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Evacuation of a person in the event of an emergency at the nuclear fatality

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Abstract
Emergency planning is a set of measures and procedures for detecting and combating accidents or incidents at nuclear facilities. It is also intended for detecting, mitigating and eliminating the consequences of releases of radioactive substances into the environment during the handling of nuclear materials, radioactive waste or spent nuclear fuel and during the transport of radioactive materials, and ensuring the collective protection of the population. The evacuation of persons is an issue that has been closely and directly linked to the civil protection of the population and the system of protection against accidents and fires for a long time. In the field of protection against the effects of accidents and fires, the legislative term evacuation of persons is used. In the field of crisis management, legal regulations work with the term evacuation of the population. The population means all persons in places threatened by an emergency, with the exception of persons who will participate in rescue work, manage the evacuation, or perform other activities related to eliminating the consequences of the emergency. In many situations, evacuation of persons is a necessary process that can prevent loss of human life threats to health and the environment. The evacuation process is modified in practical applications into a number of different forms. The standard procedure, which involves quickly leaving the endangered area in the event of an emergency, does not fully express evacuation in its entirety. This mainly concerns evacuation processes associated with the threat of radioactive substances.

Keywords
Evacuation, accident, nuclear power plant, emergency.

Introduction

Evacuation is one of the basic measures of collective protection of the population and is carried out due to the necessary time limit for the stay of persons in the endangered area. The Act of the National Council of the Slovak Republic No. 42/1994 Coll. on Civil Protection of the Population in Section 3, paragraph 10 states that evacuation means the removal of endangered persons, animals, or things from a certain area. The Decree of the Ministry of the Interior of the Slovak Republic No. 328/2012 Coll., which establishes the details of evacuation, as a generally binding legal regulation, clearly sets out the tasks and measures for all authorities, organizations, legal entities, natural persons - entrepreneurs and natural persons in the field of population protection by evacuation. (Act. No 41; Decree No. 328/2012).

Practice brings situations where it is not possible to strictly distinguish between evacuation in terms of fire protection and evacuation in terms of population protection from hazardous substances in the area. In many cases, one can also speak of mutual connection or interweaving of these two types of evacuation. To solve the issue of people's evacuation, the priority aspects are mainly the scope of the measures carried out and their duration. For this reason, the current professional literature also divides evacuation in terms of the scope of measures into:

- **Evacuation in buildings** includes the evacuation of people, one or a small number of residential buildings, administrative buildings, technological operations, and other objects.
- **Territorial evacuation,** which includes the evacuation of the population from part or all of an urban area, or a larger territorial area, whereby the population is understood here as all persons in places threatened by an extraordinary event, with the exception of persons who will participate in rescue work, manage the evacuation, or perform other urgent activities. (Yoneyama et al., 2024; Zhang et al., 2024).

In terms of length (duration), evacuation can be divided into:

- **Short-term evacuation**, when the threat does not require (within 72 hours) long-term abandonment of the building (area). Evacuees do not usually need to implement measures related to aftercare, such as emergency accommodation and emergency meals.
- **Long-term evacuation** (over 72 hours) when the threat requires long-term abandonment of the building (space). Iplementing measures related to aftercare for evacuees, such as emergency accommodation and emergency meals, is usually necessary. (Brezina, Majchút, 2023; Dzermansky et al., 2021).

Territorial evacuation (sometimes called emergency or forced) is very important for preventing injuries and limiting the consequences of nuclear accidents. These evacuations are carried out during the initial phase of the response, until victims and their property can be protected from further threats of the emergency. When an accident occurs and a large number of people are at risk in one or several territories, the protection of the population requires ensuring the evacuation of the entire territory of a municipality, district, or region. Evacuation involves the mass movement of people from the accident site to multiple destinations by various means of transport. For example, in the Fukushima nuclear disaster, there were no direct fatalities in the initial phase, but more than 300,000 people had to be evacuated from this area to avoid radioactive effects from the nuclear failure of four of the six nuclear reactors. (Kim, G. and Kim, S., 2023; Steinhauser et al., 2014).

Evacuating a large number of people in a safe and timely manner is an extremely demanding task not only for management activities but also for a number of other processes and factors with socio-economic and environmental consequences. Therefore, the development of an evacuation management model is a useful tool for supporting effective decision-making, increasing the ability to respond to emergencies and disasters, and reducing adverse effects on people and the environment (Kovanič et al., 2024a Kovanič et al., 2024a; Kovanič et al., 2024b). The overall evacuation system in response to an accident at a nuclear facility includes a number of processes with various socio-economic and environmental consequences. These processes can be influenced by several factors, such as the method of special cleaning, decontamination, persons, things and equipment, or the availability of the means of transport used and the number of people evacuated. (Ohba et al., 2021; Wilson, 2012; Malesic et al. 2014).

