Bulgarian Emergency Response System (BERS) in case of nuclear accident with exposure doses' estimation

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Abstract
A PC-oriented Emergency Response System in case of nuclear accident (BERS) is developed and works operationally in the National Institute of Meteorology and Hydrology (NIMH). The creation and development of BERS was highly stimulated by the ETEX (European Tracer EXperiment) project. BERS comprises two main parts - the operational and the accidental ones. The operational part, run automatically every 12 hours, prepares the input meteorological file used by both trajectory and dispersion models, runs the trajectory models, visualizes the results and uploads the maps of trajectories to a dedicated web-site. The accidental part is activated manually when a real radioactive releases occur or during emergency exercises. Its core is the Bulgarian dispersion models EMAP. Outputs are concentration, accumulated deposition and selected doses fields. In the paper, the BERS overall structure is described and examples of its products are presented.
Key words: nuclear accident, emergency response, early warning system, air dispersion models, radioactive exposure doses.

Sistema de emergencia búlgaro (BERS) para estimar las dosis de exposición en caso de un accidente nuclear.

Resumen
El Instituto Nacional de Meteorología e Hidrología de Bulgaria (NIMH) ha desarrollado un Sistema de Respuesta ante una Emergencia procedente de un accidente nuclear llamado BERS. Este sistema está implementado en un PC. Durante el desarrollo de BERS se tuvo en cuenta la base de datos procedente del proyecto europeo ETEX (European Tracer EXperiment).
BERS tiene dos partes esenciales, la operacional y la accidental. La parte operacional corre automáticamente cada 12 horas y su función es construir el fichero de datos meteorológicos que es la entrada (input) de los modelos de dispersión y trayectorias, correr el modelo de trayectorias, visualizar los resultados y poner los mapas de trayectorias en una página web ad doc. La parte accidental se corre manualmente cuando una emisión radiactiva ocurre o cuando se desea realizar ejercicios de emergencia. El núcleo de este sistema es el modelo de dispersión búlgaro EMAP. Las salidas proporcionadas son la concentración, la deposición acumulada y los campos de dosis seleccionados. En este artículo se describe la estructura de BERS y algunos ejemplos.
Palabras clave: Accidente nuclear, Respuesta a emergencias, Sistema rápido de alarmas, Modelos de dispersión, Dosis de exposición radioactiva.

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1. Introduction

The industrial accidents causing a release of harmful (chemical or radioactive) material to the atmosphere can have consequences extending to hundreds and even thousands of kilometers. In such a case the decision-makers need information about the possible long-range transport of pollution over the country. For that purpose computer-based Emergency Response Systems have been established in many countries, simulating and predicting the distribution of the released pollution.

Such system is developed and works operationally in the National Institute of Meteorology and Hydrology of Bulgaria. Its creation and development was highly stimulated by the European Tracer Experiment (Girardi et al. 1998). NIMH took part in all activities of ETEX with the puff model LED, results described in Syrakov & Prodanova (1994, 1998). In the second phase of ETEX a new model EMAP (Syrakov 1995) was tested performing better than LED (Mosca et al. 1997; Graziani et al. 1998).

2. Structure of BERS

The first operational version of BERS was created in 2001 (Syrakov et al. 2003) exploiting EMAP as dispersion model. In the same paper description of EMAP is given together with its verifications.

Currently BERS consists of two main parts, operational and accidental ones, both of them in two variants: for Europe and for Northern Hemisphere. The forecast period is 72 hours (3 days). BERS overall structure and modules are presented in Fig. 1.

The operational part of BERS runs automatically every 12 hours, after new meteorological information is received in NIMH via GTS of WMO. This part includes several modules performing: (i) preparation of specific meteorological file used by both trajectory and dispersion models; (ii) archiving this file for further re-simulations; (iii) running of trajectory models; (iv) visualization of results and uploading the trajectory maps to specialized web site of NIMH (http://info.meteo.bg/ews/index-en.html).

