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Sensitivity analysis via derived parameters

J.L. Cormenzana[a,*], R. Bolado[b]

[a]Consultant, Esperanza 6, 2D, 28231, Las Rozas, Madrid, Spain
[b]Institute for Energy, EC, DG-JRC, Petten, The Netherlands

Abstract

Derived parameters are simple arithmetic combinations of uncertain input parameters, that are expected to have a strong effect on an output variable of the model. Knowledge acquired by experienced modelers from the analysis of model equations and from other sources (running codes) help defining this sort of input parameters. This work summarizes the way to find derived parameters in a well-known model (Level E) and shows the benefits of introducing these parameters in the sensitivity analysis: strong dependence of outputs on them and direct physical interpretation of sensitivity analysis results.

Keywords: Derived parameters, variance based methods, graphic methods, Monte Carlo Filtering

1. Description of the work and results

The knowledge of the functioning of the system gained by an experienced modeler can be used to guide the Sensitivity Analysis. In particular, the modeler can identify some key parameters that area known (or suspected) to control the behavior of the system and are a combination of the random input parameters. These parameter are called derived parameters in this paper.

The usefulness of including derived parameters in the sensitivity analysis of Monte Carlo simulations has been tested with Level E model (NEA, 1989), that has been widely used as benchmark for Sensitivity Analysis methods. Level E model calculates the dose rate to humans due to the migration of radionuclides from a hypothetical underground nuclear waste disposal facility. Engineered barriers are modelled through a containment time (T) during which there is no release. After the containment period, the contaminant starts releasing at a fractional constant rate. Only four radionuclides are considered in this study: ^{129}I and the chain ^{237}Np - ^{233}U - ^{229}Th. The contaminant is carried by groundwater through two consecutive geosphere layers to the biosphere, where it reaches a water stream used for drinking. This model has 12 uncertain parameters (from T to W in table 1).

* Corresponding author. Tel.: +34-696330592;
E-mail address: josecor2@wanadoo.es.

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For a given radionuclide X, the study of the model equations shows that transport in each geosphere layer (layer 1, for instance) is controlled by its transport time through the layer ($t^1{}_X$), defined as the product of the layer length (l^1) times the retardation factor ($R^1{}_X$) divided by the water velocity (v^1).

For a delta injection of a stable solute into a layer, the peak release rate from the layer is inversely proportional to its transport time. When two layers are in series and a slug of solute is injected into layer 1, the peak release rate from layer 2 is approximately proportional to the inverse of the sum of transport times $t^1{}_X+t^2{}_X$.

In the Level E model the peak dose due to a radionuclide is the peak release rate from layer 2 divided by the stream flow rate in the biosphere (W in table 1), and multiplied by other constant factors.

Since the release of ^{129}I from the waste is fast compared with its transport through layers 1 and 2, it can be approximated by a delta injection into layer 1 at t=0 and we can expect that the peak dose due to ^{129}I will be proportional to the "derived parameter" $Global_I$, defined as:

$$Global_I = \frac{1}{W}\frac{1}{l^1 R_I^1 / v^1 + l^2 R_I^2 / v^2} \tag{1}$$

The correlation of $Global_I$ with the peak total dose is expected to be significant also because in Level E model the peak dose is caused by ^{129}I in 96% of the realizations and only in 4% of the realizations by the ^{237}Np chain,

Several potentially relevant "derived parameters" were identified at the beginning of the Sensitivity Analysis. The same statistics were calculated for the random input parameters and the derived parameters, keeping in mind that the "derived parameter" are correlated with some input parameters.

Many different derived parameters were considered in the Sensitivity Analysis of Level E: 1/W, $t^1{}_I$, $t^2{}_I$, $t^1{}_{Np}$, … , and $Global_I$. Table 1 shows the correlation coefficients of the 12 random input parameters and $Global_I$ with the peak total dose and the peak dose due to ^{129}I in values, ranks and logarithms. The coefficients of determination of a linear regression (R^2/R^{2*}) with the 12 random input parameters and with only $Global_I$ are shown. It is remarkable that R^2 is greater for $Global_I$ alone than for the 12 random input parameter together, especially in values.

Table 1.- Correlation coefficients for different transformations of inputs (random input parameters and "derived parameter" $Global_I$) and outputs (peak doses). Level E calculation with 10,000 runs.

		Values		Ranks		Logarithms	
Parameter	Description	Total	^{129}I	Total	^{129}I	Total	^{129}I
T	Containment time (source)	0.013	0.008	0.004	0.005	0.000	0.000
k_I	Leach rate for iodine (source)	-0.013	-0.015	-0.009	-0.009	-0.008	-0.008
k_C	Leach rate for Np decay chain (source)	0.001	-0.005	0.003	0.001	0.003	0.000
v^1	Water velocity (layer 1)	0.391	0.431	0.666	0.658	0.672	0.666
l^1	Length (layer 1)	-0.104	-0.094	-0.132	-0.126	-0.140	-0.132
$R^1{}_I$	Iodine retardation (layer 1)	-0.095	-0.138	-0.163	-0.168	-0.170	-0.178
$\gamma^1{}_C$	Np chain retardation multiplier (layer 1)	-0.054	0.001	-0.014	0.003	-0.027	-0.002
v^2, l^2, $R^2{}_I$ $\gamma^2{}_C$ (parameters of layer 2)		much smaller than for layer 1 parameters					
W	Stream flow rate (biosphere)	-0.266	-0.313	-0.682	-0.693	-0.686	-0.697
R^2/R^{2*} of the 12 random input parameters		**0.265**	**0.327**	**0.960**	**0.964**	**0.980**	**0.984**
$Global_I$		0.886	0.985	0.990	0.993	0.990	0.994
R^2/R^{2*} of $Global_I$		**0.784**	**0.971**	**0.980**	**0.985**	**0.980**	**0.987**

In all the methods used: scatter plots, cobweb plots, CSM plots, non-parametric methods (Mann-Whitney and Smirnov tests) and variance based methods, "derived parameters" (and $Global_I$ in particular) always got the highest values of the different statistics, showing its great influence on the peak doses. The rankings of importance of the parameters on the basis of the different statistics calculated were led by "derived parameters" in all the cases.

2. References

Nuclear Energy Agency (NEA), 1989. PSACOIN level E intercomparison.