RADIATION MONITORING AT THE EARLY STAGE OF AN ACCIDENT AT NUCLEAR FACILITY – ANALYSIS OF ALL TYPES OF MEASUREMENTS APPLICABLE FOR THE CORRECTION OF MODEL PROGNOSIS

Petr PECHA, Petr KUCA, Irena CESPIROVA, Radek HOFMAN
pecha@utia.cas.cz, petr.kuca@suro.cz

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Abstract

The paper concerns monitoring methods of radioactive pollution of the environment at the early stage of a radiation accident. The main objective of the paper is to identify monitoring methods suitable for the improvement of model-based predictions of a radiation situation by means of the assimilation of radiological measurements from the terrain. Data assimilation methods are statistical methods based on Bayesian filtering. As a specialized software system for the application of data assimilation in radiation protection we demonstrate the product HARP which offers advanced interactive tools for the assessment of consequences of accidental escape of radionuclides into the atmosphere. The measurements available from different channels (dose-rate monitoring networks, ground-based mobile monitoring, airborne monitoring) provide valuable information on radiation situation. However, due to different time scales, spatial scales of the type of the measured quantity, the combination or even comparison of the channels is not straightforward. The interactive subsystem ASIM of the system HARP provides effective methods for merging this complex data into a consistent analysis describing radiation situation of the terrain.

Keywords
Radiation monitoring, Monitoring network, Nuclear emergency, Model prognosis, Data assimilation, Bayesian filtering.

1 COOPERATION IN THE AREA OF THE REFINEMENT OF MODEL PROGNOSIS BASED ON THE CONFRONTATION WITH THE MEASUREMENTS OBTAINED FROM THE TERRAIN

This work is focused on the possibility to use the results of the measurements of ionizing radiation within established radiation monitoring networks in order to refine model prognoses of the development of a radiologic situation after a radiation accident. A workplace with the top know-how in the area of monitoring is the State Office of Radiation Protection (SURO), which besides others takes part in the provision of the operation of a Radiation monitoring network of the CR (RMS) and cooperates on the development and application of advanced monitoring technologies both for continuous measurements on stationary measurement points and for mobile measurements (the ground and also airborne ones). SURO as the RMS data administrator participates also in ensuring the participation of the CR in the net EURDEP enabling mutual data exchange obtained from the monitoring of the batch input and volume activities of the environment air through national monitoring networks in Europe and surrounding states and continuous publicizing of the results from this monitoring. SURO participates further in ensuring incident preparedness related to the response to incidents with prospective radiation impacts on population and the environment besides others by ensuring the continuous operation administration of the Network of early detection RMS CR (in a non-stop regime 24x7) so the information on prospective occurrence of values overcoming set levels could be available in time, properly recorded and interpreted in the system of incident preparedness of the CR. SURO is engaged also in the issue of the application of the development of radiation situation modeling in cases of radiation incidents and their potential impacts on population and the environment in the area of radiation protection and incident preparedness. For this activity SURO uses various model tools including the HARP system (see below) which is being developed in cooperation with the Institute of Theory of Information and Automatization of the Academy of Science of the CR (ITIA)

Model prognoses and the description of radiation substances diffusion have been developed in ITIA with the objective to implement advanced statistic assimilation technologies in order to increase the reliability of mathematical estimates based on the application of other information – the most important are the results of measurements taken from the terrain. In the area of the assimilation of measurements with a model prognosis of radiological situation, the activities carried out at ITIA can be, in the CR, considered as pioneering. One of the most important objectives is the operation of the assimilation in real time, where the steps responding to periods of coming measurements can gradually correct the prognosis of a model and this way gradually refine the prediction of the extent of afflicted areas for which it is necessary to consider the introduction of urgent measures, and radiation situation on the spot.

The history of the cooperation during the modeling of the pollution propagation and the consequences in UTIA and SURO

The issue of the radioactivity diffusion in the environment has been in the focus in UTIA for about 10 years, in SURO even much longer. The most significant was e.g. the international cooperation within the framework of the EU grants INCO COPERNICUS FI14P-CT96-0006 or EVANET-HYDRA project which resulted also in a collective publication with international partners. The cooperation on an international level included also the participation of SURO and UTIA in the project of the implementation of the system ROSOS in the CR which includes also the localization of the European system RODOS (Real-time Online DecisiOn Support) to conditions of nuclear facilities in the CR. A wide range of localization procedures for the chain of atmospheric and hydrologic models was elaborated – see the example of online inputs into a diagnostic mode of operation of the system RODOS (enclosure 1). Then there was the cooperation with UJV Rez and EGP Prague within the frame of a tie-in project 6/2003 whose objective was the development of own methodology procedures and program tools as a result of the requirements of the Crisis and Coordination Center of SUJB and SURO.

Specialists from SURO and UTIA actively participated in a joint Czech-Austria STEP IIb "Realistic Case Studies" (2002 and 2003) within the framework of a process from Melk which included also comparative analysis of a serious breakdown of a nuclear power-plant with a source member ST2. The specialists in the UTIA also carried out comparative calculations with the code COSYMA and the system RODOS (the version PV 4.0 implemented in UTIA).

These long-term experiences enabled the engaged collective to emphasize the weaknesses of a contemporary research and define the areas of the extension towards the development of modern assimilation algorithms. The specified goals were supported by allotting the grant 102/07/1596 by the Grant Agency of the CR. Further development of assimilation technologies within the framework of this grant project enabled, in cooperation with SURO, to verify the possibilities to apply the data from the Network of Early Detection (NED) RMS in prediction models.

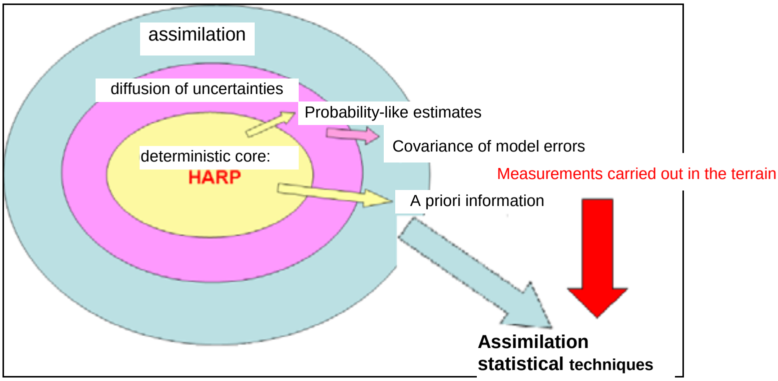

Fig. 1

Framing scheme of the environmental model HARP (HAzardous Radioactivity Propagation) and lining-up of its assimilation subsystem

At present, the UTIA (receiver) in the framework of Security research of the Ministry of Interior (provider) solves the project No. VG20102013018 called ***"Application of advanced statistic methods of the assimilation of model prognoses with the observations in the terrain in the form of a modern program***

tool for the decision making support in crisis situations": Within the solution of this project, the resulting product HARP will be adapted to the requirements of potential users with the possibility to use both just deterministic core of the system and its abundant interactive graphic support and on the other hand its full statistic operability including probability-like superstructure with the assimilation subsystem ASIM (see Fig. 1). Namely for the development of a functional assimilation subsystem, the cooperation with experts from SURO is indispensable.

Modeling or measuring – what is the optimal resource?

In the area of the estimation of the condition of a modeled system, the development progresses in two directions. First of all, in connection with the intense development of information technologies, more complex algorithms complying with advanced physical models are being implemented. It proved that one-side belief in the possibility of deterministic specification of a physical model with an unlimited ability to approach the reality is false. And neither, in consequence of a stochastic character of a task resulting from the inherent uncertainties of a model, it is not possible. On the other hand we can rely on available measurements which are, of course, rare in the space and time, and also burdened with errors. A pessimist may regard this situation as a sad one, because we have only an inaccurate model and false measurements. However, fortunately there a realistic way out of the problem represented by the synthesis of both approaches called **data assimilation.** It concerns the correction of model results using measured values whereas in the scheme of assimilation the physical knowledge, which is the information encompassed in a model, is respected concurrently. The method of assimilation takes into consideration positive features both of modeling and measurements. If there is a sufficient number of measurements, a numeric model is adjusted according to these values. In case of quality monitoring deficiency, we rely on a numeric model.

Advanced methods composed of Kalman filters and first of all methods of particle filters [24] are resolved as far as on an application level. During the research we relied on the experience and knowledge accumulated in this respect in the department of adaptive systems at UTIA where the development of these modern approaches has had a long term tradition.

Model prognoses and measurements in the terrain in the early phase of a radiation accident

The entire width of this issue outlined above will be limited to the analysis of an early phase of a radiation accident. We specify the requirements for radiation monitoring which can be used for the prediction refinement of a mathematic model of pollution propagation. An early phase of a radiation accident means the interval from the very beginning of the pollution escape until the time when a radioactive cloud leaves a monitored area. The time scale can vary from several hours up to several days. Just this phase is the most important regarding a rapid response to well-timed introduction of responding measures (sheltering, iodine prophylaxis, evacuation) in most affected areas. In the past, such analysis was not appropriate, verified program tools were missing and targeted measures were not prepared on an appropriate level. As mentioned above, due to the complexity and uncertainty of a task, we can never succeed in anywise complex and sophisticated computing codes. Only the connection of an advanced modeling with the assimilation of measured values in the terrain with the consequent recourse in separate time steps can generate really reliable estimates.

