Application of the COSMYA Code for Comparative Analysis of a Certain Accidental Releases of Radioactivity

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1 Introduction

This report mentions the continuous process of comparison of results for significant scenarios of accidental radioactive discharges generated by codes HAVAR and COSYMA. The COSYMA code is significant European product developed under sponsorship of EC by several outstanding European institutes and deals with the nuclear accident consequence assessment methods. The code HAVAR is fully localised national code standardised for purposes of calculations in the field of nuclear safety and includes executive regulations of the State Office for Nuclear Safety which are valid and obligatory for the Czech Republic. The code accepts the Czech local conditions from point of view static geographical or demographic gridded data (real spatial distribution of elevation, land use type, roughness of the terrain, population according to age categories on the variable polar computational grid) and dynamic changes of weather conditions (stepwise segmented model including local precipitation), release intensity and food chain parameters. The code offers user-friendly interactive support both for input of data and direct graphical interpretation of results.

The analysis presented here also illustrates some latest results generated by means of system RODOS (Real-time On-line Decision Support system) the customisation of which is just running in IITA.

2 A little bit of history

Whenever the estimation of radiological consequences of activity releases has been carried out for purposes of safety reports or other external use some additional procedures for verification of the generated results have been implemented. It usually insisted in a certain partial verification with regards to other commonly accepted computer codes. Even though the COSYMA code is designed predominantly for case of probabilistic calculations, its rich know-how appeared to be worthwhile for the partial deterministic calculations and successive comparative analysis. Then, since 1997 various verification runs enable to tune the local Czech codes and improve their algorithms and reliability.

The first results were published in [1] on the 4-th COSYMA Users Group Meeting in Prague where the application of PC-COSYMA code such a verification tool used in the stage of NPP design has been demonstrated. An audit of dispersion and deposition models of HAVAR system for Batch I and Batch II problems were accomplished and experience has been reflected in the process of local national codes development. The main result of [1] was verification of the local Czech ingestion model ENCONAN using COSYMA food chain model FARMLAND (originally developed in early 90's by dr. V. Kliment, NRPI Prague). The general ingestion dynamic model was adopted for average Czech conditions taking into account local consumption habits (dependence on season and age), agricultural production scheme, average agro-climatic conditions and phenologic characteristics of the plants, feeding diets of animals, time delays during processing, transport and storage of foodstuffs and feedstuffs etc. Sensitivity analysis with regards to radioactive fallout in a certain Julian day within a year was carried out and good consent with COSYMA summer ingestion has been found. At the same time the extremely high degree of conservatism introduced by the former static ingestion model was demonstrated.

The HAVAR code is developed for quick estimation of various scenarios of accidental radioactivity releases, for purposes of uncertainty analysis (several options of models are interactively offered to users), sensitivity studies and potential "worst case" studies. In all cases the accent on respect on local specific features (as detailed as possible site specific data, practice of national meteorological service, agricultural production practices and all corresponding dynamic parameters for food chain model etc.) and compliance with the new specific governmental regulations (the Czech Atomic Law) is emphasised. During the code development the new knowledge obtained also from the various comparative benchmarks is gradually absorbed and lead to the implementation of more sophisticated algorithms. It was realised for example on the effects of plume rise, near-standing building wake, washout and extension of diffusion formulas. The broad extensions were implemented into the former ingestion model ENCONAN.

Between COSYMA and HAVAR codes exist a certain differences both in the part of input data and range of solution. It emerged to be necessary to simplify the input data for the particular cases and adjust them according to the existing program limitations. We do believe the adjustment don't reduce the significance of comparison and fulfil the objectives of the process.

Since 1997 some successive activities of COSYMA application were carried out as its verification tool for important results generated for several real scenarios of estimation of radiological impact on population. It consisted in the continuous partial examinations of generated results which is described in the corresponding reports. Let us mention particularly the important scenarios related to the validation tasks no. 1 and no. 2 defined and issued by the Czech Accreditation Board. The submission to the accreditation procedure is obligatory for software used in the Czech Republic in the field of nuclear safety calculations. The results of the code HAVAR supported by the COSYMA calculations are widely commented and demonstrated in [2], part III. The same tasks analysed by the RODOS software is described in [4] and then the good consent with other products can be declared.

