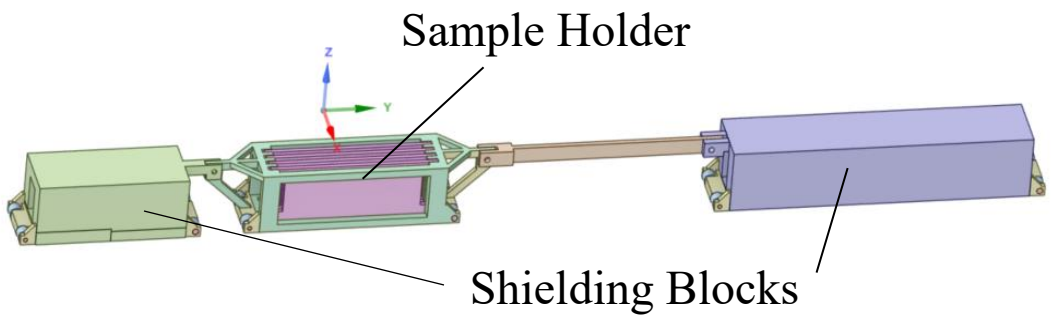


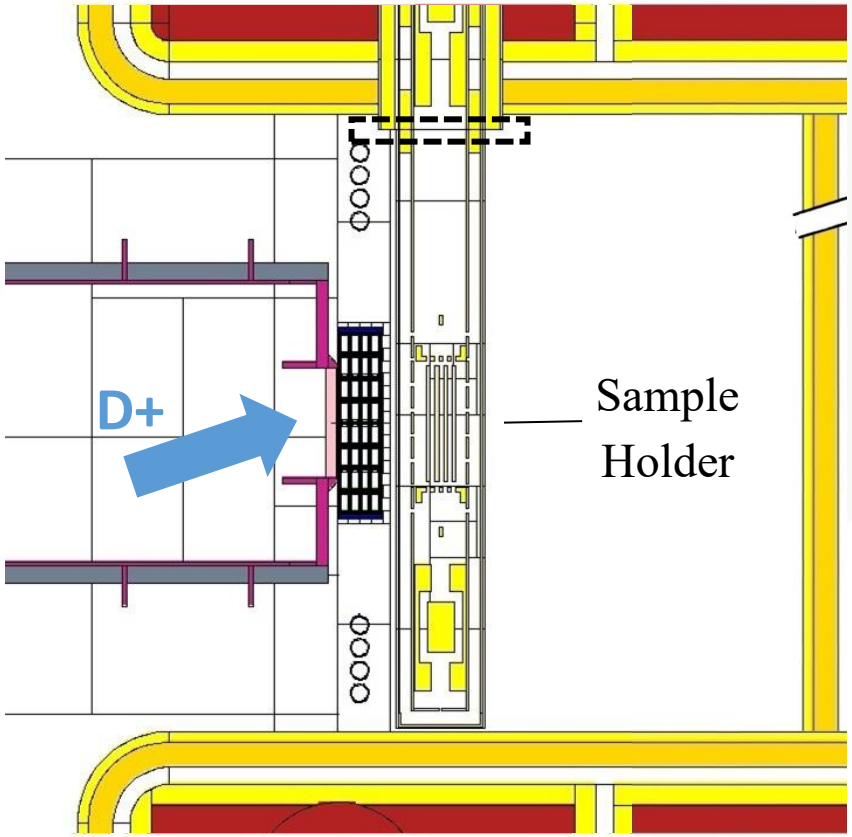


2. Radioisotope Production at IFMIF-DONES

Radioisotope production with neutrons inside Test Cell → $^{99}Mo/^{99m}Tc$

Reaction	Location	Irradiation Time (days)	^{99}Mo Activity (TBq)	Specific Activity (GBq/g of ^{99}Mo)
$^{100}Mo(n,2n)^{99}Mo \rightarrow ^{99m}Tc$	Plate 1	6	21.59	24.14
	Plate 2		18.65	20.85
	Plate 3		15.93	17.81
	Plate 4		13.63	15.24
	Total		69.80 TBq	

