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Research Article

Risks and the management of construction in the environment of nuclear facilities

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Abstract: Everything in the world is about risk, from individual decisions to global manipulations, which is of fundamental importance in a nuclear power plant environment. The question is whether, in a given situation, this risk is acceptable or no longer acceptable. In some respects, the risk analysis applied to construction projects differs from the risk analysis applied to nuclear installations. For nuclear installations, the risk as such is nuclear risk. Primary safety is nuclear safety. Secondarily, we talk about other risks, for each of which it must be assessed whether there is an impact on nuclear safety. In view of this, for investments involving a nuclear installation, the risk analysis to be carried out must be carried out at two separate levels. In the case of civil engineering works in the immediate vicinity of a nuclear installation, it is particularly important to analyse the construction risks. The main problem for a nuclear installation is the unequal subsidence, which causes the building to tilt. The primary objective is to determine the value of the expected settlement, which forms the basis for an accurate determination of the risks. The first level is the traditional construction risk analysis, and then as a second level, each risk item should be classified from a nuclear risk point of view. In this paper, we present the nuclear exposure of construction risks and the possibility of mitigating these risks through a real-time monitoring system. In our research, we are concerned with the determination of the risks of deep construction activities and their impact on a specific nuclear site. We will also investigate possible risk mitigation activities that can be used in the nuclear power plant environment and their effectiveness.

Keywords: construction risk, risk analysis, nuclear power plant, geotechnical and building monitoring

I. Introduction

Everything in the world is about risks, from the decisions of individual people to grand global situations. Everything poses a risk. Each decision has elements of financial, environmental and sociological risk [1]. The question is whether or not this risk can be shouldered under the given circumstances.

Risk can be of many kinds, the specific project always determines the type of risk, who or what is the purpose of the risk, as well as what levels are allocated [2].

Even Karl von Terzaghi dealt with the issue of risks generated by specific construction projects. When and what sort of methods allow these risks to be mitigated. The construction site itself is a separate risk factor, as is the determination of the geotechnical parameters. Furthermore, the evaluation of the results and the choice of the evaluation method also pose significant risks [3].

In general, soil and water are the two most significant factors that determine the risk levels of a given building or structure. Knowledge of the soil is far more than extensive than knowledge of the physical parameters of the soil. The mineral composition of soils, their interaction with water, and their granulometric parameters all contribute to the exact determination of the load-bearing capacity of the soil in question. Each structure must be designed and constructed according to the construction site, taking into account the special conditions of the site [4].

Any structure we design or construct has a relationship with the soil and the rocky environment, so geotechnical risks are everywhere. The accuracy of the geotechnical parameters has a significant connection with the development of risks, which was supported by the testing of the movement of natural slopes. During the review of the risks, the parameters that greatly influence the safety of the given facility must be identified. Furthermore, it is necessary to determine exactly what risk mitigation options are available [5].

In the case of nuclear power plants, the continuous analysis of risks is of great importance. The purpose of our research is to define the construction risks of nuclear power plants and to present the analysis of construction risks also the possibilities for lowering the level of these risk.

II. DEFINING RISKS

The journal publishes Research article, Review and Mini review.

Design engineers and civil engineers have two goals for each structure:

1. as cost-effective of an implementation as possible,
2. achieving long-term and short-term safety.

The simultaneous implementation of the two aspects contradict each other to some extent, if we want a cost-effective design, the level of safety can drop substantially lower. Whereas, if we plan something with complete safety, the costs can rise sharply. There are options that create consistency between the two expectations and can significantly increase the safety of the structures. The end result is always created during an iteration process [4].

In the research compiled after the construction of Budapest metro line 4, an analysis was made of geotechnical risks and the possibility of mitigating them. The result obtained during the research points out that the accuracy of the knowledge of the soil, groundwater and all other basic geotechnical and engineering geological data greatly influences the risk level. A precise correlation between geotechnical excavation density and geotechnical risks has been described [6].