Nuclear safety, in a narrower sense, can also be understood as the ability of the operator of a nuclear facility and the facility itself to ensure that the fission process does not get out of control or that radioactive substances generated during the fission process do not escape into the surrounding environment. The goal of nuclear safety is minimization. In this case, the effort is to minimize the occurrence of extraordinary events, which can be caused by multiple factors, to the greatest extent possible. Alternatively, if an event does occur, the task of nuclear safety is to minimize the release of radioactive substances into the environment and subsequently minimize their impact on the surrounding population living in the immediate vicinity of the nuclear facility. (IAEA, 2023; Corradini, Bier, 2017; Wheatley et al., 2016).

In the event of an emergency caused by a failure at a nuclear facility, it is necessary to inform the public promptly and thoroughly. For this purpose, the INES scale was created and introduced in 1990 by the International Atomic Energy Agency (IAEA). INES stands for International Nuclear Event Scale. This scale is used to assess the severity of an emergency that has occurred which is related to the use of nuclear materials. The scale has 7 levels and the boundary of each category is determined by the higher number (Figure 1). (Smythe, 2011).

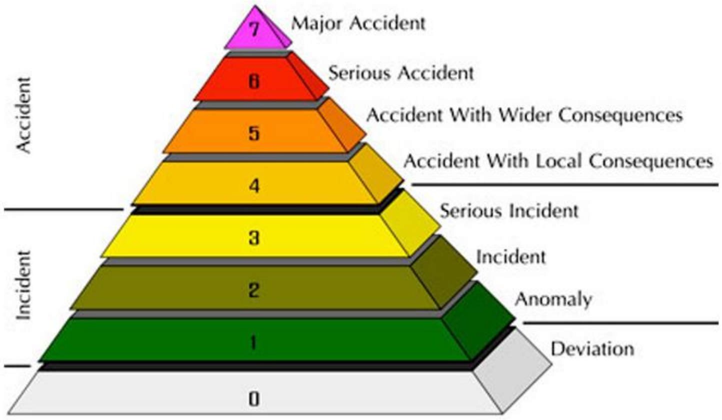

Fig. 1 The international nuclear and radiological event scale (IAEA, 2024).

The scale monitors the impact on three main areas that were affected by the occurrence of an emergency. These areas include the impact on people and the environment, the impact on radiation barriers and the impact on defence in depth. The impact on people and the environment can be understood as residents' potential exposure to higher radiation caused by the release of radioactive substances, or the scale evaluates the consequences arising in connection with this release. The scale further evaluates the impact on radiation barriers, which means their damage. Overall, it evaluates technological deficiencies that could have led to the release of radioactive material, but in this case without impact on the environment or the population. Finally, the scale evaluates the impact on defense in depth. By conducting in-depth defence, we understand the measures and the overall safety system of the facility. The scale, therefore, reveals its potential deficiencies that could have potentially prevented an accident (Kermisch and Lebeau, 2013; Mukherjee et al., 2014).

The impact on individual areas for each level of severity of the emergency event is shown in Table 1.

Nuclear energy is very important for humanity, and obtaining energy from the nucleus is a very important raw material on the market. However, since these processes can also have catastrophic consequences, great emphasis is placed on the safety measures of nuclear facilities. Furthermore, emphasis is placed on ensuring that work in power plants is carried out only by classified personnel. (Allramnah, 2023; Ashley et al., 2017).

Emergency planning is used to ensure safety and other safety-related factors. Emergency planning is a set of measures and procedures designed to detect and combat accidents, incidents and other extraordinary events that occur at a nuclear facility. This term also includes the recording, mitigating and liquidating of the consequences of a possible release of radioactive substances into the environment during the handling of nuclear materials, radioactive waste or spent nuclear fuel, the transport of radioactive substances and ensuring the collective protection of the population. (Blul, 2021; Hummel et al., 2020; Balážiková et al., 2023).

Tab. 1 General description of INES Levels (IAEA, 2024).

INES Level	People and Environment	Radiological Barriers and Contro	Defence-in-Depth
Major Accident Level 7	Major release of radio active material with widespread health and environmental effects r equiring implementation of planned and extended countermeasures		
Serious Accident Level 6	Significant release of radioactive material likely to require implementation of planned countermeasures		
Accident with Wider Consequences Level 5	Limited release of radioactive material likely to require implementation of some planned countermeasures. Several deaths from radiation	Severe damage to reactor core. Release of large quantities of radioactive material within an installation with a high probability of significant public exposure. This could arise from a major criticality accident or fire.	
Accident with Local Consequences Level 4	Minor release of radioactive material unlikely to result in implementation of planned countermeasures other than local food controls. At least one death from radiation	Fuel melt or damage to fuel resulting in more than 0.1% release of core inventory. Release of significant quantities of radioactive material within an installation with a high probability of significant public exposure.	