There are several important information sources which might improve the estimation of the development of the radiation pollution situation at an accident. Elementary physical knowledge is encompassed in an a priori estimation of the situation (time and spatial development of the radioactivity in the air, its deposition on the terrain etc.) which is obvious from the mathematic model. A significant effect ensues from the possibility to incorporate measurements which come from the terrain on-line, further the intuition supported by the experience might be important as well.

The development of a radiation accident might be so variable from the very beginning and is accompanied by such uncertainties that it is inevitable to introduce other steps. If we empathize in the role of the one who is responsible for issuing the command to start immediate measures, he will be under strong psychical and time pressure. Let us realize that a toxic cloud during several hours (or a few tens of hours) will undoubtedly get to the country borders and so there will be the overpressure to the fastest and at the same time reliable prediction of effected localities and relevant level of contamination in them. Uncertainties concerning the source of the escape, initial thermal uplift of a sweep, fluctuation field of circulation, actual dispersion and deposition characteristics etc. will not enable a reliable person (team) to decide correctly as long as he does not get other additional relevant information.

The question of the estimation of these uncertainties has been currently solved through the analysis of uncertainty and during the description of the errors propagation through a model. In recent several years the tasks carried out at UTIA were published. They represent indispensable stipulation for the movement from the estimates of the consequences of accidents on a probability base and for the application of advanced statistic assimilation procedures. In this case we refer to e.g. a website http://asim.utia.cas.cz/.

In the following chapters we will deal with the possibilities which the current configuration of RMS in an early phase of an extraordinary event can provide for the mathematic models of the pollution propagation for assimilation purposes.

2 THE DESCRIPTION OF A CURRENT SITUATION IN THE AREA OF MONITORING CARRIED OUT WITHIN RMS

2.1 Legislation

A legal frame for the system of radiation protection in the CR including the system of radiation situation monitoring on the CR territory is the Act No. 18/1997

Coll., on peaceful use of nuclear energy and ionizing radiation (Nuclear act), as amended, and consequential implementary regulations. Radiation situation on the CR territory is in a systemic way monitored and evaluated by Nation-wide radiation monitoring net (RMS), which is regulated by the National office for nuclear safety (SUJB). RMS has been established and operated according to the SUJB regulation No. 319/2002 on the operation and organization of a nation-wide radiation network, as amended, and the government resolution No. 11/1999 Coll., on the zone of incident planning, as amended, the provision of the operation and recovery of the RMS equipment is further adjusted by the CR Government resolution No. 478 of 2001-05-14, as amended and approved programs of monitoring by the license holders. Requirements for monitoring programs which beside others determine the extent of nuclear facilities surroundings monitoring ensured by the holders of permission to operate these facilities, is given by the regulation No. 307/2002 Coll., as amended by the regulation No. 499/2005 Coll.

According to the mentioned regulation SUJB No. 319 /2002 Coll., the task of RMS is especially (see § 3) to ensure monitoring of a radiation situation on the CR territory (thereinafter „monitoring“), including the transfer of the data and the administration of the information system for

a) the evaluation of a radiation situation for the sake of monitoring and the assessment of the extent of irradiation,
b) decisions on the measures aimed at decreasing or diverting irradiation in case of a radiation incident,
c) international exchange of information and the data on radiation situation,
d) making public and providing information and data on radiation situation on the CR territory.

RMS is composed of (see § 4) permanent sections of a monitoring network which work non-stop during current radiation situation and during radiation extraordinary situation, and emergency sections of a monitoring network which are activated when there is the suspicion of the rise or the rise of an extraordinary radiation situation.

RMS works in a normal regime – monitoring during a current radiation situation in which permanent sections of RMS participate let us say in an emergency regime – monitoring during radiation extraordinary situation or in case of the suspicion of its rise in which permanent and emergency sections of RMS take part (see § 5).

2.2 Monitoring

For the purposes of this engagement, especially the activity of RMS in the area of incident planning is significant (see the Government resolution No. 11/1999 Coll.) in the early phase of the escape with which we will be dealing more, i.e.:

- network of early detection,
- network of thermo-luminescent dosimeters,
- activities of mobile groups and an airborne group.

2.2.1 The network of early detection (SVZ)

SVZ is composed of a territorial network covering the whole state territory and by tele-dosimetry systems (TDS) of nuclear power-plants Dukovany and Temelin (see Fig. 2).

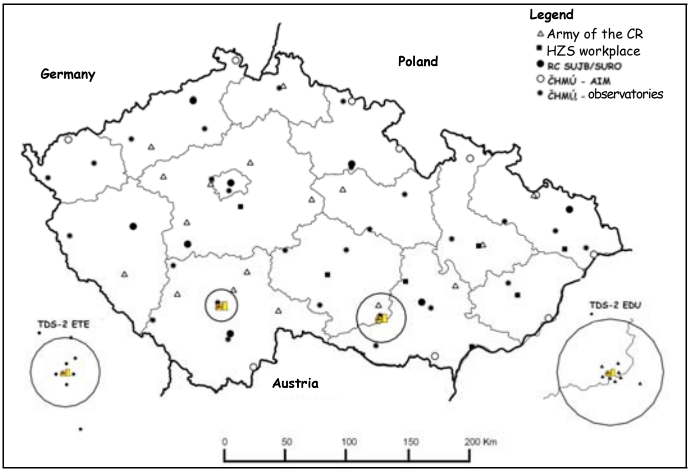

Fig. 2
The network of early detection – Territorial part and TDS ETE and EDU

2.2.1.1 Territorial network

Territorial network consists of 54 measurement points located at workplaces of SUJB (7 at RC and 1 at SUJB), SURO (1), CHMU (28 at observatories and 10 at stations AIM) and HZS (7). All these monitoring points are jointly equipped by detection systems for the measurements of the intake of a photon dose equivalent with the range of measured values from approx. 50 nSv/h to 1 Sv/h. Measured magnitude is the average value of the intake per a 10-minute measuring interval (see Fig. 3).

The results of the measurements are continuously transferred to a central RMS database

- namely from measuring points operated by CHMU: in a current radiation situation (ORaS) once per hour (always six 10-minute values in an elapsed hour), the data are available at a central database approx. between 10 – 15th minute of the following hour; in case of an extraordinary radiation situation (RaMS) the frequency of transferred values is increased to two times per hour, the data are available in a central database approx.. between the 10-15th minute of the following half an hour;
- From measuring points operated by SUJB (RC), SURO and HZS after the end of each 10-minute measuring interval, the data are available at central database up to approx. 5th minute after the end of a 10-minute measuring interval.

Fig. 3
Measuring point SVZ – territorial network – locality Dukovany (CHMU)

The measuring system is formed by a central unit Berthold LB-111 with probes LB-6500-3 (Greiber-Müller computer for measuring higher intake values from approx. 100µSv/h to 1Sv/h), and LB-6360 (proportionate computer with the range from 50nSv/h to 1mSv/h), placed standardly in the height of 1 m above the ground in an open terrain on not cultivated land and without higher objects (buildings, trees etc.) in the vicinity of the measuring equipment (except cases when the local conditions do not allow to adhere to these criteria in a full range.

The exactness of the measurements can be estimated +/- 25% within the whole range of measured energies (approx. 60-2000keV) and intakes (approx. 50nSv/h-1Sv/h) when we regard the energy and directivity dependence of detectors – see Fig. 4.

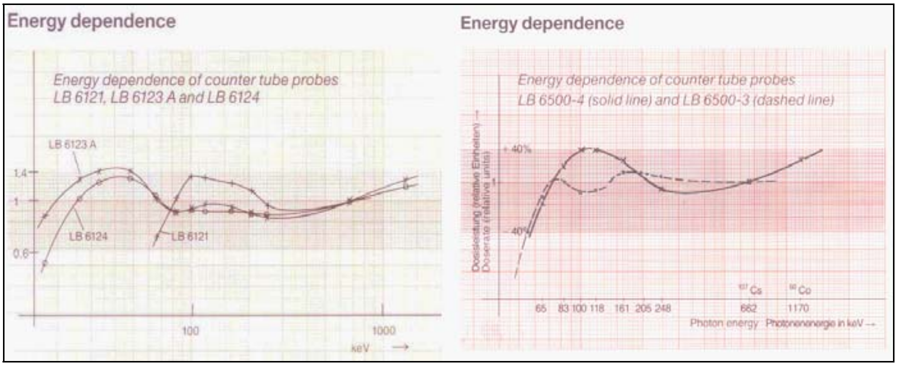

Fig. 4
Energy dependence of detectors LB 6123A (left) and LB-6300-3 (right)

Note: Due to the deformation of the energy spectrum in the place of a detector compared to the primary spectrum of a radio-nuclide source on the assumption of a balanced deployment of the volume activity of a radio-nuclide in the air (the size of the area significantly contributes to the measured intake and in the place of a detector it is only several hundreds of meters), which causes the shift of the former spectrum towards lower energies (see Fig. 5), we may regard this energy extent as sufficient [9].

