sciendo

Ybl Journal of Built Environment, Volume 9. Issue 1. (2024)
10.2478/jbe-2023-0005

REVIEW OF CONSTRUCTION RISKS IN A NUCLEAR POWER PLANT ENVIRONMENT

Eszter Horváth-Kálmán[1], Bakhtyar Saleh Ahmmad[2]

[1]Institute of Civil Engineering, Óbuda University, Budapest, Hungary
kalman.eszter@ybl.uni-obuda.hu
[2]Institute of Civil Engineering, Óbuda University, Budapest, Hungary
bakhtyar985@gmail.com

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 primarily nuclear risk. 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. 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 study, the nuclear exposure of construction risks will be presented.*

Keywords*: risk analysis, construction risk, nuclear power plant safety, geotechnical monitoring, acceptable risk, probability*

1. INTRODUCTION

Everything in the world is about risk, from individual decisions to major global situations.

Everything has risks. Every decision has financial, environmental, sociological risk elements. The question is whether that risk is acceptable or no longer acceptable in a given situation.

Several different type of risks can be present at a construction project, that is always determined / defined by the project itself, dependent on the risk owner / stakeholder, dependent on the purpose and the definition of risk levels.

Karl von Terzaghi has already taken into consideration the issue of the risks by specific construction projects. Furthermore, when and what methods allow these risks to be reduced. The specific site is a risk factor and the site-investigation method or also the measurement of soil parameters. [1].

Soil and water are the two most important factors that determine the risk levels of structures. Knowledge of soil is far more than knowledge of soil physical conditions. The mineral composition of soils, their interaction with water, and their grain structure specialities all play a role in determining the exact load-bearing capacity of a given environment. Each structure must be designed and built to suit the site, taking into account the specific conditions of the site [2].

Whatever structure is being built, it will be in contact with the soil or rock environment, so geotechnical risks are omnipresent. Leroueil and Locat have written a detailed study on geotechnical parameters, risk evolution and risk mitigation, supported by a study of the movement of natural slopes. In their review of the risks, they identified the parameters which have a major influence on the movement of slopes, i.e. which impair safety. In addition, the risk mitigation options available have been precisely identified [3].

For nuclear power plants, continuous risk analysis is of considerable importance. The aim of my research is to define the construction risks of nuclear power plants, to present an analysis of construction risks and to present options to reduce the level of construction risk.

2. DEFINITION OF RISKS

Design engineers and construction engineers have two objectives for each structure:

- economic efficiency,
- to achieve long and short-term safety.

Achieving these two aspects simultaneously trumps each other to some extent, if you want to design something economically, the level of safety needs to be greatly reduced. Whereas, if we design something with high safety, the costs can rise sharply. There are ways of reconciling the two requirements and can significantly increase the safety of structures. The final result is always the result of an iterative process [2].

The geotechnical risks and mitigation options for the construction of the Budapest metro line were presented. Furthermore, this study showed in detail that the accuracy of the knowledge of soil, groundwater and all other geotechnical and engineering geological parameters have a major impact on the level of risk. He determined the relationship between the density of geotechnical site-investigation and type of geotechnical risks [4].

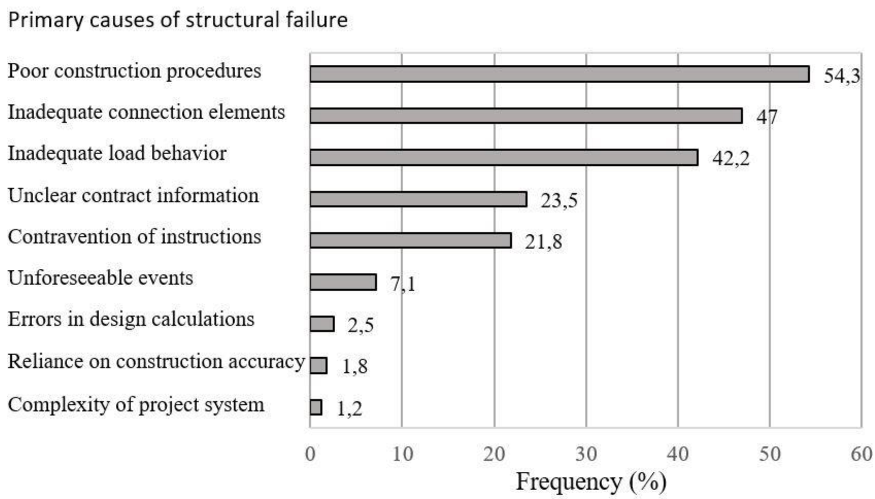

Figure 1. Risk and Safety in Civil, Environmental and Geomatic Engineering [7]

