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Potential of radioactive isotopes production in DEMO for commercial use

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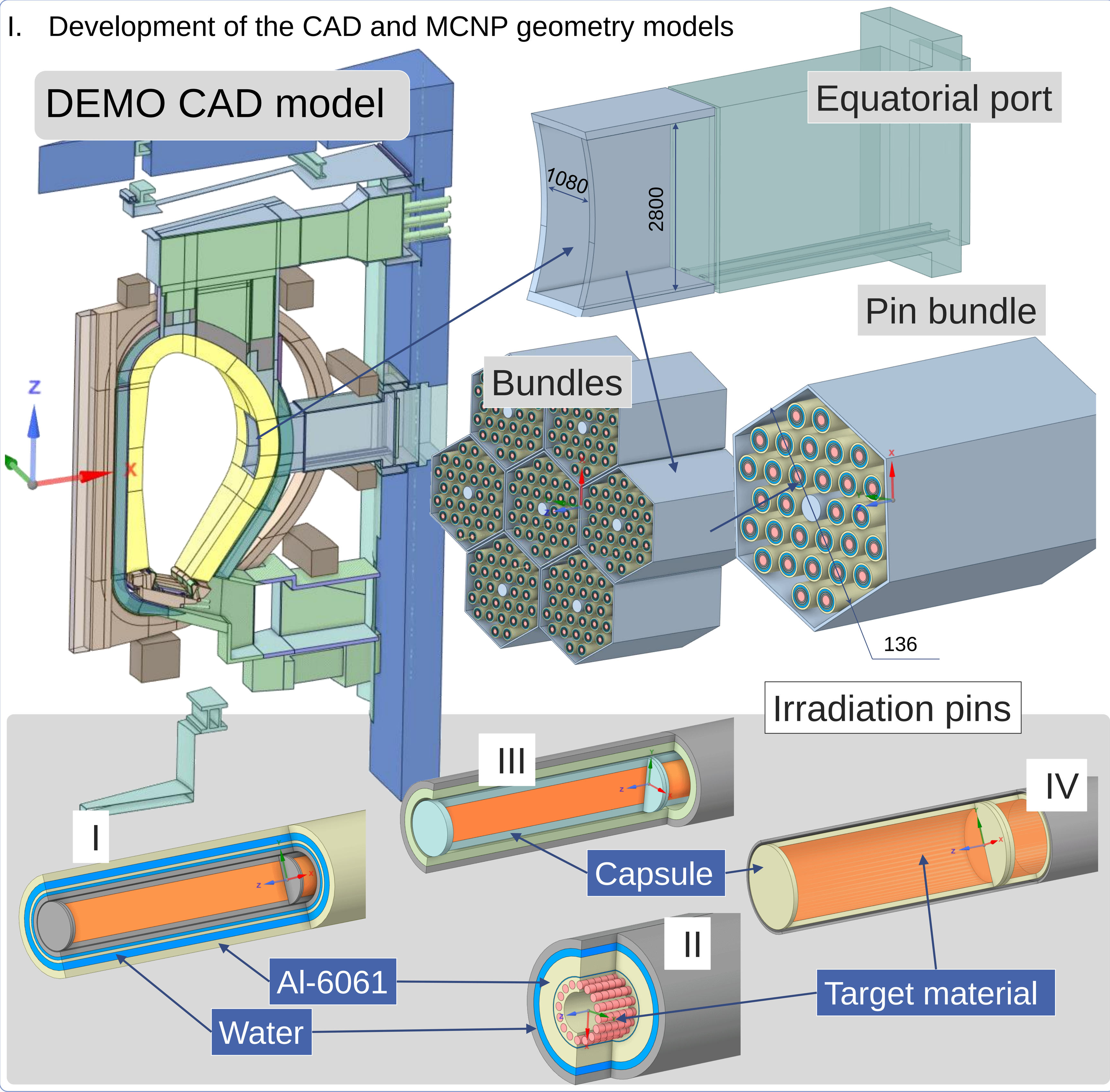
Objectives

- Assessment of the DEMO neutron source potential to generate radioactive isotopes with different half-lives for medical application