The territorial network is primarily focused on the detection of the impact of an event which occurred outside the CR territory, on the CR territory, and this corresponds with the deployment of measuring points covering the state territory which are remote generally tens of kilometers – which means that for the detections of extraordinary escapes from Nuclear Power-plant Dukovany and Nuclear Power-plant Temelin its usability is limited, universally only for the data from measuring points at observatories CHMU at Nuclear Power-plant Dukovany and Temelin.

Note: In 2010 the Network of Early Detection of the CR Army was introduced. It is formed by 17 measuring points covering the state territory and equipped similarly as nation-wide network SVZ measuring points the and working in a similar regime, the data from SVZ CRA are transferred to RMS every single hour.

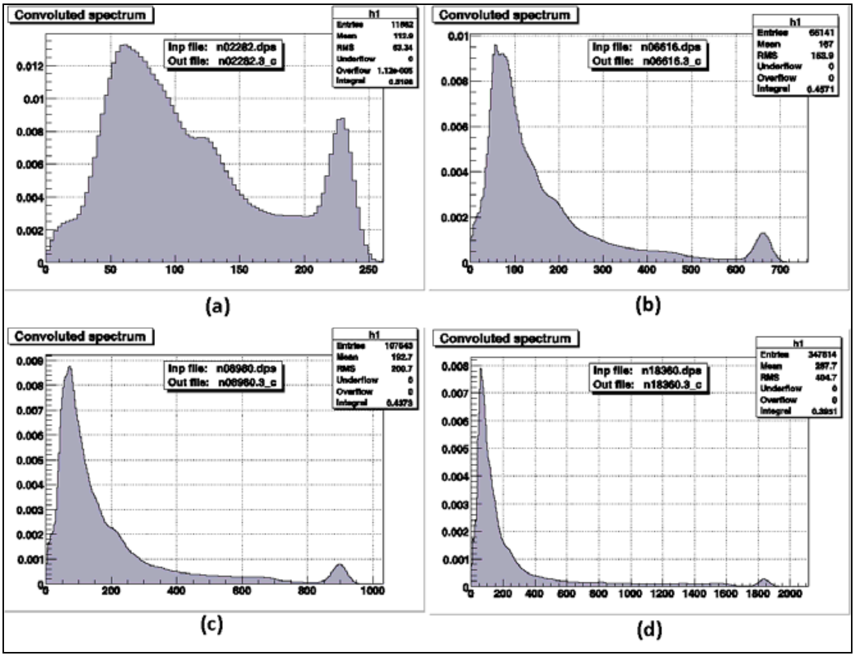

Fig. 5
The spectrum at point of a detector for the energy 228,2 keV (a); 616,6 keV (b); 898,0 keV (c); 1836,0 keV (d)

2.2.1.2 Teledosimetry system (TDS)

The basic detection system, monitoring prospective escape of radioactive substances from Nuclear Power-plants Dukovany and Temelin outside the area of nuclear power plants into the environment, is the teledosimetry system operated by the permission holder (CEZ Inc.), formed by two circuits of detectors – the inner circuit (TDS-1) with detectors located in and on the border of nuclear power plant area and the outer circuit (TDS-2) with detectors located in villages in the surroundings of the nuclear power plant.

TDS carries out permanent measuring of the dose intake with on-line data transfer to central data stowage space of relevant nuclear power plant. The measurement results are further continuously transferred to central RMS databases where they are stored – in the form of the same time matrix as the results of the territorial network measurements – as the average intake values per the 10-minute measuring interval. The data are available up to approx. 5th minute of each 10-minute interval in the central database.

The teledosimetry system of Nuclear power plant Dukovany is formed by 27 measuring points of the 1st circuit (TDS-1) located on the border of the nuclear power plant area and by 8 measuring points of the 2nd circuit (TDS-2) located in municipalities in the surroundings of the nuclear power plant (see Fig. 1). Both circuits TDS are equipped with the measuring systems Bitt RS-03/X, equipped by proportionate detectors with measuring range of intakes from 10nSv/h to Sv/h units. The detectors are placed in the height of 2,5 meters above the surface.

The teledosimetry system of Nuclear power plant Temelin is formed by 24 measuring points of the 1st circuit (TDS-1) located on the border of a nuclear power plant area (on the fencing) and by 7 measuring points of the 2nd circuit (TDS-2) located in municipalities in the surroundings of the nuclear power plant (see Fig. 1). The circuit TDS-1 is equipped by measuring systems Rados RD-02, using Geiger-Müller computers with measuring range of intakes from 10nSv/h to 10Sv/h. The detectors are placed in the height of 1,5 meters above the surface. The circuit TDS-2 is equipped by measuring systems Eberline FHZ-621, using proportionate detectors with measuring range of intakes from 10nSv/h. The detectors are placed in the height of 2,5 meters above the surface.

The part of the intake monitoring in ZHP are also mobile measuring systems for monitoring the dose intake. They are also equipped with the communication unit. Normally they are stored in a nuclear power plant but in case of a prospective escape or radionuclides from the nuclear power plant into the environment they would be operatively located in ZHP in beforehand selected localities in threatened sectors (in the wind direction from the source of propagation). They would complete this way the TDS-2 by several other measuring points.

The exactness of the measurements of TDS can be with regard to energy and directional dependence estimated to +/- 25% in the whole range of measured energies and intakes.

2.2.2 Network of thermo-luminescence dosimeters (TLD)

The network TLD is – similarly as SVZ – formed by:

- the territorial network of measuring points covering the whole state territory,
- local networks of measuring points, located in the vicinity of Nuclear Power Plants Dukovany and Temelin.

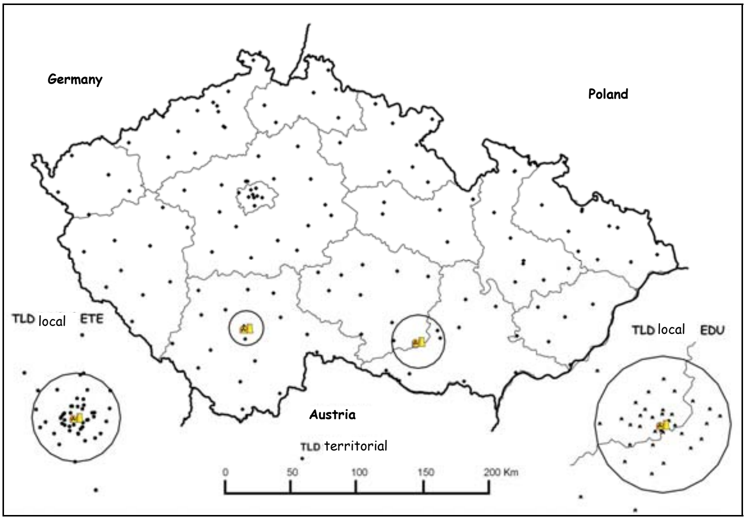

Fig. 6
The network of thermo-luminescence dosimeters – Territorial part and details of local networks

2.2.2.1 Territorial network TLD

The territorial network is formed by 184 measuring points, equally covering the state territory (see Fig. 1), whereas approx. 1/3 of detector points is located in buildings in a parallel with detectors located in the same locality in the open space in order to estimate the shielding factor of buildings. The detectors are located up on high of 1 meter above the ground.

For the evaluation, the detectors from measuring points are carried to the central laboratory of TLD in SURO equipped with a relevant evaluation device where are, at the same time, prepared "zeroed" detectors for the placement on measuring points for the next monitoring period.

The results of monitoring are transferred to a central RMS database as the value of an average intake per monitoring period.

The monitoring period in ORaS is three months (calendar quarter), in RaMS the monitoring period might be shortened according to the needs.

Measuring range of detectors is from approx. 25μSv per monitoring period.

2.2.2.2 Local networks of TLD

Local nets, located in ZHP nuclear power plants Dukovany and Temelin, are operated partly by SUJB (RC) and SURO and also by the permission holder (CEZ Inc.).

Local networks operated by SUJB (RC) and SURO are formed by 12 measuring points in ZHP EDU (see Fig. 1) and 9 measuring points in ZHP ETE (see Fig. 1), the detectors are located up on high of 1 meter above the ground. Monitoring periods are similar to the ones in the TLD territorial network.

Local networks operated by the permission holder (CEZ, Inc.) are formed by 36 measuring points in ZHP EDU (see Fig. 5 on the left) and 52 measuring points in ZHP ETE (see Fig. 5 on the right), the detectors are placed in ZHP EDU up on high of 3 meters above the ground. The evaluation of the detector is carried out in laboratories of the vicinity radiation control (LRKO) of the permission holder. Monitoring periods are similar to the ones in the TLD territorial network.

