Assessment of radiological impact of routine and accidental atmospheric releases of radionuclides to the living environment

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Abstract:
Two program products developed in ENERGOPROJEKT Prague for assessment of radiological consequences of radioactive discharges to atmosphere are presented. Routine releases during normal operation of nuclear power plants are treated by the product NORMAL where the annual-average values of near-ground activity concentration in air, deposited activity on ground and the corresponding doses are calculated on the basis of weighting by annual weather statistics. Accidental releases are analysed in the code HAVAR with option of stepwise segmentation of the real release characteristics into the chain of the consecutive Gaussian-plume segments constructed under assumption of partially constant meteorological conditions and activity release intensity.

Main objectives of calculations

The products represent efficient and user-friendly interactive tool suitable for both standard validation calculations for purposes of safety reports or assessment of various marginal or partial problems where the input parameters are incomplete or uncertain. During each stage of NPP design the compliance of safety features with national and international regulations can be proved. Owing to easy and fast interactive input of data and direct flexible graphical presentation of results on the screen the extensive uncertainty analysis and sensitivity studies can be realised.

As endpoints of the analysis the doses from the following possible pathways of radionuclide transport through the living environment in direction to the human body are assumed:

- Exposure to external irradiation from passing cloud (photons and electrons)
- Exposure to external irradiation from deposited radionuclides (photons and electrons)
- Internal irradiation caused by inhalation of radionuclides from the passing cloud
- Internal irradiation from inhalation of resuspended radionuclides, which were once deposited on the ground
- Internal irradiation resulted from activity intake from contaminated foodstuffs (more precise dynamic modelling of food chain transport oriented to the Czech conditions and local agricultural and consumption practice was adopted)

Effective and equivalent doses and/or corresponding committed doses on organs or tissues (gonads, red bone marrow, lung, thyroid, upper large intestine, skin) are evaluated for each of five human age groups. Collective doses are calculated on the basis of the real population distribution around the nuclear facility. Following the RODOS methodology the expected doses are calculated from the potential doses when effects of possible natural barriers not having character of targeted countermeasures are taking into account (shielding and filtration effect of building structures, location and occupancy factors).