Since the first atomic reactor created by Leó Szilárd in 1942, the nuclear industry has been continuously developing. And with development comes a constantly tightening regulatory environment. The 1980 Convention on the Physical Protection of Nuclear Material provides the basic framework for the peaceful use of nuclear energy. Between July 4-8, 2005 the Convention was amended within the framework of a Diplomatic Conference organized by the International Atomic Energy Agency (IAEA). The amendment became necessary due to the fight against terrorism. The amendment was unanimously accepted and signed by all countries in Vienna. To help implement the Convention, the International Atomic Energy Agency (IAEA) issued the document on the Physical Protection of Nuclear Materials and Nuclear Facilities (INFCIRC/225/rev.5, 2011), which describes the necessary structure of each state system, the classification of nuclear materials, the summarizes the protection requirements for nuclear materials in use, stored and transported, as well as the requirements for the protection of nuclear facilities against sabotage.

Working with hazardous materials, including radioactive materials, results in significant extra precautions in the given power plant and on the entire site. This is because there are significant additional regulations and requirements for the design and operation of power plants using these hazardous substances to ensure safe operation. The activities that compromise safety must be precisely defined. Defining which directly threaten human life and which indirectly affect it. The International Atomic Energy Agency provides precise regulations for this under the title Guidelines for integrated risk assessment and management in large industrial areas issued under the number IAEA-TECDOC-944, classifying health and environmental hazards. It also gives suggestions for dealing with these dangers [7].

III. CONSTRUCTION RISK

Construction risk is multifaceted by construction risk, we consider countless risk factors, from the loss of stability of the structure to a significant delay in the implementation of the project. In many cases, the significant financial risk of the project must also be classified here [8].

In 1984 R.V. Whitman created the basis for the classification of construction risks of geotechnical origin. Over the years, the theory has outgrown the tight field of dealing with risks of purely geotechnical origin and has been extended to include various other risk factors [9].

In 2020, J.-L. Briaud drew three pre-defined boundaries, which clarify the expenses of the expected death and material losses associated with the occurrence of each event [10].

Geotechnical risks ultimately lead to the entropy of structures. The causes of entropy of structures can be determined and the probability of their occurrence can be provided with a mathematically quantified value, just as there is a way to categorize the causes of risks. [8] However we cannot only talk about the risks of structures, but each project also has its own risks. Construction risks must also be taken into account from the perspective of the project [11].

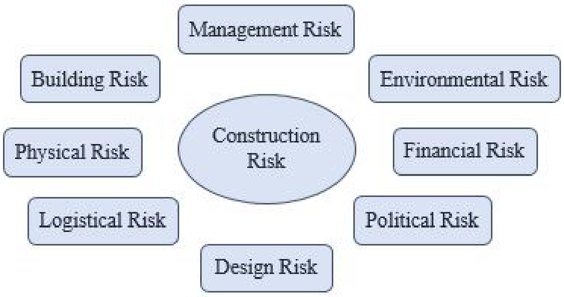


***Figure 1.** Complexity of construction risk*

Construction risk is a multifaceted concept, as shown in **Fig. 1**, it includes the project-level risks of the given construction. Such as:

1. Design risk: the risk of the adequacy of the design;
2. Political risk: influence of large and giga investments at national and international level;
3. Financial risk: the financial safety of the customer background, which ensures the continuity of the project's financing, and the sustainability of the project's budget;
4. Environmental risk: risks arising from geological, geotechnical, meteorological or other factors related to the site and its immediate surroundings;
5. Managerial risk: the risk inherent in the decisions of the project managers;
6. Execution risk: risk of "erroneous construction" during the construction phases, non-conformity;
7. Physical risk: possible pre-planned terror/violent action or random event, as a result of which the project will be structurally damaged, the duration and the cost of the construction shall increase;
8. Logistical risk: an impedimental circumstance or obstacle in the procurement and application of the entire, raw material and/or equipment necessary for the implementation of the project.

This list can of course be extended further, taking into account the specificities of each project. In each case, the location of the project, the sociological, demographic and political context must be taken into account. It is the combination of all these factors that makes it possible to accurately determine the project risk.

