Supplementary Materials for

Models with higher effective dimensions tend to produce more uncertain estimates

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This PDF file includes:

Figs. S1 to S4
The Models
Tables S1 to S5
References
1 Figures

Figure S1: Univariate functions implemented in the meta-model based on the Becker [29] metafunction.
Figure S2: Diagram flows. a) PSACOIN Level 0 model [36]. b) SIR(S) model, based on Fig. 1 in Saad-Roy [45]. c) SIR(S) with a vaccinated compartment, based on Fig. 3a in Saad-Roy et al. [45]. d) Fully extended SIR(S), based on Fig 1a in Saad-Roy et al. [46].
Figure S3: Dynamics of the PSACOIN Level 0 model [36]. The time $t$ is in years.

Figure S4: Dynamics of the SIR(S), the SIR(S) with vaccination and the extended SIR(S) proposed by Saad-Roy et al. [45, 46]. The time $t$ is in weeks and covers 5 years (260 weeks). See section 2.3 for a description of the models.
2 The models

2.1 The PSACOIN model

It describes the ideal behavior of a set of selected radionuclides buried deep into an underground disposal for nuclear waste, packed into sealed canisters and surrounded by a buffer material conceived to delay their transit time in case of canister corrosion. The nuclides are separated by the biosphere by several hundred metres of a geological formation. The simulations normally span ten million years, a time supposed to be characteristic of the nuclide transit time through the various media (barriers). The case is part of a series of benchmarks runs by the Nuclear Energy Agency of the OECD, aimed to test the agreement among several computer codes involved in the analysis of the safety of nuclear waste disposal. The description that follows is a summary of the first and simplest case, PSACOIN Level 0 [37].

2.1.1 First barrier: waste form

The leach rate $R_{wf}(t)\left(\frac{Kg}{m^2a}\right)$ is given by

$$R_{wf}(t) = R^0 H(t - \tau^D),$$

where $wf$ stands for waste form, $R^0$ is a time invariant leach rate, $t$ is time, $\tau^D$ is a characteristic leach time and $H$ is the Heaviside step function

$$H(y) = \begin{cases} 0 & y < 0 \\ 1 & \text{otherwise} \end{cases}$$

The leach rate $\tau^D$ is given by

$$\tau^D = \frac{Q}{R^0 S},$$

where $Q$ is the initial amount of waste and $S$ its surface area, both constants.

The release rate of nuclide $i$, $F_i^{wf}(t)$ is derived as

$$F_i^{wf}(t) = R_{wf}(t) I_i(t) S,$$

where $I_i(t)$ is the inventory of nuclide $i$ in mol per kilogram of waste form given by

$$I_i(t) = I^0_i e^{-\lambda_i t},$$

where $I^0_i$ is the initial inventory or nuclide $i$ and $\lambda_i$ its decay constant in $a^{-1}$.

2.1.2 Second barrier: buffer form

A buffer of thickness $X_B$ around the waste form constitutes the second barrier to the migration of radionuclides. The flow of nuclides out of the buffer, in $\frac{mol}{m^2a}$, is given by:

$$F_i^{B}(t) = H \left( t - \tau_i^B \right) F_i^{W} \left( t - \tau_i^B \right) e^{(\lambda_i \tau_i^B)}.$$
Since the buffer is supposed to be a purely diffusive barrier, the value of $\tau_i^B$ is given by

$$\tau_i^B = \frac{X^2_i R^B_i}{4 D_B}$$

$$R^B_i = 1 + \frac{\rho_B}{\epsilon_B} K_{B,i}^B (1 - \epsilon_B)$$

$\rho_B$ is buffer density

$\epsilon_B$ is buffer porosity

$K_{B,i}^B = $ buffer sorption constant for nuclide $i$

$D_B$ is nuclide independent diffusion coefficient in the buffer $\left[\frac{m^2}{a}\right]$ (S7)

