Parametric analysis of the closed water activation loop at the JSI TRIGA reactor

WATER ACTIVATION CHALLENGES

- High dose rates (~100 Sv/h) around cooling circuit (ITER)
- Large discrepancies and inconsistencies among nuclear data libraries
- Lack of:
  - water activation experiments in fusion relevant conditions
  - experimental facilities featuring high energy γ sources
  - calculation tools/methodologies for dose rate calculations

PROPOSAL

- **Design and installation of water activation loop at JSI TRIGA reactor**
  - γ detector characterization & calibration (6 MeV – 7 MeV)
  - shielding experiments using ITER relevant materials
  - integral cross-section measurements of oxygen isotopes
  - dose rates and γ spectrum measurements along the water loop
  - reference irradiation facility for benchmark experiments

CURRENT LOOP STATUS

- Design and modelling phase
- Uncertainty & sensitivity analysis
- Optimization of the main parameters

CONCLUSION

- **Total saturated activity**
  - High impact: $t_{irradiation}$
  - Low impact: water flow rate
- **Highest contribution to the total uncertainty**
  - Short + slow loop: RR, $t_{irradiation}$
  - Short + fast loop: RR, $t_{irradiation}$, T_{loop}
  - Long + slow loop: λ
  - Long + fast loop: RR, $t_{irradiation}$, λ

Water activation

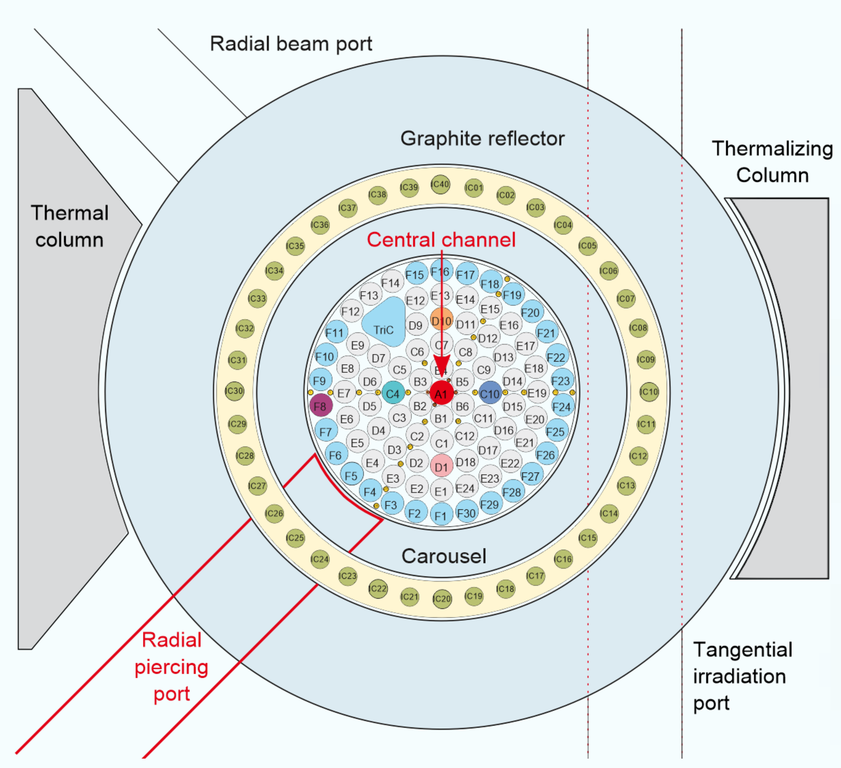
Most relevant water activation reactions and corresponding decay characteristics

