From midpoint to endpoint level radiological impacts on human health in prospective LCA: leveraging open source solutions to investigate the Fessenheim NPP decommissioning

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Context and objectives

The **CO2InnO project**[1] is a France-Germany cross-border living laboratory, investigating several aspects of the energy transition at the local scale. One of these is the study of the environmental impacts of the upcoming Fessenheim Nuclear Power Plant (NPP) decommissioning.

NPP decommissioning have been relatively neglected in academic environmental impact studies, in particular through the lens of life cycle assessment (LCA), with only 3 studies to date[2-4].

In parallel, **there has been relatively low interest in radiological impact assessment in the field of LCA**, in particular due to the lack of an appropriate and consistent life cycle impact assessment (LCIA) framework[5]. Two recently developed methodologies attempt to remedy this problem regarding impacts on human health[6]:

- **UCrad**, built as a radiological counterpart to the widely used USEtox, is designed to produce **globally averaged results adapted for technology evaluation & comparison.**
- **CGM**, drawing on analytical modeling of established risk assessment studies, is designed for **plant-scale evaluation in a screening context.**

The development of UCrad have also been pushed from the midpoint/effect level, in Sievert (Sv), to the endpoint/damage level in Disability-Adjusted Lost Years (DALYs)[7]. The approach can easily be transferred to CGM by adapting the population considered. Furthermore**, the time scale of an NPP decommissioning (at least 15 years) suggest that population evolution could cause bias in the characterization factors (CFs)** used, *a fortiori* the obtained results, **if not dynamically adjusted**.

$$CF^{\text{endpoint}} = CF^{\text{midpoint}} \cdot EF \cdot P$$

Endpoint CF = Midpoint CF · Effect Factor · Population

We resolve this by using population datasets designed for consistency with the different shared socio-economic pathways (SSPs). These datasets are imported in the **QGIS open source software**[8], and extracted population values are used **to construct appropriate CFs for the prospective endpoint-level assessment**.

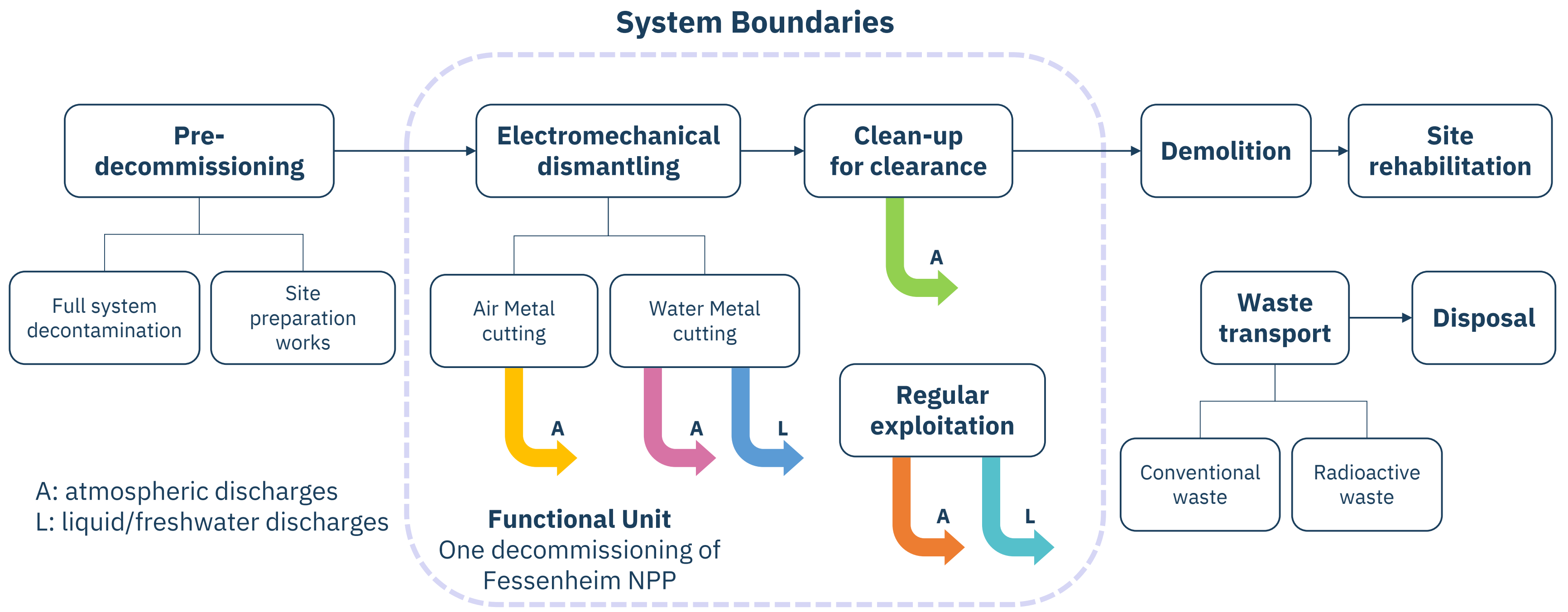
This allows us to compute the midpoint & endpoint radiological impacts on human health expected to occur during the Fessenheim NPP decommissioning, compare "static" & prospective LCA estimates, and to highlight perspectives for the development of the UCrad & CGM LCIA methods.

