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INGESTION MODELLING IN COSYMA

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Abstract. One of the aims in the design of the COSYMA ingestion model was the ability to cope in a flexible manner with the various food chain related data and results at different stages of an accident consequence assessment. Since dynamic foodchain transport models themselves are normally rather complex and require significant computing times, they are usually not included in ACA codes, but are used to calculate and tabulate the needed information in the form of data libraries. Such data files contain specific activity concentrations in the foodstuffs and their time integrals normalized to unit deposit or unit air concentration for a series of times after the accident to allow for calculations taking account of food restrictions. In an ACA run, the actual specific concentrations in the foodstuffs are obtained by multiplying the normalized concentrations taken from the data library by the ground or air concentrations in each grid point predicted with an atmospheric transport and deposition model. The paper presents the structure of the ingestion model: structure, methods and the libraries used for a nuclear accident consequences assessment.
Key words: COSYMA, dynamic foodchain, atmospheric transport.

1. INTRODUCTION

The consequences resulting from the ingestion of terrestrial foodstuffs contaminated after accidental releases of radionuclides into the atmosphere are assessed in the subsystems NL and FL of COSYMA [1]. Figure 1 shows the endpoints of the calculations and the models involved.

One of the aims in the design of the COSYMA ingestion model was the ability to cope in a flexible manner with the various food chain related data and results at different stages of an accident consequence assessment. The situation is illustrated in Figure 2 by means of the foodstuffs or food category currently implemented (solid boxes) or foreseen (dotted boxes) in

Level I is made up from those foodstuffs for which normalized activity concentrations are available from a dynamic terrestrial food chain transport model; it represents the maximum degree off detail with respect to foodstuffs possible with the ingestion model. The present maximum number of foodstuffs which can be considered in COSYMA is 10.

For most applications the parameterization of the dose and risk results — LEVEL 2 — is not need to be that detailed, so that it may be desirable to condense the information, e.g. by using the 6 food categories shown in the figure for the second level.

The agricultural production data required for some of the food chain related calculations may not be available for all the Level I foodstuffs but for some broader categories. which form, LEVEL 3 of the foodstuffs hierarchy.

Finally, the degree of detail with respect to the foodstuffs in the economics model — LEVEL 4 — is much broader than for the other levels. For instance, the current economic model distinguishes only between the three food categories milk (including ,milk products), livestock and crops.

The foodstuffs hierarchy is built up using a series of arrays containing names and pointers, which define the nature of the food items and relate the different levels to each other. The pointer arrays have to be given by the user. The advantage of this technique is that different situations can be considered without requiring changes to the code; the disadvantage is that the task of setting up the cross reference table is not trivial. However, default tables are provided for all standard applications of COSYMA, so that in general no action is required. Since dynamic foodchain transport models themselves are normally rather complex and require significant computing times, they are usually not included in ACA codes, but are used to calculate and tabulate the needed information in the form of data libraries. Such data files contain specific activity concentrations in the foodstuffs and their time integrals normalized to unit deposit or unit air concentration for a series of times after the accident to allow for calculations taking account of food restrictions. In an ACA run, the actual specific concentrations in the foodstuffs are obtained by multiplying the normalized concentrations taken from the data library by the ground or air concentrations in each grid point predicted with an atmospheric transport and deposition model.