Serious Incident Level 3	Exposure in excess of ten times the statutory annual limit for workers. Non-lethal deterministic health effect (e.g., burns) from radiation.	Exposure rates of more than 1 Sv/h in an operating area. Severe contamination in an area not expected by design, with a low probability of significant public exposure.	Near accident at a nuclear power plant with no safety provisions remaining. Lost or stolen highly radioactive sealed source. Misdelivered highly radioactive sealed source without adequate procedures in place to handle it.
Incident Level 2	Exposure of a member of the public in excess of 10 mSv. • Exposure of a worker in excess of the statutory annual limits	Radiation levels in an operating area of more than 50 mSv/h. Significant contamination within the facility into an area not expected by design	Significant failures in safety provisions but with no actual consequences. Found highly radioactive sealed orphan source, device or transport package with safety provisions intact. Inadequate packaging of a highly radioactive sealed source
Anomaly Level 1			Overexposure of a member of the public in excess of statutory annual limits. Minor problems with safety components with significant defence-in-depth remaining. Low activity lost or stolen radioactive source, device or transport package.
NO SAFETY SIGNIFICANCE (Below scale/level 0)			

Material and Methods

Emergency preparedness at the Mochovce nuclear power plant

The Mochovce nuclear power plant, located in the cadastral area of the municipality of Kalná nad Hronom, is about 11 km from Vrábě, 12 km from Levice and 14 km from Zlaté Moravie. Approximately 159 thousand inhabitants live in the danger zone with a radius of 20 kilometres from the nuclear facility. The cities with the largest population in this area are Levice, with a population of 36 thousand; Zlaté Moravce, with a population of 13 thousand; and Vráble, with a population of approximately 9 thousand (Figure 2).

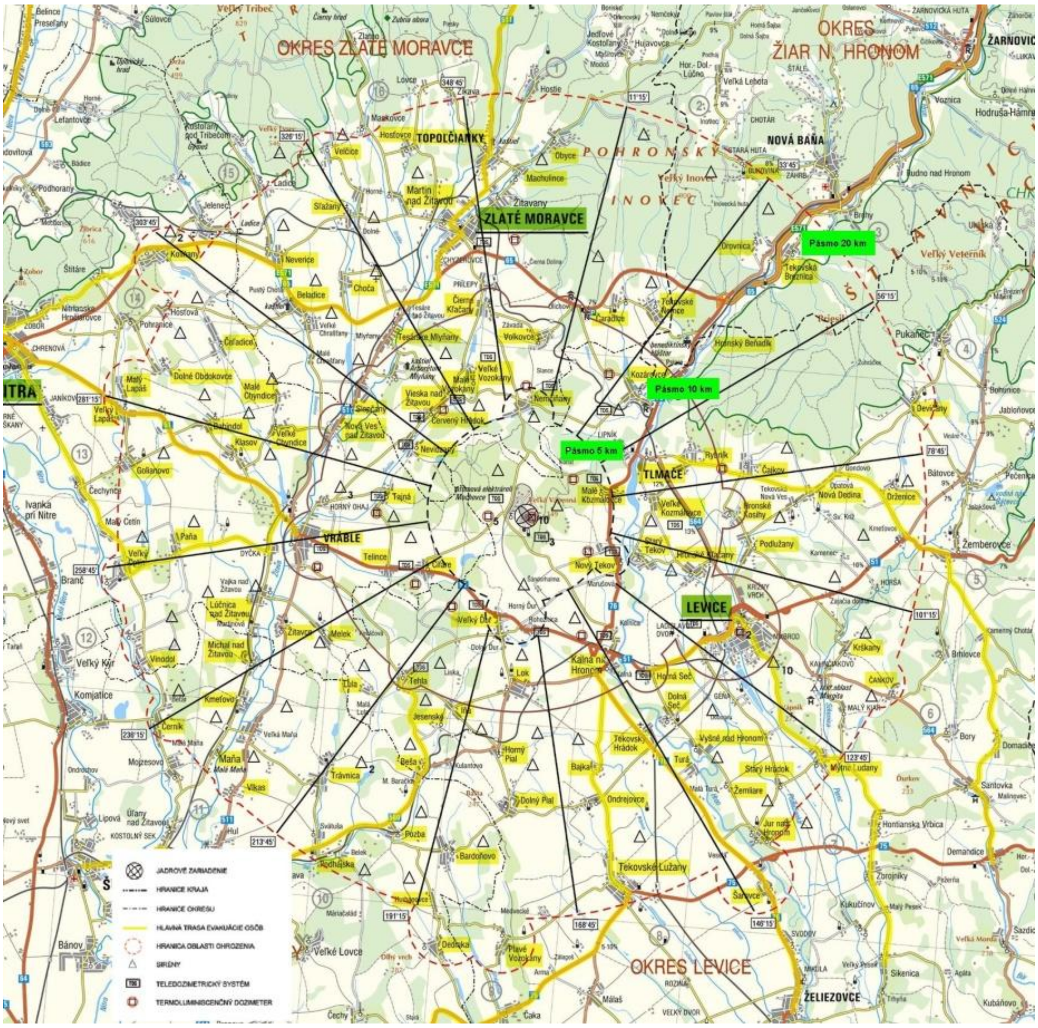

Fig. 2 Map of the danger area with marked zones and evacuation routes (source: elaborated by authors)

There are 2 reactors in operation at this nuclear facility. The power plant site includes the organizations SE-MO34, JAVYS (JZ RÚ RAO and JZ FS KRAO), for which separate emergency plans have been created with a link to "0 PLN/0001 - INTERNAL EMERGENCY PLAN EMO" (Rolinec and Balog, 2019; Pekár and Doni, 2019).