References

[1] CO2InnO Project. Interreg Upper Rhine 2021–2027, A1.3. URL.
[2] Wallbridge, *et al.*, 2013. Life cycle environmental impacts of decommissioning Magnox nuclear power plants in the UK. Int J Life Cycle Assess 18, 990–1008. DOI.
[3] Seier, M., Zimmermann, T., 2014. Environmental impacts of decommissioning nuclear power plants: methodical challenges, case study, and implications. Int J Life Cycle Assess 19, 1919–1932. DOI.
[4] Iguider, M. *et al.*, 2024. Life cycle assessment of an upcoming nuclear power plant decommissioning: the Fessenheim case study from public data. Int J Life Cycle Assess. DOI.
[5] Paulillo, A. *et al.*, 2018. Radiological impact assessment approaches for Life Cycle Assessment: a review and possible ways forward. Environ. Rev. 26, 239–254. DOI.
[6] Paulillo, A. *et al.*, 2020. Radiological impacts in Life Cycle Assessment. Part I: General framework and two practical methodologies. Science of The Total Environment 708, 135179. DOI.
[7] Paulillo, A. *et al.*, 2023. Characterizing human health damage from ionizing radiation in life cycle assessment. Int J Life Cycle Assess 28, 1723–1734. DOI.
[8] QGIS Development Team, 2024. QGIS geographic information system v3.36.3 (Maidenhead). QGIS Association. URL.

