The sensitivity analysis of the release of carbon-14 from a deep geological repository

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Introduction

The main objective of this study was to evaluate the new scientific knowledge and understanding of the behaviour of carbon-14 provided by the CAST project in the context of a Czech deep geological repository for intermediate level waste located in a hypothetical crystalline host rock environment. The aim of the sensitivity analysis was to highlight which of the parameters analysed in the CAST project were expected to have the most significant influence on the release of carbon-14 into the environment.

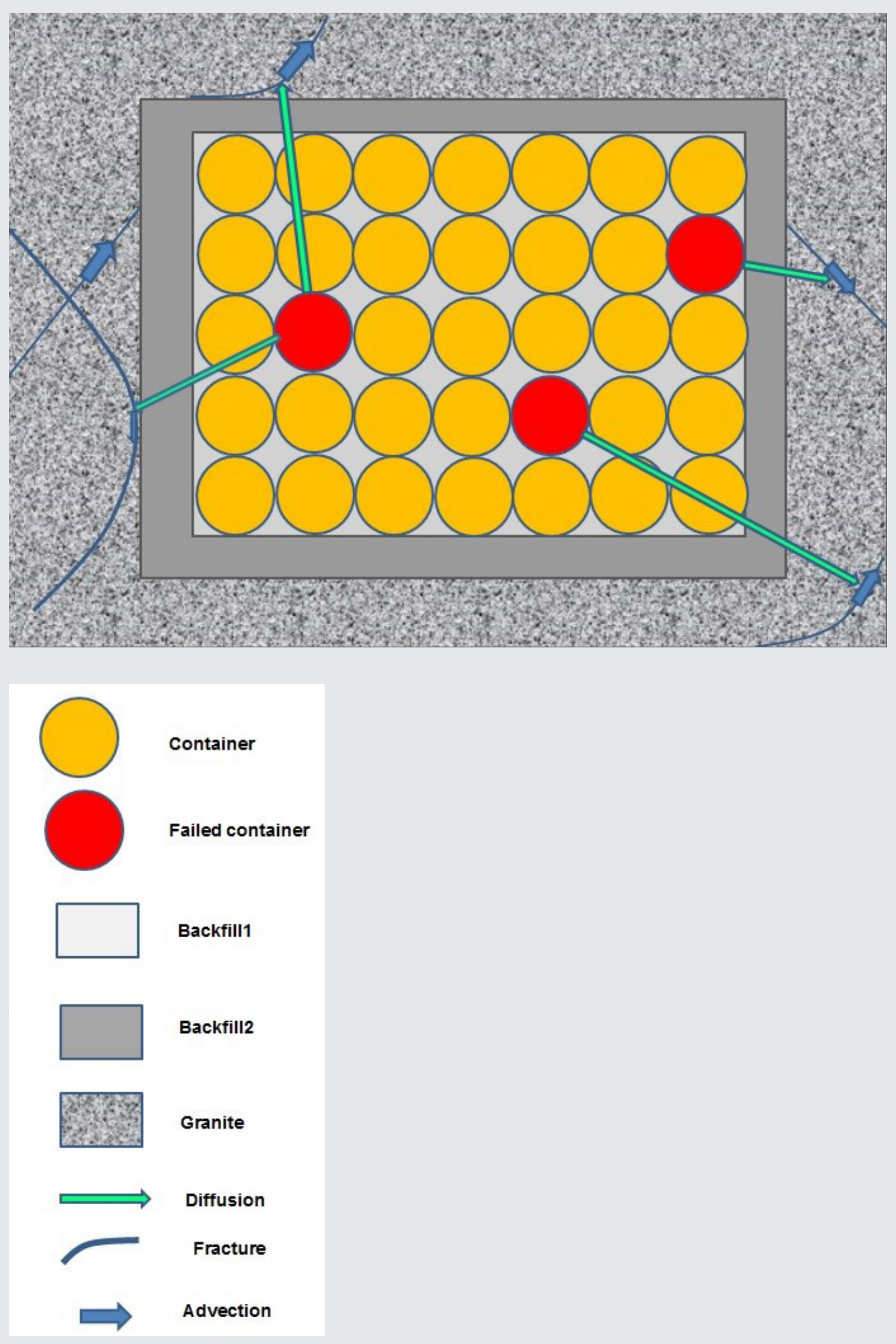
Methodology

The sensitivity analysis methodology employed in the study was based on the pseudo-random selection of values from a range of selected parameter values [1]. The first order and total sensitivity indices, which express the contribution of individual parameters to the calculated output parameters over time, were calculated [2]. The calculations were performed in the GoldSim Transport Code [3].