The SE-EMO nuclear power plant is classified according to risks into category No. 1, according to the IAEA document SSS GS-R-2 "Preparation and Response to Nuclear and Radiation Accidents". The operating permit for the SE-EMO nuclear facility for Unit 1 of the Mochovce NPP was issued by Decision of the Slovak Nuclear Regulatory Authority No. R 318/98 (28.10.1998) and for Unit 2 No. R 84/2000 (10.04.2000) to Slovenské elektrárne, a.s., Hraničná 12, Bratislava. (NRofSR, 2010).

The purpose of the internal emergency plan is to ensure the technical, personnel and documentation readiness of employees of the nuclear facility - Mochovce Power Plant and other external organizations that participate in work for nuclear facilities in dealing with events, with an emphasis on:

- reducing the risk of an accident or incident or mitigating its consequences,
- preventing serious health damage,
- reducing the risk of the probability of stochastic health effects occurring to the extent reasonably achievable (Mihok, 2020; Mišík and Hebda, 2024).

The internal emergency plan, emergency procedures and health measures plan are developed to ensure the emergency preparedness of employees of the Mochovce nuclear facility in the event of an emergency. It prescribes the necessary measures to protect the health of people and the environment not only on the territory of the Mochovce nuclear facility but also in the surrounding populated areas. (Talkhooncheh et al., 2021; IAEA, 2007).

Emergency response organization

The emergency response organization is established to coordinate and implement activities necessary to manage an emergency, prevent the development of the event, and mitigate or eliminate the consequences of this event. Since the occurrence of an emergency can be sudden, a temporary emergency response organization is established for an immediate response to the event, which immediately after the occurrence of the emergency performs the function and basic tasks of the emergency response organization. (Ardiansyah, et al., 2024; Mindas, et al. 2020).

The structure of the emergency response can be found in Figure 3.

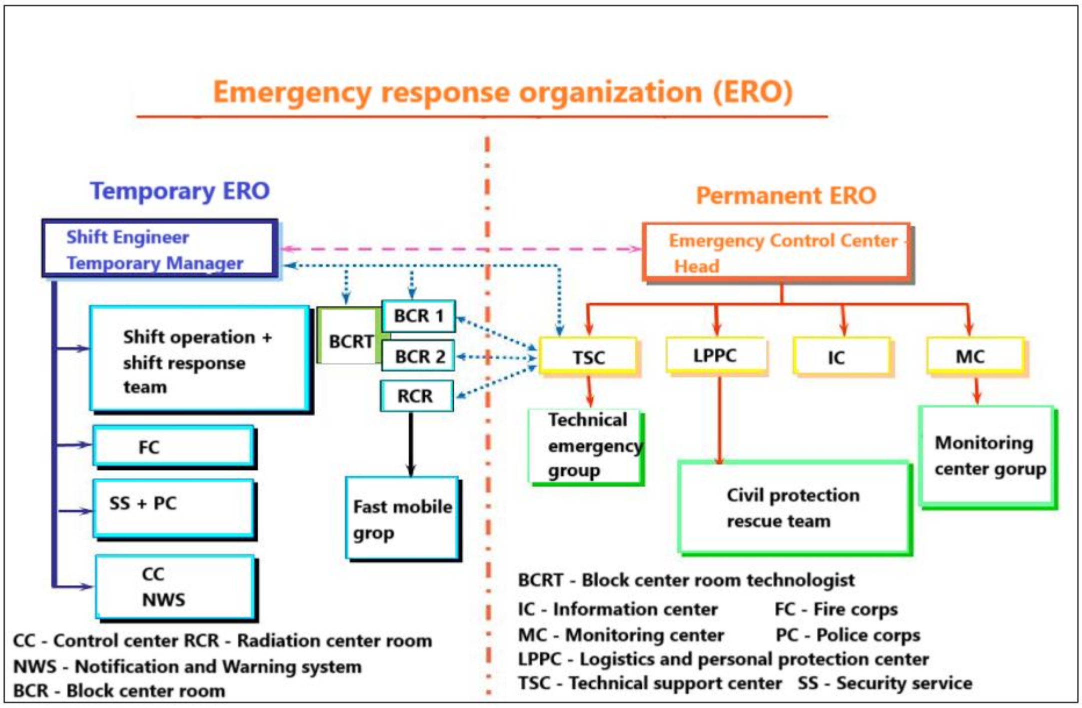

Fig. 3 – Emergency response organization in Mochovce power plant (source: elaborated by authors)

The temporary emergency response organization is made up of employees from all departments of continuous operation. The leader is the shift engineer, and the organizational structure is shown in Figure 4.

