# SPATIAL DATA SUPPORT OF MANAGEMENT OF EMERGENCIES CONCERNING NUCLEAR POWER PLANTS

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***Abstract***
*The emergencies at nuclear power plants pose a high risk to public order, life, health, and safety if radiation is released into surrounding communities and areas. Owing to this, every measure taken to make responses to this kind of mergency more effective is of great importance. Because of this, the proposed article examines the use of various kinds of spatial data to improve the management of emergencies at nuclear power plants.*

*In its first part, the article deals with the collection and evaluation of measurements of the rate of ionizing radiation equivalent dose, which the Fire Rescue Service of the Czech Republic daily carries out. These measurements further strengthen the existing radiation monitoring network in the Czech Republic. Such strengthening is especially important if we consider the endangerment of the nuclear power plants by the conflict in Ukraine and the Middle East.*

*Next, the article provides an overview of the use of spatial data for emergency management support during a simulated accident at Nuclear Power Plant Dukovany, within the framework of the exercise Zóna 2025.*

*Finally, the article attempts to formulate, based on the previously mentioned cases, guidelines for spatial data support for emergency management at nuclear power plants and for emergency management generally.*

***Keywords:*** *nuclear power plant, emergencies, spatial data*

## INTRODUCTION

In connection with the conflict in Ukraine, it was agreed with the State Office for Nuclear Safety (SONS) to have the Fire and Rescue Service of the Czech Republic (FRS of CR) conduct preventive monitoring of the radiation situation in the Czech Republic using its forces and means. The reason was the possible threat to nuclear power plants in Ukraine (1), the Chornobyl Nuclear Power Plant (2), and the Zaporizhzhia Nuclear Power Plant (3), due to the ongoing conflict (3). Unfortunately, the current global security situation is even less favorable to nuclear power plants than it was in 2022, when the measurements began. More nuclear power plants and other nuclear installations are at risk due to the conflict in the Middle East, namely the Bushehr Nuclear Power Plant (4) and the Shimon Peres Negev Nuclear Research Center (Dimona) (5).

As an example of other uses of spatial data to support emergency management at nuclear power plants, the data supporting the exercise Zóna 2025 can serve. This exercise was conducted at Dukovany Nuclear Power Station (6, 7) in 025 and focused on coordination among emergency management bodies at different levels. The spatial data used to support this exercise can be split into two main categories. The first category is static reference data used as background for emergency management decisions. The second category consists of dynamic data depicting various aspects of the situation arising from the simulated accident in the context of the exercise.

During the preparation of the static data for support of the exercise, great attention was paid to their selection, logical organization, and publication. Every effort regarding that data focused on its usability, not only during the exercise but also during the management of a real emergency at a nuclear power plant.

# MONITORING OF THE RADIATION SITUATION BY THE FRS OF CR

## The measuring points

The aim is to obtain a detailed view of the radiation situation in the Czech Republic and to promptly detect any potential impact of radioactive substances on its territory. Monitoring by the FRS of the CR, using its forces and means, significantly complements the stationary measuring points of the SONS MonRaS network for monitoring the radiation situation (8). This network contains approximately 160 points, most of which are concentrated in the emergency planning zones of nuclear power plants. The FRS of the CR adds another 251 measurement points. These points are located at stations of the FRS of the CR, where a member of staff capable of operating radiometers is always on shift (24/7/365) and can report measured values via alternative communication channels in the event of a network connection failure. In addition to these communication possibilities, the stations of FRS of the CR are evenly distributed across the area of the Czech Republic.

## Measurement, data collection and preliminary evaluation

Measurements of dose equivalent rate are carried out every day at every station of the FRS of the CR at 8:00 a.m., and on weekdays also in the chemical laboratories of the Czech Fire and Rescue Service at 8:00 a.m., at the same location pre-selected for each station or chemical laboratory.

There are predefined reasons for not carrying out the measurements:

1. The fire brigade placed at the stations carries out more important emergency interventions.
2. The detection device was sent for recalibration.