System description

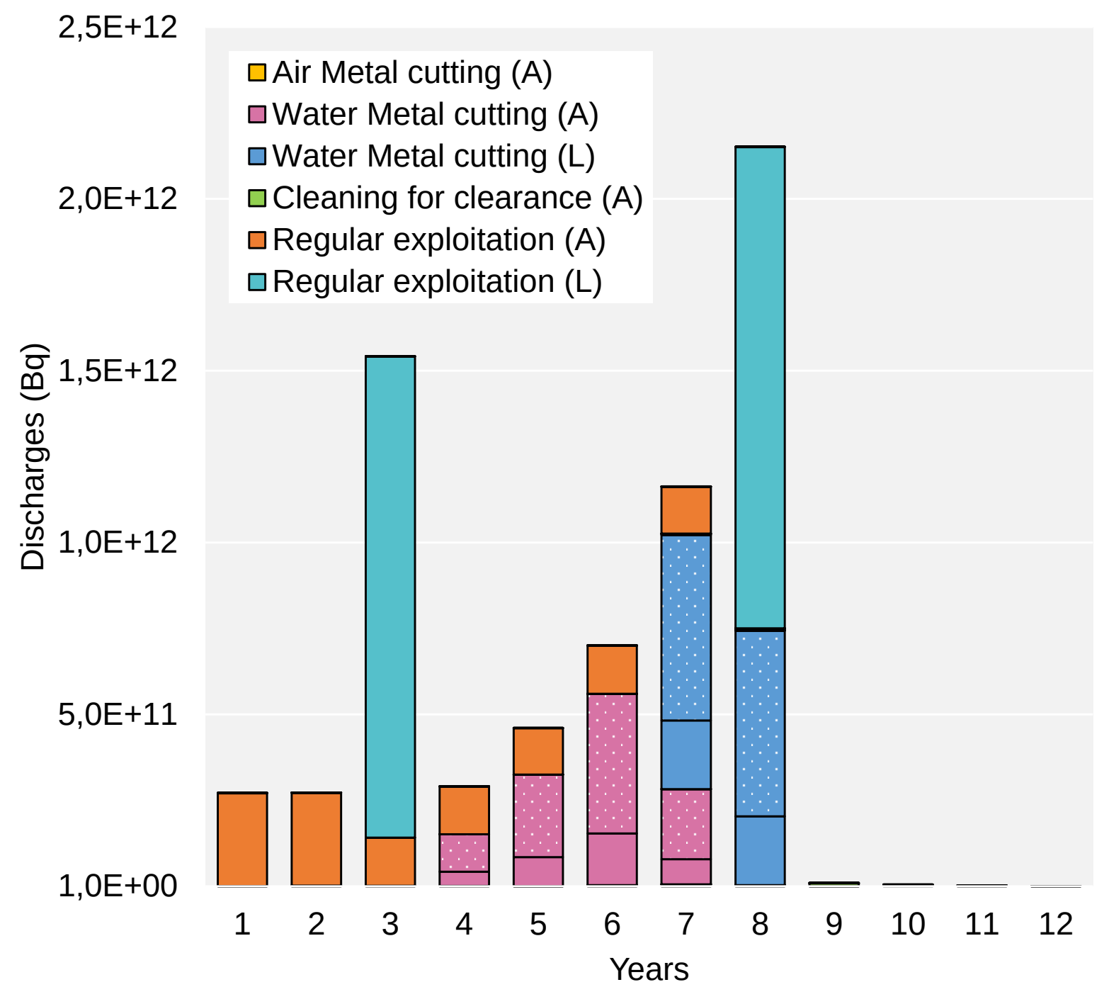
System Boundaries



A: atmospheric discharges
L: liquid/freshwater discharges

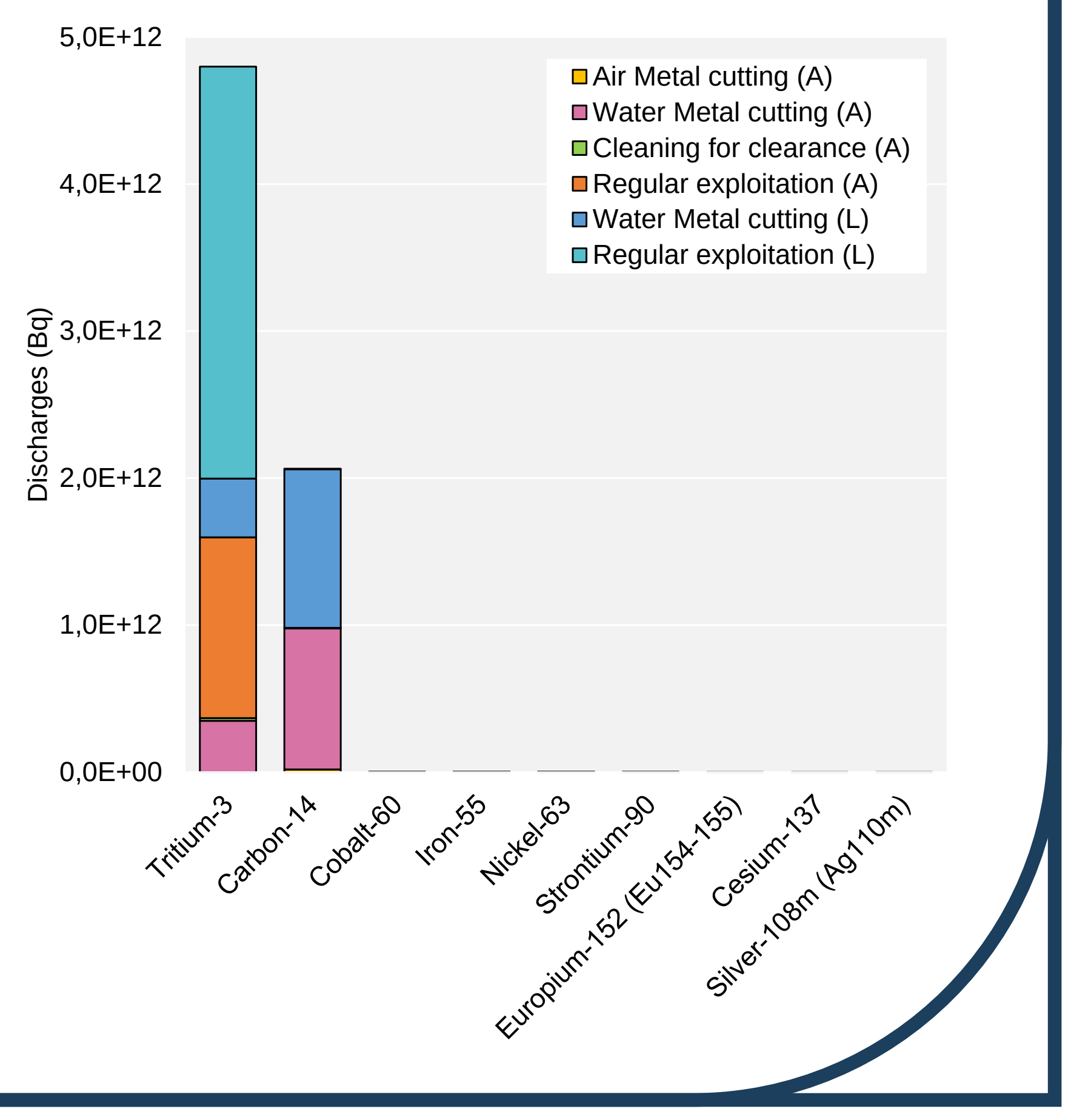
Functional Unit
One decommissioning of Fessenheim NPP