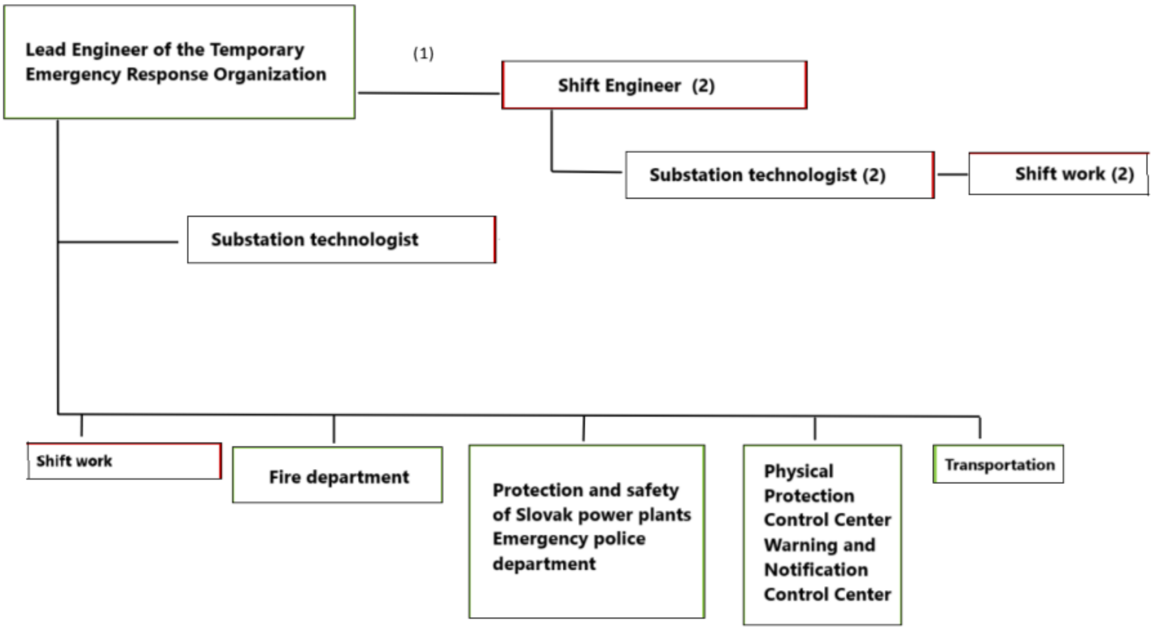

Fig. 4 Temporary emergency response organization (source: elaborated by authors)

Explanations:

1. For the start-up of unit No. 3, technological functions will be introduced into the emergency committee (Technical Support Center and Unit Control Room 3, 4) and a temporary emergency response organization, i.e. shift operations of units No. 3 and 4.
2. Functions and operational shifts that belong to the two-unit units are not affected by the event.
3. If an event occurs on both two-unit units simultaneously, the head of the temporary emergency response organization will be the shift engineer of the two-unit unit with a higher event classification. If the situation is the same, the head will be the shift engineer of units No. 1 and 2.

The temporary emergency response organization will be put on standby based on the order of the shift engineer to the individual components. Immediately after the event, activities will begin to be carried out, through which the power plant will be brought to its original and safe, non-emergency, state. Activities are also being carried out to protect people in the area of the Mochovce nuclear facility and the Mochovce power plant, and recommendations for protective measures for the vicinity of the nuclear facility are being prepared.

Results

Determining the duration of evacuation in the event of an emergency in the Mochovce NPP area

Evacuation, as one of the basic methods of population protection, ensures the safe movement of people from a threatened building to an open area and, if necessary, the transfer of people by means of transport to designated evacuation points.

The calculations will demonstrate evacuation from all objects to shelters, where each object has designated shelters with capacity. An individual representation of the shelter is shown in Figure 5. For calculation purposes, the shelter capacity will be calculated.

As shown in Figures 5 and 6, a permanent shelter with a capacity of 3,600 people is provided for objects 1, 4, 5, 6, 9, 10. A permanent shelter with a capacity of 1,500 people is provided for buildings 2 and 3. A permanent shelter with a capacity of 3,300 people is provided for buildings 11, 12, and 13. A permanent shelter with a capacity of 3,200 is provided for buildings 14, 15, 16, 17, 18, and 19, and finally, a permanent shelter with a capacity of 2,900 people is provided for buildings 20 and 21.

The evacuation process itself will be divided into five segments, namely:

- Evacuation group A, which will be evacuated from buildings 1, 4, 5, 6, 9, and 10, with a maximum capacity of 3,600 people.
- Evacuation group B, which will be evacuated from buildings 2 and 3, with a maximum capacity of 1,500.
- Evacuation group C, which will be evacuated from buildings 11, 12 and 13, with a maximum capacity of 3,300 people.

- Evacuation group D, which will be evacuated from buildings 14-19, with a maximum capacity of 3,200 people.
- Evacuation group E, which will be evacuated from buildings 20 - 21, with a maximum capacity of 2,900 people.