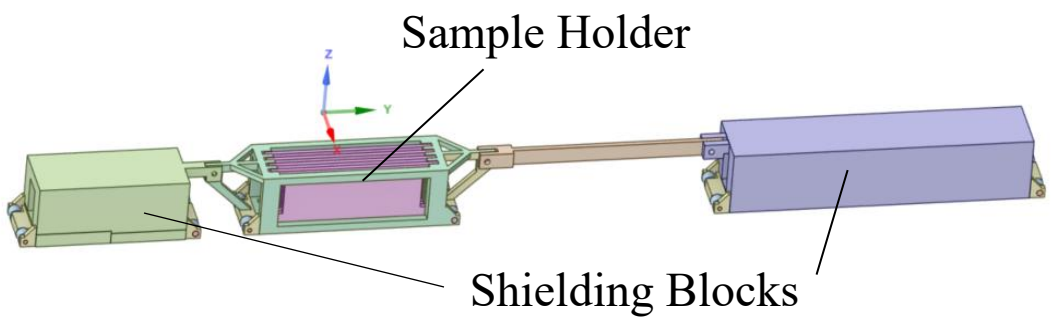




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Reaction	Location	Irradiation Time (days)	^{99}Mo Activity (TBq)
$^{100}Mo(n,2n)^{99}Mo \rightarrow ^{99m}Tc$	Plate 1	6	21.59
	Plate 2		18.65
	Plate 3		15.93
	Plate 4		13.63
	Total		323 6-day Ci



Reactor (fuel)	Current targets	Anticipated ^{99}Mo production weeks/year	Expected available capacity per week (6-day Ci ^{99}Mo)	Estimated end of operation
BR-2 (HEU)	LEU	29	8 600	2036
HFR (LEU)	LEU	38	6 200	2030
LVR-15 (LEU)	LEU	30	3 000	2028
MARIA (LEU)	LEU	36	2 200	2040
MURR (HEU)	EnMo in CRR	52	3 000	2037
OPAL (LEU)	LEU	44	3 200	2057
RA-3/RA-10 (LEU)	**LEU**	**46**	**500**	**2027 or earlier based on RA-10 introduction**
SAFARI-1 (LEU)	LEU	44	3 000	2030
RIAR (HEU)	**HEU**	**50**	**540**	**At least until 2025**
KARPOV5 (HEU)	**HEU**	**48**	**350**	**At least until 2025**

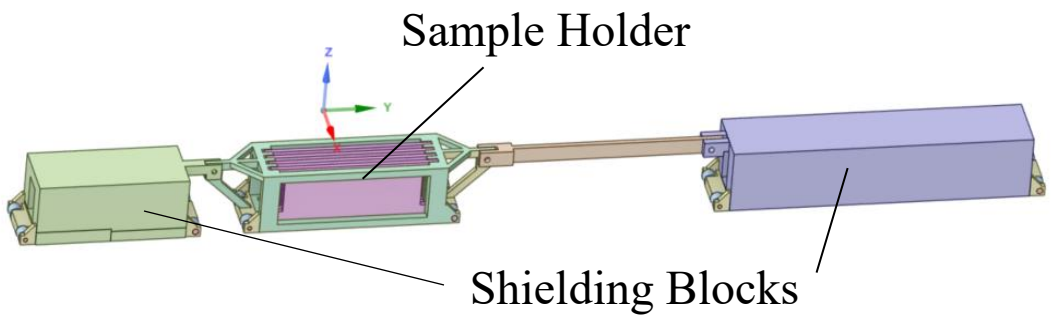
Notes: EnMo = enriched ^{98}Mo target; HEU = highly enriched uranium (>20% U-235); LEU = low-enriched uranium (<20% U-235).

✓ Quantity similar to nuclear reactors.