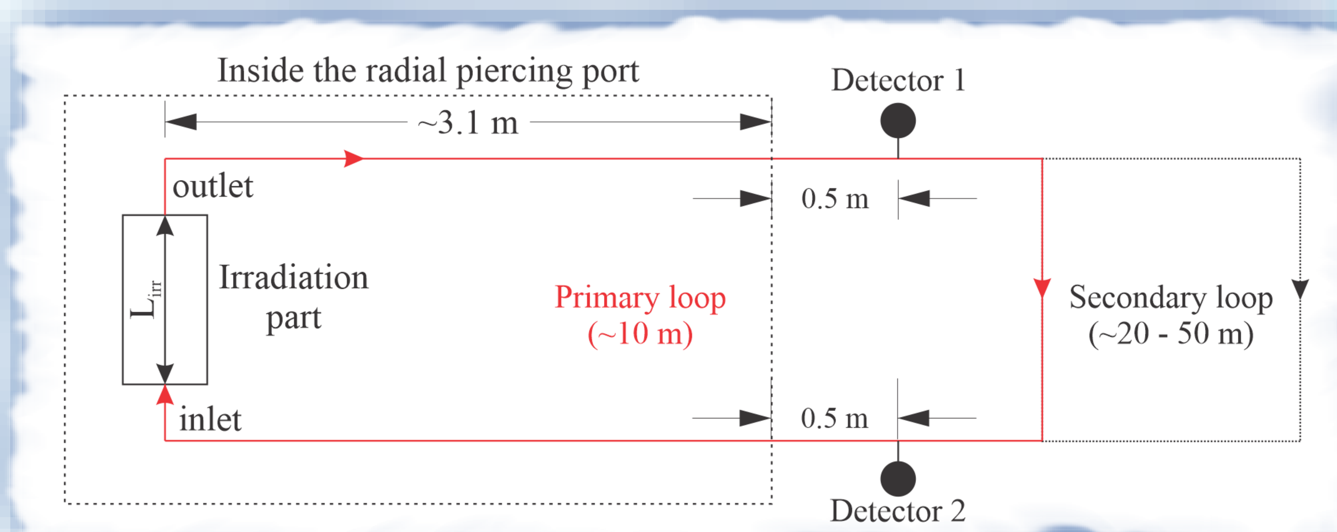
Reaction	Natural abundance of oxygen isotope	Half-life $t_{1/2}$	Major decay products	Threshold energy
$^{16}O(n,p)^{16}N$	99.76 %	7.13 s	γ: 6.13 MeV (67 %)	~10 MeV
			γ: 7.12 MeV (5 %)	
$^{17}O(n,p)^{17}N$	0.04 %	4.14 s	n: 0.38 MeV (35 %)	~8 MeV
			n: 1.17 MeV (53 %)	
			γ: 0.87 MeV (3 %)	
$^{18}O(n,\gamma)^{19}O$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

Close water activation loop

- Utilization of radial piercing port
  - high neutron flux ~10^{12} n/cm²s
- Primary loop (^{16}O, ^{17}O) & secondary loop: ^{18}O
- Commission in late 2022

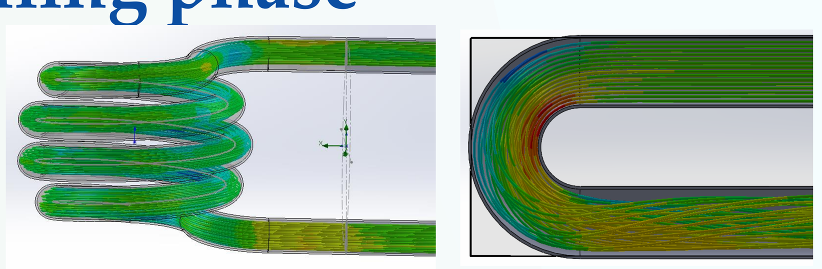




Scheme of the JSI TRIGA reactor with the basic conceptual design of the water activation loop

Design and modelling phase

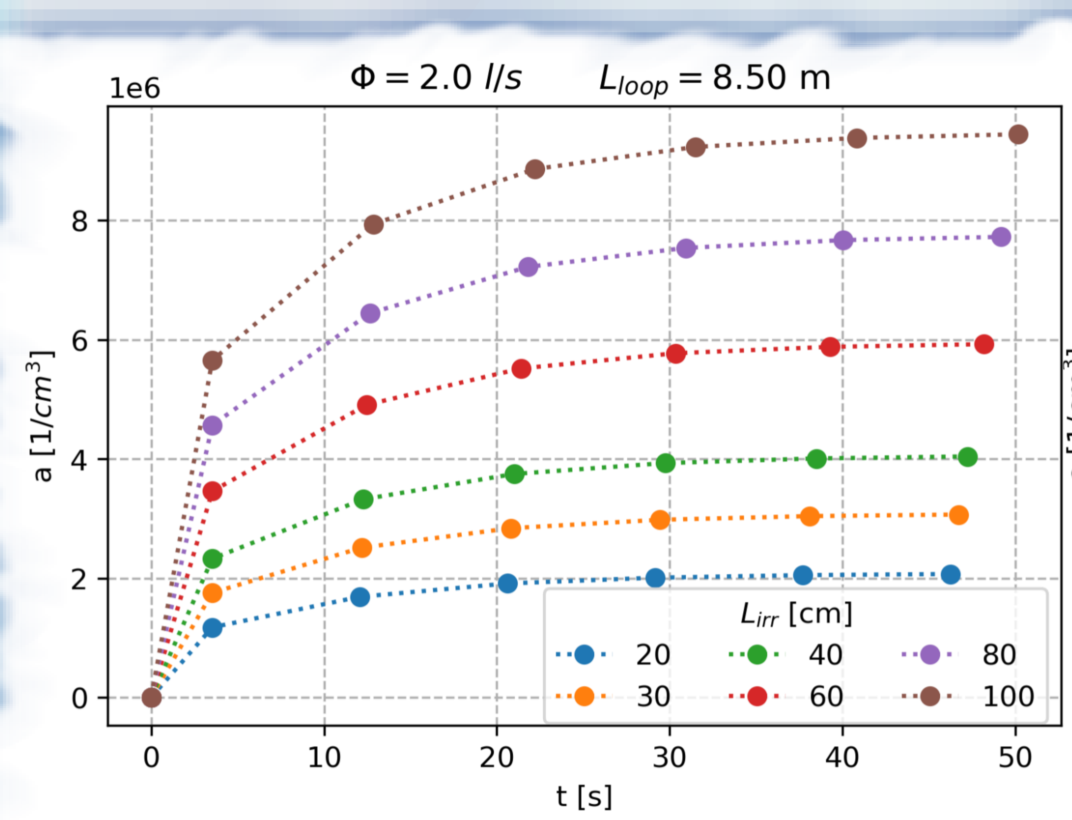
- Optimization of the main parameters
  - irradiation part, total loop length, water flow, detector's position, delay loop, etc.
- Goal:
  - high specific activity
  - low experimental uncertainty
  - flexible loop