In fact, the meteorological input to the trajectory models as well as to the dispersion model EMAP is input to the built-in PBL model. In the present, the simplest barotropic version of YORDAN model (Yordanov et al. 1983) is used. It is based on the similarity theory and needs only characteristics at the upper and lower boundaries of the PBL. The aim of the meteorological pre-processing is to obtain these parameters in the points of the domain grids. Additional information, used only by the dispersion model, is the precipitation intensity. All these characteristics are prepared from a numerical weather forecast product by a number of calculations and interpolations. Currently, NCEP GFS numerical products treated by WRF are used. Example of one of the 72-hour trajectory maps is shown in Fig. 2. Explanations are given in the already cited web-site.

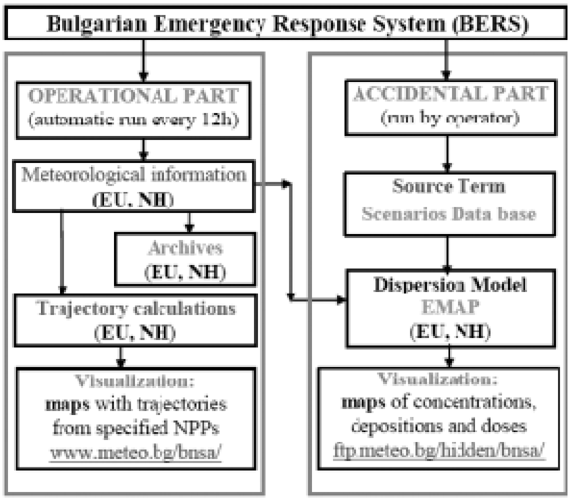


Figure 1. Structure of BERS (EU – Europe, NH – North Hemisphere version)

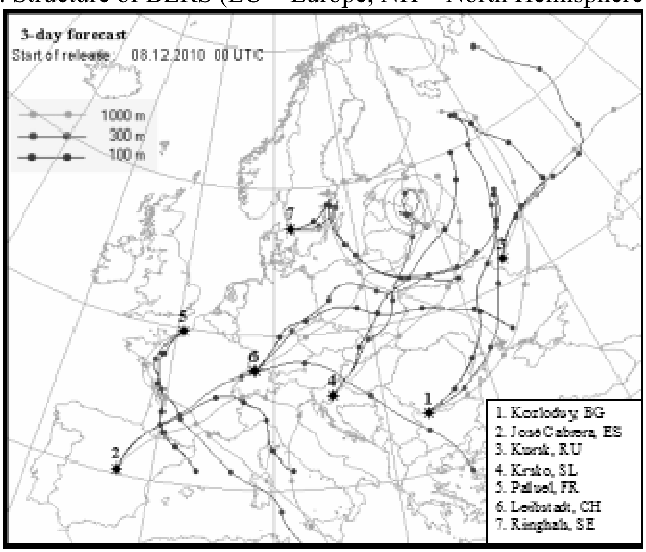


Figure 2. Forward trajectories from 7 European NPP

The accidental part of BERS is activated by operator when a real radioactive release occurs, during emergency exercise or when required by authorized users. The dispersion model EMAP needs two inputs – the already mentioned meteorological file and source data (source term). The source information for version 2001 of BERS is: source coordinates, release height, release start, release duration and release rate. Outputs are the fields of ground-level concentration and accumulated deposition.

They have been output periodically for specified moments. The concentration and deposition maps are visualized automatically and uploaded to a specific ftp-site accessible by the interested institutions.

3. Short description of the dispersion model EMAP

EMAP (Eulerian Model for Air Pollution) is a 3-D simulation model that allows describing the dispersion of multiple pollutants (Syrakov 1995). It takes into account processes as horizontal and vertical advection, horizontal and vertical diffusion, dry deposition, wet removal, gravitational settling and specific chemical transformations. Within EMAP, the semi-empirical diffusion-advection equations for scalar quantities are solved numerically on Arakawa C-type staggered grid. The horizontal resolution depends on the task solved. Vertically, terrain-following non-equidistant grid spacing (log-linear grid) is settled. Time splitting approach is applied transforming the complex problem to a number of simple tasks. As to decrease the splitting error, the one-dimensional operators are applied in reversed order each time step. The temporal resolution depends on the Courant stability condition.

