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Analysis of Water Activation Loop at the JSI TRIGA Research Reactor

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EUROfusion

BACKGROUND

- High dose rates (~100 Sv/h) around cooling circuit (ITER)
- Lack of water activation experiments in fission/fusion relevant conditions

Design and installation of water activation loop at the JSI TRIGA reactor

GOAL

- Find **optimal shape** of the **irradiation part** to achieve high activity of the water loop
- **Design criteria:**
  - Effective water volume
  - Reaction rate map
  - Pressure drop
  - Water velocity profile

METHOD

- 2-step activity calculation
  - Reaction rate calculation (MCNP + ADVANTG)
  - Further analytical transport of the activated water (without CFD)
- Hydraulic properties
  - CFD (ANSYS Fluent pack.)

RESULTS

- **"Snail"** design systematically outperforms other designs by more than 2 times
- The most important parameter is an effective water volume
- **"Snail"** design was chosen as the main shape for the **irradiation** and also for the **radiation** part of the loop

Water activation

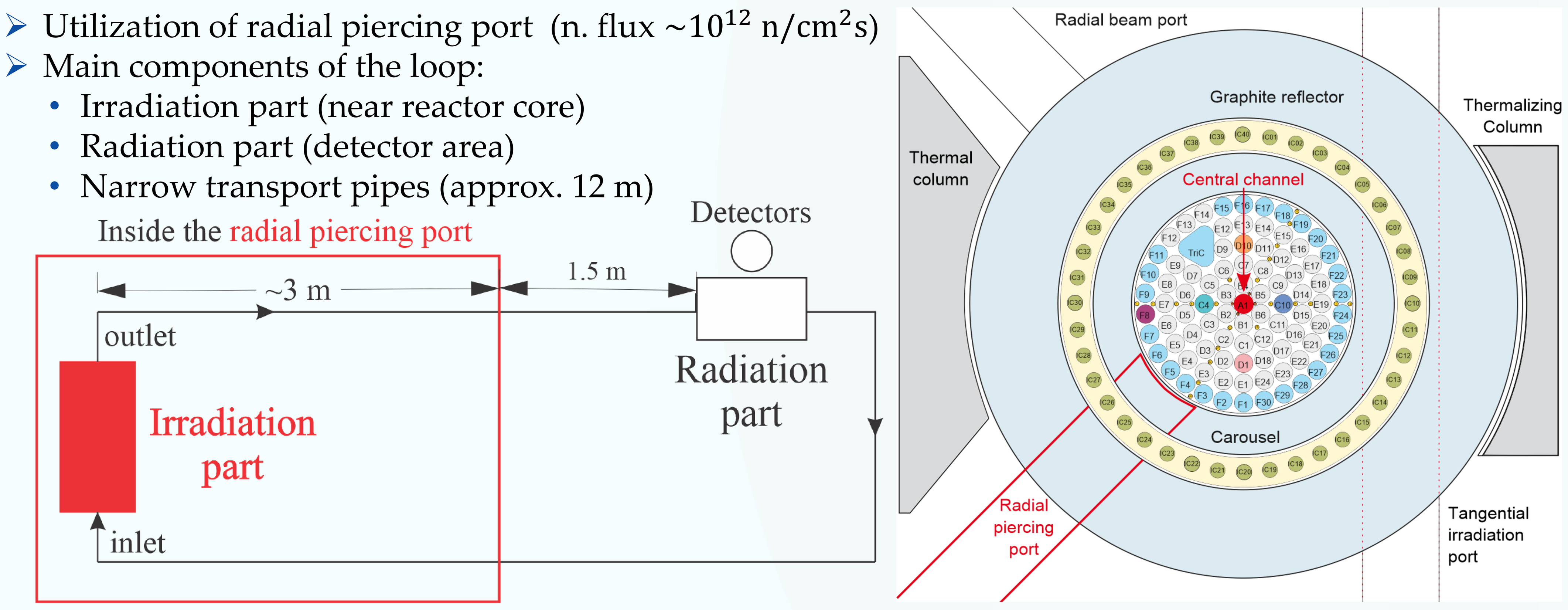
Main water activation reactions and corresponding decay characteristics

Reaction	Natural abundance of oxygen isotope	Half-life $t_{1/2}$	Major decay products	Threshold energy
$^{16}O(n,p)^{16}N$	**99.76 %**	**7.13 s**	**γ: 6.13 MeV (67 %)**	**~10 MeV**
			γ: 7.12 MeV (5 %)	
$^{17}O(n,p)^{17}N$	0.04 %	4.14 s	n: 0.38 MeV (35 %)	~8 MeV
			n: 1.17 MeV (53 %)	
			γ: 0.87 MeV (3 %)	
$^{18}O(n,\gamma)^{19}O$	0.2 %	26.9 s	γ: 0.20 MeV (96 %)	< 1 eV
			γ: 1.36 MeV (50 %)	

- **0.6 %** of **fission neutrons** are above 8 MeV (IRDF-II)