Conceptual Model

The conceptual model (Fig. 1) of a vault containing intermediate level waste from the decommissioning of Czech nuclear power plants assumes that the canisters containing the waste will be surrounded by a cement backfill material (backfill 1) inserted into the spaces between the canisters and a second cement backfill material (backfill 2) along the interface between the vault containing the canisters and the crystalline host rock.

Fig. 1: Conceptual model of a disposal cell for calculation purposes



Tab. 1 Selected range of parameter values for sensitivity analysis

Parameter	Unit	Min	Max	Mean
μ (lifetime of the canisters)	a	10	100	31
τ (leaching rate)	a^{-1}	$1\cdot10^{-5}$	0.1	0.001
Porosity (backfill)		0.2	0.5	0.35
Reference diffusivity	$m^2 s^{-1}$	$2\cdot10^{-9}$	$2\cdot10^{-9}$	$2\cdot10^{-9}$
Relative diffusivity (backfill)		1	10*	
Tortuosity		0.5	1	0.75
Porosity (granite)		0.005	0.02	0.01
Solubility (Inorganic)	$mol\ l^{-1}$	$1\cdot10^{-6}$	$1\cdot10^{-5}$	$5\cdot10^{-6}$
Solubility (organic)	$mol\ l^{-1}$	unlimited	unlimited	unlimited
Kd (backfill1, 2) (Inorganic/ organic)				
	$m^3 kg^{-1}$	2/1e-7/0*	20/1e-2	5/1e-4
Kd (geosphere) (Inorganic/ organic)	$m^3 kg^{-1}$	2/1e-7/0*	20/1e-2	5/1e-4
GeoIN (flow rate)	$m^3 a^{-1}$	0.01	100	1
GeoT (transport time)	A	10	$1\cdot10^4$	316
Qeq [3]	$l\ a^{-1}$	0.01	1	0.1
Inventory in one WP	Bq	$5\cdot10^{12}$	$5\cdot10^{13}$	$1.6\cdot10^{13}$
Volume of the repository (waste only)	m^3	160	800	480
Total number of WPs		40	200	120
Maximum activity of all the WPs	Bq	$1\cdot10^{14}$	$1\cdot10^{15}$	$3.2\cdot10^{14}$

Conclusions

The sensitivity analysis revealed that carbon-14 in the organic form only is capable of exerting a non-negligible impact on repository safety; that the release of carbon-14 in the free gas phase may exert a significant impact; and that the leaching rates of carbon-14 from the waste forms and the equivalent flow rates between the backfill and the host rock fracture network make up the most important parameters with respect to influencing the release of carbon-14 into the environment. It was also shown that if the sorption of organic forms of carbon-14 on the host rock is substantiated, then it may exert a significant impact on the release rates of carbon-14 into the biosphere.

The latest results of the CAST project make a significant contribution to the understanding of the behaviour of carbon-14 in deep geological repositories and will, in the future, assist in the compilation of advanced safety assessments for the future Czech deep geological repository. However, the results of the CAST project relating to the determination of the ratio of inorganic and organic forms of carbon-14 expected to be released during the degradation of the radioactive waste remain ambiguous. It seems, as suggested by Wieland and Hummel [5], that neither the experimental evidence obtained to date, nor the thermodynamic modelling allow for the drawing of well-supported conclusions in this respect from the current results.

References

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Results

Comparison of the release of carbon-14 in its organic and inorganic forms

Tab 2. Comparison of the maximum flow rate values of carbon-14 through the model compartments in its inorganic and organic forms (FC-B1 flow from the waste package to backfill 1, FB1-B2 flow of carbon-14 from backfill 1 to backfill 2, and FB2-G flow of carbon-14 from backfill 2 to the host rock matrix)

Carbon-14 form	F_{C-B1} [Bq/yr]	F_{B1-B2} [Bq/yr]	F_{B2-G} [Bq/yr]	Well dose [mSv/yr]
Inorganic	1.56×10^{10}	4.33×10^{8}	7697	3.25×10^{-8}
Organic	1.12×10^{10}	1.05×10^{10}	4.42×10^{9}	1.87×10^{-2}

Sensitivity analysis of the release of carbon-14 with respect to changing leaching rate, inventory and equivalent flow rate