The dose rate is measured using hand-held radiometers DC-3E-98 (9). For data processing purposes, the dose rate is considered identical to the dose equivalent rate. By 9:00 a.m., data from the region is collected at the regional operational and information centers (OPIS). By 10:00 a.m., they are then collected centrally at the National Operational and Information Center (NOPIS).Here, a preliminary evaluation of the data is conducted daily to identify gross errors, such as incorrect device readings or incorrect data format.

If possible, the errors are corrected by a NOPIS employee. If the measured value deviates from the background levels common in the Czech Republic (approximately 0.3-3 μSv/h), the fire brigade from which the values come is informed via NOPIS and KOPIS, and another measurement is carried out. If the dubious value is measured repeatedly, the territorially competent chemical laboratory of the FRS of CR is called to the site to verify the measurement and remeasure the value.

## Data evaluation

Depending on the severity of the security situation, subsequent evaluation of the measured data is carried out either every day of the week or only on working days, with the option to immediately call a member of staff to evaluate the data in the case of a sudden deterioration in the security situation.

The evaluation consists of checking the data, merging data from individual regional fire departments, and creating charts and maps that clearly and understandably depict the radiation situation.

The first of the generated reports is a histogram of measured values (Figure 1). A histogram is a graphical representation of data distribution using a bar chart with columns of equal width, where the column width indicates the width of each interval (class). The height of the columns expresses the frequency of the monitored quantity in a given interval (10).

This graph allows quick detection of values above the normal background level and of unnatural distributions of measured values. It provides a summary overview of the radiation situation. The distribution of the measured data automatically controls the width of the intervals (classes) and their number. When dividing into classes, the interval widths obtained according to the Sturges and Freedman-Diaconis rules are used. Such an approach ensures the best possible description of the measured data using a histogram during automatic processing (11), rather than dividing values into predefined classes. It is important to choose the correct interval width, as an incorrect width can significantly reduce the histogram's information value.

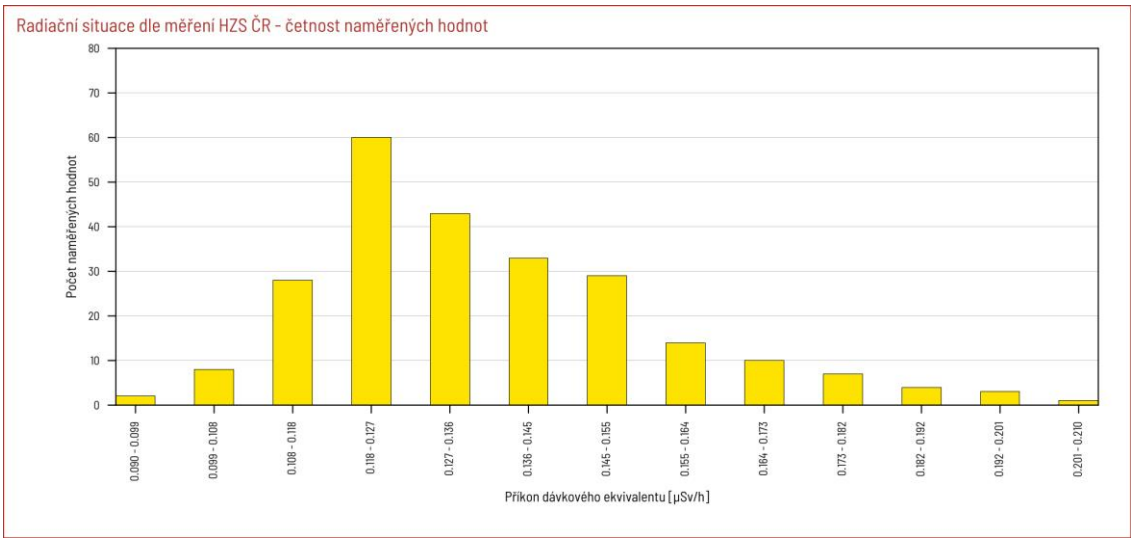



*Figure 1. Histogram of measured values. The x-axis represents the intervals of radiation dose equivalent rate, and the y-axis represents the frequencies of the measured values in these intervals.*

The Pareto diagram (12) of measured values (Figure 2) is very similar to the previously mentioned histogram. It is used to show the importance of individual categories. It is a type of chart that combines a column and a line graph. The columns showing the frequency for individual categories are sorted by size (largest on the left, smallest on the right), and the line represents the cumulative frequency. The line starts at the first column, and each subsequent point is increased by the value corresponding to the category to which it belongs, i.e., the one above which it is displayed in the graph. Thus, the line shows the accumulation (here, the sum) of the values in the current category and the categories to its left. The cumulative frequency is usually expressed as a percentage. The percentage values are then the second scale on the vertical axis of the graph. In Figure 2, this chart is divided into two subcharts for clarity.