3 Continuous process of comparison

Recent requirements on radiological impact assessment analysis lead to the further code development and its extensions with objective to carry out more detailed sensitivity studies and uncertainty analysis. It calls for more profound comparison procedures which would replace the previous partial verification steps. Extensive estimation of radiological consequences of several types of accidental radioactive discharges from NPP have been carried out recently. It was related both for releases from the primary circuits into containment and postulated releases out of hermetic zone directly to atmosphere (locked rotor accident, control rod ejection accident, steam generator tube rupture, main steam line break accident on PWR, some kinds of loss-off-coolant accidents). On the basis of thermohydraulic analysis of the events and successive conservative solution of activity transport through primary and secondary circuits (effort for maximisation of the released activity) the final strength and dynamics of activity release were estimated. Further reduction into stepwise segmented form has been applied and then the segmented source terms of the releases has been generated and submitted for the successive radiological impact assessment. Among this scenarios for two of them the more detailed and profound verification with COSYMA calculations was accomplished:

- for scenario PIPE : rupture of instrumentation pipe out of hermetic zone for samples extraction from volume compensator

- for scenario MSC : guillotine main steam collector rupture such a representative scenario covering the main steam line break accidents

In both cases we were engaged also in the process of overall activity transport solution and corresponding release source terms generation. The results are in possession of the Czech Energetic Company. Another scenario connected with the Large Break Loss Of Coolant Accident (LB-LOCA) for a certain PWR has been postulated on the basis of available data in common technical references and experience, mainly associated with the design basis accident and severe accidents constructed in the RODOS system for training purposes. Successive overall comparison benchmark has been started and documented in [3] in the middle of 2001 year. The results were extended this year and the extraction of the interesting dependencies is documented here.

4 Comments on LB-LOCA accident scenario and its breef description

A large break loss-of-coolant-accident (LB-LOCA) results from a pipe rupture of the reactor cooling system of the primary circuit of reactor. The large break is defined as a rupture with a total cross-section area equal to or greater than 0.1 m^2. The limiting LB is postulated for double-ended cold leg guillotine process in a section of the main coolant piping . The sequence of events for LB-LOCA starts with depressurization of the reactor cooling system which results to decrease of saturation temperature and increase in containment pressure. An emergency safeguards function signal is generated and initiates the countermeasures for limitation of consequences of the accident such as reactor trip and borated water injection. The successive fuel rod cooling is provided by blowdown of the primary system inventory, injection of liquid primarily from the accumulators refilling the vessel and core and supplemented by pumped safety injection.

Rapid depressurization of the primary system accompanied by high mass flow rates through the broken loop could lead to nearly complete coolant inventory loss and core uncovery. The fuel cladding temperature rise to a maximum as core heat transfer degrades. The cladding temperature rise is terminated as flow reverses through the core. Continued operation of the emergency core cooling system pumps supplies water during long-term cooling and core temperatures are reduced to long-term steady state levels associated with dissipation of residual heat generation. Let us assumed that emergency countermeasures (including the operator emergency actions) are adjusted in order to ensure the acceptance criteria for the LOCA. Large break LOCA evaluation model, which generates the source term for calculations of the radiological consequences of the LB-LOCA, is referred to be based on the advanced thermal-hydraulic computer codes which are consistent with approach used in several European blocks.

5 Construction of source term for successive assessment of radiological consequences of the specified LB-LOCA

The aim of this report is not thorough description of solution of thermal-hydraulic transient processes and activity propagation. Let us mention only, that the balance of activity in the reactor core for initial reactor power and burnup is solved and the thermal-hydraulic analysis of the containment environment during the transients enables modelling of full-pressure approach. It takes into account the location of inner structures, inner sources of mass and energy due to outflow from the break, effect of the containment spray system, heat transfer on the walls and removal processes affecting the activity balance. The successive balance of activity in the containment environment is computed and no fuel melting is expected. Transport of activity from dehermetised fuel rod claddings (≈ 1% of cladding failures is assumed due to transients in early stage of the accident) into the containment considers the deposition of the activity on the inner containment surfaces, washing of radionuclides by sprays and other activity removal mechanisms from the containment atmosphere. Under the further assumption that the reactor core remains amenable to cooling during and after the break the main source of the final activity release into free atmosphere is based on the peak pressure technical specification containment leak rate for the first 24 hour.

The intensity of the nuclide releases has rather complicated time dependency. For purposes of the Gaussian plume segmented calculations the total time of release has been split to 4 segments, the release characteristics are assumed to be constant within each segment. Considerable role plays time integral of activity (integrated within each time segment) which represents stepwise function between particular segments. For purposes of comparison procedure the further simplification of input data has been applied in order to bring the values as closest as possible with regard to the limitations of the respective codes (and , simultaneously, to reduce the amount of necessary calculations corresponding to the objective of the validation procedure).