Due to the necessity to carry out the evaluation of detectors in TLD laboratories, the results from monitoring through TLD nets are not available until a specific off-set (in the number of days).

2.3 Mobile groups, airborne group

An inseparable part of RMS are:

- **Mobile groups** (MS) which carry out the monitoring of doses, dose intakes and activities of radionuclides in the terrain, the sampling of the environment and the placement and exchange of dosimeters in the networks of thermo-luminescence dosimeters.
- **Airborne group** (LeS) which carries out, if needed, monitoring of large-scale areas (measuring of dose intakes; areal or mass activities of artificial or natural radionuclides). Its operation is ensured by the SUJB (SURO) in cooperation with the Ministry of Defense (ACR).

2.3.1 Mobile groups operation

In case of a radiation breakdown both nuclear power plants elaborated their incident plans based on the analysis of prospective incidents sequences (The CR nuclear power plants are obliged to analyze the impacts of all prospective radiation breakdowns which are likely to occur with the probability higher than 10^{-7}). These plans are linked to external incidents plans where besides other things also the procedures for planning and implementation of protective measures in the vicinity of the power plants are specified in the so called Zone of Incidents Planning (ZHP) with the objective to mitigate prospective impacts of a radiation breakdown.

ZHP are set to the distance of 20 km for the nuclear power plant Dukovany and 13 km for the nuclear power plant Temelin. If there is the suspicion of the potential escape of radioactive substances into the vicinity of a nuclear power plant, the population is given the signal for sheltering, iodine prophylaxis and waiting for further information in case of the necessary evacuation. For certain breakdown sequences which count with the beginning of the radioactive substances escape into the vicinity the earliest after 10 hours since the outbreak of an incident, the evacuation of population is theoretically possible just before the approach of the contaminated cloud. However, due to the severity of such an action, it is more suitable to shelter the citizens (at least those who cannot escape themselves) and wait for other information. The sheltering is supposed to take at most 2 days. Other instructions/guidelines – i.e. the decision on the end, let us say the prolongation or extension of sheltering and on potential performance of evacuation of sheltered citizens would be issued by virtue of further information following the real situation i.e. the magnitude of the escape, meteorological conditions in the relevant territory and especially the results of **measurements carried out directly in the terrain.**

At an early phase of a radiation breakdown it is therefore necessary to carry out promptly the measurements which will serve as the groundwork for the decision on these urgent protective measures. The important information, which the system of crisis management in the CR keeps at disposal before the escape of radionuclides itself, are modeled prognoses of a rising radiation incident at nuclear power plant based on real technological data, a real meteo-situation and in advance calculated incident sequences. Other significant information acquired already during the escape are the values of dose intakes from the teledosimetry network of dosimeters dislocated in the area of a broken down power plant (approx. 25 detectors in every nuclear power plant. These pieces of information may help identify the direction of the escape and together with the prediction models to tip the areas of monitoring of attending mobile groups.

In another (middle and late) phase it is then necessary to decide on the sequential protective measures, i.e. on the regulation/prohibition, or the permission for food distribution from the affected territory, on the measurements in the agriculture, water system etc.

The activity of each MS is, in case of a radiation breakdown, controlled by the crisis management orders, nevertheless, especially for the early phase it is necessary to have prepared and trained procedures and pre-prepared taxiways, documentation etc.

2.3.2 The sequence of activities

a) An early phase:

For the decision at an early (escape and after-escape) phase of a radiation breakdown it is necessary to map as soon as possible the contaminated territory. It would be ideal if we could map with pilotless devices; however, at present, they are not available and due to legislation problems neither will be. So the measurements of dose intakes (DP) repose on the mobile groups and the airborne group.

The contemporary strategy results from the presumption that monitoring by mobile groups and the airborne group will start basically after the end of the radionuclides escape. (Note: Sometimes, it might happen, in dependence on the type of an accident and real meteo-conditions, that some measurements would have to start already in the course of the escape. This prospective situation would come into consideration only when the length of the escape would prevent the early measurements inevitable for the decision on sheltering or evacuation of population, and especially the escape in progress must not significantly contaminate the crew (due to the protection of the MS and LeS members´ health.) Also device equipment of monitoring teams must not be affected (due to the interpretability of final measurements). Measured values of dose intakes at a specific place and time help precise above mentioned model prognosis aimed at obtaining the most reliable groundwork for decision making – whether to evacuate, and if so, when and where. A specified prognosis allows to adjust the monitoring strategy "inside" the affected area.

The territory which covers ZHP around both nuclear power plants is, according to the wind direction, divided into 16 sectors. In case of a radiation breakdown, for the first phase of measurements, 17 traces have been planned. Each trace covers 3 neighboring sectors, the trace no. 17 leads along the near vicinity of a nuclear power plant. The number of affected sectors is estimated and their selection is made according to the above mentioned prediction models and a real meteo-situation. At the beginning of the measurement after the passage of a contaminated cloud it is necessary to scale all affected sectors and also neighboring sectors from both sides, 1 MS would pass trace no. 17, therefore the trace along the vicinity of a damaged nuclear power plant. The task of mobile groups is to pass along pre-prepared traces in ZHP in selected sectors in both directions with parallel measurements of dose intake (the dose estimate per a set time-period). Based on the results of traces measurements and revised prediction models, the Crisis Staff (KS) let us say Regional Crisis Staff (RKS) will make decisions on the next MS activity: either repeated passing through pre-defined traces and measuring of dose intakes, or measuring of dose intakes directly in pre-selected resident units with sheltered population (Fig. 7).

Beyond the ZHP frontier the monitoring traces are not pre-set; nevertheless the situation when it is necessary to scale promptly and carefully also this area might occur, because there will not be, by definition, citizens in shelters and it will be necessary to decide immediately if it is inevitable to introduce imminent measures, and if so, where and which ones. Therefore it is also, here, necessary to count with MS in order to carry out rapid mapping of doses and prospective distribution of dosimeters. The traces of these teams would be submitted to KS or RKS using through points in dependence on a current situation.

In dependence on a real situation, the MS would, based on the order of KS/RKS, carry out the exchange of detectors in the network of TLD.

A significant help during the monitoring of a contaminated area in the first phase of a breakdown could be an airborne group [8]. During the air measurement it is possible in a relatively short period to scale a large territory. It is obvious that in the first phase it is not necessary to scale potentially contaminated area with a high sensitivity. The task of LeS is to carry out the "control" of the results of prognosis models. The results of measurements are elaborated into maps so that it would be possible to confirm and specify the borders of contamination. In this phase it is sufficient to measure dose intakes (preferably converted to values 1 m above the surface). The results of such measurements will be charged with quite a big error, but for the first estimates, especially with the subsequent scaling of critical points by ground teams, will be sufficient.

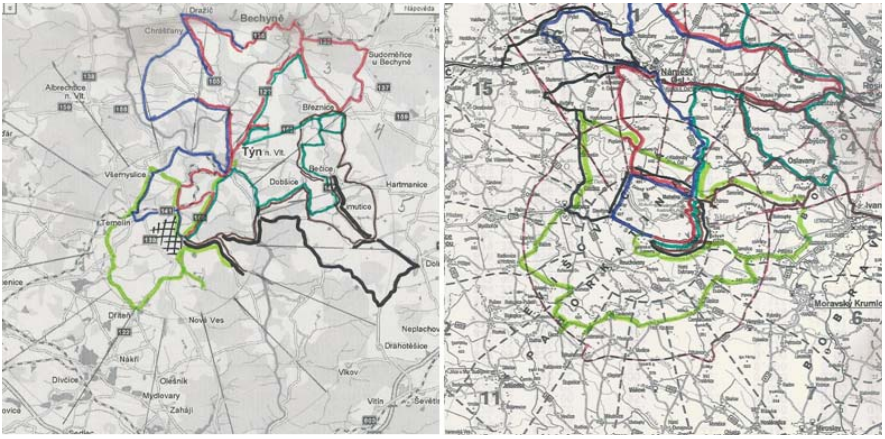

Fig. 7
Traces in ZHP of nuclear power plant Temelin in sectors 1 – 5 and a trace 17 (on the left, light green); Traces in ZHP of nuclear power plant Dukovany in sectors 1 – 4, 16 a trace 17 (on the right, light green)

More precise measurement must be carried out so that its result would be available within 48 hours at the latest since the announcement for sheltering. This period is even shorter due to the period during which MS and LeS could not monitor because of a lasting significant escape.

The application of aerial measurements in the first phase of a breakdown depends on the possibilities of a helicopter since – similarly as with MS – it is necessary to start monitoring as soon as possible after the cloud passing. Also the daily and yearly period, the weather as well as the time needed for the helicopter ascending is very important – with the ACR it amounts 12 hours, with the PCR the period is substantially shorter. Therefore in the first phase it is suitable to cooperate with the Police of the CR, during the late phase, where the time is not so important, the army helicopter can be used.

b) Middle and Late Phase

Measurements in the **middle and late phase** are focused on the achievement of the groundwork for the regulation of the consequent, let us say, long term measurements – the end of evacuation, rule out the relocation, regulation of food chains etc. in order to avert the subsequent reasonless irradiation of population.