Annual radioactive discharges estimates

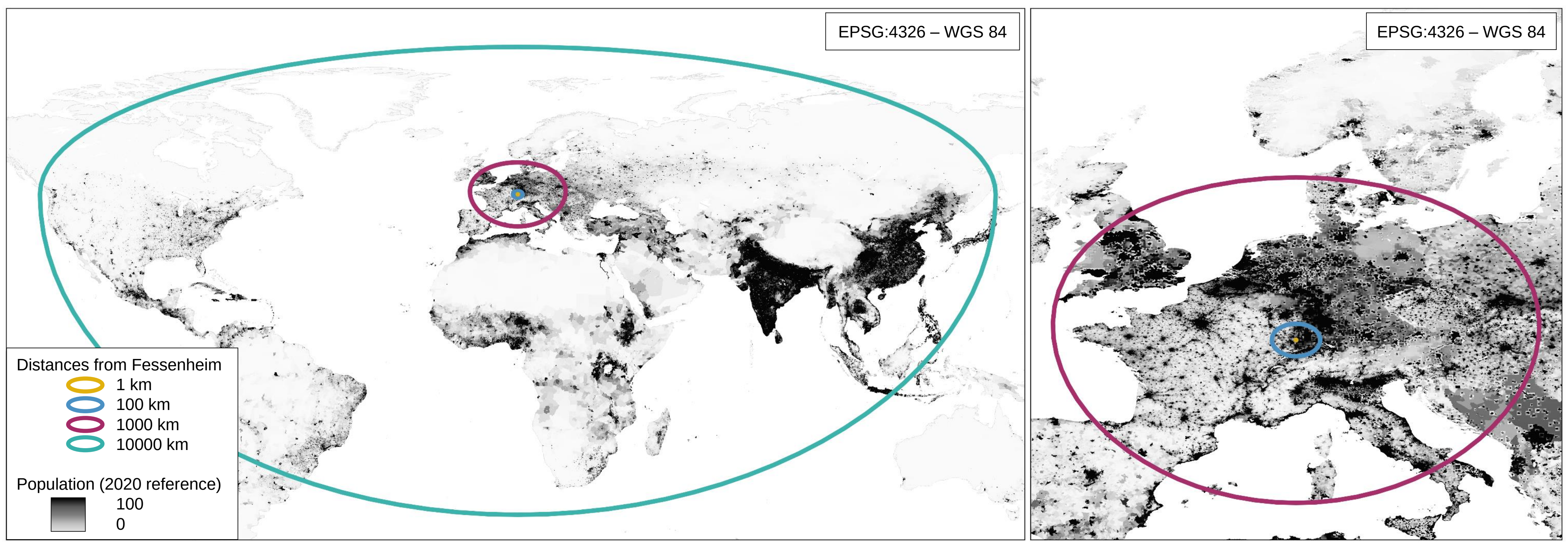


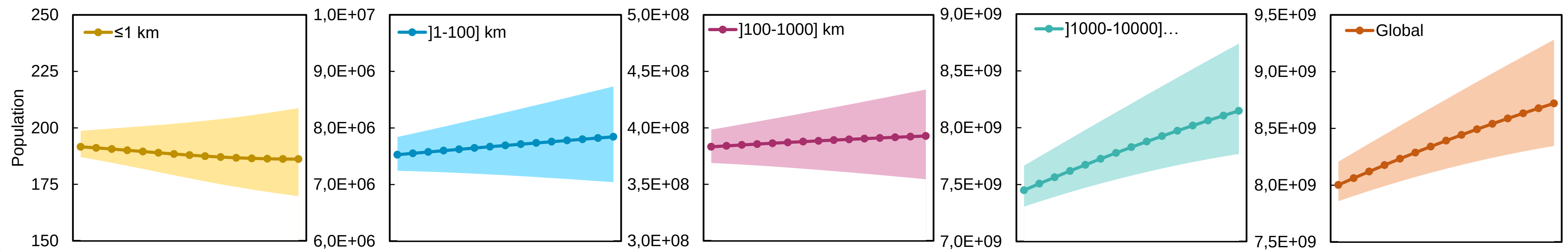
The plain color and white dots pattern in respectively represents ^{3}H and ^{14}C.
Other RNs contribute too little to be visualized.