2. Radioisotope Production at IFMIF-DONES

Radioisotope production with neutrons inside Test Cell → $^{99}Mo/^{99m}Tc$

Reaction	Location	Irradiation Time (days)	^{99}Mo Activity (TBq)
$^{100}Mo(n,2n)^{99}Mo \rightarrow ^{99m}Tc$	Plate 1	6	21.59
	Plate 2		18.65
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	Plate 4		13.63
	Total		323 6-day Ci



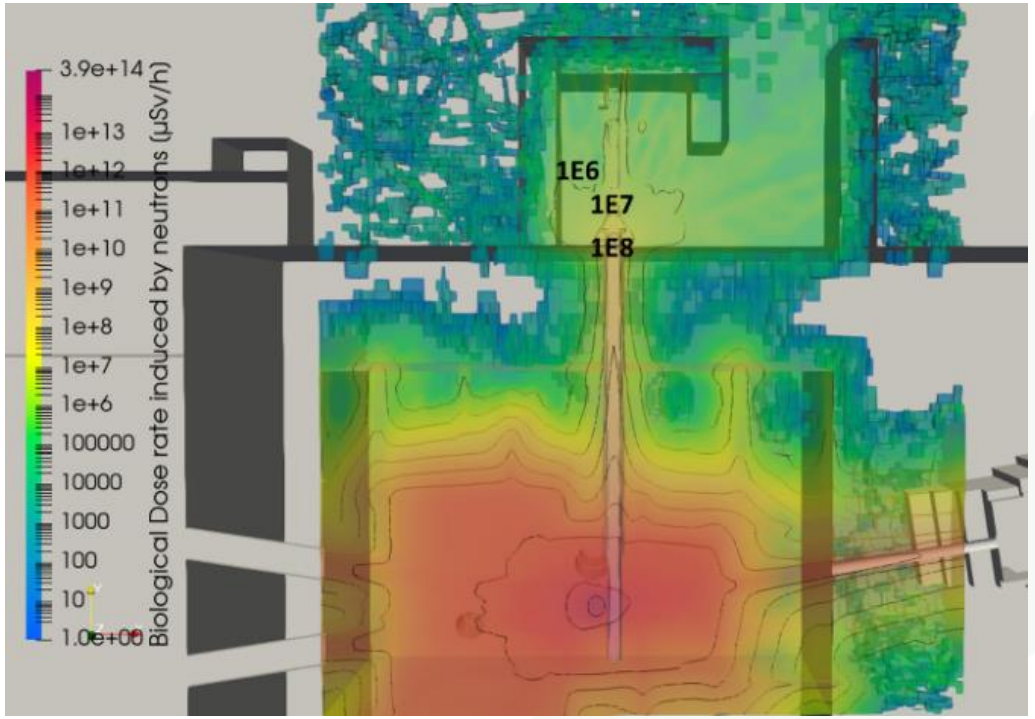


Figure.- Biological dose rate [µSv/h] induced by neutron streaming in TC adjacent room during IFMIF-DONES operation with the target holder in reloading position: (a) SS316L shielding

✗ Lateral insertion is not the best method due to the high dose rates in the adjacent room.

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IFMIF-DONES could help to reduce the problem of lack of facilities for the **RI production**.

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Production via deuterons is competitive with conventional ^{165}Er production routes and the yield of ^{177}Lu could be enough for preclinical studies.

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A prototype for RI production **has been validated**; which can dissipate **1 kW/cm^2** of power.

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Production via deuterons is competitive with conventional ^{165}Er production routes and the yield of ^{177}Lu could be enough for preclinical studies.

A prototype for RI production **has been validated**; which can dissipate **1 kW/cm^2** of power.

Production via neutrons is highly cost-effective in quantitative terms for ^{99}Mo/^{99m}Tc, making it a very valuable complementary activity; however, **research into new methods for introduce and remove samples is needed.**

3. Conclusions and outlook

IFMIF-DONES could help to reduce the problem of lack of facilities for the **RI production**.

Production via deuterons is competitive with conventional ^{165}Er production routes and the yield of ^{177}Lu could be enough for preclinical studies.

A prototype for RI production **has been validated**; which can dissipate **1 kW/cm²** of power.

Production via neutrons is highly cost-effective in quantitative terms for $^{99}Mo/^{99m}Tc$, making it a very valuable complementary activity; however, **research into new methods for introduce and remove samples is needed.**

IMPRONTA Granada 2026 Award for the **Thesis titled "Isotope Production in DONES"**, in recognition of its regional and social impact in Granada.

Thank you for your attention.

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