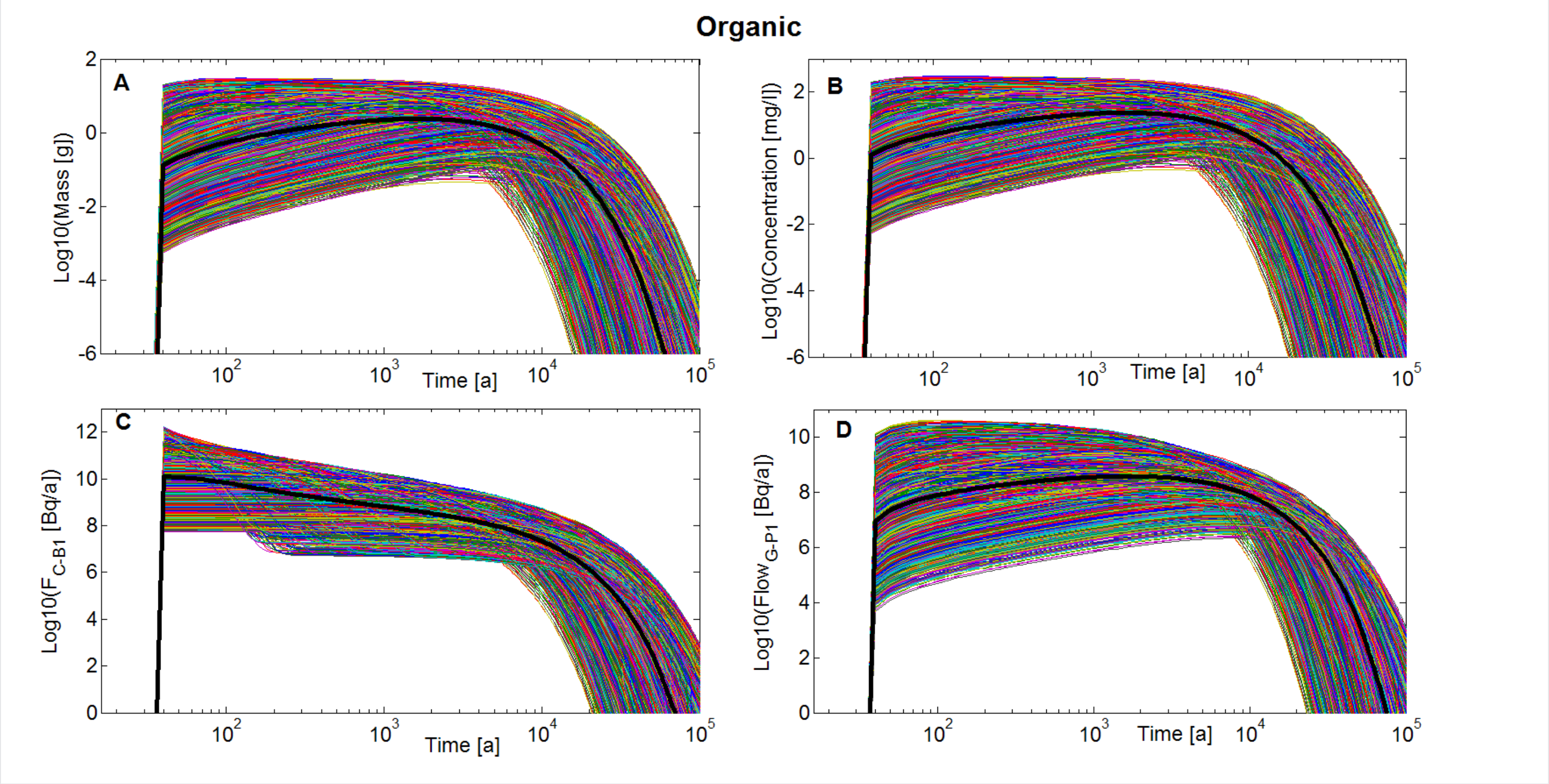

Fig.2 Evolution of the output parameters over time for organic forms of carbon-14. Change in the mass of carbon-14 in the waste packages (A), concentration of carbon-14 in the waste packages (B), flow of carbon-14 from a waste package to the backfill (C) and the flow from the backfill to the fracture network (D)