Closed-water activation loop

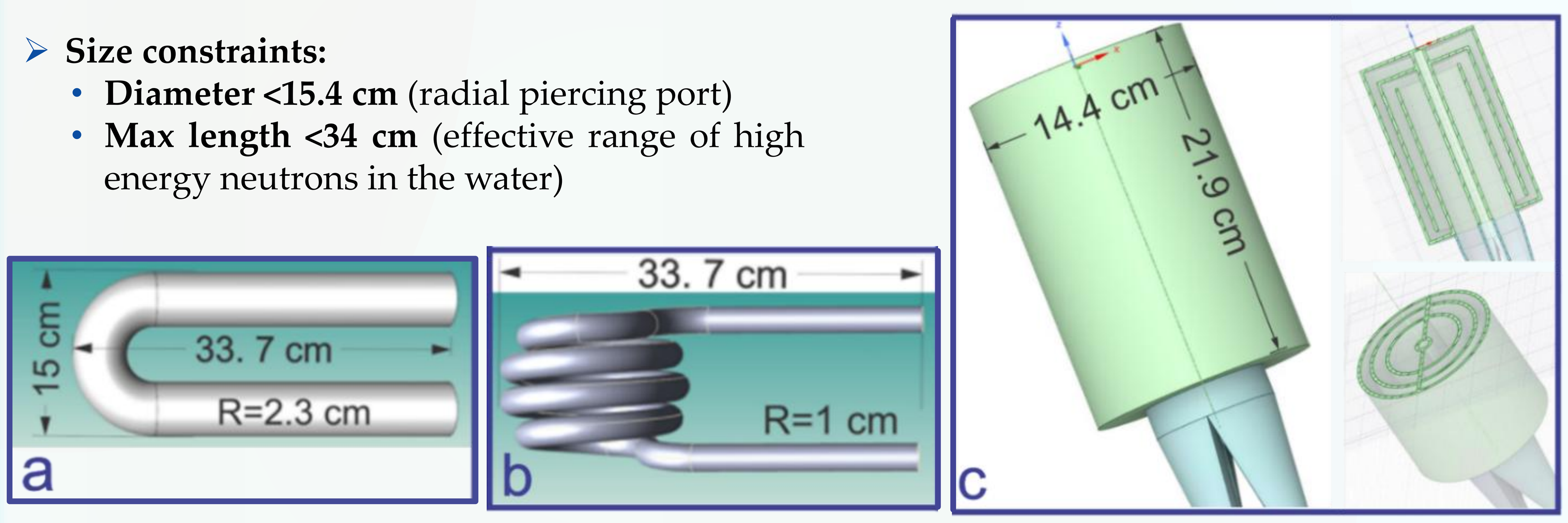
- Utilization of radial piercing port (n. flux ~10^{12} n/cm^{2}s)
- Main components of the loop:
  - Irradiation part (near reactor core)
  - Radiation part (detector area)
  - Narrow transport pipes (approx. 12 m)



Scheme of the JSI TRIGA reactor with the basic conceptual design of the water activation loop

IRRADIATION PART ANALYSES (3 different shapes based on the complexity level)

- **Size constraints:**
  - **Diameter <15.4 cm** (radial piercing port)
  - **Max length <34 cm** (effective range of high energy neutrons in the water)



"U-turn"
- Low complexity
- Wide pipe
- Single 180° turn
- **V = 1.13 l**

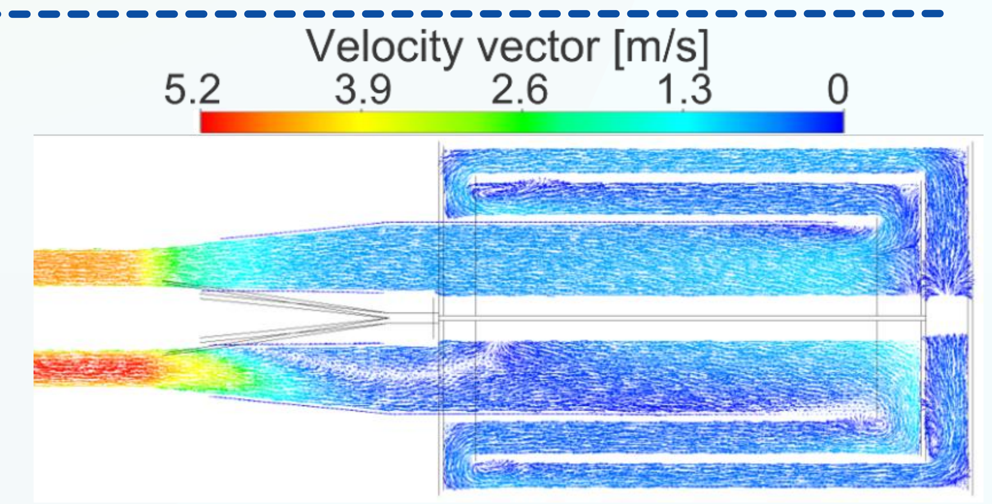
"spiral"
- Medium complexity
- Smaller pipe
- Several turns
- Closer to the core
- **V = 0.52 l**

