Sensitivity Analyses of COMIDA2 Parameters in WinMACCS on Japanese Food Doses

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Abstract: COMIDA2 is one of the modules in WinMACCS calculation code typically used for Level 3 PRA. It contains a semidynamic food-chain model for calculating individual and population doses via food ingestions after a release of radionuclides into surrounding environments. Based on a series of parameters that were adjusted for environmental conditions in Japan, we aimed at finding key parameters that affected health risk outputs such as LCF (latent cancer fatality). To this end, sensitivity analyses were conducted on selected parameters of COMIDA2 using a global sensitivity index, Sobol' index. In conclusion, settings on annual agricultural productivities should be cared firstly to calculate food ingestion doses, particularly population doses, in advance; contribution of food ingestion doses to total dose was minor under the current data set; some physical parameters related to soils were important for agricultural crops like grains; for milk and beef meat, parameters related to hay were important.

Keywords: Level 3 PRA; WinMACCS; COMIDA2.

1. INTRODUCTION

After the Fukushima Daiichi nuclear accident, attention was focused on radioactive contamination of Japanese foods. Production systems of vegetable and animal crops as well as eating habits vary by country and region. Since food ingestions are one of the main routes of exposure to radioactivity, the route ought to be considered to understand the risk of the operation of nuclear facilities on public health. CRIEPI has been promoting the Level 3 PRA project in Japan and has adopted WinMACCS code that was developed by Sandia National Laboratory (SNL) to calculate public exposure risks. The code is equipped with the optionally available module COMIDA2 which can calculate the dynamics of radioactive substances in food webs and the amount of exposure caused by human food ingestions [1,2].

The aim of this study is to extract major COMIDA2 parameters that need to be preferentially specified. To this end, we performed a sensitivity analysis of those parameters used in COMIDA2 module. Though US NRC reported consequences of a sensitivity analysis on COMIDA2 parameters, it was limited to local sensitivity analysis [3]. We constructed a new metamodel using COMIDA2 parameter inputs and outputs of ingestion doses produced by WinMACCS and conducted a global sensitivity analysis that also considers interactions between parameters. Those results will be discussed below.

2. MATERIALS AND METHODS

Firstly, uncertainties were given for each COMIDA2 parameters; a uniform distribution was adopted for all input parameters; the lower and upper limits were half and twice representative values. For the representative values, values specific to Japan like annual food ingestions were used as necessary in addition to the default settings used in the United States [4,5]. As for other WINMACCS settings, we used a population distribution and meteorological data as site data for an area surrounding a virtual nuclear power plant in Japan. As source term inputs, data were cited from a published literature on Level 3 PRA conducted by U.S.NRC [6]. The project property was set as shown below. All calculations in this study were performed using WinMACCS ver 4.0.

- Atmospheric dispersion model: Gaussian plume, power law, time-based.
- Plume meander: none.
- Weather sampling: Nonuniform bin sampling.
- Mixing height: Day only.
- Plume source: Area source.
- Plume rise: Density and flow model.

- Dose model: Linear no threshold without KI model.
- Cohort: 1, Type = Circular.
- Segment model: Wind shift without rotation.
- Speed multiplier model: none.
- Keyhole evacuation model: none.

In the simulations, a dataset was created using LHS (Latin Hypercube Sampling) for the parameters that were to be given uncertainties. The metamodels were created using a library “LightGBM” in Python. We quantified the uncertainty of output food ingestion doses and extracted parameters that had a relatively large contribution to the doses. As the sensitivity index of parameter contributions, we adopted the Sobol' index, which is based on the relative ratio of the variation of each parameter terms and interaction terms to the overall variation [7]. Though nine food categories are prepared for COMIDA2 module to calculate food ingestion doses, for simplicity we omitted one category, “other animal type”, from discussions below.

3. RESULTS

As a result of the sensitivity analysis, relatively important parameters to food ingestion doses were identified (Figure 1). For all food categories the parameter PRODUC_RATES was found to be the most contributing one to the food doses. There were some differences in contributing parameters between vegetable crops and animal crops. Except for PRODUC_RATES, parameters FD, PROCLOSS, CR, PSR and XR were important for doses of vegetable crops while parameters ZKP, BEEF_RATES (DAIRY_RATES or POLTRY_RATES), PROCLOSS, TC and CONSUM_RATES were important for doses of animal crops (see Table 1 for descriptions of each parameter). In addition, some parameters related to hay like CR_HAY and DAIRY_RATE were important for dose of milk.

While orders of importance among parameters by the food category may change in some cases (e.g., FD and PROCLOSS for the category “GRAINS”), the results of the local sensitivity analysis and the global sensitivity analysis were generally in agreement (see Figure 1). In other words, parameters identified as important ones in the local sensitivity analysis were also important in the global sensitivity analysis.

Table 1. Descriptions of top 5 important COMIDA2 parameters for each food categories. Units are shown in the parenthesis.