Advective terms are treated with the TRAP scheme (Syrakov 1995; Syrakov & Galperin, 1997), which is a Bott type one. A 3rd order Bessel polynomial is used for fitting the concentration distribution in the space around any grid point. While displaying the same simulation properties as the Bott scheme (explicit, conservative, positively definite, transport ability, limited numerical dispersion), the TRAP-scheme occurs to be several times faster. The boundary conditions are fixed at income flows, and “open boundary” type – at outcome ones.

Diffusion equations are digitized by means of the simplest implicit (in vertical) and explicit (in horizontal) schemes. Both schemes have 1st order accuracy in time and 2nd order accuracy in space. The horizontal diffusion coefficients are constants (defined by the user) and the lateral boundary conditions for diffusion are “open boundary” type. The vertical diffusion coefficient varies in space and time depending on PBL stability (as calculated by YORDAN). The bottom boundary condition is a flux-type one; the top boundary condition is optionally “open boundary” or “hard-lid” type.

The dry deposition is accounted for as bottom boundary condition for the vertical diffusion equation. The dry deposition flux is determined as product of the roughness level concentration and the dry deposition velocity. The last parameter depends on many factors. In the current version of EMAP, it is assumed depending only on the type of the pollutant and on the character of land coverage. This parameter must be specified in advance. In the surface layer (SL), a parameterization that allows one to have the first computational level at the top of the SL is applied. It provides a good estimate for the roughness level concentration and accounts also for the action of continuous sources placed on the earth surface (Syrakov & Yordanov 1997).

The simplest decay approach is applied for the wet removal, coefficient depending on pollutant properties and on rain intensity.

The EMAP model used to be applied in many tasks: study of annual acid, lead, cadmium, mercury and benzo(a)pyrene loads over the region of Southeastern Europe.

The model passed validation and evaluation in some international exercises: participation in the ETEX study, EMEP/MSC-E inter-calibrations of lead and cadmium models. In Fig. 3 and 4, the EMAP simulation of ETEX First Release is shown.

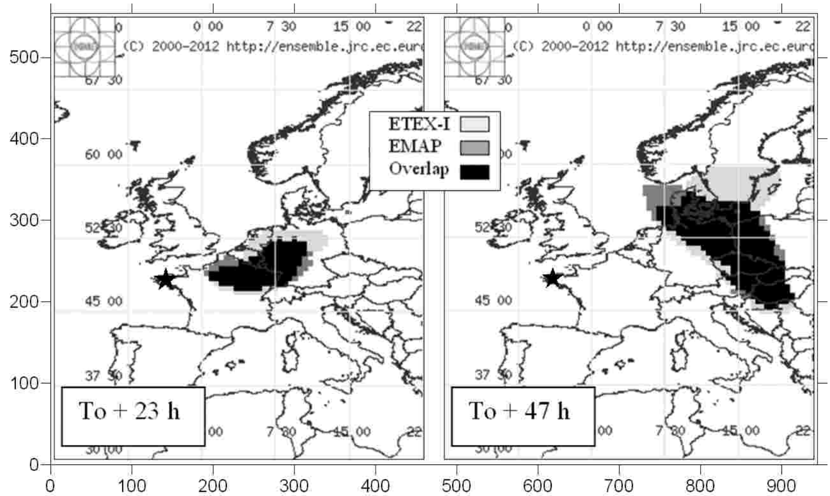


Figure 3. Overlapping of measured and simulated by EMAP tracer spots for two moments after the release start To (the asterix indicates the release position).

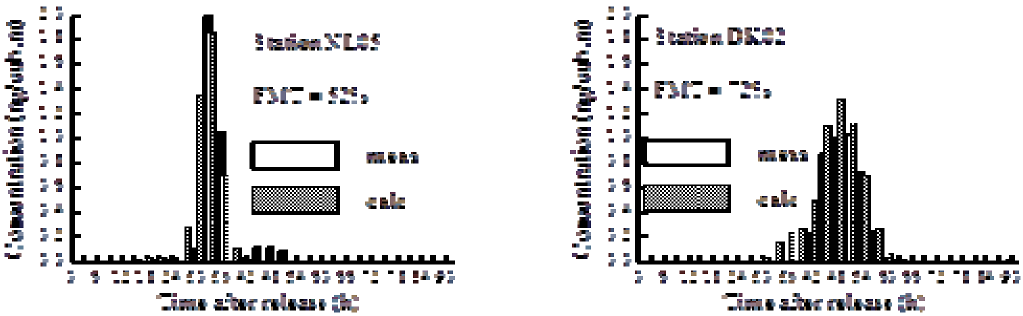


Figure 4. Time evolution of measured and calculated concentrations in two measuring stations (in Nederland and in Denmark)