All activity released originally during about 21 000 sec with real release dynamic segmented into 4 stepwise segments mentioned above has been reduced to one segment of 4 800 sec duration. A set of 15 nuclides has been selected for calculation which represents more than 92% contribution to the total doses. Corresponding source term was generated (total release in Bq):

Table 1:	**KR85M**	**3.5300E+11**	**KR88**	**8.0000E+11**
	RB88	**1.4400E+11**	**I131**	**1.2800E+11**
	TE132	**2.8900E+08**	**I132**	**1.7100E+11**
	I133	**2.5100E+11**	**XE133**	**4.0900E+12**
	I134	**2.3700E+11**	**CS134**	**3.7000E+10**
	I135	**2.5100E+11**	**XE135**	**1.0700E+12**
	CS136	**1.6000E+10**	**CS137**	**1.8500E+10**
	CS138	**1.8100E+11**		

Because of a certain limitation of the codes other input data has been simplified and adjusted as close as possible in order to use the code capability optimally. The negligible differences remained, but those are not expected to cause remarkable influence on comparison. Uniform terrain approach has been adopted and the basic input definitions adopted as:

source geometry :	**single point**
atm. stability category :	**F**
wind speed at 10m :	**1.0 m/s**
no. of windrose dir.:	**16**
no. of radial dist. :	**35** (from 0.666 to 100 km from the source)
terrain orography:	**flat**
terrain roughness:	**urban type**
dispersion $\square_z$, $\square_y$:	**exponential KFK-Jűlich**
no. of time segments:	**1 segment**, total activity is released during 4800 s with constant intensity
release height:	**45 m**
thermal power of release :	**0 MW**
vertical velocity of release :	**0 m/s**
near-standing build.:	**50 m** (width), **44 m** (height)
precipitation:	**no**
mixing height for F cat.:	**200 m**
release duration :	**4 800 s**
critical age group:	**adults**

Besides that, the other first class priority values for calculation had to be adjusted. As for dispersion, σ_z and σ_y according to KfK / Jülich empirical exponential formulas for urban rough terrain has been used for all codes involved (COSYMA, HAVAR, RODOS). A certain reduction into the box approximation has been applied far from the source (> 10 km). Similarly, for dry deposition velocities v_g the following values (spatially constant) have been adjusted in each code (correspond to the grass land use type everywhere):

v_g = 0.015 m/s .... dry deposition velocity for elemental iodine form
v_g = 0.0015 m/s .... dry deposition velocity for aerosols
v_g = 0.00015 m/s .... dry deposition velocity for organically bound iodine

Washout coefficient Λ (s^{-1}) represents the effect of precipitation scavenging and the rate of wet deposition on the ground. It depends on physical-chemical form *f* of airborne nuclides (aerosol, elemental iodine, organically bound) and precipitation intensity I (mm/h). COSYMA and RODOS use such a default the power law Λ (f,I) = a(f) * $I^{b(f)}$. HAVAR code uses liner expression Λ (f,I) = const(f) * I . Thanks to flexibility of the code HAVAR its source code of could be changed for the comparison purposes and adjusted according to COSYMA defaults. Good agreement is illustrated on Fig. 2b.

For precise procedure other criteria have to be fulfilled. From this point of view we must have on mind that the individual Gaussian dispersion model itself are not quite same (volume source model in PC COSYMA, segmented plume for HAVAR). A certain differences could appear in other semi-empirical formulas used for description of particular effects of plume rise, near-standing building wake, vertical wind speed profile, spatial discrimination of the polar grid etc. Some details were discussed in [1]. At this stage we have not adjusted the effect into the precise correspondence, partly because other additional changes in the source code would be necessary in a particular code.

6 Generation of results using COSYMA and HAVAR codes for simplified LB-LOCA

All results relate to the total activity releases according to Table 1. The basic driving variables for the successive calculation of radiation doses are presented and compared:

1. ***Near-ground activity concentrations of radionuclides in air and its time integrated values***
2. ***Activity deposited on the ground for each radionuclide***

Both variables are directly used for the doses calculation when (roughly speaking) multiplying them by corresponding dose conversion factors. The following pathways of irradiation are taken into account:

External irradiation: **cloudshine, groundshine**

Internal irradiation: **inhalation, inhalation of resuspended nuclides, ingestion**

To comply with necessary safety criteria, various kinds of doses are generated, mainly:

3. ***Effective dose for early phase of accident – during period 2 days (without ingestion)***
4. ***Effective dose for early phase of accident – during period 7 days (without ingestion)***
5. ***Effective dose during period of 1 year including the committed doses from internal activity intake***
6. ***Committed effective dose for late phase of accident – during period of 50 years (with ingestion)***

Some partial results related to the stability category F (Pasquill-Giffort notation) for the main driving variables of near-ground activity concentration in the air and deposition on the ground have been selected here in figures 1, 2, 3. The behaviour of aerosol (Cs137) and elemental (I131) physical-chemical forms of nuclides are illustrated on figures 1 and 2. The only exception regarding to stability category is displayed on Fig. 2 b, where category D is assumed with overall precipitation 5 mm/hour and wind velocity 5 m/s at meteorological measuring height 10m.