### 2.1.3 Third barrier: the geosphere

The nuclear waste is separated from the biosphere by a geological formation (geosphere) of thickness $X_G$, which both delays and spreads the nuclides. The migration into the geosphere is driven by advection (transport by water flow) and dispersion. The flow in $\frac{mol}{a}$ is

$$F_{iG}^G(t) = H(t - \tau_i^B - \tau_i^L) H(\tau_i^B + \tau_i^H + \tau_i^D - t) \frac{\tau_i^D}{\tau_i^H + \tau_i^D - \tau_i^L} F_{iB}^B(t') \epsilon^{-\lambda_i(t-t')}$$

where

$$\tau_i' = \left( \frac{t - \tau_i^B - \tau_i^L}{\tau_i^H + \tau_i^D - \tau_i^L} \right) \tau_i^D + \tau_i^B$$

and $\tau_i^L$, $\tau_i^H$ are the upper and lower roots of the following equation of second degree in $\tau_i^G$ (in $[m]$):

$$X_G = 2 \left( \frac{D_G \tau_i^G}{R_i^G} \right) + \frac{V_G \tau_i^G}{R_i^G}$$

where

$$R_i^G = 1 + \frac{\rho_G}{\epsilon_G} (1 - \epsilon_G) K_{D,i}^G$$

$\rho_G$ is geosphere density

$\epsilon_G$ is geosphere porosity

$K_{D,i}^G = $ geosphere sorption constant for nuclide $i$ $\left[\frac{m^3}{kg}\right]$ (S11)
and $D_G = D_G^0 + \alpha_G V_G$, in $\frac{m^2}{a}$, where

$$D_G^0 = \text{diffusion coefficient of nuclide } i \text{ in geosphere} \quad \left[\frac{m^2}{a}\right]$$
$$\alpha_G = \text{dispersivity in geosphere} \quad \left[\text{m}\right]$$
$$V_G = \text{groundwater velocity in geosphere} \quad \left[\frac{m}{a}\right].$$

(S12)

### 2.1.4 Fourth barrier: biosphere

The model for the biosphere considers that the flow $F^G_i$ coming from the geosphere is entirely intercepted by an abstraction well used for drinking water. The concentration $C_i$ of a given nuclide in the water is given in $\frac{Bq}{m^3}$, where $Bq$ stands for becquerel, the SI unit for radiation:

$$C_i = \frac{F^G_i A_i}{W},$$

(S13)

where $A_i$ is the molar specific activity of nuclide $i$ in $\frac{Bq}{mol}$, and $W$ the abstraction rate in $\frac{m^3}{a}$. Thus the resulting dose to humans is simply

$$H_i = C_i W m D_i,$$

(S14)

expressed in $\frac{Sv}{a}$, where $Sv$ stands for sievert, the SI unit of dose equivalent describing the biological effect of ionizing radiation. The other terms in the equation are $W_m$, the water consumption rate by a human drinking the water of the well, in $\frac{m^3}{a}$, and $D_i$ a dose factor converting the ingested becquerels into sieverts.

### 2.1.5 Uncertain parameters

Tables S1–S2 present the probability distributions used to characterize the uncertain parameters and the constant values of PSACOIN Level 0 respectively.

### 2.2 The irrigation water withdrawal model

Many Global Hydrological models compute irrigation water withdrawals with variations of the following equation:

$$y = \frac{I_a (ET_c - P)}{E_p},$$

(S15)

where $y$ is a scalar representing irrigation water withdrawals [$m^3$], $I_a$ is the extension of irrigation [$m^2$], $ET_c$ is the crop evapotranspiration [$m$], $P$ is the precipitation [$m$] and $E_p$ is the irrigation efficiency [-].

$ET_c$ is calculated as $ET_c = k_c ET_0$, where $ET_0$ [$m$] is the reference crop evapotranspiration (usually grass or alfalfa) and $k_c$ [-] is a coefficient that accounts for the differences between $ET_0$ and the crop under study (wheat in our case).
Table S1: Probability distributions used to describe the uncertainty in the parameters of the PSACOIN Level 0 model. a = annum.

| Input | Unit | Description                                    | Distribution                      |
|-------|------|------------------------------------------------|-----------------------------------|
| $R^0$ | Kg m$^{-2}$ | Time-invariant leach rate | Logunif($10^{-2.57}$, $10^{1.11}$) |
| $X_B$ | m | Thickness of buffer | $U(0.5, 5)$ |
| $K_B$ | m$^3$ Kg$^{-1}$ | Buffer sorption constant | Lognorm($-2.38$, $0.143$) |
| $K_G$ | m$^3$ Kg$^{-1}$ | Geosphere sorption constant | Lognorm($-3.38$, $0.3$) |
| $D_0$ | m$^2$ a$^{-1}$ | Diffusion coefficient | $N(0.04, 0.001)$ |
| $X_G$ | m | Thickness of geosphere | $U(10^3, 10^4)$ |
| $\alpha_G$ | m | Dispersivity in geosphere | Logunif($10^{0.3}$, $10^{2.3}$) |
| $V_G$ | m$^2$ a$^{-1}$ | Groundwater velocity in geosphere | Logunif($10^{-3}$, $10^{-1}$) |
| W | m$^3$ a$^{-1}$ | Abstraction rate | $U(5 \times 10^5, 5 \times 10^6)$ |
| $W_m$ | m$^3$ | Human water consumption rate | $U(0.7, 0.9)$ |