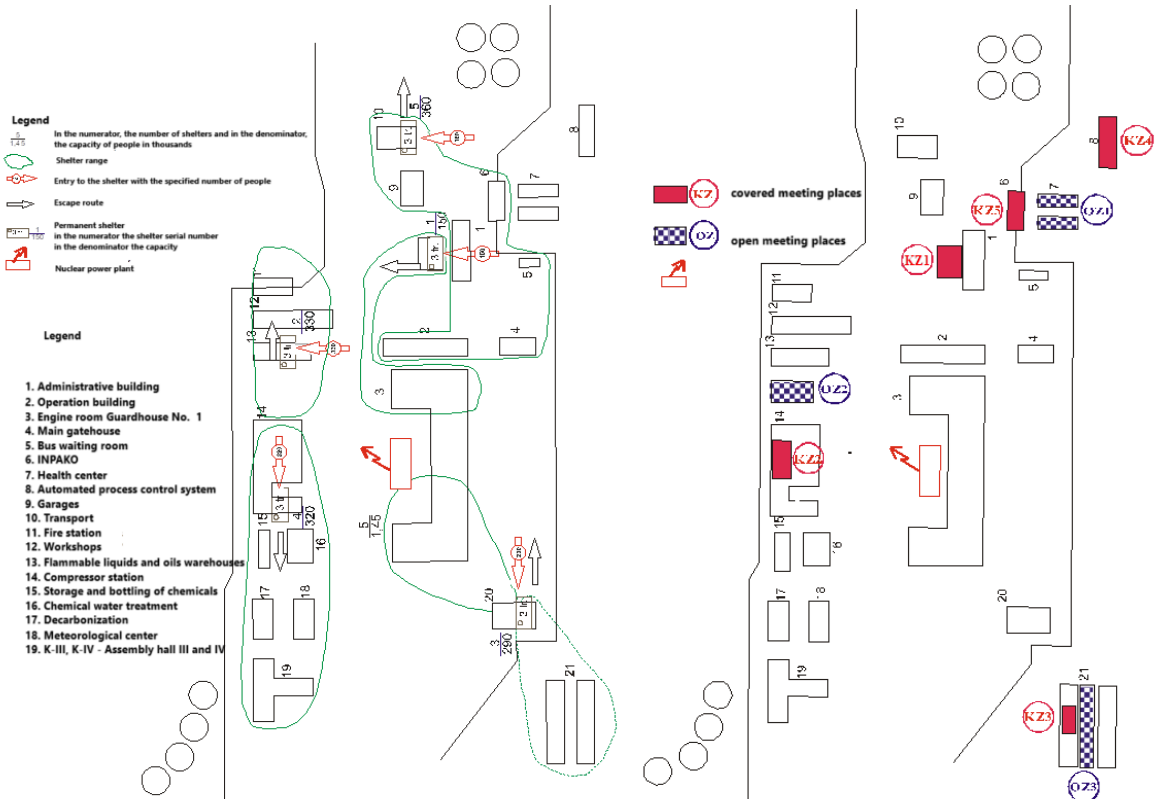

Fig. 5 Graphic plan for hiding employees and persons taken into care (source: elaborated by authors)

Forecasting the movement of people during an evacuation is a fundamental aspect of assessing its safety. It is necessary to clearly distinguish between the time it takes for people to move through the building and the total time needed to evacuate people from the building (RSET). RSET (Required Safe Egress Time) refers to the duration of time required for the safe evacuation of the occupants of a building after the signalling. RSET is calculated as the sum of three separate components – the alarm time, evacuation delay/pre-movement time and movement time. In general, an evacuation can be considered safe if the time required to evacuate RSET persons is less than, or at worst equal to the time available to evacuate ASET (available safe egress time).

Therefore:

$$RSET \leq ASET \qquad (1)$$

The time required for the evacuation of REST persons remains from the partial time intervals:

$$RSET = t_d + t_v + t_r + t_z + t_u \qquad (2)$$

Where:

t_d - time from the occurrence of an emergency to detection [min];
t_v - time from detection of an emergency to declaration of evacuation [min];
t_r - the period from the declaration of evacuation to the decision of the persons to initiate it [min];
t_z - time from the decision to start the evacuation to the actual start of the evacuation [min];
t_u - expected evacuation time (time for people to move through the facility) [min] (Poon, 2014).

The t_d, t_v, t_r and t_z values will be set to 1 minute. The expected evacuation time will be determined based on the following mathematical relationship:

$$t_u = \frac{0{,}75\,.l_u}{v_u} + \frac{E.s}{K_u.u}\ [\text{min}] \qquad (3)$$

Where:

E – number of evacuated persons [-];
s – coefficient of evacuation conditions [-];
v_u – speed of movement of people [m.min^{-1}];
K_u – unit capacity of the escape lane [os.min^{-1}.u^{-1}];
u – countable number of escape lanes [–];
l_u – length of the escape route [m]. (Baek et al., 2023).