The determination and further management of construction risks can be defined as a significant task at the start of the project, in the planning phase. Construction risks are always project-specific. A unique procedure must be followed.

IV. Safety of Nuclear Power Plants

The safety of nuclear power plants is guaranteed by several separate methods.

We distinguish 3 main safety functions, all three safety functions must be able to individually ensure the safety of the power plant and its environment (**Fig. 2**).

The three safety functions:

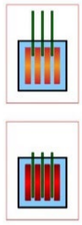
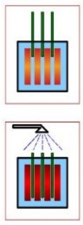
1. Regulation and closure of chain reaction	2.Cooling	3.Containment
		

***Figure 2.** Safety functions of nuclear facilities*

The purpose of the 3rd safety function is the containment of radioactive materials, which includes a series of engineering dams. The outermost engineering shell is the containment itself [12].

In addition, the Safety System must be distinguished. Among the safety-important systems of nuclear facilities, those that were designed and installed partially or exclusively for the purpose of performing safety functions are classified as part of the Safety System, in the nuclear industry, equipment whose sole function is to maintain safety is called a Safety System. In all cases, they become necessary only after an initial undesirable event. Their application and purpose is to maintain and restore safety, as well as to mitigate the consequences of undesirable processes.

Another element of the safety protocol is Protection in Depth, which is divided into 5 levels (**Fig. 3**):

1. Conservative design, high-quality construction and operation; Preventing abnormal operation and malfunction.
2. Adequate regulation, operating limits and prevention of exceeding them; Correct handling of abnormal operation and detection of malfunctions.
3. The start of automatic safety systems and the necessary human interventions; Handling plausible dimensioning accidents.
4. Additional measurements and action plans. Dealing with serious accidents, mitigating the consequences and mitigating the severity.

5. Accident prevention action plan; mitigating the consequences of radioactive emissions outside the facility [13].

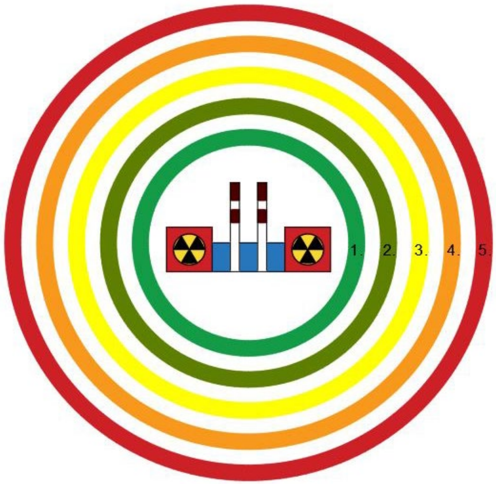


Figure 3. *Protection in depth*

The nuclear risk is synonymous with the full protection of the environment. No radioactive material may leak into the environment, which could endanger the environment or the lives of the surrounding people [14].

In the online book Risk and Safety in Engineering written by J. Köhler, the author writes in detail about the risks of impacts on structures and the probability of occurrence of risks. A separate section is devoted to the risks of nuclear power plants as a special structure with special risks. The conclusion states that the malfunction of nuclear power plants can occur as a result of one or more failures of the components and systems that make up the systems, thereby making the power plants generally safer.

The critical system of nuclear power plants is the reactor cooling system and their control valves, the malfunction of which can lead to the loss of reactor cooling, which in turn can have serious consequences, such as reactor damage and possible zone meltdown. Further studies have shown that both physical and human causes are important. Leaks and natural malfunctions are the main physical causes, while human errors result from inadequate maintenance and plant design errors [15].

In the case of nuclear power plants, we can differentiate external and internal threats. External threats are those that do not arise from nuclear technology, but from other external influences. There may be dangers arising from natural disasters, as well as dangers arising from human activity. This also includes construction risks.

In the case of nuclear power plants' large or early emissions, the occurrence frequency criterion of 10^{-6}/year must be met, and the transport of the excess heat to the final heat sink must be ensured. The frequency of its loss cannot be greater than 10^{-7}/year. That is, the annual frequency of the risk of serious accident operating conditions, which can lead to environmental pollution or catastrophe, cannot exceed 10^{-7}/year. This level of risk involves significant mortality risk and material risk.