Parameter name	Description
BEEF_RATE	Meat cattle feed rate (kg dry/day)
CONSUM_RATES	Consumption rates (kg/year)
CR	Soil-to-plant concentration ratio (-)
DAIRY_RATE	Dairy cattle feed rate (kg dry/day)
FD	Dry-to-wet mass ratio (-)
PROCLOSS	Contamination reduction factor (-)
PRODUC_RATES	Annual agricultural production rates (kg/m^2)
PSR	Root soil bulk density (kg/m^3)
TC_MILK	Transfer coefficients for milk (days/L)
XR	Thickness of root zone soil (m)
ZKAD	Adsorption rate constant (1/day)
ZKP	Percolation rate constant (1/day)
ZKW	Weathering rate constant (1/day)

4. DISCUSSIONS

Aside from parameters related to vegetable or animal biology, several physical parameters were identified as important ones. Since PSR and XR are related to soil leaching rate and root uptake rate, respectively, they are thought to have a large contribution to food doses, particularly to doses for vegetable crops (U.S.NRC, 1998). While IAEA1994 recommends that XR = 20 cm is a good approximation for most crops [8], it might be more realistic in Japan to assume a wider range for XR inputs considering literature data of root zone soils thicker than 20 cm [9].

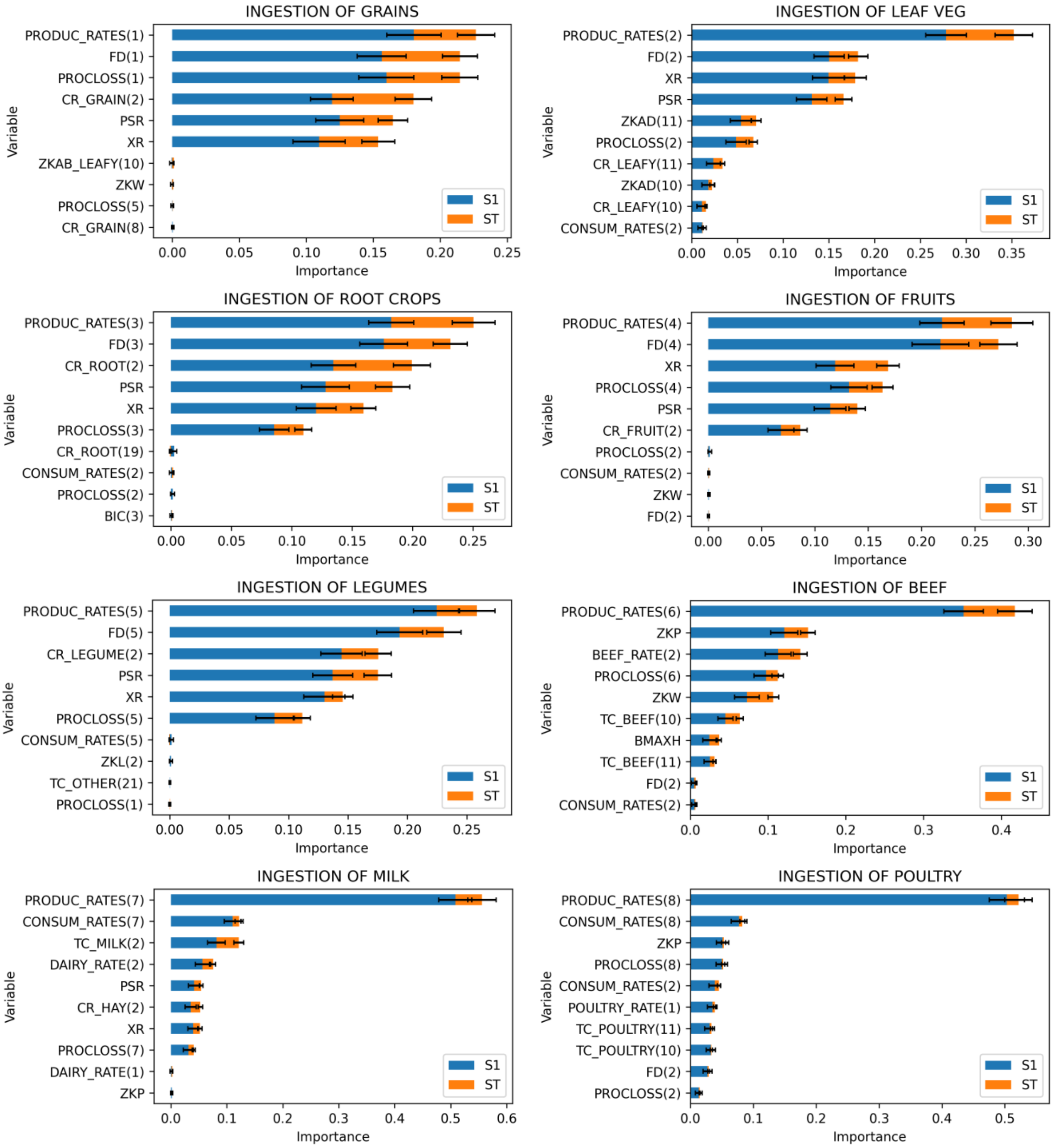

Figure 1. Top 10 COMIDA2 parameters that contributed to population doses caused by ingestions of each food categories. S1 and ST represent sensitivity indices considering a single parameter variance only and considering variance for interactions among parameters, respectively. Error bars indicate 95% credibility intervals. *Numbers in the parenthesis indicate orders of the parameters in the forms where several input parameters need to be specified.