Fig.1: Time integrated near ground activity concentration in air
near-standing building 50 x 44 m, direction 1, flat terrain,
uniform landuse (grass) + roughness (0.20m), model KFK - urban

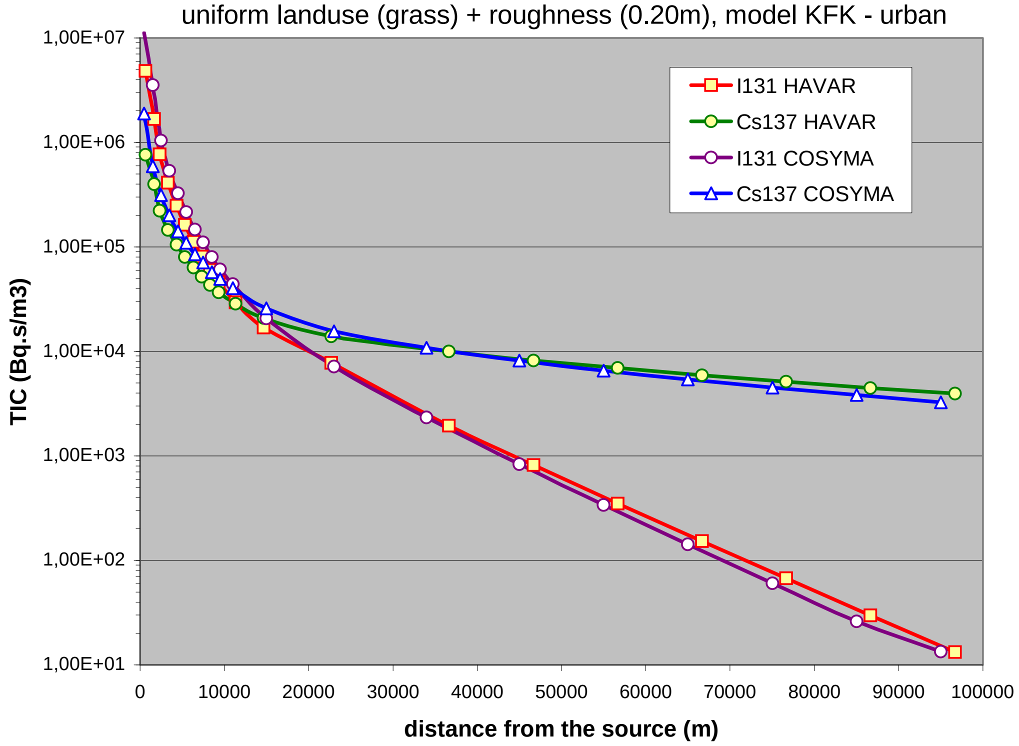
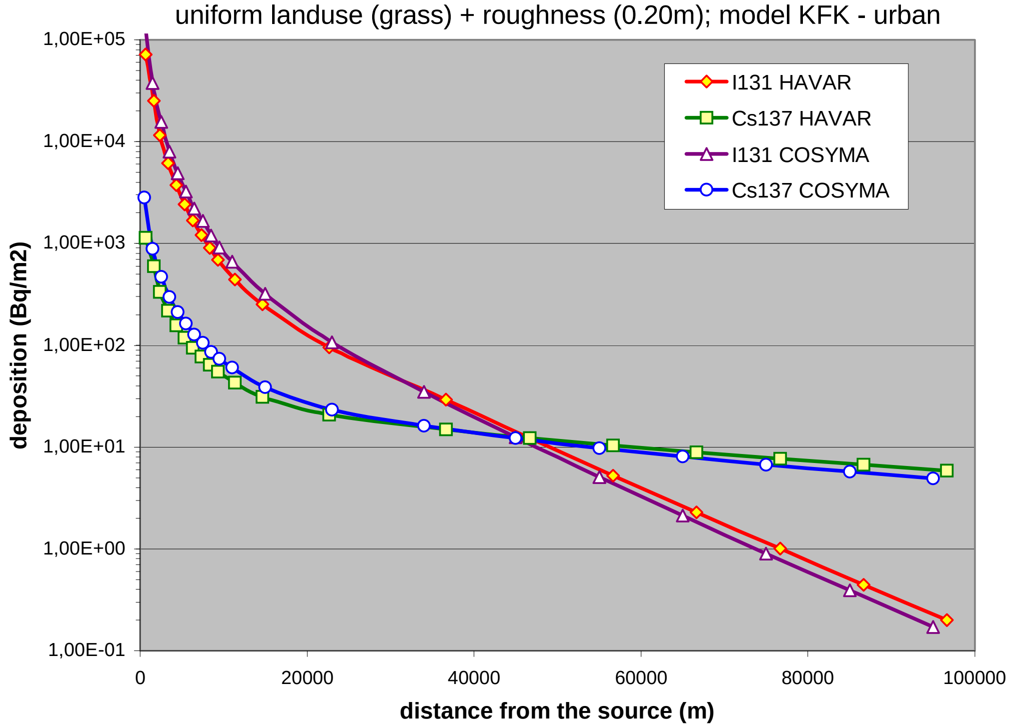