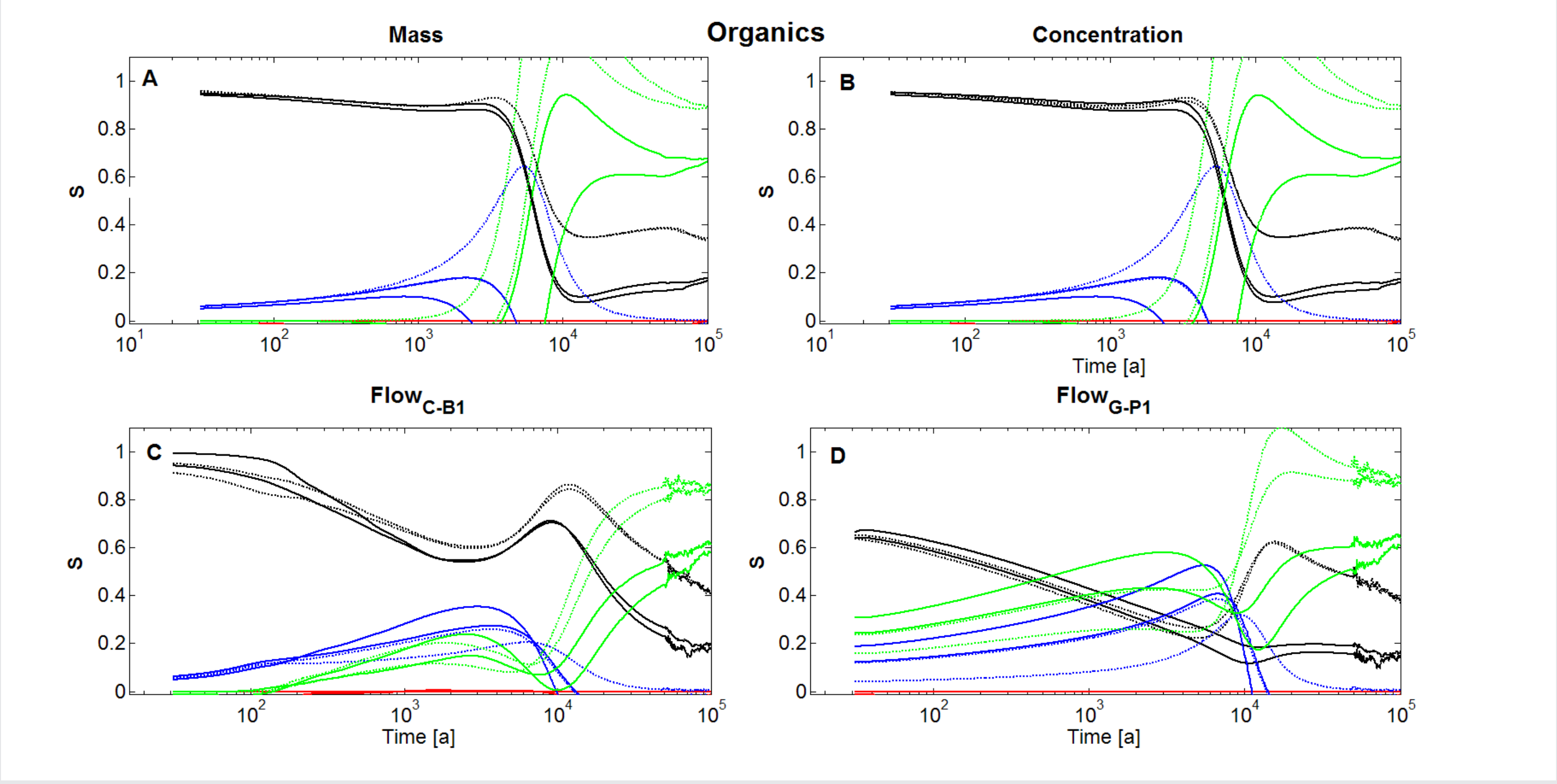

Figure 3: Dependence of the sensitivity indices over time for variations in the leaching rate, solubility, inventory and equivalent flow rate for organic carbon-14 species (mass of organic carbon-14) (A), concentration in the waste package (B), the flow of carbon-14 from a waste package to the backfill (C) and the flow from the backfill to the fracture network (D). Sensitivity index for organic species (leaching rate - black lines, solubility - red lines, inventory - blue lines, Q_{eq} - green lines).

Sensitivity analysis of the release of carbon-14 with respect to changing sorption coefficients, porosity and equivalent flow rate