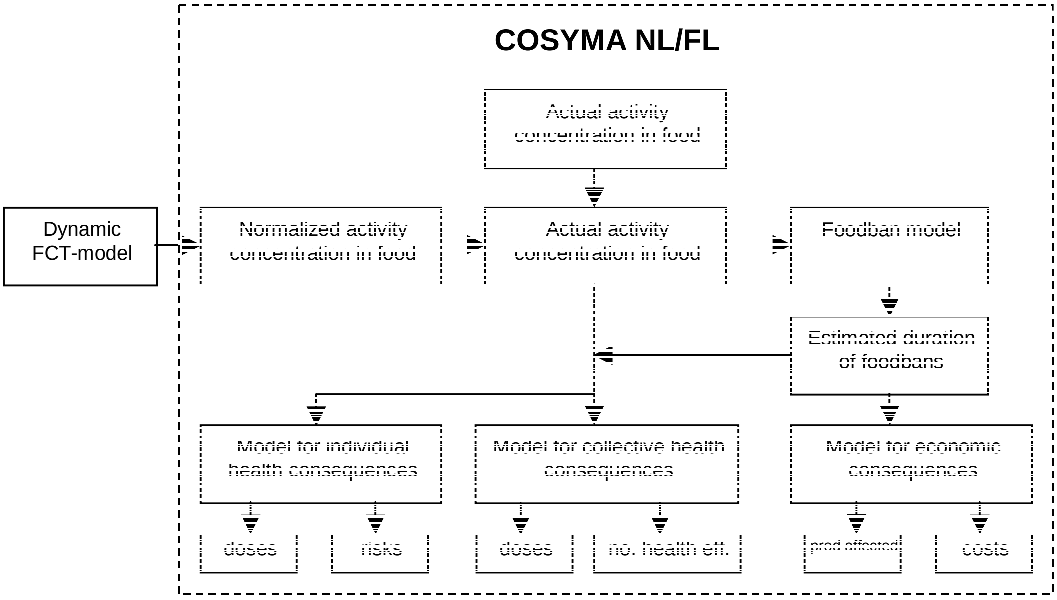

Figure 1. Ingestion related calculation and results.

In COSYMA, the data interface between the foodchain transport model and the atmospheric dispersion and deposition model is the total activity initially deposited on the ground. At present, no difference is made between the activity deposited by dry and wet deposition processes.

Several libraries giving the concentrations of a range of nuclides in the foodstuffs of interest are provided with COSYMA. The one currently in use [2] was derived from data calculated with a version of the GSF-model ECOSYS. This model provide concentrations in milk, beef, pork, potatoes, grain and three different types of vegetables according to German consumption habits. Values are given for the 30 fission products and actinides. Values for the 14 activation products provided by a GSF work [3] will be added to the library. The second default library contains data from the NRPB-model FARMLAND [4]. It gives both activity concentrations as well as time integrals for milk, beef, sheep, potatoes, grain and green vegetables. Additionally, data for liver from cows and sheep will be included, which may be useful when considering releases with significant actinide content, since these radionuclides tend to concentrate in offal rather than in meat.

All of the dose – and risk final results in COSYMA refer to the average population, rather than to critical groups. Therefore, the code allows the specification of average delay times between production and consumption of the foodstuffs (user defined or default values), which are used to derive appropriate modifying factors for the foodstuff concentrations. For milk, different delay times for milk consumed in fresh and processed form can be used. For agricultural production data, the only suitable library currently available is the one prepared by NRPB [5] which covers all European countries and gives the amount of annual production for the Level 3 foodstuffs (except pork) shown in Figure 2. Data for cow ad sheep liver are also provided, but for the present applications of COSYMA they are simply added to beef and sheep, respectively. The resolution of the grid is about 100 km square. The fractions of produce used for human consumption is accounted for in the data.

In COSYMA, seasonal effects are taken into account by using two versions for each of the foodchain transport data libraries, one for a release on January 1st to represent an accident in winter (“November-March”) and one for a release in July 1st to represent an accident in summer (“April-October”). In an ACA run, each weather sequence is, depending on its real date, attributed either to the winter or to the summer period and the corresponding foodchain data set is selected by the program. In addition, it is also possible to generate results for one of the above time periods alone or to use a single data set for all times of the year as suggested in [6].

2. FOODBANS

Foodbans can be assumed to be imposed or withdrawn on the basis of intervention levels either based on activity levels in food or on individual doses. In either case the intervention levels used for imposing and withdrawing the bans need not be the same and the user has considerable freedom to specify his requirements. Output from the foodban model is a data set of “foodban flags”, which gives for each grid element the estimated ban duration for each of the Level 1 foodstuffs in coded form. This data set is used by all modules of COSYMA requiring information about foodbans.