Total radioactive discharges per radionuclide



Estimation of population dynamics with QGIS for damage assessment

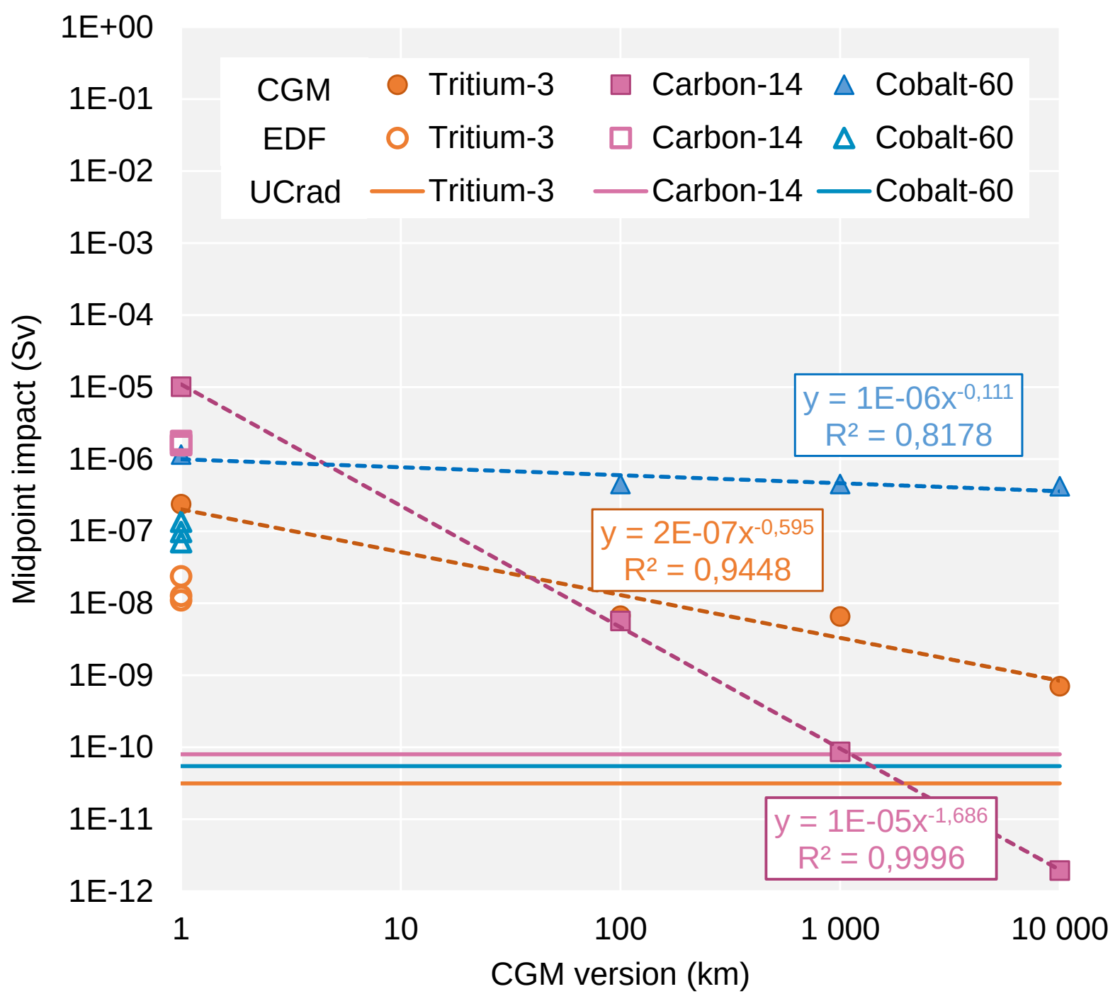




UCrad & CGM midpoint impacts

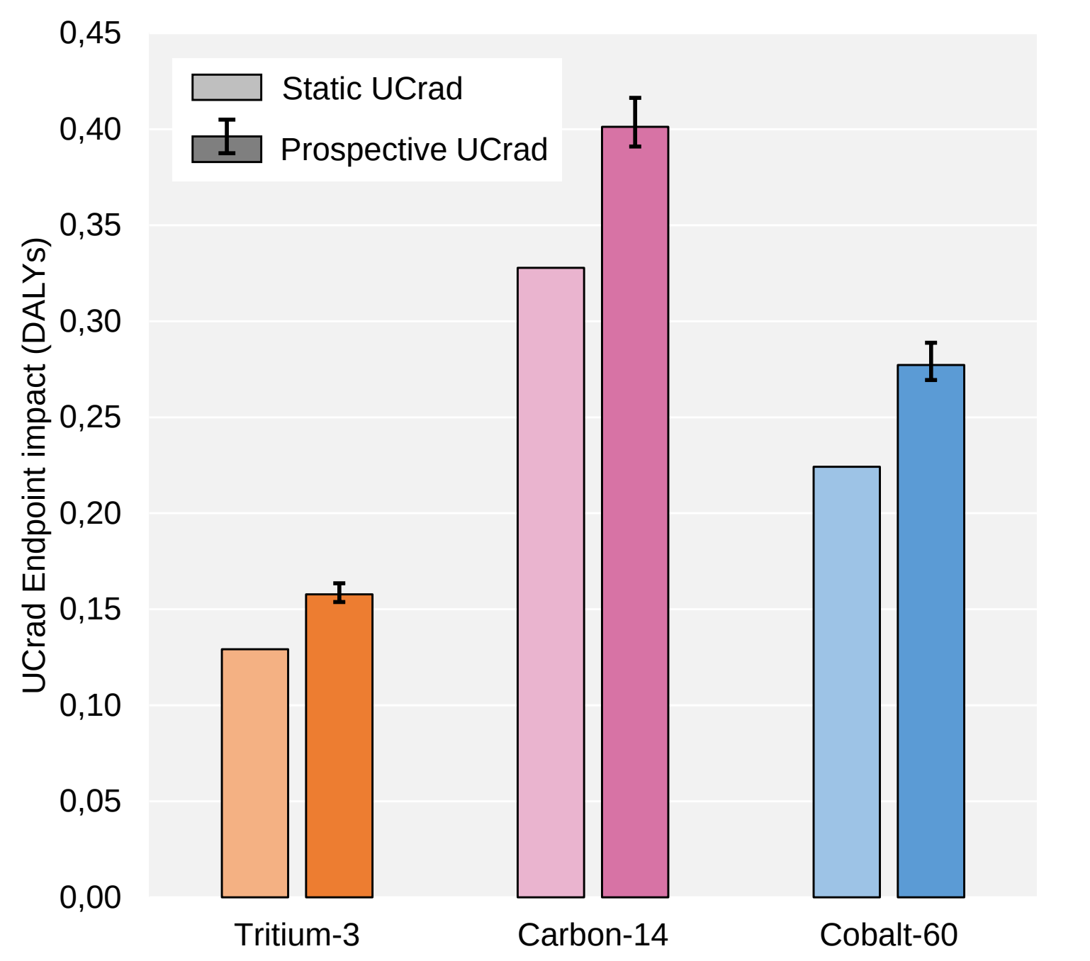
Method	Relative contributions (%)			Total (Sv)
	Tritium-3	Carbon-14	Cobalt-60	
CGM 1 km	2.04	87.36	9.98	$1.16\cdot10^{-5}$
CGM 100 km	1.44	1.22	97.31	$4.64\cdot10^{-7}$
CGM 1000 km	1.42	0.02	98.54	$4.56\cdot10^{-7}$
CGM 10 000 km	0.17	$5\cdot10^{-4}$	99.82	$4.22\cdot10^{-7}$
UCrad	18.94	48.04	32.86	$1.66\cdot10^{-10}$