Fig.2: Activity concentration deposited on the ground
near-standing building 50 x 44 m, direction 1, flat terrain,
uniform landuse (grass) + roughness (0.20m); model KFK - urban



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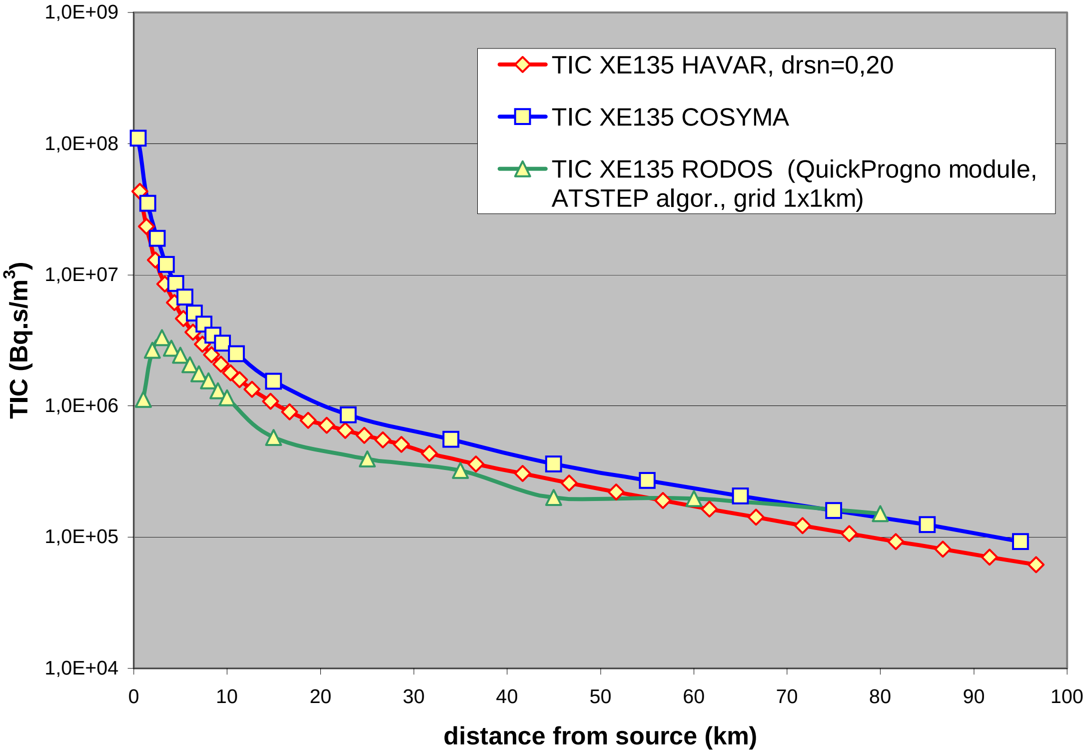
More detailed analysis (including the RODOS results) for noble gas (Xe135) is illustrated on Fig. 3. Let us remark that the RODOS results were taken away directly from the graphical output on display. Furthermore, its low values in vicinity of the source are caused by our rather rough selection of calculation grid 1 by 1 km (ATSTEP RODOS algorithm generates mean values on the grid). To avoid misunderstanding we have to declare, that the advanced RODOS system provides much more precise and sophisticated options than are our simplifications mentioned on Fig. 3 and later on Fig. 5. The reader of this report is kindly asked to treat the RODOS results as a draft illustration. On the other hand the RODOS customisation in its complex UNIX environment requires enormous effort which for this case don't correspond to our illustrative aims.