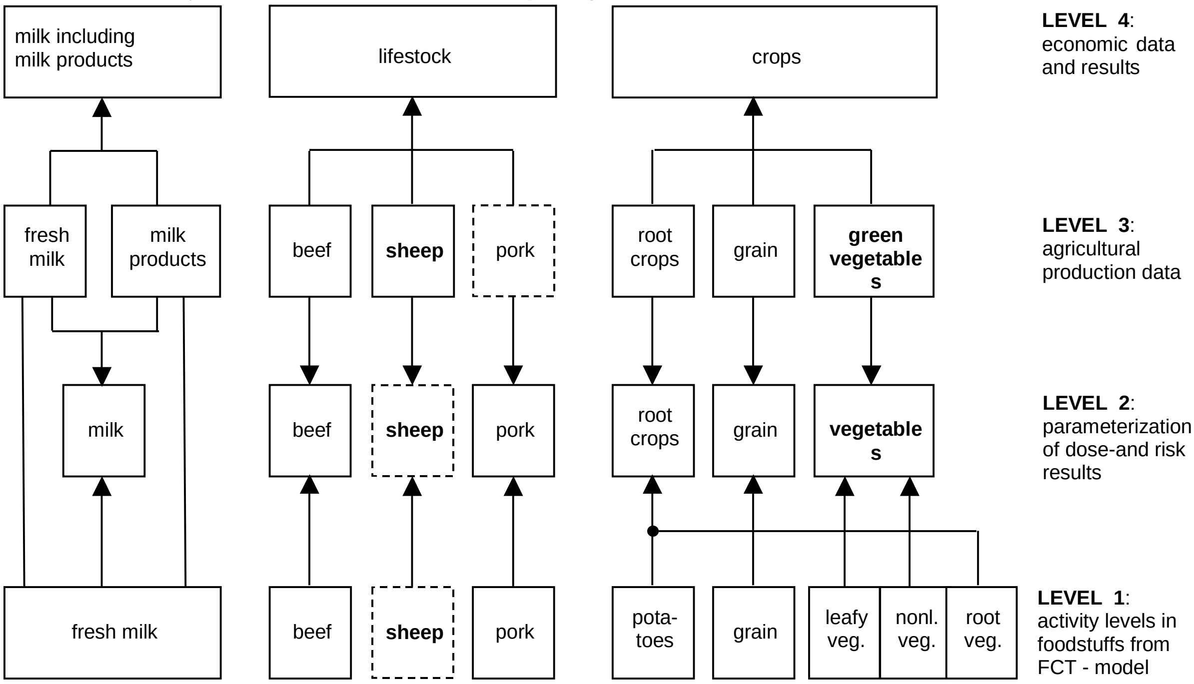

Figure 2: Current foodstuff levels in COSYMA

If based on activity levels in food, the user can input the intervention levels for the range of foodstuffs and nuclide groups he has defined. The program will sum the concentrations of the nuclides in each group for comparison with the corresponding intervention level. If based on doses, the user can select which organ and foodstuffs are to be taken into account for banning. Individual foodstuffs can be combined to form food groups, in the sense that the sum of the doses from all members of each group will be compared with an intervention level holding for the whole group rather than for the individual members. A ban is assumed to be imposed for all food group members, if the intervention level for any one of the organs to be considered with the group is exceeded; the intervention levels used for imposing and withdrawing the bans need not be the same.

The calculation of the individual doses is done with age-dependent consumption rates given by the user and corresponding age-dependent dose version factors taken from a library described in next section. If the dose intervention levels are assumed to apply to the average rather than the critical group, average delay times between harvest and consumption can be specified for each foodstuff. A similar delay is not considered if the bans are to be based on activity levels. However, in both cases losses of activity during normal food processing are always implicitly accounted for, because these processes are already considered in the foodchain transport models and thus contained in the data generated by them.

For each of above methods, a set of default values for the food categories, the organs and the intervention levels is provided in COSYMA; the present default intervention levels are given in Table 2. The default values for the maximum permitted levels in food are based on the EC Council Regulations [7] and are assumed to apply to individual foodstuffs. The dose intervention levels are based on the ICRP-40 Principles for Planning [8]. However, they are currently assumed to apply to the food category “average food basket for adults”, i.e. to the dose sum resulting from the consumption of all the Level 1 foodstuffs by an average adult consumer, which is the proceeding of the US Reactor Safety Study WASH-1400 [9].

The food categories used for banning, i.e. for comparison with intervention levels, are valid for the purpose of banning alone and are not used outside the foodban module. All foodstuffs belonging to the same category with respect to the intervention levels get the same foodban flag. For example, when using the dose intervention levels in Table 2 applied to the "average food basket", identical flags are assigned to all Level 1 foodstuffs.