In this phase the MS and Les will carry out more specified monitoring – area oriented more detailed measurements of soil contamination doses using gamma spectrometry, taking together/distribution of thermo-luminescent dosimeters, sampling of food chains, the environment etc.

The task of the **airborne group** will be detailed mapping of affected (also potentially affected) areas with the emphasize on the limitation of a contaminated territory and on searching for so called "hot spots" – relatively small areas with substantially increased contamination in comparison with the surroundings. Similarly as in the first phase, the measurements are carried out on beforehand defined parallel lines. Due to the fact that these measurements are not already finite as during the first phase, it is therefore possible (and by reason of the exactness also necessary) to choose substantially smaller gaps in the lines: from 50 – 250 meters. The monitoring results are again dose intakes recounted to 1 m above the ground; however, as long as the contaminant is not a mixture too complicated (which, usually in several days after the breakdown is not), it is possible to carry out the estimates of area activities of the most important (artificial) radionuclides – ^{137}Cs and ^{131}I.

Monitoring networks will precise the results on the surface in localities selected by an airborne group (hot spots)

- through dose intakes both in the place, and on the run in a vehicle,
- through spectrometric measurements in the place and
- they will carry out sampling of the environment with the subsequent scaling in a spectrometric laboratory.

For middle and late phase, the time is not so critical, monitoring can be carried out with regard to the place, extent and level of contamination, season, etc.

2.3.3 The number and equipment of the mobile groups and the airborne group

Mobile groups

In the CR within the radiation monitoring network (RMS – Radiation Monitoring Network) works at present 36 mobile teams from SUJB departments (18 MS), MoD (2 MS), MoI (1 MS PCR and 5 MS GD FRS), MoF (8 MS) and 2 MS pertain to nuclear power plants Dukovany and Temelin). SUJB is a control body, it is responsible therefore for provision of preparation and operation of monitoring networks (MS). SUJB together with SURO participate in the systematic guidance of MS.

The equipment of separate mobile teams depends on their position in the system and on the activities they carry out (see Table. 1); for each phase of an accident, slightly different equipment is needed:

- **early phase –** for measurements and dose mapping all monitoring networks must be equipped with detectors of dose intake gamma and measuring systems for trace measurements, GPS for accurate determination of the position and some monitoring networks must have also a set of particular thermo-luminescence or electronic dosimeters. Personal signal electronic dosimeters are apparent.
- **middle and late phase –** monitoring networks must be equipped with the devices used in early phase, moreover, it is necessary to have a scintillation detector for spectrometric measurements, or better a semiconductor detector (plus a spectrometric track if it is not a part of a detector), devices for the sampling of the environment including a mobile sampling device for aerosols, alter. iodine (iodine cartridges for this device).

According to device requirements we can divide these monitoring networks into three groups (Table 1 – groups with the simplest equipment – basic groups A, groups able to carry out also simple spectrometric measurements – basic groups B and special groups – a mobile spectrometric laboratory focused especially on complex monitoring in the middle and late phase directly in the terrain. Besides these groups there is an airborne group. It means that in the early phase only basic groups – type A and B will move out, a special group will move out later - in the middle and late phase.

Table 1
Division of monitoring networks according to their activities and equipment

Group	activity	devices	staff	Attendance time [h]	Number of groups
basic A	•dose intake measurements •Pick-up/ distribution TLD/ELD data counting from ELD	• personal electronic dosimeter • mobile measuring system •detector for dose intake measurements, GPS; TlD, ELD, ELD scanner	2 + 2 (driver + operator)	6-h + attendance time or 2-h alert phase	6 RC SUJB 8 GRC
basic B	•Scintillation spectrometry •surface contamination measuring •sampling of the environ.	• spectrometer (GR 135) • detector of sur-face contamination • Detector of neutrons (signaling) •set of devices for sampling	2 + 2 (driver + operator)	2-h alert phase + attendance time	5 HZS 2 RC SUJB 1 SURO (1 PCR)
special	•Semi-conductor spectrometry •sampling of aerosols	• portable HPGe detector with a spectrometric track • device for aerosols sampling •detector of neutrons (doses)	1 + 2 (driver + 2 operators)	6 hs + attendance time	1 SURO
air	air spectrometry	air spectrometric system with a HPGe detector	2 operators + 1 assessor + driver + helicopter crew	24 hs and more (in dependence on a helicopter)	1 SURO ACR/PCR

For the future we can consider increasing the number of basic groups A where we will consider using the persons who are acquainted with the risk - not specialists for radiation monitoring. The equipment will be a simple device for automatic measurements of doses connected to geographic coordinates. These groups will be used especially for less contaminated areas in order to proof modeled prognoses and the selection of another strategy of monitoring of these areas with regard to the implementation of subsequent long-term protective measures.

Air borne group

The operation of the airborne group is ensured by the air team from SÚRO in cooperation with the ACR or the CR Police which provide a helicopter with the crew.

The procedure during monitoring is the following: Parallel lines fly to a selected area – polygon where the direction of lines is determined by the terrain (e.g. in case of valleys is more appropriate to fly facing the valley) and the shape of a selected polygon (big time losses occur at the turns and transfer from one line to another; therefore, it is more appropriate not to design lines which are too short). Another important parameter of monitoring is the distance of lines. There it is necessary to make a compromise between the time and accuracy (the more the lines are closer to each other, the higher probability of discovering of so called “hot spots” is, because there is a steep increase of dose intake in a relatively small area). The gaps between lines are commonly between 50 – 500 m, but if it is necessary they might be e.g. 2 km as it happened during the exercise Zone 2010, see Fig. 8 [10, 20].

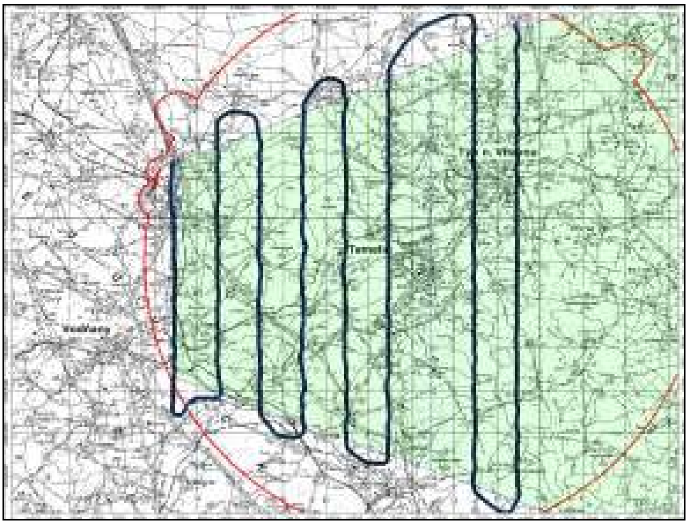

Fig. 8

Air monitoring – the result of monitoring during the exercise Zone 2010 (dose intakes recounted to 1 m above the ground; all measured values were on the background level)

For air measurements within the RMS network we apply spectrometric IRIS (**I**ntegrated **R**adiation **I**nformation **S**ystem, PicoEnvirotec). The IRIS system is highly effective spectrometric system which is advantageous for the monitoring of a terrain with relatively low contamination (e.g. even today on the major part of the CR territory we can measure with it the contamination of the soil by ^{137}Cs as a result of nuclear power plant breakdown in Tchernobyl). On the other hand this high detection effectiveness may cause problems during measurements in the first phase of a nuclear power plant breakdown because the dose intakes might be high. The detector might be overloaded and even if we increase the distance from the ground (currently we fly from 50 – 200 m) the situation is not better. Therefore it is suitable to use also other – simpler devices. Such an example is the system for the dose intakes measurements PDOSE (PicoEnvirotec), appropriate for stationary and first of all mobile measurements in a vehicle or helicopter.

In order to specify the composition of a contaminant we may use a spectrometric track with a semi-conductor detector.

2.3.4 The description of selected devices for mobile groups and an airborne group

Mobile groups

a) Measurements of dose intakes

The elementary measurement carried out by mobile groups is the measurement of dose intakes. At present, mobile groups use several types of devices for the measurements of dose intakes. Their properties are summarized in Table 2 [10]. The utilization of individual devices differs according to their capability to measure various levels of dose intakes, and according to the capability to discover e.g. radionuclides radiating photons of low energy. All devices are verified according to the law on metrology. The uncertainty of the measurement varies up to 25 %.