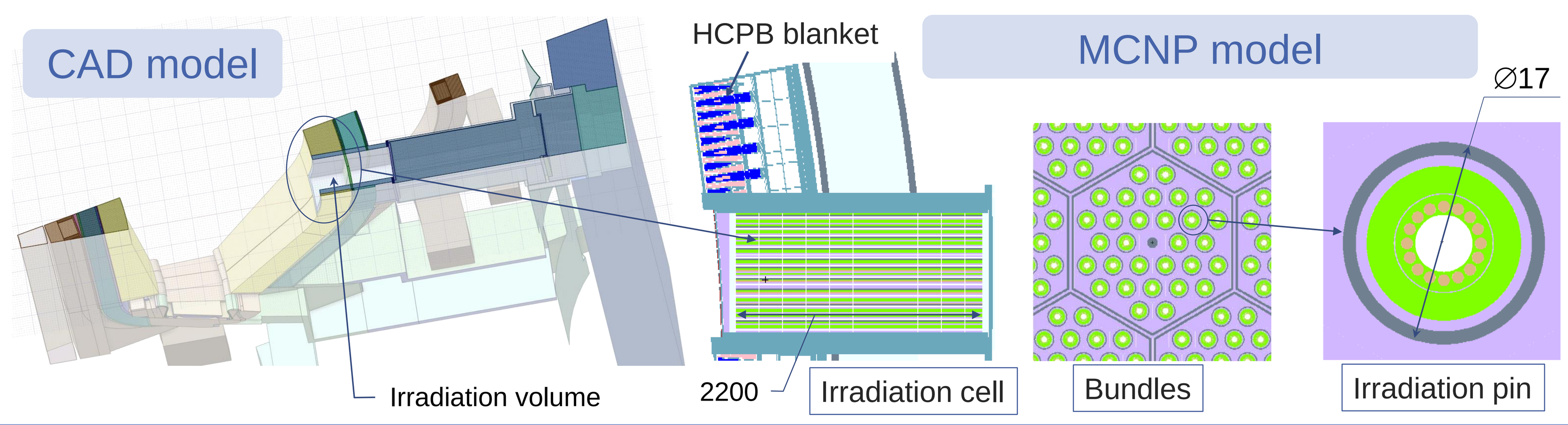
Workflow

- Preparation of the DEMO CAD model with an irradiation port
- Conversion into the MCNP geometry representation
- Development of the DEMO model with HCPB blankets and integrated Irradiation Cell (IC)
- MCNP simulation to get neutron spectra in the IC
- Activation analyses in the IC(s)
- Analyses of the results

I. Development of the CAD and MCNP geometry models



II. MCNP6.2 calculations to provide neutron spectra in the IC.

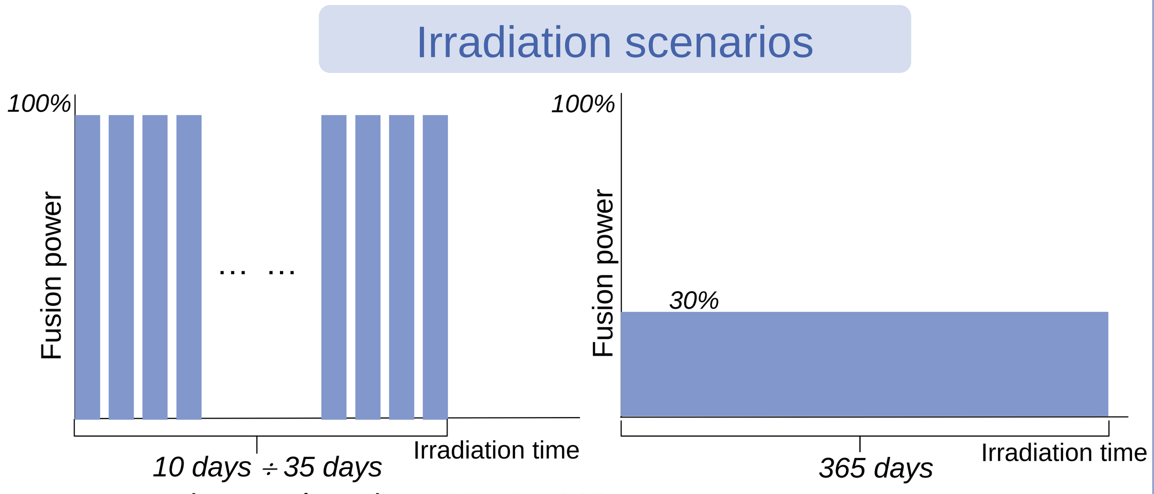


III. FISPACT II activation calculations.

Production of radioactive isotopes with different $T_{1/2}$

1. ^{99}Mo(65.94h), ^{153}Sm(46.27h), ^{90}Y(64.0h)
2. ^{131}I(8.04d), ^{177}Lu(6.734d), ^{192}Ir(73.83d), ^{103}Pd(16.99d), ^{186}Re(3.718d), ^{169}Yb(32.026d), ^{125}I(59.408d)
3. ^{60}Co(5.2714y), ^{204}Tl(3.78y)