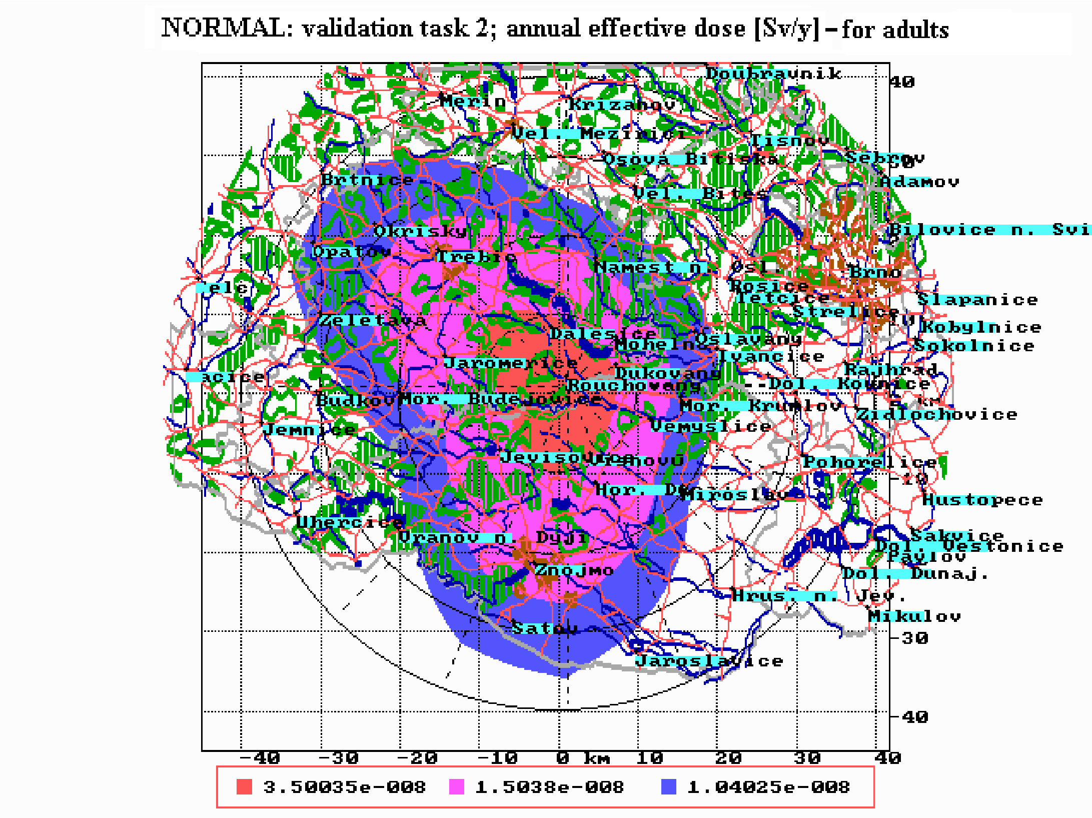


fig. 1: *Results of NORMAL calculations (obligatory task 2 issued by the Czech accreditation board – full description in [8]); KfK model for dispersion; map background and annual weather statistics : NPP Dukovany*

Chain of transport of radionuclides initially discharged into atmosphere

Ones the radioactive material is released from venting stacks, containment or building roofs, the admixtures are incorporated in the plume and drifted in the downwind direction. The polluted plume expands horizontally and vertically due to turbulent diffusion in the atmosphere. The radionuclides are bound in the plume in a certain physical-chemical forms (aerosols, elemental form, organically bound) and during the dispersion are removed from the plume due to several removal mechanisms. The process results in the plume depletion, mainly due to:

- radioactive decay
- dry deposition (gravitational setting and deposition due to contact of the contaminated plume with the ground, vegetation or urban structures)
- wet deposition – removal by rainout (precipitation formation process inside of the plume) or by washout (interaction between falling drops and admixtures)

Radioactive decay and daughter build-up have to be taken into account during the period of the plume travel for concentration of activity in air and during the period of persistence on the ground for activity deposition. Main important effects occurring at areas of near region and at far distances up to 100 km from the source of pollution are regarded usually using semi-empirical formulas derived from the field experiments. Two main kinds of atmospheric releases are analysed here:

1. Continuous radioactive discharges during normal operation of a nuclear power plant having character of routine releases. In this case the mean annual average values are determined on the basis of annual weather statistics. The intensity of radioactive material discharges from the source (usually at height about 100 m of the venting stacks) is assumed to be more or less constant over a year. Such situation is treated by the code NORMAL.
2. Accidental short-term releases from sources at various heights and generally with strong time dependency of their intensity. The period of duration is assumed to be within the range from several hours to several tens of hours and then the possible changes of the meteorological situation should be taken into account. The code HAVAR presents a certain simplified solution of the irregular situations based on the Gaussian plume segmentation scheme.

Choice of atmospheric dispersion and deposition models

Atmospheric dispersion of airborne nuclides is determined by mechanisms of advection and diffusion transport. The advection model provides wind field characteristics. The diffusion processes in the planetary boundary layer are initiated by turbulent motion of atmosphere and cause the spread of admixtures vertically to transport direction. According to these two processes of advection and diffusion, atmospheric dispersion model consists of two separate models of flow and diffusion.

A single-point flow model (wind speed and direction is assumed to be constant over the entire analysed area) and Gaussian straight-line diffusion model are used here. Diffusion categories according to Pasquill-Gifford notation enable to distinguish various turbulent state of atmosphere. The approach is accepted in general for such analysis where averaging and many times repeating procedures take place. It holds true for the NORMAL code in which the weighting by the annual weather statistics provides the mean annual average values.

For case of accidental releases analysed in the code HAVAR the above solution showed to be useful for description of a certain marginal studies or for estimation of the “worst cases” of a hypothetical situation. For description of the real accidental release scenarios was developed segmented Gaussian plume model. The real process is divided into several time segments during which the weather characteristics and release intensity is assumed to be constant. Each segment is treated separately and the resulting values are given by superposition of the partial results. Then, the solution can take into account time changes.

The question is, how these time changes are reflected in the whole area of NPP. Here we refer to more detailed discussion in [9, 10]. Let us notice only that the HAVAR code includes some optional dispersion models with more sophisticated algorithms (hybrid plume-puff model ATSTEP according to [4] or the latest pure “multiple-puff” superposition scheme where more precise boundary layer modelling is introduced).