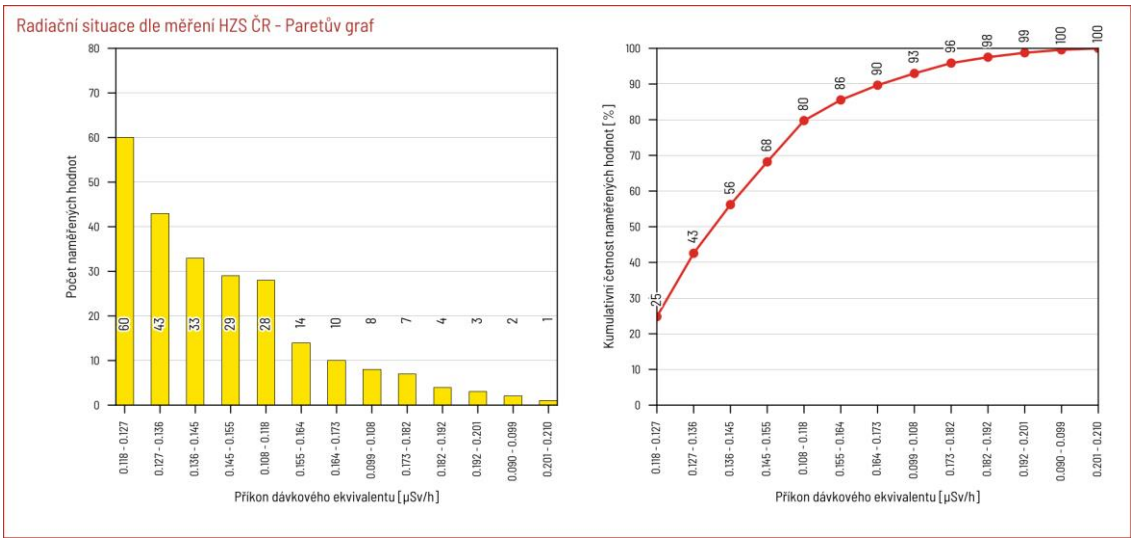



*Figure 2. Pareto chart of measured values. In the first sub-chart, as in the previous chart (Figure 1), the x-axis represents the intervals of radiation dose equivalent rate, and the y-axis represents the frequencies of the measured values in these intervals. But, in this case, the frequencies are sorted by magnitude. In the second sub-chart, the cumulative percentage of the values from the first chart is depicted.*

Another way to visualize measured data is in the form of maps (Figures 3, 4) using spatial information about the measured data, since each measurement is accompanied by information about the location on the earth's surface to which it is related, the location of the HZS CR station, or the HZS CR chemical laboratory.