"snail"
- High complexity
- 3-cylinder blocks
- Vertical XZ wall
- Complex connecting part
- Perfectly fit inside the port
- **V = 2.72 l**

Hydraulic properties

- CFD calculations: ANSYS Fluent package
  - **Pressure drop** VS flow rate
  - **Water velocity flow profile** VS flow rate
- Minimal stagnation points/vortexes

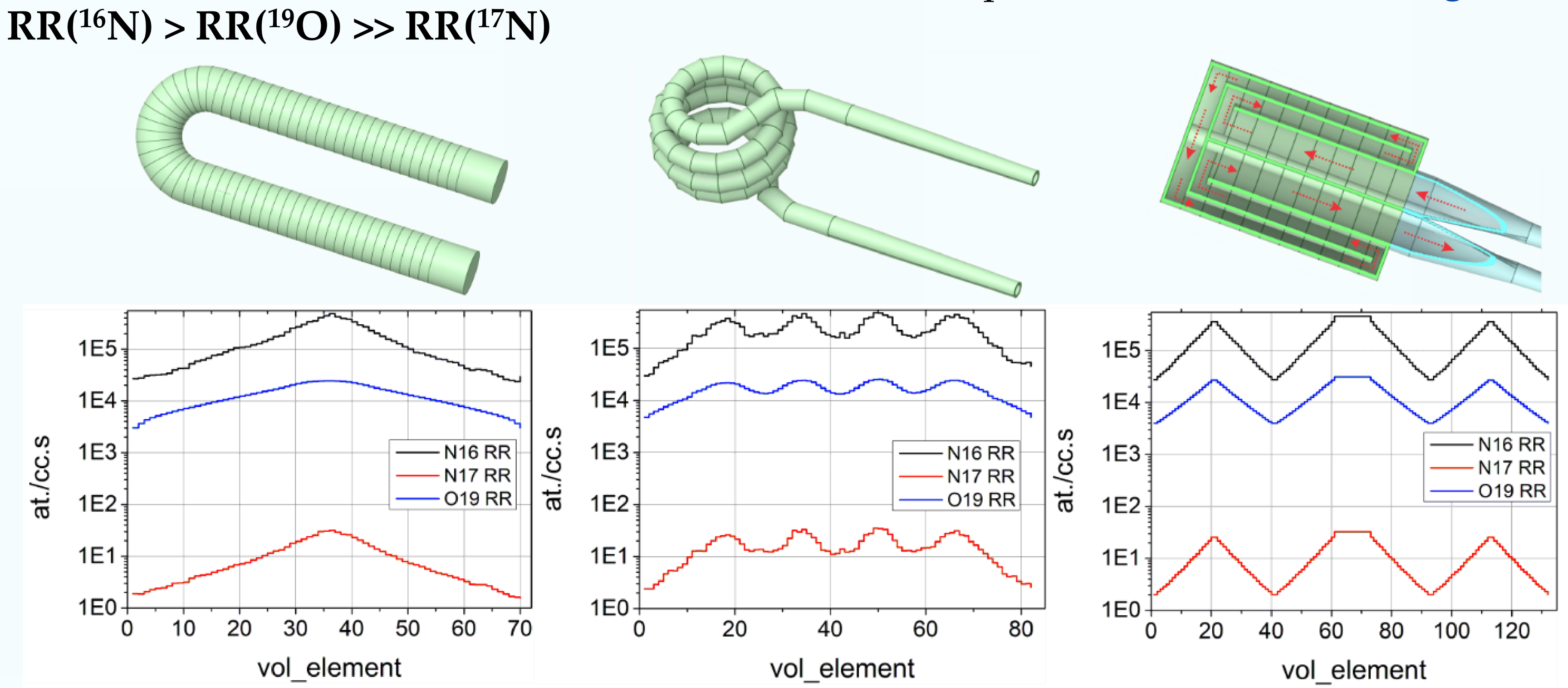
does not differ significantly between analysed designs !!!



Water velocity profile within the snail design at a flow rate of 1 l/s

Reaction rate map

- Calculation: MCNP (particle transport) + ADVANTG (variance reduction)
- Reaction rate values as a function of volume element (position) → **self-shielding effect**
- **RR(^{16}N) > RR(^{19}O) >> RR(^{17}N)**



Activity calculation

$$a_{sat}(\Phi) = \frac{R\left(1-e^{-\lambda t_{irr}}\right)e^{-\lambda t_{trans}}}{1-e^{-\lambda(T_{loop}+t_{irr})}}\left(1-e^{-\lambda t_{rad}}\right)\frac{\Phi}{\lambda}$$

- Activity [Bq] inside the radiation part
- Closed-water loop → build-up factor
- Saturation achieved at about 0.4 l/s
- **A(^{16}N) > A(^{19}O) >> A(^{17}N)**
- Higher values → easier measurement

"Snail" design outperforms "U-turn" & "spiral" by more than 2 times