Table 2

Devices for the measurement of photon dose intakes used in MS; their basic parameters

Device	Range of dose intakes measurements	Detector	Energy range [keV]
DC-3E-98	up to 10 mGy/h	GM	50 - 1500
FH 40 G	100 nSv/h-1 Sv/h	proportionate	50 - 1300
NB 3201	40 nGy/h - 100 mGy/h	plastic scintillator	35 - 1500
GR-130/135	GM: 0,01-100 mSv/h NaI(Tl): 0,01-50 μSv/h	NaI(Tl)+GM	50 - 3000
RP 2000	100 nGy/h -10mGy/h	GM	50 - 1500

Explanatory Notes: GM – Geiger-Müller tube, NaI(Tl) – scintillation detector.

b) Measurements of dose intakes on the run

For these measurements we use the MK mobile system. The system consists of a detector of dose intake GR 130 or GR 135 that enables to record measured data into a notebook. GPS finds out and records into a notebook relevant coordinates to each measurement. A notebook with the application PDE+ records all data to the memory and enables to draw them into the map ground-work for higher lucidity. Errors in measurements are here obviously higher than in stationary measurements of dose intakes. A number of factors plays here an important role - the type of a vehicle, driving velocity and the place where the vehicle moves (flat country, valley . . .).

c) Personal signal electronic dosimeters

For simple (temporary) measurements we can use personal electronic dosimeters which all crews of monitoring networks are obliged to have about one. However, it is obvious that these measurements will be burdened with a big error and the measurements results will be regarded only as the orientation ones.

Airborne group

a) IRIS

IRIS system contains 4 scintillation crystals with the volume of 4 liters (together 16 liters), the equipment for the position detection (GPS), altimeter, navigation device ensuring the exact navigation along air profiles and a resistant notebook. During air monitoring the measured spectra and data on the position and the height above the terrain are recorded into the notebook memory. Later from these data, using software, we can determine dose intakes and area activity of selected artificial radionuclides, let us say mass activity of natural radionuclides. Fast, simple evaluation of measured spectra is carried out with programs PEIView (part of IRIS system), for detailed evaluation of measurements commercial SW PRAGA is used. The length of separate measurements can be set within the interval of one to tens of seconds, currently we use 1 second. IRIS measures dose intakes in a helicopter (with the SW it is recounted to the reference height 1 m above the ground) and thanks to its spectrometric properties, it is capable also to carry out qualitative and quantitative analyses of a contaminant for selected artificial radionuclides (e. g. ^{137}Cs, ^{131}I, ^{60}Co, ^{88}Kr), as long as the measured mixture of radionuclides is not too complicated.

At present, similar device equipment (IRIS) is available in the ACR, but it has not been connected to the structure of RMS yet. Air devices of the reconnaissance have not been implemented yet.

b) PDOSE

PDOSE is a detector of dose intake which includes also GPS, therefore it is capable to record not only dose intakes but also position data with each measurement and so it is possible, based on these data, to carry out even prompt drawing of measured dose intakes into surveillance maps.

Measuring unit contains two Geiger-Müller detectors (small and a big one), which are automatically switched over according to registered frequency of impulses, measurement range is 20 nGy/h - 400 mGy/h. The unit encompasses also a module for wireless communication and a GPS receiver. Measured data (both radiation and position ones for subsequent drawing of measured data into lucid maps) are recorded into MDA (Mobile Data Acquisition system), which consists of a small computer, a module of wireless communication (Bluetooth) and a GPS receiver. The databases are subsequently evaluated through SW PEIView (for prompt simple evaluations) namely PRAGA Ground (for precise evaluation). The duration of sampling might be from 1 second to several minutes, for air measurements it is suitable to use 1 second for the sampling duration. It is necessary to realize that the device measures and shows the dose intake on board of a helicopter because it does not have an integrated module for the measurement of the height above the terrain and therefore it is not capable to carry out corrections of the height change which in case of flat terrains does not have to be a problem – helicopters are capable to keep a flight level with quite high reliability (usual flight level is 100 m ± 20 %, in case of monitoring during a breakdown the flight level would be higher). Even this way measured values are quite reliable and predicate about the situation on the ground [21].

c) Spectrometric trace; detector Falcon

For spectrometric measurements during flight monitoring we use a spectrometric trace with a semi-conductor detector HPGe (ORTEC, relative effectiveness 25 %, FWHM 1.9keV for ^{60}Co, 1.33 MeV, with the analyzer DigiDart (4096 channels) and a notebook with the program Maestro (ORTEC) or a compact semi-conductor detector determined for terrain measurements Falcon 5000® Portable HPGe-Based Nuclear Identifier. These detectors are relatively of a low effectiveness but in case of a high level of the terrain contamination it is possible to use these detectors also for simple mapping with limitations similar to PDOSE.

2.3.5 Comparison of selected devices for terrain measurements

In 2006 – 2007 the SURO carried out within the project [9] - comparison of measuring methods and the compatibility of results measured with selected systems and devices used in the Radiation Monitoring Network in the CR. They were:

- flight devices – IRIS system tested for two types of used helicopters
  - BELL 412 in cooperation with the Police of the CR,
  - Mi 17 in cooperation with the ACR,
- ground devices
  - measuring of dose intakes during the vehicle ride (MK system),
  - “point” measurement of dose intake (GR 130 a GR 135),
  - measurement of in-site (spectrometric “point” measurements),
  - sampling and subsequent laboratory spectrometric measurements.

Parameters of an IRIS and MK systems and a detector GR 130/135 have been described above.

Spectrometric measurements using spectrometric traces were carried out in selected localities (Fig. 9). The system consists of a semi-conductor detector (ORTEC) with a relative effectiveness 25 %, FWHM 1,9 keV (60Co, 1,33 MeV) and the analyzer DigiDart (4096 channels; ORTEC). Measured out spectra were evaluated using program Maestro (ORTEC). Detector was placed on a stand 1 m above the ground. The time for spectrum gathering was 1800 seconds and the dead time was 2 – 3 %. The uncertainties of measurements varied from 10 – 20 %.

Fig. 9
Spectrometric in site measurements

Fig. 10
The map of the polygon

In several localities of measurements in site we carried out the sampling of the surface layer of the soil. The soil was taken according to procedures for mobile groups, i.e. the area of 20 x 20 cm^2 was demarcated and gradually the plants and the soil layer into the depth of 5 cm and into the depth of 20 cm were taken away. This way obtained samples were transferred to a spectrometric laboratory in SURO where the content of artificial (^{137}Cs) and natural radionuclides (^{40}K, U-range and Th-range) was determined.

For the testing we used the polygon territory of the area of approx. 10 x 10 km^2 in the central part of Bohemia, south-east of Prague near the town Vlasim (Fig. 10). The polygon territory is slightly downy, the altitude varies from 250 to 520 m., from the green the meadows and fields prevail, forests are approx. on 20 % of the territory. On the territory there are natural radionuclides of the concentration which is usual on the CR territory (^{40}K, Ra-range and Th-range) and as a result of the Tchernobyl breakdown there is also ^{137}Cs (1-20 kBq/m^2).

Detailed results of comparisons are given in [9], here we provide only the most important findings.

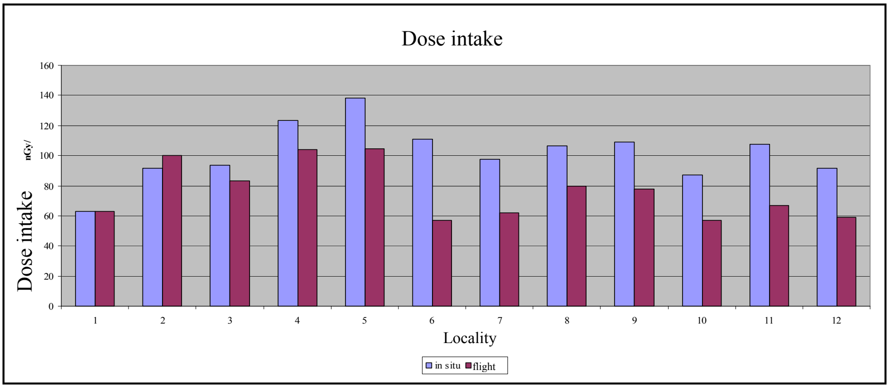

Fig. 11
Comparisons of measured dose intakes in selected localities
(blue—in site measurements; red – flight measurements)[nGy/h]

From resulting figures and tables it is obvious that all compared measurements are compatible despite the fact that sampling and soil sample measurements "map" only the area of 400 cm^2 (in dependence on the height of the flight), therefore we do not compare quite same "samples" because the polygon area is not in so far homogeneous. Flight measurements (at flight level 100 m above the ground) differ from those on the ground maximally up to 40 % (Fig. 11, Fig. 12), at lower flight levels the results would be even better – up to 20 %.

In 2009 other devices suitable for prospective measurements on a board of a helicopter were tested [21]. Within the comparisons, the IRIS and PDOSE systems (both PicoEnviroTec) were tested and also a semi-conductor trace with the detector

ORTEC (see the parameters above). The devices were placed on a board of a helicopter during training monitoring of a territory near Pribram (the area suitable for testing due to the high inhomogeneity of natural radionuclides contained in soil).