Within wind field and dispersion calculations many other factors have to be taken into account such *thermal structure* of the atmosphere, surface *roughness* and other *land cover* characteristics, *orography* of the terrain, *reflection* from the ground and top of the mixing layer or inversion layers, the effect of initial *plume rise* due to vertical momentum and buoyancy, recirculation in the *wake region* of the near standing buildings. The effects are usually expressed by semi-empirical expressions derived from experimental results. Nevertheless it includes a certain degree of uncertainties. That is why the several alternative models are available in NORMAL or HAVAR products which enable user to analyse the problem from different points of view.

Dynamic food chain modelling

For radioactive fallout in a certain Julian day of a year (the case of accidental releases treated in HAVAR) the transport of activity due to ingestion pathway is modelled. Contamination of plants due to foliar and root uptakes is considered. Further activity transport into edible parts of plants, feedstuffs and animal products is described taking into account corresponding time dependencies resulted from agricultural production process, agro-climatic conditions, phenological characteristics, feeding diets of animals, etc. Then, the corresponding time-dependent contamination of foodstuffs is determined and ingestion doses are calculated on the basis of the local human consumption habits considering both season and age dependent rates and time delays occurring during processing, storage and transport of foodstuffs.

A special modification of the food chain model algorithm was developed for case of continuous long-term immersion of ecosystem into the contaminated environment. Instead of final activity deposition the driving variable is changed to deposition velocity which can be assumed to vary in time. The model is built in the code NORMAL and its detailed description is given in part I-Methodology of [8]. So far “local production – local consumption” scheme is adopted in both products. Miscellaneous local food chain model data valid for the individual radioecological regions of the Czech Republic were collected recently for purposes of the RODOS system customisation. The process of data acquisition is reviewed in [7] and its results are partially used for actualisation of input parameters into our products.

Conceptual structure of the codes

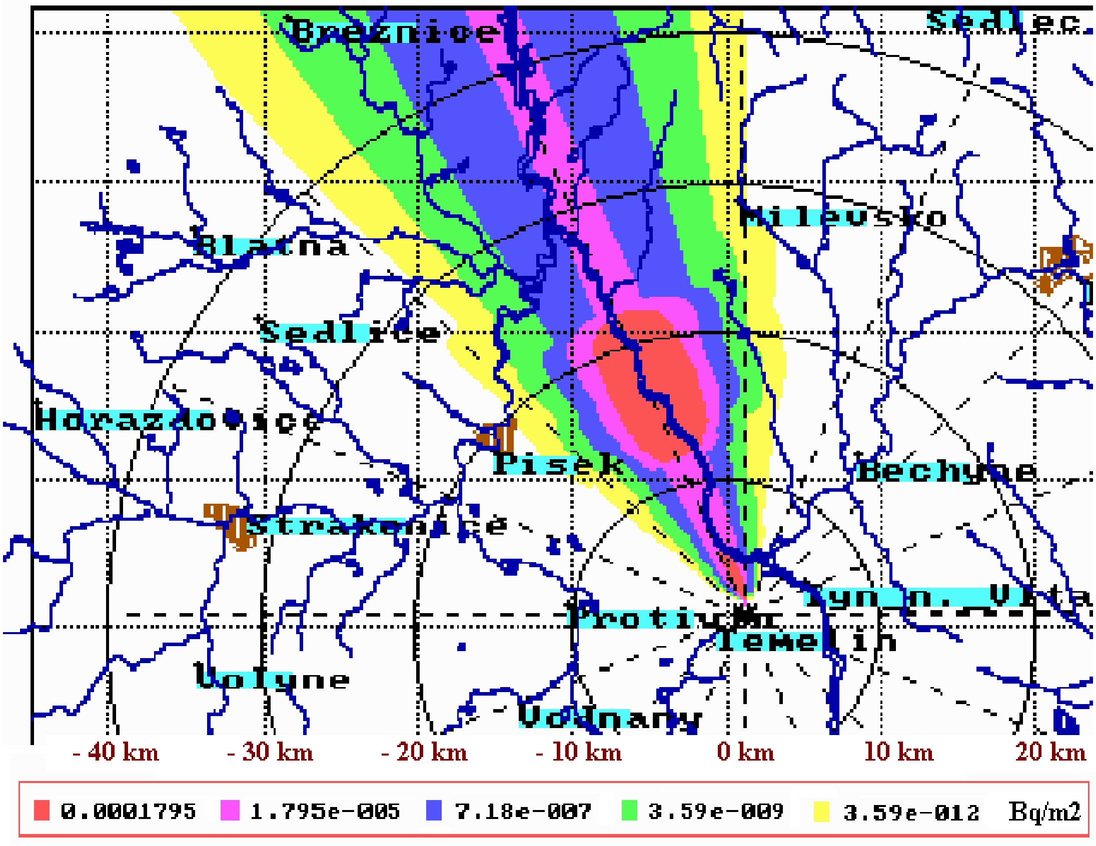
Both products NORMAL and HAVAR have the same structure and interactive support for input of data from display and graphical presentation of results. The user can choose optional selection of basic dispersion models (HOSKER scheme for rural areas, KfK-Julich model for urban type, BOX model and some other their modifications). Automatic check of input data entered from the input panels, their archivation for latter recalling, online helps and online graphical presentation of results with plenty of additional options are offered on the screen menus. Besides the basic safety estimations the designer can perform quickly also various marginal calculations, analysis of uncertainties and sensitivity studies. Detailed description of the user friendly interactive support is given in the corresponding users guides for both products NORMAL and HAVAR (parts II of [8] and [9]).