After the calculation of the foodban flags in the way described above, two modifications to the flags are made in the ban module. The first one is always carried out and takes account of the other long-term countermeasure "relocation": in COSYMA it is assumed that in a relocated area no agricultural production will take place until resettlement. Therefore, in all grid elements affected by both relocation and foodbans, all foodstuffs for which the foodban duration was estimated to be shorter than the duration of relocation get a foodban flag corresponding to the relocation time span. The second modification is optional and can be steered by the user: it is possible to assign common foodban flags to different Level 1 foodstuffs in the sense that the most restrictive ban time found for any of the foodstuffs to be combined in this way is assigned to the corresponding individual foodstuffs. For example, when using the maximum permitted levels for foodstuffs from Table 1 applied to the individual Level 1 foodstuffs, the user may request that the foodstuffs "beef", "sheep" and "pork" shall all be assigned the same (maximum) flag. The default setting is such that all Level 1 foodstuffs belonging to the same Level 2 food category will have the same flags.

Table 1: Current default intervention levels for foodbans

Maximum permitted levels for foodstuffs [Bq/kg or Bq/l]			Intervention levels based on doses
	Dairy Produce	Other Foodstuffs	Introduction: Committed dose equivalent (effective or thyroid) ≥ 5 mSv due to ingestion in first year
Isotopes of Sr	125	750	
Isotopes of I	500	2000	
Isotopes of Cs	1000	1250	Withdrawal: Committed effective dose equivalent due to ingestion in one of the following years
Pu-239, Am-241	20	80	

3. Dose and risk calculations

The calculations of individual doses and risks from the ingestion pathways in COSYMA are always carried out under the assumption that all food consumed is produced at the point of consumption, and that the required amount of food is produced in each grid element (local production and consumption approach).

For the calculations of collective ingestion doses and risks, two models are included in COSYMA. The first is the local production and consumption model, which requires the information about the number of individuals in the grid elements. The second model is based on the assumption that all contaminated food produce is consumed somewhere (agricultural production approach) and requires the information about the amount of agricultural production in the grid elements.

In ***Local production and consumption approach***, the doses are calculated for an average adult member of the population. Default consumption rates derived for average adult consumers in the FRG [2] are provided (see Table 2), but other values may be given by the user. The dose per unit intake data are taken from libraries derived from a large data base, which contains time-, age- and sex- dependent dosimetric data for inhalation and ingestion obtained from metabolic models developed by GSF. Other metabolic models are available for calculating the required values. A comparison between the GSF values and values obtained with models developed at NRPB has been carried out for ingestion doses [10]; the results showed good agreement between the two data sets.

The calculations of the risk of fatal stochastic somatic effects allowing for the time- and age variation of dose and risk and the age distribution in the population are carried out using the activity-risk coefficient (ARC). The individual risk in each grid element is calculated by multiplication of the appropriate ARC and the amount of activity deposited; the number of health effects is obtained by multiplying in each grid element the individual risk by the number of individuals and then summing the contributions from all grid elements.

Table 2: Average consumption rates [kg/a] for adults used as default values for ECOSYS

milk	beef	pork	potatoes	grain products	leafy vegetables	non-leafy vegetables	root vegetables
115	20	50	70	95	20	25	15

Values of the activity-risk coefficients per unit deposit are precalculated for a series of starting times after the accident and stored in data libraries. The activity risk coefficients for ingestion are calculated using data about the age- and life expectancy distributions in the population, time dependent concentrations of radioactivity per unit deposit in the foodstuffs, age dependent consumption rates, and time- and age dependent dose per unit intake data and risk coefficients. For the consumption rates, values which were derived for the FRG [2] are used. The dose per unit intake data library is the one mentioned above, the risk coefficients data base has been provided by GSF [11]. The current default data set for the ingestion activity risk coefficients was obtained using the ECOSYS data for the concentrations of radioactivity in the foodstuffs.