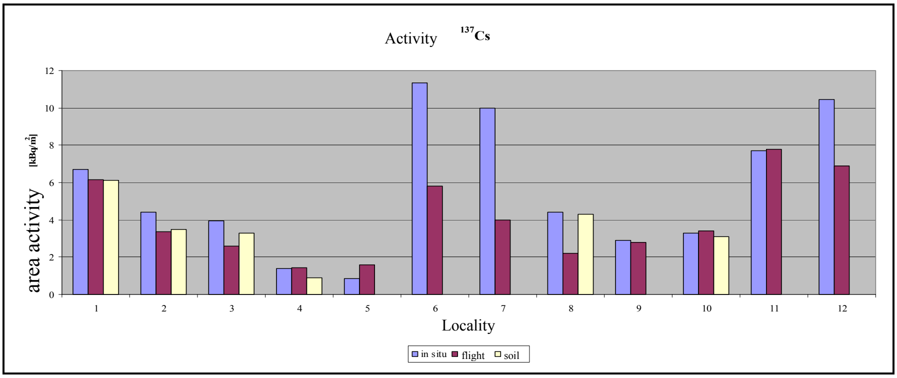

Fig. 12
Comparison of measured out area activities of ^{137}Cs [kBq/m^2] in selected localities (blue – in site measurements; red – flight measurements; yellow – laboratory measurements of soil samples)

The spectrometric trace proofed to be applicable even if it is necessary to count with substantial time consumption needed for the evaluation. With regard to low effectiveness of a detector it is obvious that the error in such measurements is big and most likely in this form for the purposes of a code HARP inapplicable (however, not for respective incident measurements where the low effectiveness of a detector would be rather an asset.

PDOSE system is suitable for situations in which the IRIS system is inapplicable. Under such circumstances it is necessary to be aware that the device measures the dose intake on a board of a helicopter and that this value is though proportional to the dose on the ground, namely 1 m above the ground but it is influenced by the height in which the helicopter flew in an instant of measurements. Nevertheless this value – as an indicator of the dose intake – is possible to accept in most cases. However, also here the applicability of the results for the purposes of the HARP code is highly limited.

3 ANALYSIS OF THE INFLUENCE OF THE NUMBER AND DISLOCATION OF THE NETWORK RECEPTORS ON THE QUALITY OF DATA ASSIMILATION AND PREDICTION

The influence of the number and dislocation of receptors of the network (measuring places SVZ) on the exactness of assimilation at early phase of a radiation breakdown can be demonstrated on a simple example when we consider a hypothetical escape from a nuclear facility during which a radioactive cloud is generated and flows above the terrain. We suppose that the network receptors from the beginning provide measured values in regular time intervals. The aim of the assimilation here is to specify continuously the estimate of time and spacial distribution of selected radiologic magnitudes (e.g. volume activity of the air) and to approach as much as possible the occurred physical reality.

In order to simplify it, let´s focus only on the radiation from the cloud, i.e. we do not count with the radiation caused by radioactive material deposited on the terrain due to the wet and dry deposition. In this example we assimilate the concentration of the activity from the air given by the prediction model of spreading, with the dose intake measurements from the cloud which are provided by the network receptors. Prospective actual escape is simulated by the atmospheric dispersion model, i.e. it is so called “twin” experiment where the measurements are simulated by a dispersion model initiated by some referential values and perturbed by accidental noise which simulates errors in the measurements. This commonly used technique has three basic advantages. Partly we evade the fact that real data suitable for testing of methods under development are not available and moreover this approach ensures the transparency of the entire experiment. We can objectively evaluate the conformity of the assimilated model with the one which was used for the simulation of a real escape. However, the most important fact is that this technique enables us to test the assimilation method for a wide range of meteorological and other conditions and assess this way their robustness. Cumulation values of the concentration of the activity from the air of the nominal escape used for the simulation of the measurements we can see in Fig. 13. (on the right).

In order to compare the influence of the receptors density on the quality of the prediction we consider two configurations of receptors which approximately cover the square of the one side length of 20 km and the source of the escape is located in its center. Both configurations are formed by receptors dislocated into three centered circles surrounding the source. The circle which is the nearest to the source represents the receptors located directly in the area of a nuclear facility, namely on its border. There are two rather extreme cases. The first configuration, marked in the following text as a *thin net*, is formed by six receptors in each circle, i.e. altogether 18 receptors. The second configuration, marked in the following text as a *dense net*, is formed by twenty receptors in each circle, i.e. altogether 60 receptors. The assimilation is carried out for the first 90 minutes after the initiation of an imminent one-shot escape with the duration of a time step of 10 minutes, i.e. altogether 9 assimilation steps are carried out.

The chosen assimilation methodology described e.g. in [23], has been developed at UTIA AV CR, within the frame of a Security research of the MoI of the CR project VG20102013018. It rises from the sequential methods Monte-Carlo where a large number of probable scenaria of contamination spreading is generated and by means of the assimilation of the measurements the most probable of them are statistically suitably combined. It is a general methodology applicable to all classes of parametricized atmospheric dispersion models.

In Fig. 12 and Fig. 13 we can see the results of assimilation for both considered configurations SVZ. Receptor points are demonstrated by means of circles. The assimilation estimates after assimilation steps 3, 6 and 9 are demonstrated here. In the *k*-step the estimate of a spacial distribution of the activity concentration in the air carried out by means of the assimilation of all measurements from time steps *0* to k is the best.

In Fig. 12 it is obvious that a thin configuration of the net does not provide enough informative measurements and the assimilation algorithm cannot sufficiently accurately determine the real direction of the escape spreading. However, its probability-like character gives us the guarantee that none of probable possibility is excluded and the resulting cumulation value of the concentration activity covers a wider area which of course includes also the one actually affected. From the results in Fig. 13 it is obvious that a dense network provides more informative data and the localization of a real escape is more precise in all time steps.

In Fig. 14 we can see the comparison of assimilated estimates for the thin and dense network with a nominal model. The fact that neither in the dense network the exact conformity with a nominal model occurred is caused by the uncertainty in the whole problem (e.g. errors in the measurement) and also by the probability-like character of an applied assimilation algorithm where the result is the probability-like distributions describing the estimated radiologic magnitude. More about this issue can be found in [22], where more complicated assimilation scenaria are documented.

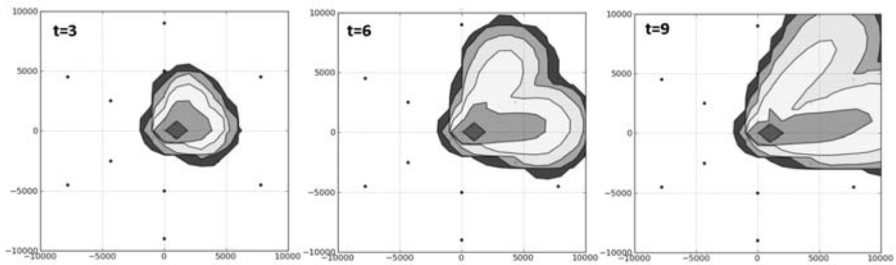

Fig. 12
Time course of assimilation for a thin network

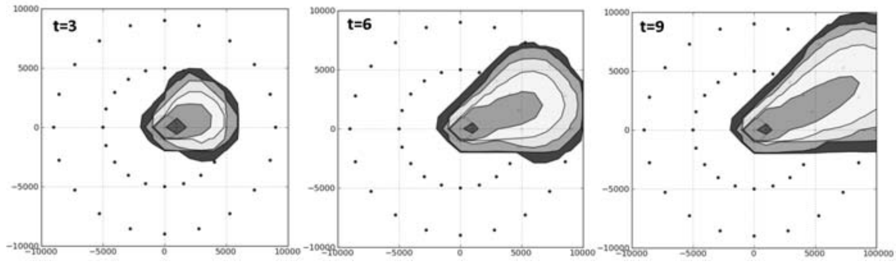

Fig. 13
Time course of assimilation for a dense network

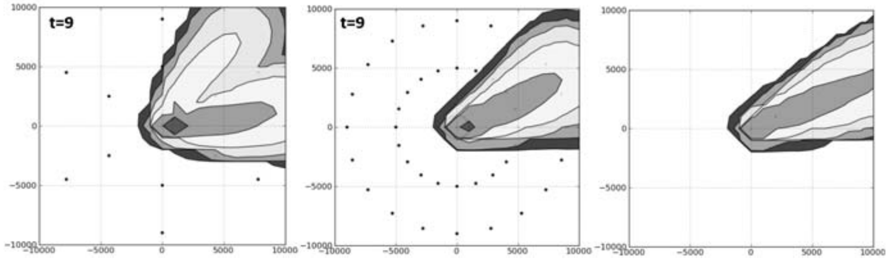

Fig. 14
Comparison of a real cloud trace (on the right) with the results of assimilation for a thin network (on the left) and a dense network (in the middle)

4 SUMMARY: WHAT CAN BRING PROFESSIONAL MONITORING OF A RADIATION SITUATION FOR MODEL PROGNOSES AND VICE VERSA

Methods of assimilation of model prognoses and measured data are able to provide the crisis management with the synthesis of all available data including the information on uncertainty. From these data it is possible to deduce automatic or semi-automatic advice for crisis decision making such as maps of expected contamination or maps of the areas where it is necessary to take imminent measures. We would like to mention also another important application which is the development of software means for **the proposal and verification of the configuration of monitoring networks.**

The simple example of two possible configurations of the network demonstrated how the density of measuring stations, while reducing the uncertainty in prediction of contamination, plays an important role. Current network of measuring stations approaches the scenario with a thin network and the following research goal is to generate methodology for the suggestion of the receptors topology to complete and densify the current network. Techniques of stochastic assimilation enable to evaluate the quality criteria for various submitted configurations of the network and therefore enable to choose the most appropriate one.