In COMIDA2, it is assumed that the concentration of radioactive substances in animal crops is in equilibrium with the concentration in pasture, feed, and surface soil. Therefore, parameters such as ZKP which is the leaching rate constant from surface soil to unstable soil, and ZKW which indicates the degree of transfer of radioactive materials to surface soil from the surface of vegetation, contributed to the food doses for animal crops.

For ingestion doses of all food categories, the parameter PRODUC_RATES was identified as among the most important variable. This is likely because COMIDA2 calculates population doses based on inputs of annual production rates for the foodstuffs and thus the doses are proportional to the agricultural productivity of the land in question [2]. Then we examined the sensitivity of this parameter on Japanese health risks using

WinMACCS based on the input dataset explained above. Figure 2 shows simulated CCDFs (complimentary cumulative distribution function) of LCF with different magnitudes of PRODUC_RATES inputs.

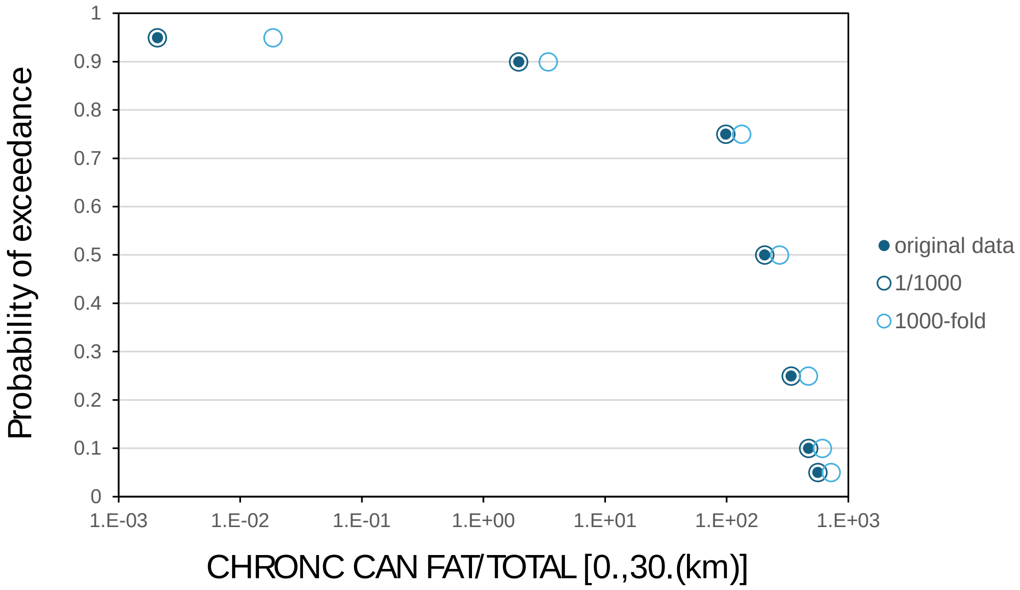

Figure 2. CCDFs of LCF for the population living between 0 to 30 km from the virtual plant with varying magnitudes of inputs of the parameter PRODUC_RATES.

When PRODUC_RATES inputs that were much reduced (1/1000) from originally estimated values were used, LCFs were nearly identical between reduced and original cases. This was also the case for another health risk metrics, the average individual risk for the long-term cancer fatality. It seems that due to the limited contribution of the food doses to the total doses considering all possible exposure pathways, the PRODUC_RATES reduction did not affect those health metrics. On the other hand, when input values were much higher (1000-fold), LCF increased as shown in visually different CCDF. The examination here suggests that WinMACCS health risk metrics are not sensitive to COMIDA2 parameters, at least under the current dataset for Japanese population. Indeed, 1000-fold values of PRODUC_RATES are not realistic in Japanese agricultural environments. Such situation is similar to the ones when there is no restriction for productions of contaminated food crops and/or no restriction for consumptions of contaminated foods with very high radioactivity. Yet it is unlikely that such situation will occur under the current criteria of the limitation up to 1 mSv for the annual exposure by food ingestions in Japan.

It is worthwhile to note that parameters identified as unimportant can be treated as fixed values during simulations in the future. Since the most important COMIDA2 parameter, PRODUC_RATES, did not significantly affect Japanese health risks, many parameters, particularly the ones that did not appear in Table 1 may be treated as fixed values. Instead, parameters related to other major exposure routes like long-term ground shine ought to be examined more carefully.

5. CONCLUSION

Under the current dataset for Japanese population, WinMACCS health metrics were not sensitive to COMIDA2 module parameters. Therefore, many COMIDA2 parameters may be treated as fixed values to reduce calculation costs. However, if there is a special need to focus on food ingestion doses, insights obtained in this study could help understand what parameters ought to be examined and determined as input data in priority to the other many parameters.

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