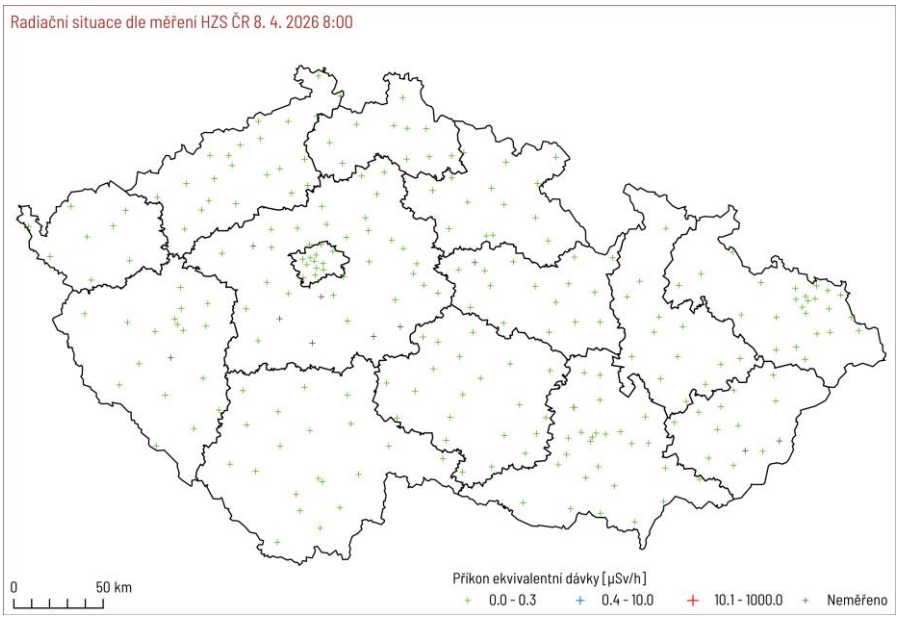



*Figure 3. Spatial distribution of measuring points with indication of the magnitudes of measured values.*

However, for estimating the effects of ionizing radiation on the population or the responding unit, it is not very advantageous to work with measured values in the form of a point layer (Figure 3). It is necessary to perform spatial interpolation to obtain a qualified estimate of the dose rate equivalent at any point in the Czech Republic (Figure 4).

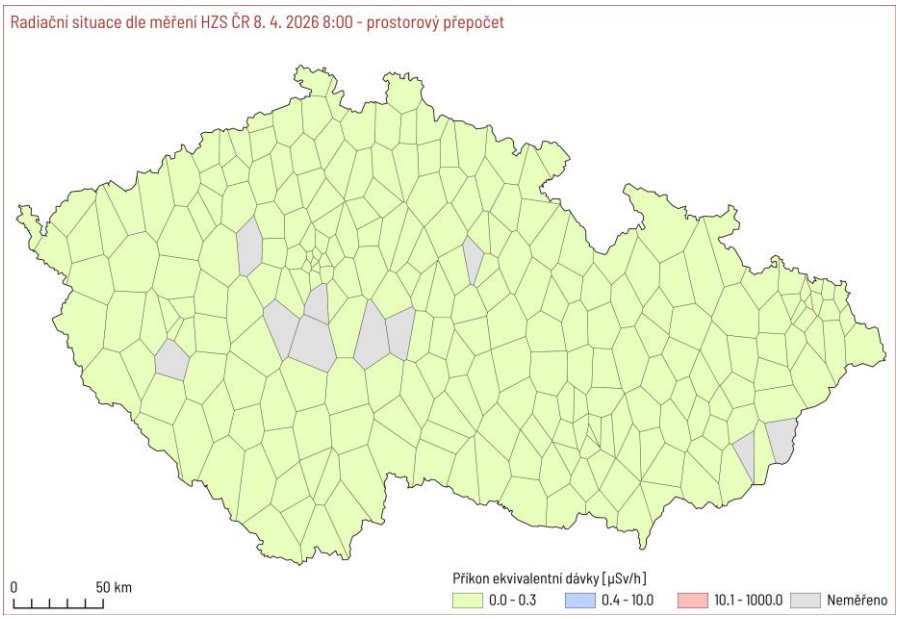



*Figure 4. Spatial interpolation of measured values using Thiessen polygons with indication of the magnitudes of measured values.*

There are several advanced methods for performing this interpolation (13). The simplest of these is the Thiessen polygon method. This mathematical procedure is known by several names, such as Voronoi or Voroné polygons, tessellation or decomposition, Dirichlet tessellation or Wigner–Seitz cells (14, 15), because it is used in several very distant fields due to its simplicity and straightforwardness.

The very idea of dividing a surface using Thiessen polygons based on a given set of points appeared as early as 1644 in the work of René Descartes, in which the author dealt with the arrangement of matter in the solar system.

In spatial interpolation using Thiessen polygons, the value at a given point where no measurement was made is identical to the value at the measured point closest to this point. The territory of the Czech Republic was therefore divided based on measurement points using Thiessen polygons so that all points of the area within a given polygon are closer to the generating measurement point than to any other measurement point. Subsequently, each polygon is assigned a dose equivalent rate based on the value determined at the relevant measurement point.