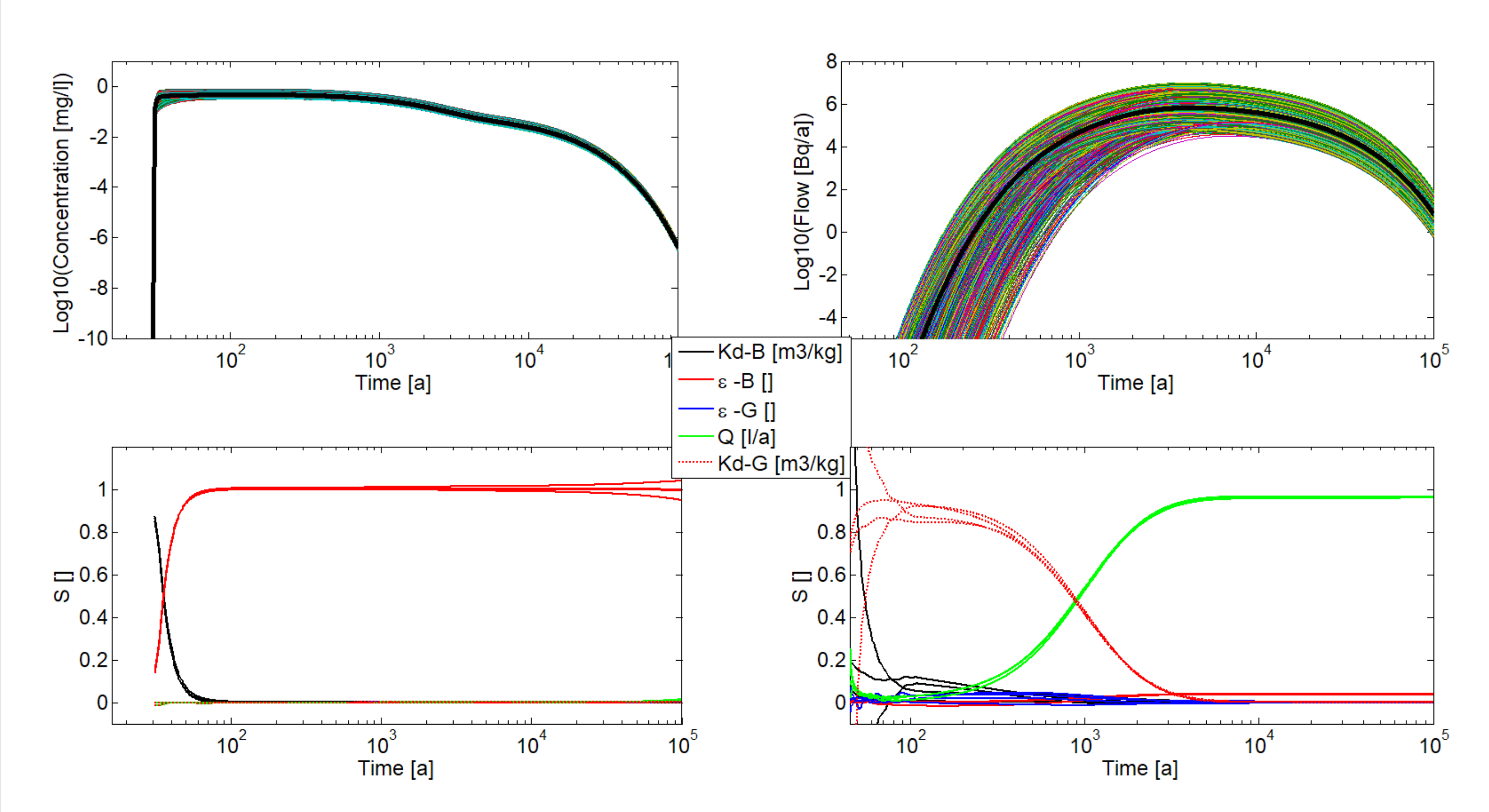

Fig. 4 Dependence of the sensitivity indices over time with respect to varying sorption, porosity and the equivalent flow rate for the transport of organic carbon-14 species (mass of inorganic carbon-14) (A), concentration in the canister (B), the flow of carbon-14 from a waste package to the backfill (C) and the flow from the host rock matrix to the fracture network (D). Sensitivity index for organic species (Kd backfill - black lines, Kd granite – dotted red lines, porosity backfill - red lines, porosity granite - blue lines, Qeq - green lines).

Release of carbon-14 in the free gas phase

Tab. 3 Comparison of the maximum flow rate values of carbon-14 through model compartments in the gaseous and aqueous forms (F_{C-B1} flow of carbon-14 from the waste package to backfill 1, F_{B1-B2} flow of carbon-14 from backfill 1 to backfill 2, F_{B2-G} flow of carbon-14 from backfill 2 to the granite)

Medium/saturation	F_{C-B1} [Bq/yr]	F_{B1-B2} [Bq/yr]	F_{B2-G} [Bq/yr]	Well dose [mSv/yr]
Gas/0.5	1.57×10^{10}	1.34×10^{10}	5.99×10^{9}	2.53×10^{-2}
Water/0.5	1.57×10^{5}	6.18×10^{5}	9.68×10^{4}	4.10×10^{-10}