Irradiation scenarios

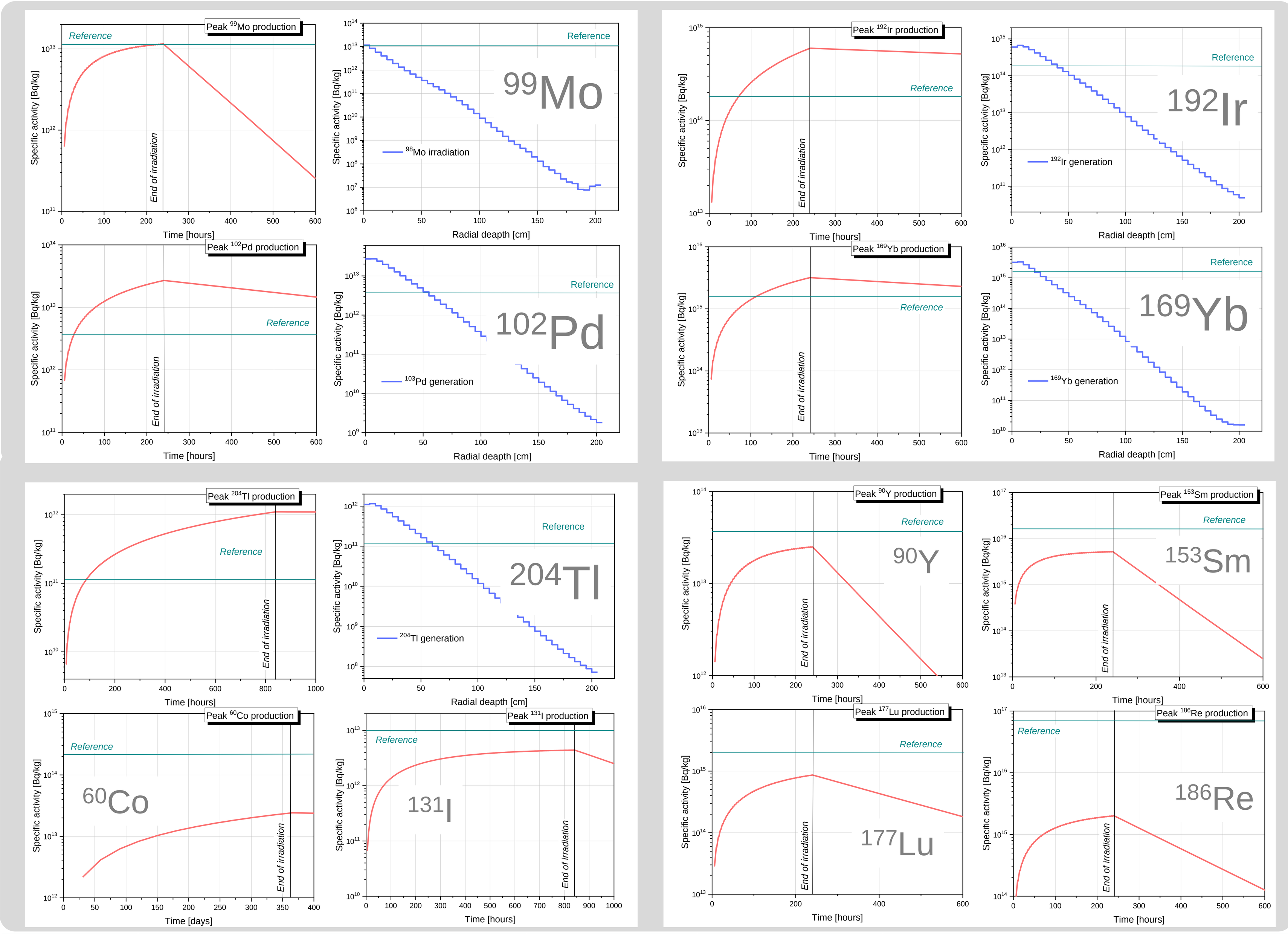


1. Modern nuclear data: TENDL-2021
2. Very detailed neutron spectra structure: 709 groups
3. Different irradiation schemes