In the paper we consider two different equations for $ET_0$, the Priestley-Taylor and the FAO-56 Penman-Monteith [42]. The former reads as

$$ET_0 = \alpha \frac{\Delta A}{\Delta + \gamma},$$

(S16)

whereas the latter reads as

$$ET_0 = \frac{0.408\Delta A + \gamma \frac{900}{T_u + 273} w v}{\Delta + \gamma (1 + 0.34w)},$$

(S17)

where $A$ is the net radiation minus the soil heat flux (MJ m$^{-2}$ d$^{-1}$), $\Delta$ the gradient of saturated vapour pressure (kPa 9C$^{-1}$), $\gamma$ the psychometric constant (kPa 9C$^{-1}$), $\alpha$ the Priestley-Taylor constant, $T_u$ the mean daily air temperature at 2m (ºC), $w$ the average daily wind speed at 2m (m s$^{-1}$) and $v$ the vapor pressure deficit (kPa). See Allen [70] for an explanation of the constants.

### 2.2.1 Uncertain parameters

See Puy et al. [41, 71] for an explanation of the uncertainties involved in the calculation of irrigation water withdrawals, including the selection of the probability distributions used in this paper (Table S3).

### 2.3 The epidemiological models

We use the Susceptible-Infected-Recovered [SIR(S)] models by Saad-Roy et al. [45] (Equations S18–S19) and by Saad-Roy et al. [46] (Equation S20). See Tables S4–S5 for a description of the parameters and coefficients, and Saad-Roy et al. [45, 46] for a full explanation of the models’ dynamics.

The most simple SIR(S) reads as
Table S2: Constants of the PSACOIN Level 0 model. $a = \text{annum}$.

| Constant | Unit | Description                              | Value       |
|----------|------|------------------------------------------|-------------|
| $I_0$    | mol Kg | Initial inventory of radionuclide        | $2.035 \times 10^{-5}$ |
| $\lambda$ | a    | Decay constant of radionuclide           | $1.07 \times 10^{-5}$ |
| $S$      | m$^2$ | Surface area of radionuclide             | $1.2 \times 10^6$ |
| $Q$      | Kg   | Initial amount of waste                  | $2 \times 10^8$ |
| $\rho_B$ | Kg m$^{-3}$ | Buffer density                          | $1.85 \times 10^3$ |
| $\epsilon_B$ | - | Buffer porosity                          | $0.099$ |
| $D_B$    | m$^2$ | Diffusion coefficient in buffer          | $0.03$ |
| $\rho_G$ | Kg m$^{-3}$ | Geosphere density                      | $1.85 \times 10^3$ |
| $\epsilon_G$ | - | Geosphere porosity                       | $0.3$ |
| $A$      | Bq   | Molar specific activity                  | $2.04 \times 10^{11}$ |
| $D$      | Bq m$^{-3}$ | Dose factor conversion                | $2.3 \times 10^{-9}$ |

where $S_P$ denotes fully susceptible individuals, $I_P$ denotes individuals with primary infection that transmit at rate $\beta$, $R$ denotes fully immune individuals (as a result of recovery), $S_S$ denotes individuals whose immunity has waned at rate $\delta$ and are again susceptible to infection, and $I_S$ denotes individuals with secondary infection.