4. Dose response version of BERS

The general conclusions from just presented Version 2001 of BERS are that it is able to describe relatively adequately the time behavior of one or limited number radio-nuclides. The nuclides are dispersed as gas (dry deposition velocity and wash-out coefficient specified by user) and the output is time series of concentration and deposition fields. In Fig. 5, an example of visualized BERS output is presented.

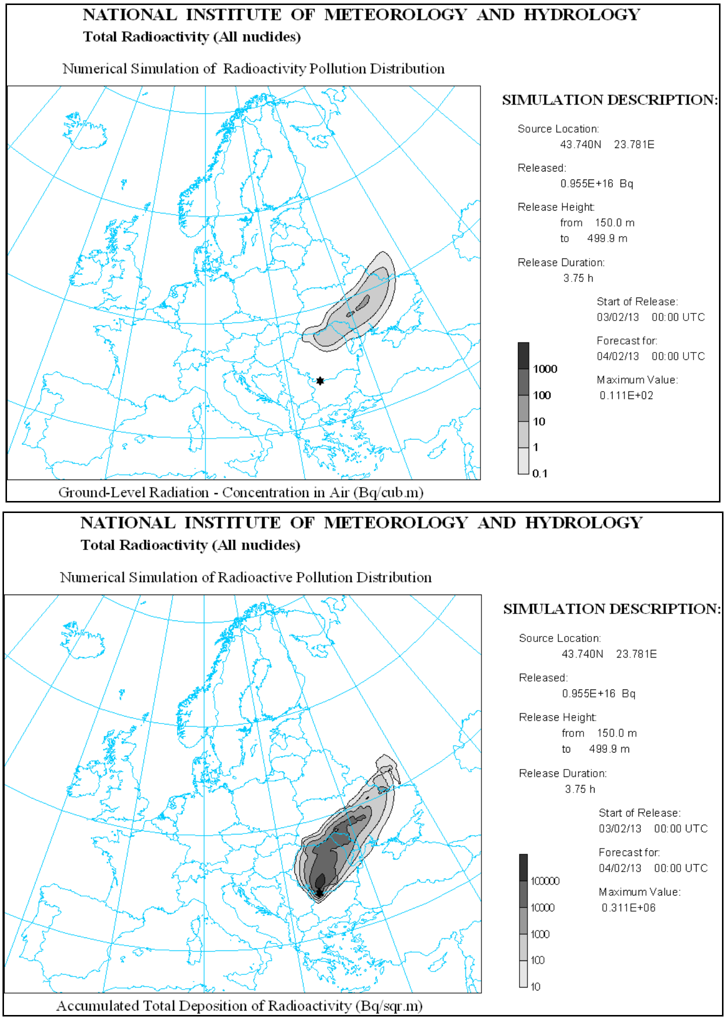


Figure 5. Example of BERS output – 24-hour forecast for concentration and total deposition fields (simulative release from NPP “Kozloduy” - the asterix)

It is clear that decision makers need one or few integrated parameters that reflect the harm influence of radioactivity on population and environment. These indicators have to be studied enough and, as a results, their thresholds being established and introduced in the local and international legislation. Such integrated indicators are the exposure doses. The upgrade of BERS with dose response modules is the essence of its recent version (version 2007).

Experienced radiologists were attracted to choose limited number of doses keeping the following criteria: (i) human related; (ii) short-term significance and (iii) well defined thresholds and respective action and measures. It worth to be mentioned that rich literature on the matter exists - papers, regulations etc. In BERS, the next doses were chosen:

- Absorbed dose in thyroid glance from inhalation of iodine isotopes Dt;
- Effective dose from inhalation of radioactive substances Di;
- Dose from external exposure (De) to the radioactive plume (air submersion Da) and ground shining (ground contamination Dg); De=Da+Dg.