IV. Post-processing of the results

- Processing of the results is fully automated
- Task size independent
- Flexible adjustment of the requests
- The specific data can be restored:
  - *Time evolution of the activity/decay heat for a group of the cells*
  - *Time evolution of the activity/decay heat for isotope(s) in cell(s)*
  - *Results for dominant nuclides*
  - *Uncertainty assessment (only decay phase)*
  - *Specific data, masses, differential activity (α, β, γ)*
  - *Special data for the chosen time step(s)*

V. Analyses of the results



Isotope	$T_{1/2}$	Reaction [target material]	Irradiation campaign, days [camps/year]	Max. specific activity, [reference], Bq/g	Max. yield[1], commercial yield[2], [total yield/year], TBq	Price assessment, M$/year
^{99}Mo	65.94 hours	^{98}Mo(n,γ)^{99}Mo [^{98}Mo]	10 [11]	1.2·10^{10} [1.2·10^{10}]	4.4·10^{1}* 1.4·10^{2}* [1650]*	10÷30
^{192}Ir	73.83 days	^{191}Ir(n, γ)^{192}Ir [Na_2IrCl_6]	10 [11]	6.7·10^{11} [6.85·10^{10}]	3.0·10^{1} 1.9·10^{2} [2200]	20÷60
^{103}Pd	16.99 days	^{102}Pd(n, γ)^{103}Pd [^{102}Pd]	10 [11]	2.7·10^{10} [3.7·10^{9}]	1.2·10^{1} 7.6·10^{1} [847]	20÷90
^{169}Yb	32.026 days	^{168}Yb(n, γ)^{169}Yb [Yb_2O_3]	10 [11]	3.2·10^{12} [1.6·10^{12}]	7.5·10^{1} 3.8·10^{2} [4290]	20÷70
^{204}Tl	3.78 years	^{203}Tl(n, γ)^{204}Tl [Tl]	35 [3]	1.2·10^{9} [1.4·10^{8}]	8.8·10^{0} 5.6·10^{1} [168]	-
^{125}I	59.408 days	^{124}Xe(n,γ)^{125}Xe →^{125}I [^{124}Xe]	10 [11]	6.5·10^{14} [6.0·10^{14}]	2.6·10^{-1} 1.5·10^{0} [17]	15÷55
^{60}Co	5.2714 years	^{59}Co(n,γ)^{60}Co [Co]	365 [1]	2.4·10^{10} [2.2·10^{11}]	6·10^{2} - [2200]	0.1÷30
^{131}I	8.04 days	^{130}Te(n,γ)^{131}Te →^{131}I [TeO_2]	35 [3]	4.4·10^{9} [1.0·10^{10}]	1.0·10^{3} 5.3·10^{3} [18000]	40÷200
^{90}Y	64.0 hours	^{89}Y(n,γ)^{90}Y [Y]	10 [11]	2.5·10^{10} [3.7·10^{10}]	3.1·10^{2} 1.2·10^{3} [15400]	5÷140
^{153}Sm	46.27 hours	^{152}Sm(n,γ)^{153}Sm [Sm_2O_3]	10 [11]	5.2·10^{12} [1.5·10^{13}]	1.0·10^{1} 3.2·10^{1} [429]	20÷80
^{177}Lu	6.734 days	^{176}Lu(n,γ)^{177}Lu [Lu_2O_3]	10 [11]	8.7·10^{11} [4.2·10^{13}]	3.9·10^{1} - [2310]	50÷220
^{186}Re	3.718 days	^{185}Re(n,γ)^{186}Re [^{185}Re]	10 [11]	2.0·10^{12} [6.8·10^{13}]	2.7·10^{1} - [1210]	20÷400

[1]Edge 50 mm of the pins
[2]Total activity in all radial segments of the pins above 0.1×Reference
**Six-days activity*

V. Conclusions

- DEMO volumetric neutron source is a powerful and valuable tool for the radioactive isotopes production
- The Irradiation Cell can be integrated in the DEMO design to replace NBI ports
- DEMO has a significant potential of the radioactive isotopes production for the medical applications
- The use of the IC for the production of the short-lived isotopes is more preferable compared to the long-lived ones
- An assessed optimistic potential income from the IC supports economical and social acceptance of the DEMO project

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.