Spatial interpolation performed this way makes it easy to determine the received dose equivalent when passing through polygons with different dose equivalent rates, or to estimate it in areas outside the measurement points. The results obtained by spatial interpolation of measured data can thus serve as one of the important bases for qualified decision-making directly related to the protection of the life and health of the population and responding units.

In addition to maps and charts depicting the current radiation situation, a brief record of data processing is also created, which contains, in text form, the most important characteristics of the processed data set:number of measurement points in individual regions:

1. number of inactive measurement points with their identification,
2. number of measurement points with a zero value,
3. number of measurement points above the threshold level of 0.3 μSv/h,
4. statistical summary of data, such as maximum and minimum values and the arithmetic mean.

### The tools used for data processing

For data processing, a program created at the Department of Communication and Information Systems of the Ministry of Interior - General Directorate of the Czech Fire Service was used. The program was originally used to process maps and charts for the Statistical Yearbook of the Czech Fire Service and gradually for other statistical materials. Fortunately, it was possible to quickly adapt this program to process data on the radiation situation in the Czech Republic. The program is written in Python 3 and uses well-established Python libraries for data processing and plotting. For data processing, it uses the NumPy (16), Pandas (17), and Geopandas (18) libraries. For map creation, the ArcPy (19) library, and for graph creation, the Matplotlib (20) library.

## THE DATA FOR EMERGENCY MANAGEMENT SUPPORT DURING EXERCISE ZÓNA 2025

### The reference data

To select the reference data and its organization, the GIS experts from the FRS of the CR regions that are affected by the zones of emergency planning of nuclear power plants (6, 7, 21, 22) met with the GIS experts from the General Directorate of the FRS of the CR to carefully review the content of the Central Data Warehouse of the FRS of the CR. Upon mutual agreement, the data with potential for use in emergency management at nuclear power plants were identified and grouped into categories. The following categories were chosen:

1. Integrated Rescue System. The category contains spatial data on both professional (FRS of the CR) and volunteer fire brigades, the Police of the Czech Republic, and emergency medical services, mainly the locations of their stations and areas of responsibility.
2. Dukovany Nuclear Power Station. The category contains spatial data on evacuation routes, routes for emergency service vehicles, the internal structure of the emergency planning zone, traffic control in the emergency planning zone, decontamination stations, and checkpoints on the zone borders.
3. Temelín Nuclear Power Station. The same data as in the previous case, plus a zone of forbidden navigation on the Vltava River.
4. Unified Warning and Notification System. Data on sirens and other sirene-like systems, including data on the control signal transmitters.
5. Administrative division/subdivision of the Czech Republic. This data was enriched with information on the population, namely the numbers of permanent and non-permanent residents.
6. Data concerning population protection in the South Moravian Region (region affected by the emergency planning zone of the Dukovany Nuclear Power Station). The region-specific data were included in accordance

with the demand of the FRS of the CR personnel responsible for crisis management. The data in this group concerned the places where people with limited orientation and mobility are placed (such as older people's homes or care homes, and preschool and school education centers), as well as places where farm animals are placed. It also contains data on critical infrastructure.

7. Data concerning population protection in the Vysočina Region (region affected by the emergency planning zone of the Dukovany Nuclear Power Station). The same data as in the previous case.

### The data depicting the simulated situation during the exercise

For the purpose of the exercise Zóna 2026, the simulated incident at Dukovany Nuclear Power Station was considered. The data depicting the situation was split into the following categories:

1. The data concerning the spread of the radioactive material after the incident.
2. The data depicts in detail various measures taken to protect the population.
3. Data from the mobile observation teams' exercise on the real equivalent dose rate during their journey across the emergency planning zone of the Dukovany Nuclear Power Station.

### The data publication and availability

After data selection, the data were transferred into a newly created spatial database containing data related to the nuclear power plant topic. Based on the data, the maps were created in ArcGIS Pro. Each previously defined data category was placed in a separate map, which was published as an ArcGIS Server map service. The published ArcGIS Server services were linked into a Terinos systém (23, 24), which enables serving customized map compositions to each user and managing user privileges for each published layer. Such an arrangement enables flexible editing of existing published layers and the addition of newly created layers, while still allowing users with only limited GIS knowledge to view layers that they need.