In ***Agricultural production approach***, the collective ingestion dose is estimated from the amount of activity deposited, the concentrations of radioactivity in the foodstuffs per unit deposit, the annual amount of produce taken from the agricultural production data grid, and the committed dose equivalent per unit intake of activity. The calculations are carried out for average adult members of the population using the dose per unit intake data described above. The estimation of the number of fatal stochastic somatic health effects with the production approach makes use of the assumption of a linear dose-response-relationship, which means that the total incidence of health effects in an exposed population is related to the collective dose. Therefore, the number of the health effects under consideration is calculated by multiplication of the collective dose derived in the way described above with a risk factor averaged over the whole population. The average risk factors used as default values [1] were provided by the GSF and are consistent with the age-dependent risk coefficient GSF data described in the previous section.

4. RESULTS

We have considered a CANDU 600 nuclear reactor with the specific core inventory. For the release we considered a design basis accident (Late core disassembly with hydrogen burn, 25 – 30 hours duration) with a release of 90% noble gases, 0.1 % iodine, and 0.01% fission products. For the ingestion modeling we have considered the default parameters of the model, both for the food chain and the countermeasures. The results regarding the contributions (in %) of exposure pathway ingestion, for the radius 2.50 km from the site are presented in Table 3.

Table 3. Contributions (in %) of exposure pathway INGESTION - *radius: 2.50 km*

Nuclide ID	NUCLIDE	Bone Marrow	Bone Surface	Breast	Lung	Somach	Thiroid	Whole body
50	SR- 89	0.03	0.02	0.01	0.01	0.05	0.01	0.06
51	SR- 90	89.71	94.88	3.8	3.29	4.15	3.13	56.25
63	ZR- 95	0	0	0	0	0.01	0	0.01
83	RU-103	0	0	0	0	0	0	0
85	RU-106	0.04	0.02	0.44	0.38	0.77	0.37	0.76
103	TE-129M	0.15	0.16	0.07	0.06	0.18	1.23	0.34
114	I -131	0	0	0	0	0	0.12	0
126	CS-134	2.85	1.42	25.06	26.79	26.72	26.96	12.11
129	CS-137	7.22	3.5	70.63	69.46	68.03	68.19	30.26
136	CE-141	0	0	0	0	0	0	0
138	CE-144	0	0	0	0	0.09	0	0.19

In Table 4 are presented the contributions (in %) of foodstuffs to mean individual dose by ingestion calculated for the whole distance band and presented for the distance of 2.50 km from the site. The initial potential areas affected by foodbans taken into account for the imposement of the countermeasures are presented in Table 5.

Table 4. Contributions (in %) of foodstuffs to mean individual dose by ingestion at *2.50 km*

FOODSTUFF	Bone Marrow	Bone Surface	Breast	Lung	Stomach	Liver	Thiroid	Whole body
MILK	34.42	36.11	6.4	6.13	6.64	5.99	5.99	23.81
BEEF	0.39	0.27	2.44	2.44	2.41	2.44	2.41	1.17
PORK	7.57	3.76	70.73	71.24	70.17	71.46	70.51	31.48
GRAINPRD	19.56	20.61	2.18	2.05	2.25	1.99	1.99	12.83
POTATOES	6.59	6.54	7.31	7.31	7.31	7.31	7.41	6.89
LF.VGTBL	13.13	13.85	1.02	0.94	1.07	0.9	0.9	8.43
NL.VGTBL	13	13.39	6.43	6.4	6.53	6.38	7.23	10.57
ROOTVGTB	5.34	5.45	3.51	3.49	3.62	3.54	3.55	4.82

Table 5. Potential areas affected by foodbans (km^2) - initial:

FOODSTUF	MAX. AREAS	Mean areas	Fract. 99.9	Fract. 99.0	Fract. 90.0
MILK	5.10E+02	5.10E+02	5.10E+02	5.10E+02	5.10E+02
BEEF	5.10E+02	5.10E+02	5.10E+02	5.10E+02	5.10E+02
PORK	5.10E+02	5.10E+02	5.10E+02	5.10E+02	5.10E+02
GRAINPRD	5.10E+02	5.10E+02	5.10E+02	5.10E+02	5.10E+02
POTATOES	5.10E+02	5.10E+02	5.10E+02	5.10E+02	5.10E+02
LF.VGTBL	5.28E+02	5.28E+02	5.28E+02	5.28E+02	5.28E+02
NL.VGTBL	5.28E+02	5.28E+02	5.28E+02	5.28E+02	5.28E+02
ROOTVGTB	5.10E+02	5.10E+02	5.10E+02	5.10E+02	5.10E+02

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