The nuclear industry has been developing steadily since the first atomic reactor was created by Leo Szilárd in 1942. This development has been accompanied by an increasingly stringent regulatory environment. The 1980 International Convention on the Physical Protection of Nuclear Material (CPPNM) and its Amendment provides the basis for the physical protection of nuclear materials. The Convention was amended in the framework of the Diplomatic Conference organised by the IAEA from 4 to 8 July 2005. The amendment was made necessary by the fight against terrorism, which was unanimously accepted and signed by all countries in Vienna. In order to assist the implementation of the Convention, the International Atomic Energy Agency (IAEA) has issued a document on the Physical Protection of Nuclear Material and Nuclear Facilities (INFCIRC/225/rev.5, 2011), which summarizes the elements of the state systems for implementation, the categorization of nuclear material, the protection requirements for nuclear material in use, storage or transport, and the requirements for the protection of nuclear facilities against sabotage [5].

Working with hazardous substances, including radioactive and radiological substances, requires significant extra precautions at the plant and the whole site. High risk activities and their mitigations activities must be defined. It is crucial to define which activities endanger human life directly and which ones have an indirect impact. The International Atomic Energy Agency (IAEA) Guidelines for integrated risk assessment and management in large industrial areas, number IAEA-TECDOC-944, provide detailed guidance on identifying high-risk activities, classifying hazards that are harmful to health and those that are harmful to the environment. It also provides recommendations for the management of these hazards [6].

3. CONSTRUCTION RISK

Construction risk is multifaceted. By construction risk, we mean a myriad of risk factors ranging from structural failure to significant delays in project completion. In many cases, it also includes the significant financial risk of the project [7].

In 1984, R.V. Whitman laid the foundation for the classification of geotechnical construction risks. Over the years, the theory has moved beyond the narrow scope of treating risks of purely geotechnical origin and has been extended to include various other risk factors [8]. The study was then supplemented with limits on the costs and deaths associated with the risks. [9]

Geotechnical hazards ultimately lead to the failure of structures. The causes of failure of structures can be determined and the probability of their occurrence can be mathematically calculated. It is possible to categorise the causes of risks [7].

But it's not just the risks of the structures that we can talk about, there are also specific risks for each individual project. We also need to consider project risks [10,11].

Construction risk is a multifaceted concept, as shown in Figure 2, it encompasses the project-level risks of a given construction. Such as:

design risk: the risk of design adequacy;

1. political risk: the influence of large and mega investments at national and international level;
2. financial risk: the financial security of the client's backing to ensure the continuity of project financing and the sustainability of the project budget;
3. environmental risk: risks arising from geological, meteorological or other factors relating to the site and its immediate surroundings [17,18];

4. management risk: risk inherent in the decisions of the project managers;
5. construction risk: construction defects inherent in the construction phases;
6. physical risk: a possible pre-planned act of terror/violence or accidental event that may result in structural damage to the project, increase construction time, construction cost;
7. logistical risk: a negative circumstance or obstacle in the procurement and use of all the raw materials and/or equipment necessary for the realisation of the project.

Figure 2. Complexity of construction risks (own figure)

The identification and further management of construction risks can be defined as a major task already at the project initiation and design phase. Construction risks are always project specific. A specific procedure must be followed.

4. NUCLEAR POWER PLANT SAFETY

The safety of nuclear power plants is guaranteed by several distinct methods. Three main safety functions are distinguished, each of which must be able to ensure the safety of the plant and its environment. The three safety functions are shown in Figure 3.

Safety Function 3 is the containment of radioactive materials, which includes a series of engineering barriers. The outermost engineering barrier is the containment building [12].

In addition, a distinction must be made between the Safety System. Among the safety systems of a nuclear power plant, we include those safety systems that are designed and installed partly or exclusively to perform safety functions. In all cases, their application is only required after an initial undesirable event and their purpose is to maintain and restore safety and to mitigate the consequences of undesirable processes.