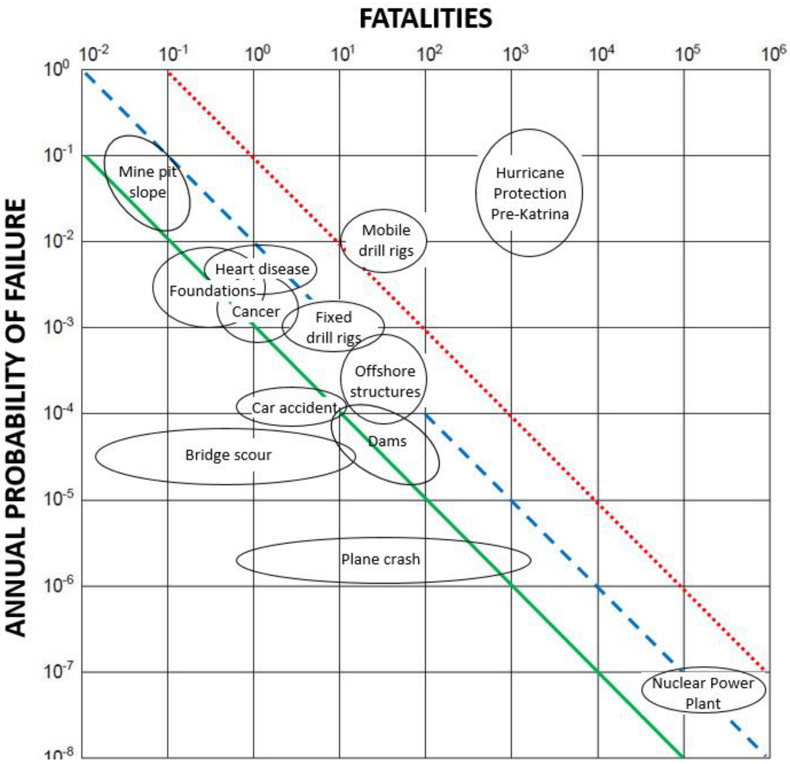


Figure 4. *Risks of serious accident operating conditions of nuclear power plants, associated financial and mortality risk*

We placed the operational state of serious accidents of nuclear power plants in the network of probability of occurrence, death and financial risk.

On the **Fig. 4** can be seen that the risk of nuclear power plants in a serious accident operating condition is very small, but the direct or indirect death rate associated with it can extend up to 1 million people, and the loss of production and the financial side of damage can also be measured in billions of dollars.

V. Geotechnical and Building Movement Monitoring System as a Guardian of the Environment

When opting for a monitoring system, it is essential to determine exactly what the purpose of the measurement is, what conclusions we want to draw from the results of the measurement during processing, and what exactly we want to measure with it.

In engineering, we can divide the measurable elements into three large groups:

- Movement measurements: settlement measurement; tilt measurement; twist measurement; deformation measurement.
- Voltage measurements: soil pressure measurement; pore pressure measurement.
- Change over time of all measurement results listed above.

The precisely formulated measurement goal also determines the type of measuring instruments to be used during the building movement and geotechnical monitoring system.

After the precise definition of the purpose of the measurement, it is necessary to compile the requirements for the instruments of the monitoring system and their priority.

Requirements in relation to instruments:

- **Reliability:** In all cases, the accuracy and resolution requirements of the data measured by the instrument must be precisely determined, as well as the accuracy and deviation.
- **Real-time processing of measurement results:** The processing speed of the measured results in nuclear facility environments requires real-time processing. That is, the measured result becomes visible at the moment of the measurement, and we receive a picture of the position and condition of the examined structure without delay.
- **Measuring lifetime of the instrument:** When opting for instruments, the criteria of the instrument's durability and the environment in which it should be placed in must be taken into account. Is outdoor or indoor placement required? With regards to the instrument being placed below the surface, should it measure below or above groundwater? Also, how aggressive the ground water or the soil is.
- **Method of data management:** The collection of data and their transmission to the specified server/storage location determines the level of data management of the monitoring system.