They are calculated as sums of concentrations/depositions of different radioactive nuclides multiplied by specific coefficients.

As to calculate doses, big number of different nuclides has to be treated by the System (over 100 according to the literature) that is not realistic from operational point of view because this requires enormously long time. BERS was updated to simulate the evolution of limited number of nuclides that are the most important as released quantities during nuclear accidents and biological effect. On the base of scrupulous analysis of many scenarios for various European reactors, 31 radioactive nuclides are recognized as the most important (Syrakov at al. 2009). The radioactivity of the rest of isotopes is accounted for by adding it to the one of the chosen nuclides.

It occurs that the individual handling of these 31 nuclides demands quite long time and is also not acceptable due to operational considerations. A possible compromise is the grouping of various nuclides and forming eight lump pollutants (LP). The grouping is made on the base of the closeness of physical, radiochemical and dispersion characteristics of nuclides:

- LP1: Long living noble gases (Kr-85, Xe-133, Xe-133m)
- LP2: Medium time living noble gases (Xe-135,Kr-85m, Kr-88+Rb-88)
- LP3: Short living noble gases (Kr-87, Xe-135m, Xe-138)
- LP4: Gaseous iodine (I-131, I2)
- LP5: Radioactive carbon and tritium (H-3, C-14)
- LP6: Long living aerosols (Cs-137, Sr-90/Y-90, Pu-239, Co-60, Cs-134)
- LP7: Medium time living aerosols (Zr-95, Sr-89, Nb-95, Cs-136 and others)
- LP8: Short living aerosols (Te-132, I-133, I-135, I-132, Cs-138)

Total radioactivity (sum of LPs) is calculated as output only. In Fig. 5, just the summary concentration and deposition fields are presented.

One can notice that good deal of the accounted nuclides is aerosol. A number of improvements were made in the code as to describe aerosol specific processes, mainly gravitational settling and the changes in aerosol size spectrum cause by this settling (Syrakov & Galperin 1998).