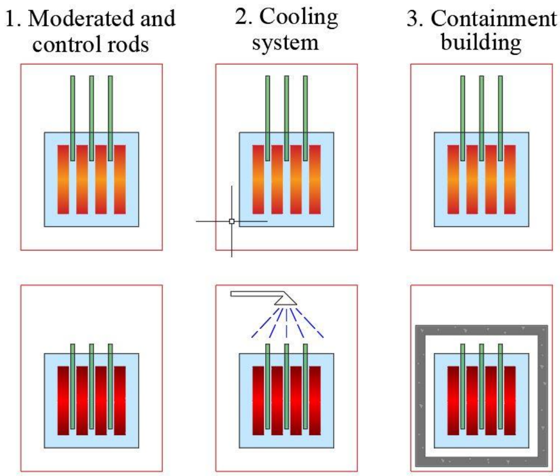

Figure 3. Nuclear power plant safety functions [12]

Another element of the security protocol is the Defence of Depth, which is divided into 5 levels:

1. Conservative design, high quality construction and operation; Prevention of irregular operation and failures.
2. Appropriate regulation, operating limits and prevention of exceeding them; correct management of irregular operation and detection of faults.
3. Start-up of automatic safety systems and necessary human interventions; Management of probable scaling accidents.
4. Supplementary measurements and measures. Management of severe accidents, mitigation of consequences and reduction of severity.
5. Accident management plan; mitigation of the consequences of off-site releases of radioactive effluents [13].

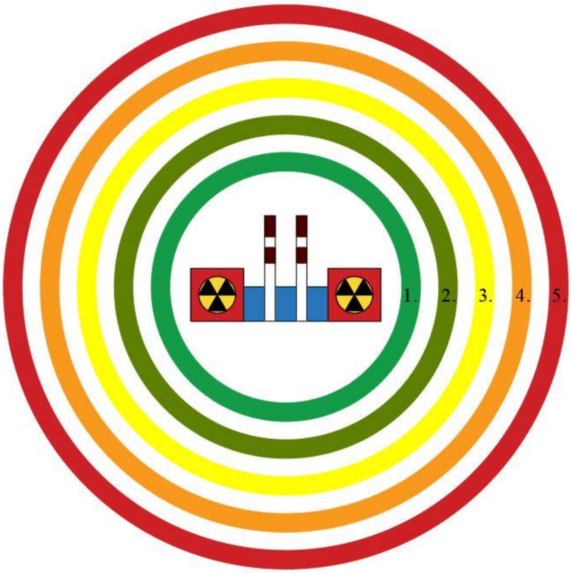

Figure 4. Defence of Depth [12]

Nuclear risk means full protection of the environment. No radioactive material can be released into the environment that could endanger the environment or the lives of people in the vicinity [14].

In the online book Risk and Safety in Engineering by J. Köhler, he writes in detail about the risks of impacts on structures and the probability of risks occurring. He devotes a separate section to the risks of nuclear power plants as a priority structure with priority risks. The research states that the failure of nuclear power plants is the result of the simultaneous failure of multiple systems that make up the power plant. The failure of one system does not result in a major accident, thus increasing safety.

The critical system in a nuclear power plant is the reactor cooling system and its control valves, the failure of which can lead to loss of reactor cooling, with severe consequences such as reactor damage and possible zone meltdown. Figure 5 gives an overview of the distribution of valve failures in the different subsystems of an operating nuclear power plant. It can be seen that most failures occur in the piping and instrumentation systems. Further investigation has shown that both physical and human causes are important. Leakages and natural failures are the main physical causes, while inadequate maintenance and plant design flaws are the causes of the majority of human failures [15].