VI. Building Movement and Geotechnical Monitoring System Elements

Just as during every single construction investment, there are points and structural elements that must be specially measured and checked in the case of nuclear facilities.

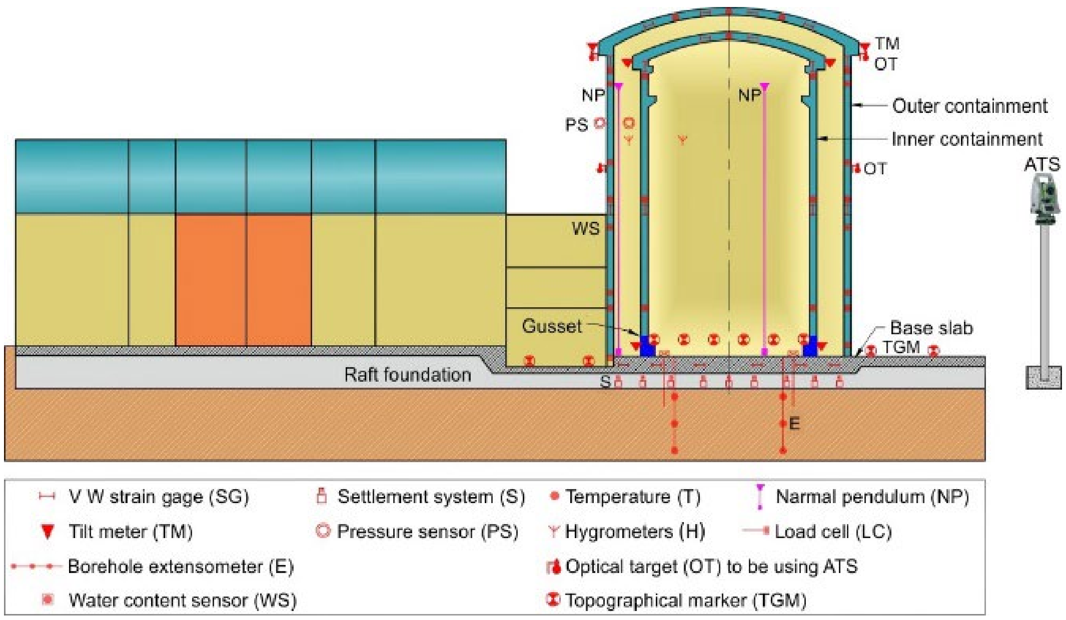


***Figure 5**. Outline plan of the monitoring system of nuclear power plants [16]*

Fig. 5 shows the recommended devices and measurement points that are necessary during the safe long-term operation of a nuclear power plant.

They can provide data on the state of the structural elements and built-in materials, and their state changes during operation. These proposed measuring devices go beyond the current research topic, which is the possibility of reducing construction risks by using real-time building movement and geotechnical monitoring systems.

Among the elements of the entire monitoring system, I shall put emphasis on and discuss those that promote safe construction investments and construction works in the unmonitored environment of nuclear power plants and other nuclear facilities.

As already summarized in the previous chapter, several types of movement can be measured with special instruments. Furthermore, in order to monitor the soil-structure interaction, voltages, changes in voltage, and displacements must be registered.

Several monitoring measurement systems can be distinguished for measuring displacements and deformations, which should be used in combination during the construction of each monitoring system (**Fig. 6, 7**).

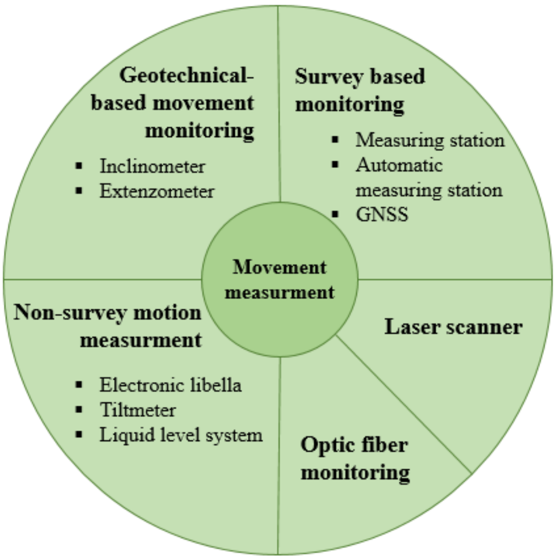


Figure 6. *Movement measurement instruments*

In addition to deformations and displacements, the other major area to be measured is the monitoring of voltage.