## THE LESSONS LEARNED

Based on the previously mentioned facts, the following approaches to supporting spatial data for emergency management at nuclear power plants should be formulated:

1. To address an emergency at a nuclear power plant, a system for collecting data on the radiation situation should be established.
2. Such a system should cover the state's entire area, not only the location of nuclear power plants. It should cover the state's area as uniformly as possible to estimate the current radiation situation and its temporal development.
3. The system should be regularly tested to identify its weaknesses and keep people trained.
4. The system should cover the entire life cycle of the collected data, from measurement through collection and processing to final data storage.
5. The spatial data that can support emergency management in the event of an emergency at a nuclear power plant should be identified and logically organized into groups.
6. The various scenarios of its usage should be considered. To meet the demands of these scenarios, the mechanisms for their publication should be established.

## CONCLUSIONS

Since its inception in 2022, the system for monitoring the radiation situation by the forces and means of the FRS of the R has operated seamlessly without any substantial problems, despite its simple means. The data is transferred between the regional operational centers and the national operational center of the FRS of CR via MS Excel spreadsheets, and for evaluation, a program is used that was primarily intended to generate charts and maps for the statistical yearbook of the FRS of CR. The system's simple design proved suitable and sustainable. The results of the evaluation of the radiation situation conducted by the FRS of CR are regularly submitted to the FRS of the CR management and to the SONS as a basis for decision-making. If necessary, more advanced algorithms can be deployed

for spatial interpolation of measured values, providing a better description of the radiation situation in the Czech Republic (25).

Luckily, until now (10th April 2026), no value has been detected that exceeds the maximum level of the normal background interval in the Czech Republic, which is from 0.05 to 0.3 μSv/h.

But after four years of system operation and the risks associated with the world's current turbulent security situation, we must ask ourselves whether there are ways to improve the system. The future improvement of the system should focus on the following areas to flexibly respond to current security risks:

1. Parallel execution of individual subtasks, which would allow full use of current computing capabilities and, at the same time, significantly speed up program execution and enable the corresponding output to be provided in an even shorter time than today.
2. Permanent storage of the measured values in the full-featured enterprise quality database with a suitable structure for its easy access and use across the FRS of CR.
3. The collection of data through the web-based interface, in addition to the current data collection system. Such an approach enables better enforcement of data consistency and quality.

In the unlikely event that the current security situation suddenly improves, the efforts to improve the system will not be wasted, as it can also be used to monitor radiation levels in the event of an emergency at a nuclear power plant in the Czech Republic.

The exercise Zóna 2026 demonstrated that the selection of the spatial data and its categorization were successful. The selected data fully met the spatial data needs during the exercise, and no additional data were requested from emergency management bodies. Also, the splitting of the data into the categories proved logical, and there were no complaints during the exercise about the selected category structures. Also, the methods for publishing the data were adequate and will be used in subsequent exercises and real emergencies.

As a result of the exercise, the spatial data, split into categories, was prepared and is ready for future exercises or real emergencies at nuclear power plants. Also, the ways to make data available to users are set.

Based on the previously mentioned facts, common guidelines focusing on selected aspects of spatial data support of emergency management at nuclear power plants were formulated. Such guidelines should be formulated as much as possible to help responsible personnel prepare for emergencies.

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## BIOGRAPHY



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I was born in Prague in 1973. In 1991, I graduated from the Institute of Chemical Technology in Prague with a degree in chemical engineering. After that, I worked in various research institutions and universities. In 2005, I joined the Fire and Rescue Service of the Czech Republic. I am currently a member of the Department of Information and Communication Technologies of the General Directorate.
My work here is now focused on various ICT, GIS, statistical, graphic, and programming issues.
My favorite technologies are Python, Java, JavaScript, CSS3, HTML, Oracle DB, PostgreSQL, SQLite, ArcGIS Pro, and CorelDRAW.
In 2024, I successfully finished my PhD study at Masaryk University, Faculty of Science, Department of Geography, where I studied cartography, geoinformatics, and remote sensing.