In the demonstrative example we considered the distribution of receptors into regular circles, in the suggestion of a real configuration of receptors many other factors will have to be taken into account. Both technological (energy and communication means availability, protection against the damage or theft, etc.), and economic (the price for the establishment of the network and its operation and maintenance), demographic (residential density with highlighting the monitoring of densely populated areas), politico-social etc., which with high probability will result in specific limitations concerning both the number of suggested receptors, and the possibilities of their distribution. At the same time it is necessary to take into consideration local conditions for the prospective area including long-term weather characteristics determining prevailing wind directions.

Evaluation methods which are under development should be able from the determined set of potential configurations of receptors, stationary or also mobile ones, built with regard to all relevant factors and limitations, to choose the one which will provide the collection of measurements with the highest information value when we think of its application for automatic or semi-automatic assimilation systems.

CONCLUSION

A selected method enables from a respective set of potential configurations of receptors, assembled with regard to all relevant factors and limitations, to choose the one which will provide the set of measurements with the highest information value from the viewpoint of its application for automatic or semi-automatic assimilation systems.

The method enables to optimize the configuration of the network of receptors in a selected area with regard to the aspect of the quality of the assimilation of the terrain data and from them resulting quality of model prognoses. The application of the described tool for the development of comprehensive methodology for the suggestion of the topology of receptors of the monitoring network upon the respective set of limitation is the object of the next research within the above mentioned grant project of Security Research MoI VG20102013018 solved in UTIA and a project VF20102013018 solved by SURO.

Résumé

To support crisis decision making and control in case of a nuclear power facility accident resulting in the escape of radioactive substances into the atmosphere, it is necessary to have an access to as much detailed and actual information as possible regarding the actual radiation situation on-site and on a prognosis of its potential development. In practice there are usually the data available, on one hand the monitoring radiation situation data obtained through monitoring networks - during the early development phase of an event there are particularly dose rate data measured through stationary monitoring networks (on territorial and local levels) - and from the monitoring performed by ground-based and airborne mobile groups; and on the other hand model prognoses of potential development of radiation situation provided by computer systems.

In order to increase the accuracy and reliability of model prognoses, it is suitable to use the assimilation method of real data from field measurements to correct the computed model prognoses. An effective tool for such assimilation is the ASIM module built in the HARP system, allowing advanced information assimilation from various kinds of monitoring performed independently, involving

as well data assimilation from the measurements performed in various time matrixes, which may not correspond to a time step of calculation.

Another factor influencing the quality of radiation situation information is a configuration of monitoring networks in the surroundings of nuclear power facility. Within the HARP project, the developed subsystem allows to analyze an influence of monitoring points location in a respective area on the quality of obtained information about the actual radiation situation. On the base of this analysis the subsystem subsequently enables to realize a project of monitoring points topology optimization in the area, taking into account not only radiation monitoring factors, but also the deviation influence assessment from the ideal topology given by factors, both technical ones (such as the availability of electricity, of communication means etc.) and economical ones (reduction of monitoring points number by reason of expenses on the network build-up and operation).

The application of developed tools for data assimilation and analysis of monitoring networks topology is a scope of the follow-up research within a grant project of the Security Research controlled by the Home Office of the Czech Republic.

Literature

[1] CESPIROVA, Irena et. al. Airborne measurements (IRIS, semi-conductor detector, PDOSE). *Nuclear energy safety,* 2010, vol. 18. ISSN 1210-7085.

[2] CESPIROVA, Irena, FRONKA, Ales. Comparison of airborne and ground measurements. *Nuclear energy safety,* 2008, 3/4. ISSN 1210-7085.

[3] CESPIROVA, Irena, HULKA, Jiri. Is UAV applicable for monitoring in case of a radiation accident? In *1. National conference - Civil pilotless systems: Specialized air company.* Prague, 2008. ISBN 978-80-902522-2-6.

[4] CESPIROVA, Irena, PASKOVA, Zuzana, MATZNER, Jan. The activity of airborne and mobile groups during the exercise Zone 2010. In *Volume abstract – DRO.* Trebon, CR, 2010.

[5] CESPIROVA, Irena, PROUZA, Zdenek. Activity of Mobile and Aerial Groups during Radiation Emergency. In *International Symposium on In Site Nuclear Metrology As A Tool For Radioecology*. Rabat, Morocco, 2008.

[6] FRONKA, Ales, CESPIROVA, Irena. Brief description of the setup of the Czech measurement technique, with a special focus on the development ofter 2002. In *Workshop On Aero-Gammaspectrometry, Federal Office for Radiation Protection.* Berling, 2010.

[7] FRONKA, Ales, CESPIROVA, Irena. The system of modern data acquisition – including airborne gamma measurements in case of severe NPP accident. In *Workshop On Aero-Gammaspectrometry, Federal Office for Radiation Protection.* Berling, 2010.

[8] HOFMAN, Radek. *Application of Advanced Data Assimilation Methods in Off-site Consequence Assessment*. [Dissertation thesis.] Prague: FJFI CVUT, 2011.

[9] HULKA, Jiri, et. al. *Methods of evaluation of contaminated territory after radiation accident – significance of the structure and function of scenic shelter*. [Final research report of research and development project SUJB no.1/2008.] State office of radiation protection, 2010.

[10] HULKA, Jiri. *Development, verification and implementation of new procedures, methods and methodologies of radiation situation monitoring and irradiation of persons focused on the evaluation of radionuclides escape into the environment from nuclear power plants and monitoring of their vicinity, further focus on express methodology*. [Final research report on the research and development project. SUJB no.3/2006.] State office of radiation protection, 2007.

[11] IAEA. EPR-First RESPONDERS. *Manual for First Responders to a Radiological Emergency*. Vienna, 2006.

[12] IAEA-TecDoc – 1162. *Procedures for Assessment and Response during a Radiological Emergency*. Vienna, 2000.

[13] Government Regulation No. 11/1999 Coll. on incident planning zone of the state.

[14] PECHA, Petr, HOFMAN, Radek, KUCA, Petr. Lessons learned from former radiation accidents on development of software tools for effective decision making support. In *11th International Conference on Present and Future of Crisis Management 2009*. Prague, CZ, 2009.

[15] PECHA, Petr, HOFMAN, Radek, SMIDL, Vaclav. Bayesian tracking of the toxic plume spreading in the early stage of radiation accident. In *The 2009 European Simulation and Modeling Conference*. Leicester, GB, 2009.

[16] PROUZA, Zdenek. *Methods and measures for the diminishing of the occurrence and elimination of consequences of terrorist misuse of radioactive substances*. [Final research report on a research and development project SUJB VAV no.2/2008.] State office of radiation protection, 2010.

[17] PROUZA, Zdenek, SVEC, Jiri. *Intervention in case of a radiation extraordinary event*. Ostrava: Edition SPEKTRUM 57. pp. 125. ISBN 978-80-7385-046-3.

[18] SANDERSON, D.C.W., McLEOD, J.J. Recent Applications and Developments in Mobile and Airborne Gamma Spectrometry. In *Proceedings of International Symposium RADMAGS'98*. Stirling, UK, 1998.

[19] STROBL, C., et. al. Aero-gammaspectrometry as an Important Tool after a Nuclear Accident. In *ALARA Issue arising for Safety and Security of Radiation Sources and Security Screening Devices*. Vienna, Austria, 2009.

[20] TMT Handbook. *Triage, monitoring and treatment of people exposed to ionizing radiation following a malevolent act*. 6th EURATOM Framework Programme for RTD, 2008. Available at www: <www.tmthandbook.org>.

[21] Regulation SUJB No. 307/2007 Coll. on radiation protection.
[22] Regulation SUJB No. 319/2002 Coll., on function and organization of nation-wide radiation monitoring network.
[23] Act No. 18/1997 Coll., as amended (Atomic act).
[24] Reports on radiation situation in the Czech Republic territory, State office of radiation protection, Prague, 2003 – 2007. Available at www: <www.suro.cz>.

Abbreviations

RMS	Radiation monitoring network
MS	Mobile group
LeS	airborne group
SURO	State office of radiation protection
KS	crisis staff
RKS	regional crisis staff
SUJB	National authority for nuclear safety
RC SUJB	Regional center of National authority for nuclear safety
ZHP	Incident planning zone
JE	nuclear power plant
GPS	Global Positioning System
ACR	Army of the CR
PCR	Police of the CR
GRC	General customs directory
TLD	Thermo-luminescence dosimeter
ELD	Electronic dosimeter