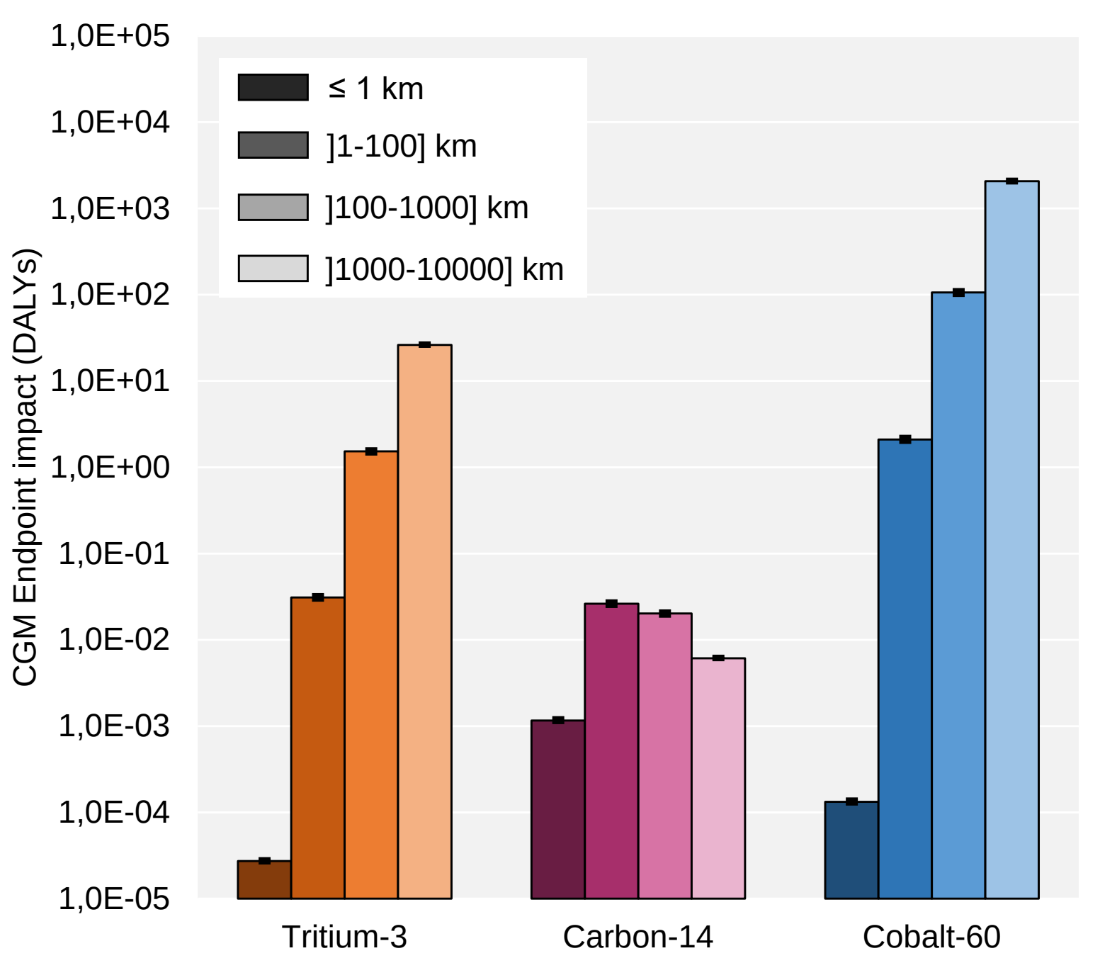
3 radionuclides dominate the midpoint impacts, contributions depending on the LCIA method