Tab. 2 The value of the coefficient of evacuation people (STN 92 0201)

Evacuated persons	**Method of evacuation**	**The value of the coefficient of evacuation of people**					
		Escape route					
		Unprotected	Partially protected A	Partially protected B	Protected type A	Protected type B	Protected type C
Capable of independent movement	synchronous	1,0	1,0	1,0	1,0	1,0	1,0
	successive	Not applicable	Not applicable	0,9	0,8	0,7	0,6
With limited ability to move	synchronous	3,0	3,0	2,9	2,8	2,8	2,8
	successive	Not applicable	Not applicable	2,6	2,4	2,2	2,0
Incapable of independent movement	synchronous	4,0	4,0	3,8	3,6	3,6	3,6
	successive	Not applicable	Not applicable	3,2	2,8	2,6	2,4

The speed of movement of people and the unit capacity of the escape lane are defined in Table 3.

Tab. 3 Speed of movement of people v_u and unit capacity of the escape lane K_u (STN 92 0201)

Escape route	**Speed of movement of people v_u in meters per minute**		**Unit capacity of the escape lane K_u in the number of persons per minute**	
	Protected escape routes	Unprotected escape routes and partially protected	Protected escape routes	Unprotected escape routes and partially protected
On the plane	30	25	40	35
Down the stairs	25	20	30	25
Up the stairs	20	15	25	20

Table 4 shows the number of people who will be evacuated to individual shelters, with the maximum distance from the shelters being taken into account for calculation purposes.

Where: Number of people per shelter and their distance from the shelter.

Tab. 4 Number of people per shelter and their distance from the shelter (source: elaborated by authors)

Evacuation groups	**Number of people**	**Maximum length of escape routes [m]**
Evacuation groups A	**3 600**	**50**
Evacuation groups B	**1 500**	**40**
Evacuation groups C	**3 300**	**45**
Evacuation groups D	**3 200**	**55**
Evacuation groups E	**2 900**	**80**

According to equation (3), the t_u will be subsequently calculated, where only the escape routes are protected in the objects, and constants are inserted into the equations accordingly.

Evacuation groups A:

$$t_u = \frac{0{,}75\,.l_u}{v_u} + \frac{E.s}{K_u.u}\ \text{[min]};$$

$$t_u = \frac{0{,}75\,.50}{30} + \frac{3600.1}{40.1} = 91{,}25\ \text{[min]}.$$

Evacuation groups B:

$$t_u = \frac{0{,}75\,.l_u}{v_u} + \frac{E.s}{K_u.u}\ [\text{min}];$$

$$t_u = \frac{0{,}75\,.40}{30} + \frac{1500.1}{40.1} = 38{,}5\ [\text{min}].$$

Evacuation groups C:

$$t_u = \frac{0{,}75\,.l_u}{v_u} + \frac{E.s}{K_u.u}\ [\text{min}];$$

$$t_u = \frac{0{,}75\,.45}{30} + \frac{3300.1}{40.1} = 83{,}6\ [\text{min}].$$

Evacuation groups D:

$$t_u = \frac{0{,}75\,.l_u}{v_u} + \frac{E.s}{K_u.u}\ [\text{min}];$$

$$t_u = \frac{0{,}75\,.55}{30} + \frac{3200.1}{40.1} = 81{,}37\ [\text{min}].$$

Evacuation groups E:

$$t_u = \frac{0{,}75\,.l_u}{v_u} + \frac{E.s}{K_u.u}\ [\text{min}];$$

$$t_u = \frac{0{,}75\,.80}{30} + \frac{2800.1}{40.1} = 72\ [\text{min}].$$

Table 5 shows the resulting evacuation time to individual shelters.

Tab. 5 The resulting times for the evacuation of people (source: elaborated by authors).

Evacuation groups	t_d [min]	t_v [min]	t_r [min]	t_z [min]	t_u [min]	RSET [min]
A	1	1	1	1	91,25	95,25
B	1	1	1	1	38,5	42,5
C	1	1	1	1	83,6	87,6
D	1	1	1	1	81,37	85,37
E	1	1	1	1	72	76

Discussion

In the event of an emergency where it is necessary to evacuate and subsequently hide employees and persons located in the facilities of the nuclear power plant, it is necessary to proceed in accordance with the internal emergency plan of the Mochovce nuclear power plant.

When performing individual actions in accordance with the internal emergency plan, it is necessary to follow all instructions contained therein. It is necessary to emphasize that in the event of an emergency, the times necessary for the evacuation of persons and subsequent hiding of persons are not included in the internal emergency plan and are not even calculated. All activities are tested during regular exercises, and the listed activities are compared with those in the internal emergency plan. In the presented study, the times for evacuation and hiding of persons were recalculated, where the emphasis was placed on the maximum capacity of individual shelters. Of course, the number of nuclear employees is clearly significantly lower.

According to commonly available data, it ranges around 5000, while the number of people who may be in the area of the Mochovce nuclear power plant is diverse, taking into account the number of people who are carrying out the construction of new units of the Mochovce nuclear power plant, as well as the number of suppliers and external entities, including people who are, for example, on excursions or are in the Mochovce nuclear power plant facilities for certain reasons.