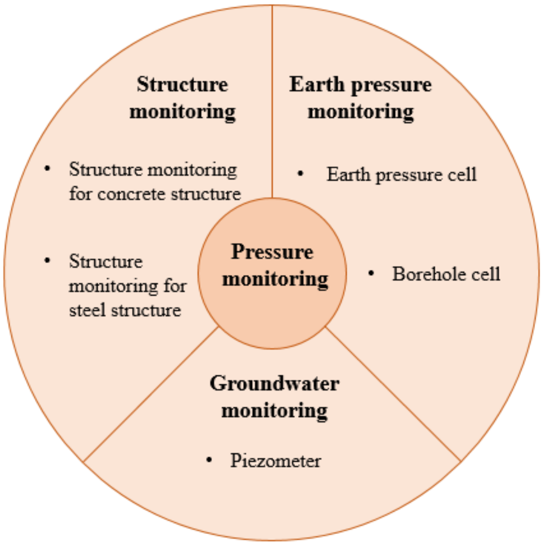


***Figure** 7. Stress measuring instruments*

In order to continuously analyse the soil-structure interaction, it is worthwhile to place monitoring elements for the direct measurement of voltage in the case of new constructions during the planning and construction period. These structural voltage devices can also be placed on existing structures, so the effect of increased voltage on the existing structure can be monitored. That is, in the case of existing structures, we can determine voltage indirectly. The voltage measuring device placed on the test section of concrete structures is able to determine voltage values acting on the structure from displacements between two fixed points. In the case of steel structures, it is possible to use measuring devices that can be fixed by welding or gluing. Similarly to concrete structures, in the case of steel structures it is also possible to indirectly determine voltage values from displacement measurements.

In both cases, the frequency of the measurements can be adjusted and programmed. Real-time measurement results can be determined with the devices.

VII. Management and Application of Data, Alarms:

The uniform management of certain measuring devices is crucial for setting up a real-time monitoring system. The reading results from each measuring device should be put together on a single surface, with the use of a standardized scale and system. The underlying reason is the need to make safe, well-founded decision during the evaluation of the obtained measurement results.

The data read from the measuring instruments has to be forwarded to a central data logger, which collects and transmits all the results to the central protected server, where the results are stored, while the processes of evaluation and display are synchronized.

International practice demonstrates that during the investment the data measured by the monitoring system is stored on 3 independent protected servers. One of the 3 protected servers is owned by the Investor, another belongs to the Contractor, and the third one is owned by the Independent Operator that manages the monitoring system. The data stored on the servers can only be modified and any data can be deleted by simultaneously entering an authorization password. In this case, unwanted changes to measurement results can be avoided.

In the design of the monitoring system, it is essential to determine those levels of criteria for each measurement point of the given building that serve as milestones during the operation of the monitoring system. For existing facilities, I think it is important to note that entering status "0" is considered to be a critical action. Therefore, test operation for a significantly long period of at least half a year, i.e. operations in order to set up status "0" are required before the commencement of the actual construction works. In order to determine the temperature and groundwater compensation levels, 1 full year is required for setting up status "0". The level of false alarms can be reduced to a minimum by properly determining status "0", as well as by specifying the associated cyclic curves for temperature and groundwater. The results are displayed in a geoinformation system prepared for the test facility.

Invariably, the determined alarm levels need to be indicated for each measurement type and point.

Once the alarm levels have been reached, the geoinformation system is to trigger an automatic alarm to the professionals concerned both via mobile phone and e-mail.

The applied elements of the planned monitoring system have to be defined in a manner where the measurement results provided by them can be managed in a geoinformation system.