Prospective UCrad & CGM endpoint impacts

Not taking into account expected population future dynamics → **[17-21.8]% of expected global damages missing (UCrad)**





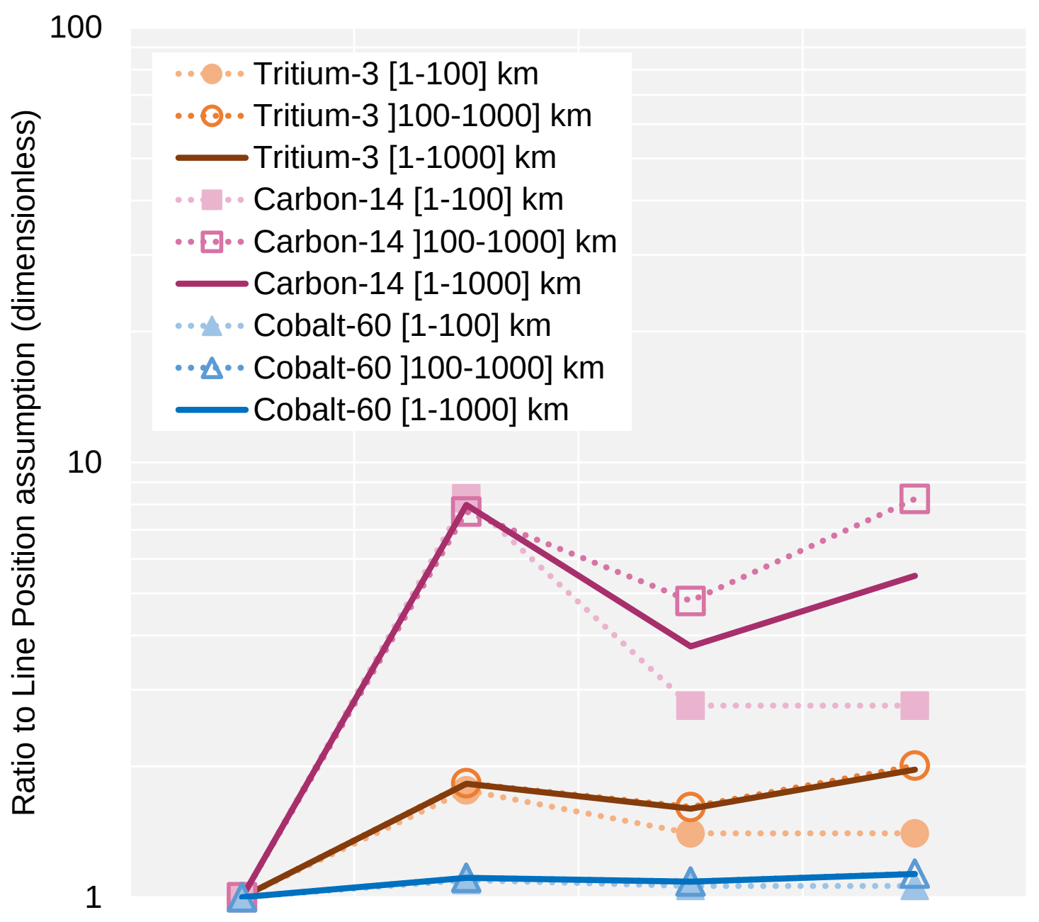
Static UCrad
Original characterization factors

Prospective UCrad
Prospective datasets of global population used to modify the CFs

Prospective CGM 1 – 10 000 km
Population inside each spatial interval uniformly extracted and treated as aggregated at the farthest boundary

CGM limits & perspectives

Influence of population distribution on a simplified case



Problematic

Simplifying assumptions on population distribution

Midpoint impacts *fits* implemented in QGIS

Solution?

Towards endpoint impacts representative computation?

Perspective

Our special thanks to A. Paulillo regarding technical questions on UCrad & CGM

This work is part of the CO2InnO project, which is funded by the European Union (Interreg Upper Rhine 2021–2027, A1.3)

Interreg
Co-funded by the European Union
France – Germany – Switzerland (Upper Rhine)