Comparison benchmarks and areas of applicability

An extensive comparative studies were done for the products NORMAL (comparison with PC CREAM code – see part III of [8]) and HAVAR (see part III of [9] and comparison with deterministic COSYMA runs [5] and partial results of RODOS calculations [6]). The corresponding comparative studies are attached to Methodology description and User manual of each product. The harmonisation with the outstanding European codes brought benefit in NORMAL and HAVAR methodology improvement and at the same time revealed areas where the further development effort should be concentrated.

NORMAL and HAVAR codes are used in ENERGOPROJEKT Prague for purposes of dose calculations in the Safety Reports for the Czech nuclear power plants and as a tool for solution of some partial problems appearing during various stages of NPP design. As a latter one can be mentioned modification of the codes for purpose of analysis of local irrigation with contaminated water or co-operation with TGM- Water Research Institute in Prague related to possible “worst “ contamination of the river Vltava (see fig. 2).

HAVAR: “Worst case” study – Deposition of Cs137 on Vltava river during intensive local atmospheric precipitation (accidental 10 hours release):



<u>**fig. 2**</u>: *An example of HAVAR application for purposes of extremal “worst case” situation analysis: fallout on river Vltava ; 10 hours release of Cs137 (intensity 1 Bq/s); intensive local atmospheric precipitation 10 mm/h between km 11 – 16 (all the release time); KfK disper. model, Pasquill stabil. category D; map background: drainage and settlements vector layers around NPP Temelin*

Conclusion

Both products NORMAL and HAVAR are “alive” products with continuous development and maintenance under sponsorship of ENERGOPROJEKT Prague. Then, any changes initiated either by the new requirements of users during their activities related to NPP design or by the new regulations issued by the national authorities for areas of the nuclear safety can be easily implemented with short response time. Particular models of the systems are customised for the territory of the Czech Republic and particularly for localities of both NPP Dukovany and Temelin. The products were submitted for process of standardisation according to the rules following the new Czech Atomic Law. The process is obligatory for any software used for calculations in the field of nuclear safety. Important part of the standardisation process is demonstration of given obligatory validation tasks.

Finally, the <u>reasons for own development</u> of the codes should be pointed out. The development team can ensure fast response with regard to realisation of corrections, modification and extensions. Input module is adjusted according to available national data regarding its existing specific format and local practice of its collection (maps, special national system of co-ordinates JTSK, practice of meteorological service). Input subsystem provides tool for reconstruction of missing data and periodic actualisation of some categories (for example generation age-dependent population data on the polar grid on the basis of official periodic annual statistics). Compliance with the new specific governmental regulations (Czech Atomic law) is ensured. Own development process can provide an efficient user-friendly open system tailored to designer's needs which takes into account specific local and national features.

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