Fig.3: Comparison of COSYMA - HAVAR - RODOS results

Large break-LOCA scenario for 1 puff; release of 1.07E+12 Bq of Xe135

Near-ground time integrated activity concentration of Xe135 in air [Bq.s.m-3]



Roughly speaking, the doses are calculated in common such a product of the respective main driving variable and the corresponding dose conversion factor. As the main driving variables are found out in good consent (Fig. 1, 2, 2b, 3), we should have to expect good consent of the doses. But more detailed analysis has revealed a certain discrepancy for doses from inhalation pathway. 2-days doses (from Fig.4) or 7-days doses (fig.5) of the HAVAR results are evidently higher then the COSYMA results. Explanation of this fact follows from the intentionally conservative way how the inhalation dose conversion factor for inhalation (Sv/Bq) are extracted. For HAVAR calculations the most conservative values are taken from the regulation no. 184 of State Office for Nuclear Safety. The dose conversion coefficients published here are based on metabolic models of the latest ICRP publications and different values are given for particular pathways of absorption of substances containing radionuclides in the body liquids. For I131, Cs134 and Cs137 the variability is shown in table 2, where the conservative (maximum) HAVAR options are marked blue and bold:

Table 2:

nuclide	*Dose conversion coefficient for inhalation (Sv/Bq)*		
	fast	*medium*	*slow*
I131	**7.4E-9**	2.4E-9	1.6E-9
Cs134	6.6E-9	9.1E-9	**2.0E-8**
Cs137	4.6E-9	9.7E-9	**3.8E-8**

The corresponding COSYMA values for dose conversion factors for inhalation lie lower which was proved in [3] from the COSYMA output file *loca.lpt* . As expected (and illustrated on the Fig. 4 and 5), the differences are substantially mitigated for long term doses in the later stages of the accident.

Comment on ingestion calculations:
An audit of the ingestion model implemented into the HAVAR product in comparison with the FARMLAD ingestion model of COSYMA was done in [2]. It enables calculation of doses from internal intake of activity by ingestion for arbitrary Julian day of fallout of radionuclides in relation to vegetation periods, transport of nuclides through animals, processing and consumption delays and others. The basic scheme of the model is presented in [3]. It should be point out that:

- so far only local production and local consumption approach is adopted
- for consumption baskets which have to be split into age categories the averaged consumption data for England was used for COSYMA calculations and average Czech consumption rates was used for HAVAR
- with regard to the day of fallout, only winter/summer options are offered in COSYMA panels; HAVAR enables calculations with more detailed discrimination (see fig. 3 - two curves for the day off fallout July 31 and alternatively July 1)

In common, we have to say that it is nearly impossible to adjust all input data to be the same for both codes. The possible differences are analysed during successive sensitivity studies. Nevertheless, the consent of results seems to be good also for doses in late stage of the accident as is evident from the figure 3 and table 3. We do not expect great differences caused by the rather small input data inconsistency.

Text pr Fig.4:

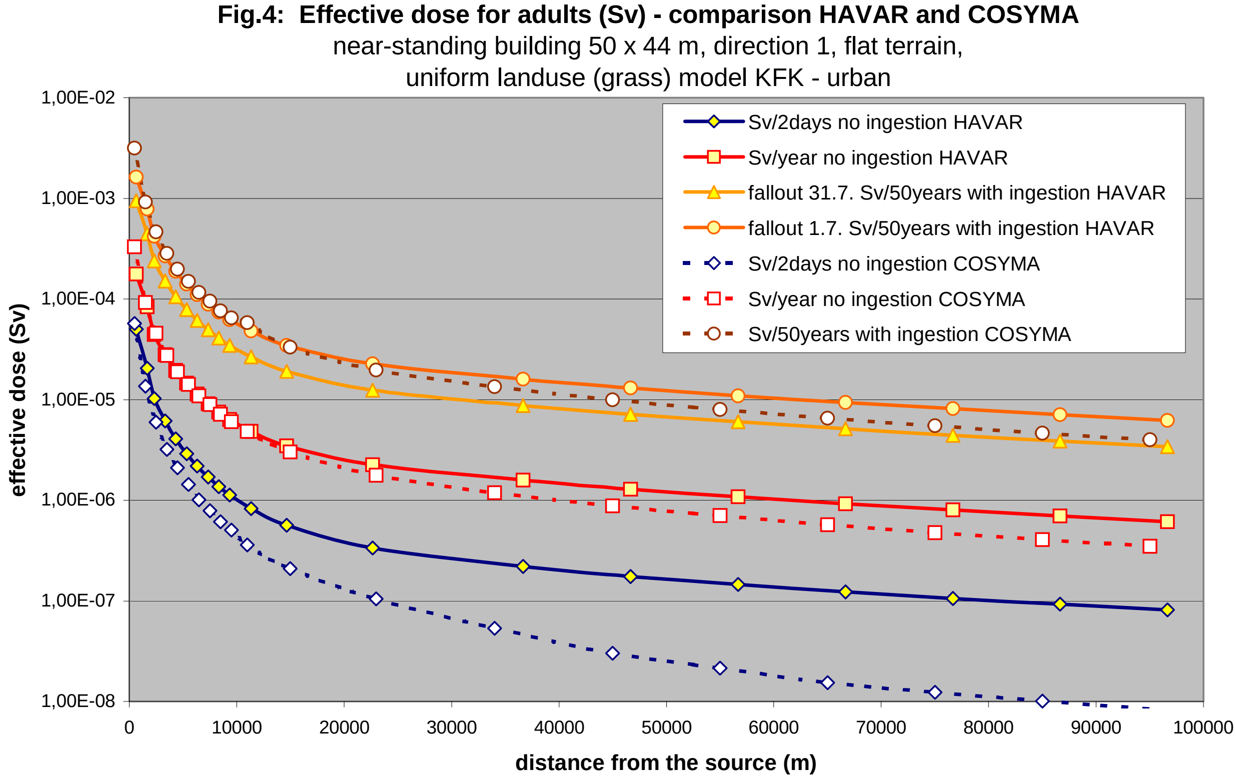
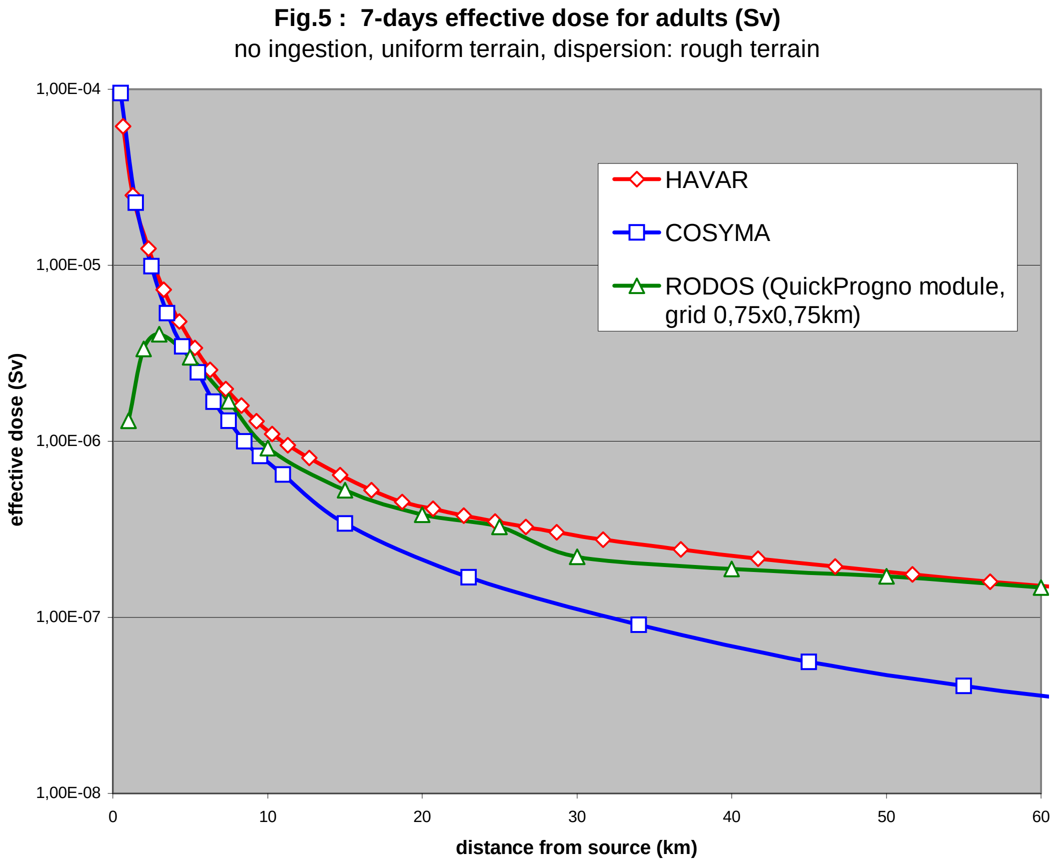