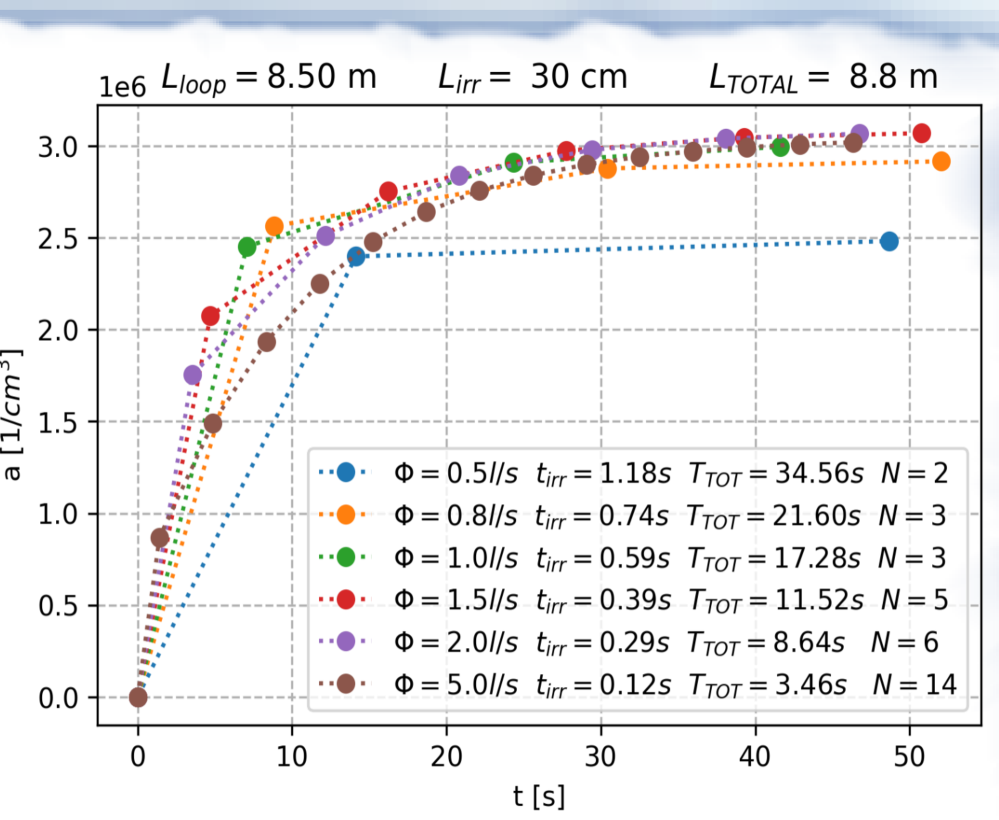


Different designs of the irradiation part

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

Specific saturation activity at detector



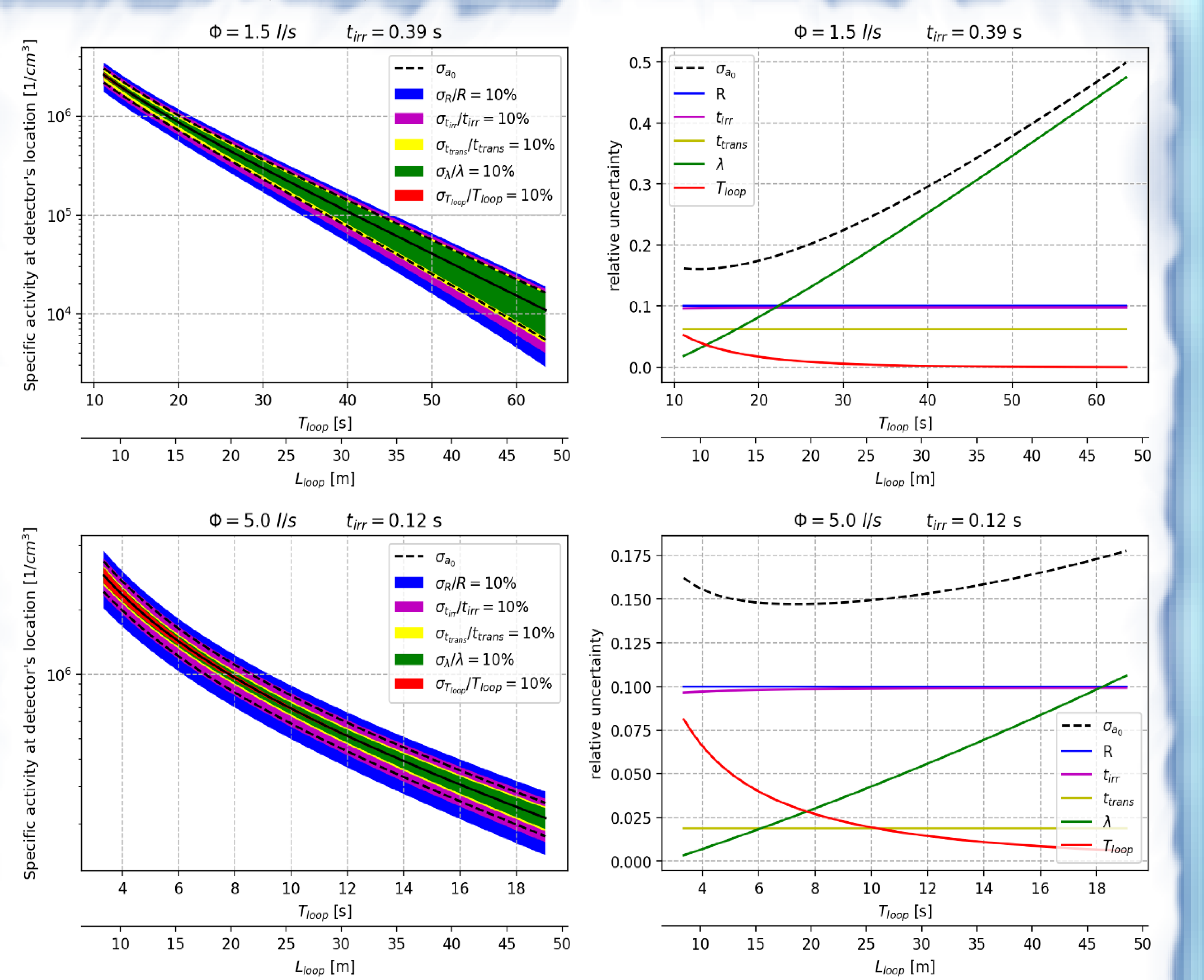


Specific activity of ^{16}N at the "detector 1" position in dependence on time, time scale until activity reaches 99 % of the saturation value

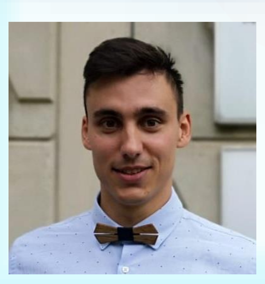
Uncertainty & sensitivity study

- Relative uncertainty of all parameters set to 10 % $\left(\frac{\sigma_R}{R}, \frac{\sigma_{t_{irr}}}{t_{irr}}, \frac{\sigma_{trans}}{t_{trans}}, \frac{\sigma_\lambda}{\lambda}, \frac{\sigma_{T_{loop}}}{T_{loop}}\right)$
- Loop characteristics:
  - length: 8.5 m to 48.5 m
  - water flow: 1.5 l/s & 5 l/s

$$\sigma_{a_{sat}} = \sqrt{\left(\sigma_R \frac{\partial a_0}{\partial R}\right)^2 + \left(\sigma_\lambda \frac{\partial a_0}{\partial \lambda}\right)^2 + \left(\sigma_{t_{irr}} \frac{\partial a_0}{\partial t_{irr}}\right)^2 + \left(\sigma_{t_{trans}} \frac{\partial a_0}{\partial t_{trans}}\right)^2 + \left(\sigma_T \frac{\partial a_0}{\partial T_{loop}}\right)^2}$$



Uncertainty (left) and sensitivity (right) study of the specific activity at the "detector 2" position in dependence on the water loop size and flow rate



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