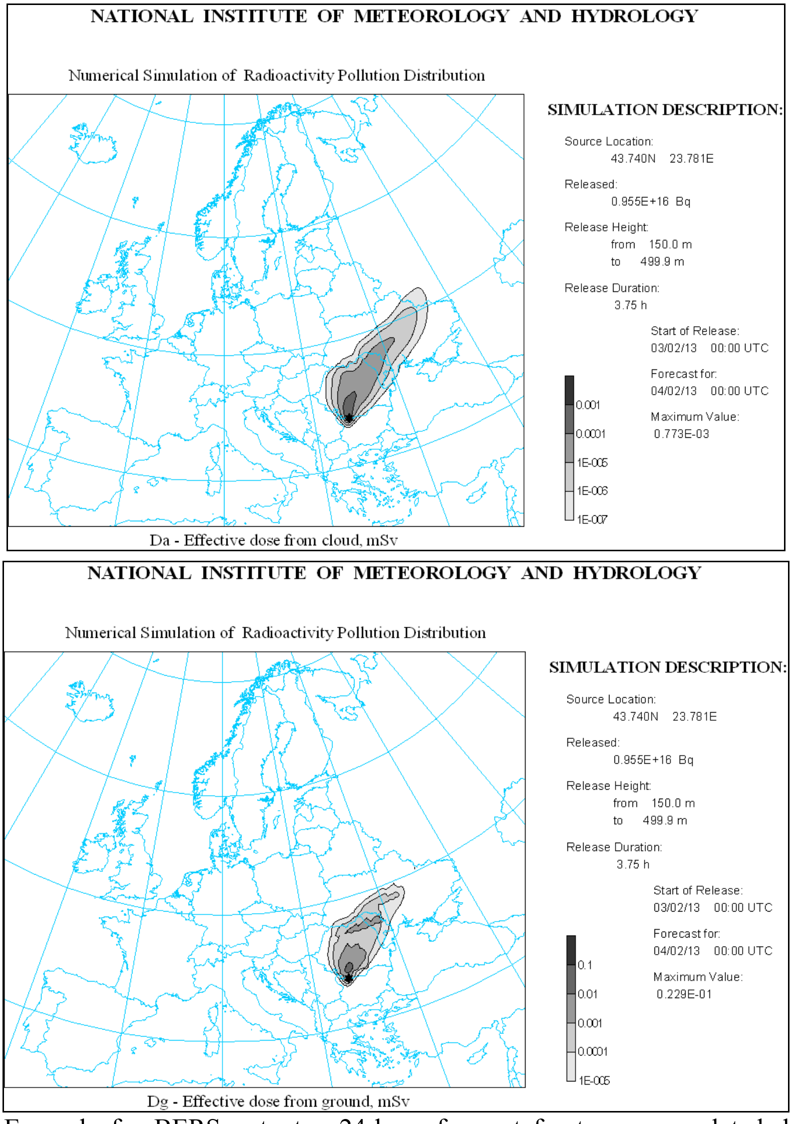


Figure 6. Example for BERS output – 24-hour forecast for two accumulated dose fields, created by a simulative release from NPP "Kozloduy" (the asterix). They correspond to the concentration and deposition fields from Fig. 5.

In order to account for the new requirements, BERS code has been rewritten following the next principles and performance order:

- The radioactive intensities of all 31 nuclides are input to the System (source term).
- The Lump Pollutants are composed and specific, common for the group, decay rates are calculated by weighted averaging of individual rates.
- The percentage of each radionuclide in each LP is stored.
- The evolution of each LP is simulated – transport, diffusion, deposition, gravitational settling (for aerosol), radioactive decay.
- The doses are calculated and accumulated at each time step; for the purpose, the individual nuclide's concentrations and depositions are reconstructed from LP ones exploiting the stored percentages.
- At specified moments current fields of LP concentrations and depositions as well as those of the doses are output (see Fig. 5 and 6).

5. Source term (scenario data base)

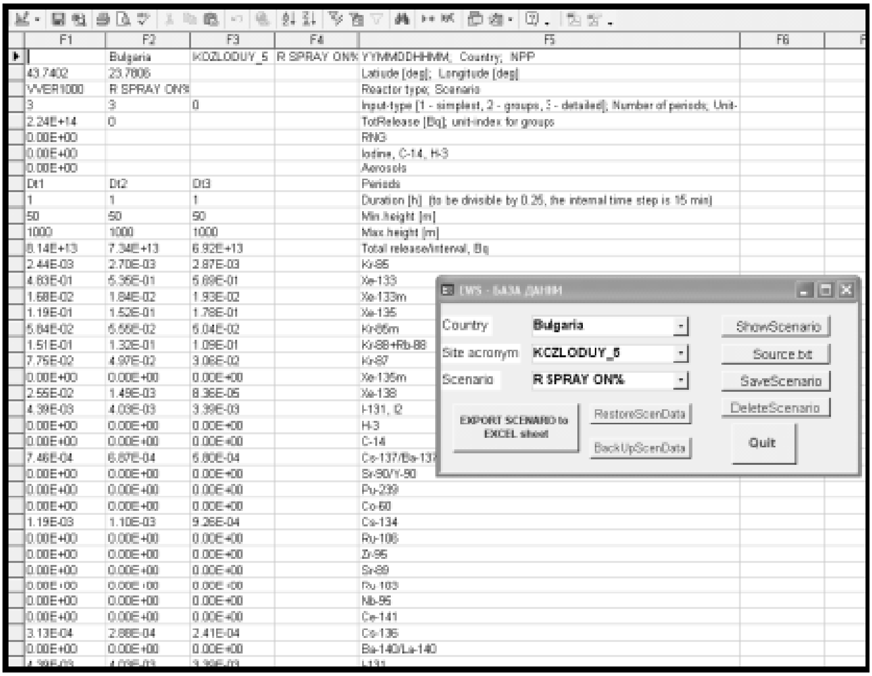
Feeding directly the new BERS version with the source parameters is quite a tough task mainly because of the big number of nuclides. The task is more difficult in case of evolving source. In such a case the released time is divided to periods with relatively constant release rates and the input parameters change respectively.

In order to increase the operational use of BERS, a scenario data base has been created on *Microsoft Access*, following the next criteria:

- flexibility and accounting for different kinds of initial information
- changeing of source parameters in the course of the accident
- varying with time release parameters (height, rates etc.)
- fast input (operational requirement).