The SIR(S) with a vaccination term reads as

\[
\begin{align*}
\frac{dS_P}{dt} &= \mu N - \beta S_P \frac{I_P + \alpha I_S}{N} - \mu S_P \\
\frac{dI_P}{dt} &= \beta S_P \frac{I_P + \alpha I_S}{N} - (\gamma + \mu)I_P \\
\frac{dR}{dt} &= \gamma(I_P + I_S) - (\delta + \mu)R \\
\frac{dS_S}{dt} &= \delta R - \epsilon \beta S_S \frac{I_P + \alpha I_S}{N} - \mu S_S \\
\frac{dI_S}{dt} &= \epsilon \beta S_S \frac{I_P + \alpha I_S}{N} - (\gamma + \mu)I_S
\end{align*}
\] (S18)
Table S3: Summary of the uncertainty in the parameters of the irrigation water withdrawal model.

| Input | Description                        | Distribution          |
|-------|------------------------------------|-----------------------|
| ∆ Vapour pressure | U(0.0796, 0.0804) |
| γ Psychrometric constant | U(0.065, 0.066) |
| A Net radiation minus soil heat flux | U(297.55, 402.448) |
| T_α Mean air temperature | U(9.9, 10.1) |
| w Wind speed | U(2.67, 2.95) |
| v Vapor deficit | U(0.26, 0.29) |
| k_c Crop coefficient | U(0.45, 1.14) |
| I_a Irrigated area | U(42.9, 144.5) |
| E_a Field application efficiency | U(0.49, 0.88) |
| E_c Conveyance efficiency | U(0.64, 0.96) |
| M_f Management factor | U(0.5, 0.97) |
| P Precipitation | U(0, 0.1) |

\[
\frac{dS_P}{dt} = \mu N - \beta S_P \frac{I_P + \alpha I_S}{N} - \mu S_P - s_{vax}\nu S_P
\]

\[
\frac{dI_P}{dt} = \beta S_P \frac{I_P + \alpha I_S}{N} - (\gamma + \mu)I_P
\]

\[
\frac{dR}{dt} = \gamma (I_P + I_S) - (\delta + \mu)R
\]

\[
\frac{dS_S}{dt} = \delta R - \epsilon \beta S_S \frac{I_P + \alpha I_S}{N} - \mu S_S + \delta_{vax} V - s_{vax}\nu S_S
\]

\[
\frac{dI_S}{dt} = \epsilon \beta S_S \frac{I_P + \alpha I_S}{N} - (\gamma + \mu)I_S
\]

\[
\frac{dV}{dt} = s_{vax}\nu (S_P + S_S) - \delta_{vax} V - \mu V
\]

where \( V \) denotes vaccinated individuals.

The SIR(S) extended with different vaccination strategies reads as
Tables S4–S5 respectively present the probability distributions used to characterize the uncertain parameters and the constant values of the epidemiological models.

2.3.1 Uncertain parameters

Tables S4–S5 respectively present the probability distributions used to characterize the uncertain parameters and the constant values of the epidemiological models.
Table S4: Probability distributions used to describe the uncertainty in the parameters of the epidemiological models, selected from Saad-Roy et al. [45, 46].

| Input | Description | Distribution |
|-------|-------------|--------------|
| $\epsilon$ | Reduction in susceptibility to secondary infections relative to primary ones | $\mathcal{U}(0.4, 1)$ |
| $\alpha, \alpha_1, \alpha_2, \alpha_V$ | Reduction in the infectiousness of secondary infections relative to primary ones | $\mathcal{U}(0.8, 1)$ |
| $\nu$ | Fraction of the fully and partially susceptible populations vaccinated each week | $\mathcal{U}(0.001, 0.009)$ |
| $t_{vax}$ | Time at which vaccination is introduced | $\mathcal{U}(48, 78)$ |

Table S5: Constants of the epidemiological models by Saad-Roy et al. [45, 46].

| Constant | Description | Value |
|----------|-------------|-------|
| $\gamma$ | Recovery rate primary / secondary infections | 7 / 5 |
| $\delta$ | Wane rate of full immunity from infection | 1 / 52 |
| $\mu$ | Birth rate to enter the susceptible class $S_P$ | 1 / $(50 \times 52)$ |
| $\epsilon_{1_v}$ | First level of immune protection | 0.1 |
| $\epsilon_{2_v}$ | Second level of immune protection | 0.05 |
| $\omega$ | Interdose period | 0 |
| $\rho_1$ | Waning rate of vaccinal immunity 1 | 0 |
| $\rho_2$ | Waning rate of vaccinal immunity 2 | 0 |
| $\delta_{vax}$ | Rate at which vaccinal immunity is lost | 1 |
| $\epsilon_1$ | Effect of vaccine 1 | 0.7 |
| $\epsilon_2$ | Effect of vaccine 2 | 0.7 |
| $d$ | Fraction of previously infected partially susceptible individuals (SS) for whom one dose of the vaccine gives equivalent immunity to two doses for fully susceptible individuals | 0.5 |
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