VIII. Conclusions

The purpose of the risk analysis is to precisely define all work phases that may affect the operation of the power plant under protection at any level.

The risk analysis yields an accurate view of the risk index of the defined work phases.

The risk index is objective, based on which the necessary tasks and interventions can be worked out.

The risk analysis needs to encompass a precise description of the auxiliary technologies, proposals and other devices that can be used during risk mitigation. In many cases, on the level of permitting plans, in preparation for the events when their application becomes necessary. It is particularly important in a power plant environment where each technological change, further construction interventions are allowed only with the special approval of the competent authorities.

In the context of nuclear power plants, it is indispensable to define the auxiliary technologies accurately, and present them to the permitting authorities on the level of designs, and in the case of nuclear power plants to the local IAEA.

In today's world, where an energy crisis is starting to emerge, some nuclear power plants are being shut down in some places, whereas elsewhere new ones are being built, developed or transformed, or extended operating hours are being introduced, accurate risk analysis is essential to ensure safe operations.

New power plants are being erected, and are often built in the immediate vicinity of existing power plants that are already at the end of their operating lifetimes. The construction of new power plant units increases the risks associated with the safe operation of the existing power plant to an unprecedented extent.

What is to be achieved? The goal is that the entire construction of the new power plant units should consist of work processes that belong to an acceptably low (L) risk classification. If it cannot be achieved, then it becomes necessary to identify the technological options, changes in the construction schedule and auxiliary technologies that allow risks to be largely mitigated.

The risk analysis should present an itemized list of all the phases of construction, each of which needs to be provided with a specific risk index. In the case of activities classified as carrying medium, high and very high risks, a proposal for potential risk mitigation measures has to be made. When opting for risk mitigation potentials, feasibility and the degree of risk mitigation should be the principal considerations.

In the case of nuclear power plants, economical realization is not the goal to be set, rather the sole option should be maximum safety. Achieving this level of safety is essential even if an operating nuclear power plant becomes involved in another construction project. An example in this respect is when new units are constructed next to operating nuclear power plant units. This is how the level of risks affecting nuclear power plants can be minimized.

In the case of nuclear facilities, safety should be considered above all other aspects, and cannot be questioned.

Nuclear safety is the absolute priority. In some cases, however, construction risks can cause unforeseen, unexpected situations that to a certain extent can compromise the nuclear safety of the given nuclear facility. To avoid such situations, continuous monitoring is necessary for each intervention, construction activity in the entire area of nuclear facilities. It also extends to the elements of the monitoring system for geotechnical properties and the movement of buildings that is used during construction works.

In all cases, the elements selected for the monitoring system should complement each other, and their measurement results need to be managed in a geoinformation system. All the measurement results have to be integrated into a standardized alarm system. As part of the monitoring plan, an action plan corresponding to the given alarm levels needs to be drawn up.

For those risk elements where medium and high risk levels can be determined even after the implementation of risk mitigation actions, it is recommended to develop an additional safety action plan and intervention proposal as early as on the level of the planning of monitoring activities. The underlying reason is that in certain cases additional security activities may call for the construction of additional measuring devices as to be integrated into the projected monitoring system.

In all cases, the movements of building follow the movements occurring in the ground mass with delays in time, and therefore – in order to enhance safety – geotechnical monitoring system elements need to be added to building movement measurements.

All the measurement results have to be integrated into a standardized alarm system.

As part of the monitoring plan, an action plan corresponding to the given alarm levels needs to be drawn up.

Each projected monitoring system has to fit or be able to work in compatibility with the elements of currently operated measurement system for building movements in case there is such a system installed in the measurement area. The existing points of measurement have to be maintained and integrated into the system to be operated in the future.

By using a properly constructed real-time monitoring system, the probability of construction risks in the environment of nuclear facilities can be significantly reduced to almost zero.

AUTHOR CONTRIBUTIONS

E. Horvath-Kalman: Nuclear risk; risk analysis, geotechnical monitoring system.

B. Elek: Risk analysis, construction risk.

DISCLOSURE STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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