The calculated evacuation times mentioned in the present article are the maximum times with which it is necessary to operate in terms of the maximum capacity of individual shelters and people taken into care. Of course, before declaring an evacuation, it is necessary to perform certain procedures when evaluating events and their consequences, which are shown in Figure 6.

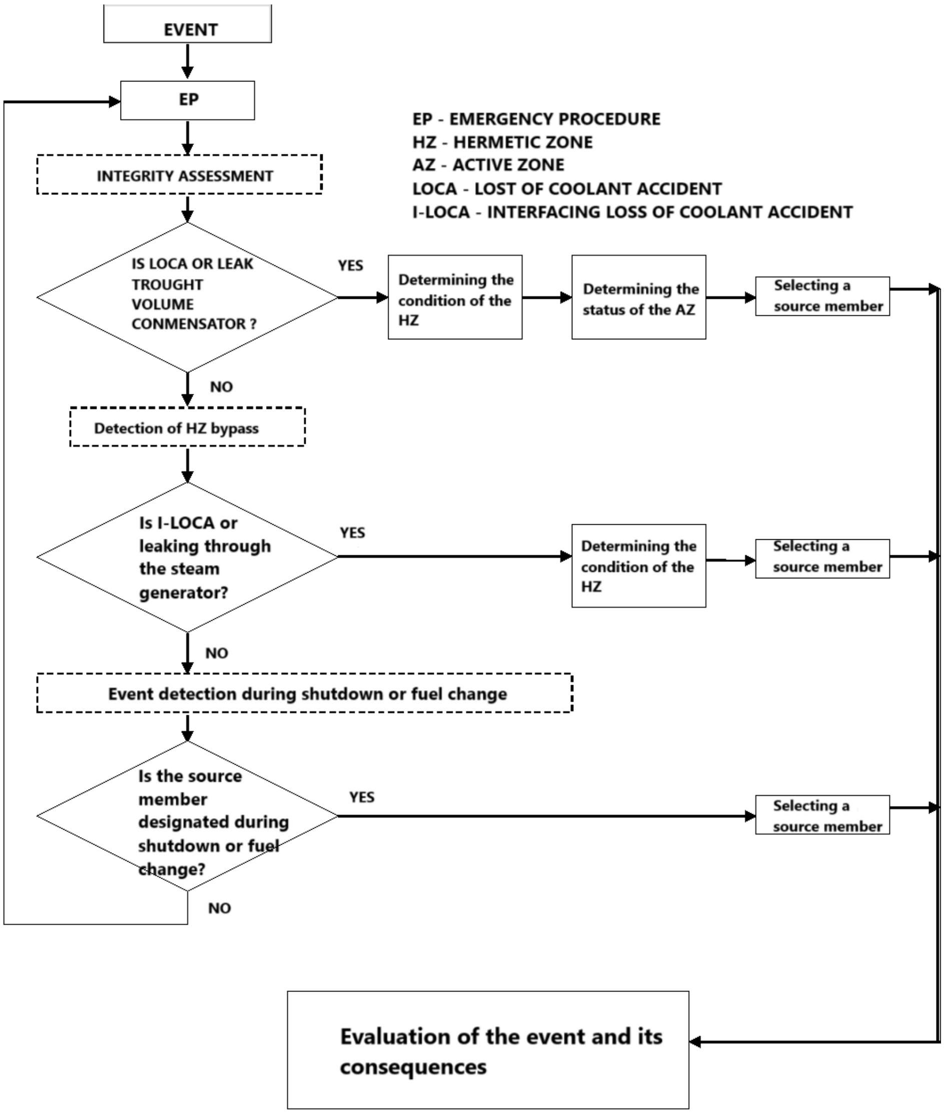

Fig. 6 - Flowchart of the procedure for assessing events and their consequences(source: elaborated by authors).

Conclusions

Evacuation activities are related procedures. The complexity of these procedures increases with the number of evacuees and the size of the evacuated facility. A nuclear power plant, as a large and extensive facility with special emphasis on evacuation safety, is a specific facility from the point of view of evacuation. In most emergency situations, when there is a release of radioactive substances, the evacuation must also extend to adjacent areas of the facility. This is one of the reasons why great emphasis is placed on safety in these facilities. Another reason is the danger to which members of the responding units may be exposed in the process of managing the situation. Therefore, the work focuses on the activities that are performed during evacuation and when managing situations at the Mochovce nuclear power plant and describes the duties of individual components and persons involved in managing the emergency situation.

The main purpose of implementing evacuation measures is to ensure the technical, personnel and documentary readiness of Mochovce Nuclear Power Plant employees and external organizations participating in work for Mochovce Nuclear Power Plant to successfully cope with events classified according to the classification, with emphasis on:

a) reducing the risk of an accident or breakdown, or mitigating their consequences

b) preventing serious health damage (death, serious injury)

c) reducing the risk of the probability of stochastic health effects (e.g. cancer, hereditary manifestations) to the reasonably achievable extent.

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