Fig.4: Effective dose for adults (Sv) - comparison HAVAR and COSYMA
near-standing building 50 x 44 m, direction 1, flat terrain,
uniform landuse (grass) model KFK - urban
1,00E-02
1,00E-03
1,00E-04
1,00E-05
1,00E-06
1,00E-07
1,00E-08
effective dose (Sv)
0
10000
20000
30000
40000
50000
60000
70000
80000
90000
100000
distance from the source (m)
Sv/2days no ingestion HAVAR
Sv/year no ingestion HAVAR
fallout 31.7. Sv/50years with ingestion HAVAR
fallout 1.7. Sv/50years with ingestion HAVAR
Sv/2days no ingestion COSYMA
Sv/year no ingestion COSYMA
Sv/50years with ingestion COSYMA

Text pro Fig. 5:



7 Comment on unification of inputs for various codes

The further development has established close connection of inputs with the existing external fine gridded geographical data. The newly developed data preprocessor transforms for each NPP site the detailed available spatial information related to elevation, roughness and land use type (in absolute geographical coordinates) to the required calculating polar grid with variable cells (relatively to the NPP position). This way a common data platform is established among codes using geographic grid (e.g. RODOS) and other ones based on calculations in the polar coordinates (COSYMA, HAVAR, MACCS, …). The process of mutual transformation is illustrated on the Fig. 6. Fine gridded data with high degree of resolution (0.0025 by 0.0025 of geographical degree for longitude by latitude – roughly 180m by 250 m) has been bought and transformed to the polar coordinates relatively to the site position.

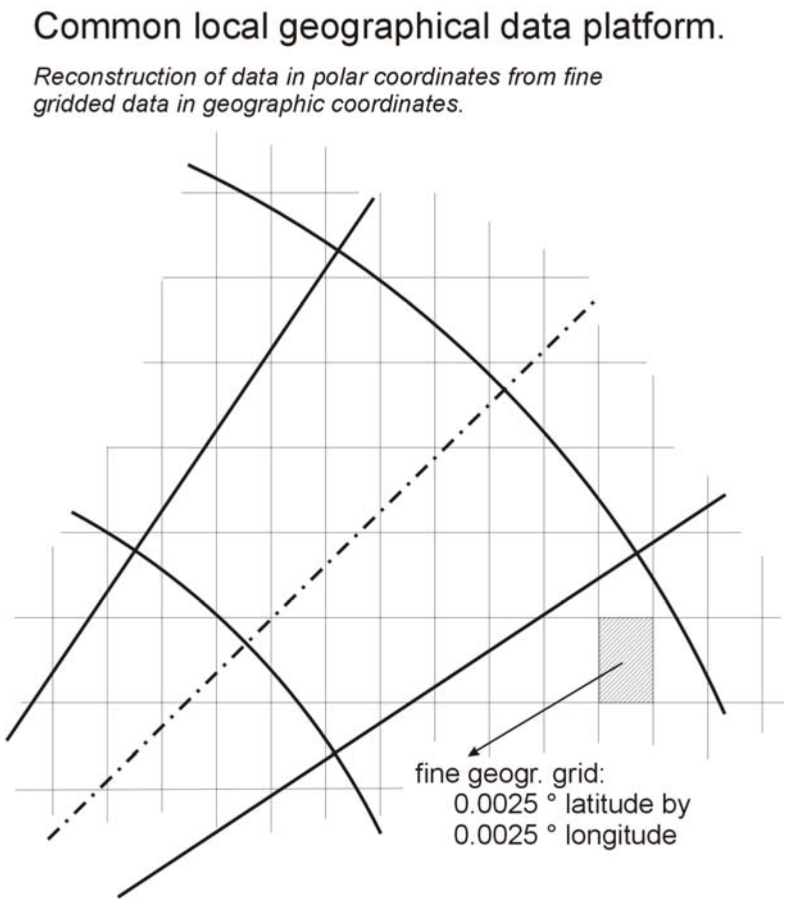


Fig. 6

For example the more detailed information relating to the land use (5 categories: water, grass, agricultural, forest, urban) enables to generate the occurrence (%) of each category and then to calculate the mean weighted value of the dry deposition velocity v_g on each polar cell (on the basis of the maximum v_g for fully developed plant canopy recommended in the RODOS product for each physical-chemical form of the radionuclide – aerosol, elemental, organic, noble gas – see Kuca, P. (2001)). The value of the coefficient of dry deposition is expressed as sum of partial dry depositions velocities weighted by the annual weather statistics. Alternative way is to derive the prevalent type of the quantity within a polar sector.

Similar transformations were accomplished for spatial distribution of demographic information according to six age categories of population and a specific algorithm for agricultural production gridded data generation from mean district annual values is in progress.

References

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