Together with creating the Source Term shell, a lot of work has been done filling up this data base. It was done using the Database of basic source terms of European NPPs for emergency response purposes (Scenario Database, 2007). It contains more than 2000 typical scenarios for all reactors in Europe (usually several for each European NPP). These scenarios handle 55 radio nuclides and the time discretization is 1 hour – usually from 1 to 3 (maximum 5) hours. The scenarios are re-estimated as to contain the 31 nuclides selected for BERS. Part of original nuclides is grouped minimizing the error by accounting for the most significant nuclides – those with awaited high activity and biological impact. In addition tritium and C-14 isotopes are included.

In Fig. 7, the main sheet of the created *Access*-database is displayed. The country, the reactor and the accident type are being chosen by drop-down menus. The *Access*-shell permits correcting of any data, creating new scenarios and adding them to the scenario database.



F1	F2	F3	F4	F5	F6
	Bulgaria	KOZLODUY_5	R SPRAY ON%	YYMMDDHHMM; Country; NPP	
43.7402	23.7806			Latiude [deg]; Longitude [deg]	
VVER1000	R SPRAY ON%			Reactor type; Scenario	
3	3	0		Input-type [1 - simplest, 2 - groups, 3 - detailed]; Number of periods; Unit-	
2.24E+14	0			TotRelease [Bq]; unit-index for groups	
0.00E+00				RNG	
0.00E+00				Iodine, C-14, H-3	
0.00E+00				Aerosols	
Dt1	Dt2	Dt3		Periods	
1	1	1		Duration [h] (to be divisible by 0.25, the internal time step is 15 min)	
50	50	50		Min.height [m]	
1000	1000	1000		Max height [m]	
8.14E+13	7.34E+13	6.92E+13		Total release/interval, Bq	
2.44E-03	2.70E-03	2.87E-03		Kr-85	
4.83E-01	5.36E-01	5.69E-01		Xe-133	
1.68E-02	1.84E-02	1.93E-02		Xe-133m	
1.19E-01	1.52E-01	1.78E-01		Xe-135	
5.84E-02	6.56E-02	6.04E-02		Kr-85m	
1.51E-01	1.32E-01	1.09E-01		Kr-88+Rb-88	
7.75E-02	4.97E-02	3.06E-02		Kr-87	
0.00E+00	0.00E+00	0.00E+00		Xe-135m	
2.55E-02	1.49E-03	8.36E-05		Xe-138	
4.39E-03	4.03E-03	3.39E-03		I-131, I2	
0.00E+00	0.00E+00	0.00E+00		H-3	
0.00E+00	0.00E+00	0.00E+00		C-14	
7.46E-04	6.87E-04	6.80E-04		Cs-137/Ba-137	
0.00E+00	0.00E+00	0.00E+00		Sr-90/Y-90	
0.00E+00	0.00E+00	0.00E+00		Pu-239	
0.00E+00	0.00E+00	0.00E+00		Co-60	
1.19E-03	1.10E-03	9.26E-04		Cs-134	
0.00E+00	0.00E+00	0.00E+00		Ru-106	
0.00E+00	0.00E+00	0.00E+00		Zr-95	
0.00E+00	0.00E+00	0.00E+00		Sr-89	
0.00E+00	0.00E+00	0.00E+00		Ru-103	
0.00E+00	0.00E+00	0.00E+00		Nb-95	
0.00E+00	0.00E+00	0.00E+00		Ce-141	
3.13E-04	2.88E-04	2.41E-04		Cs-136	
0.00E+00	0.00E+00	0.00E+00		Ba-140/La-140	
4.39E-03	4.03E-03	3.39E-03		I-131	

Figure 7. Example of determining the source term – a scenario for NPP "Kozloduy", results presented in Fig. 5 and 6.

6. Conclusions

The new version of BERS was implemented in NIMH from December 2007. From that time on many cases were run. Very detailed interpretation of the results was made by experienced radiologists, taking into account the different isotope's composition, release duration, radioactivity levels, meteorological conditions. Results are recognized as quite promising.

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