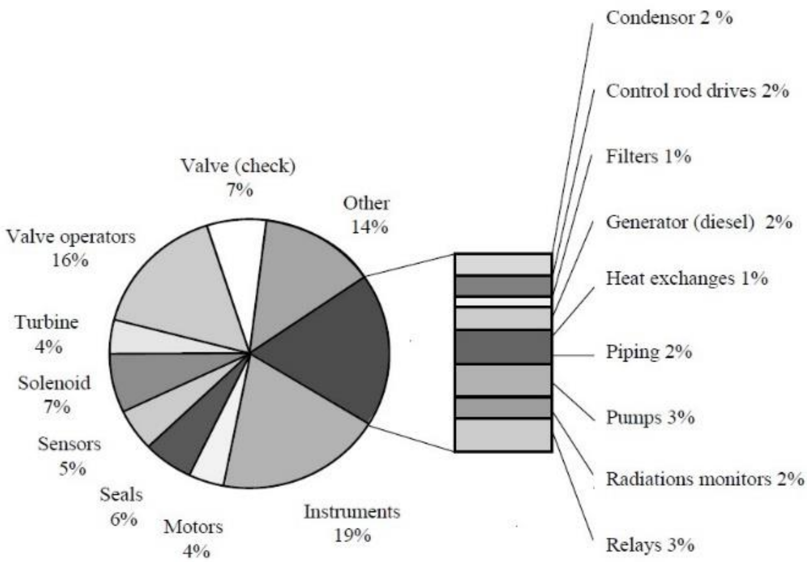

Figure 5. Distribution of valve failures on the various subsystems of boiling water nuclear power plants [15]

This is the point where nuclear risks need to be separated from construction risks.

For nuclear power plants, we distinguish between external and internal hazards. External hazards are those that do not arise from nuclear technology but from other external influences. There may be hazards arising from natural disasters and hazards arising from human activities. They also include construction risks.[16]

For nuclear power plants, a frequency criterion of 10-6/year in the case of a large or early release must be met and the transport of residual heat to the final heat sink must be ensured. The frequency of this loss should not be higher than 10-7/year. In other words, the annual frequency of the risk of a Major Accidental Operational Condition, which could lead to environmental pollution or disaster, shall not exceed 10-7/year. Such a level of risk is associated with a significant risk of fatalities and material risk.

The operating conditions of major accidents at nuclear power plants have been placed in a net of probability of occurrence, fatality and financial risk.
It can be concluded that the risk associated with the Severe Accidental Operational Condition of nuclear power plants is very small, but the associated direct or indirect fatality rate can be close to 1 million people, and the financial costs of lost production and damage can be measured in billions of dollars.

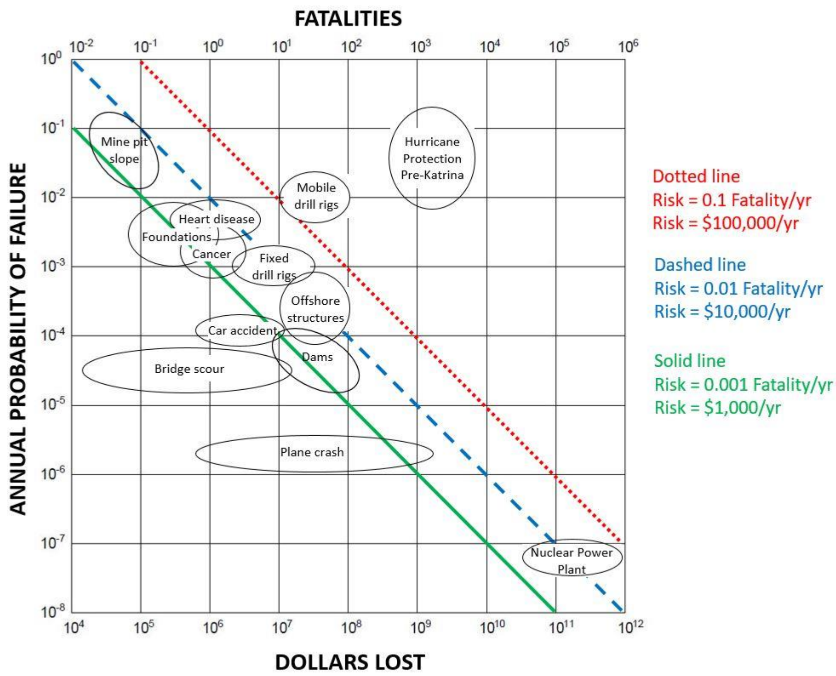

Figure 6. Calculated risk assessment of nuclear power plant and other major engineering installations (own figure adapted from Whitman's diagram)

5. CONSTURCTION RISK ANALYSIS

Construction risk analysis is a well-known procedure with a considerable literature background. The assessment should be compiled according to known guidelines, which present the probability and severity of risks in a matrix. The probability and severity matrix used contains 5x4 elements (see Tables 1, 2 and 3 below). The criteria for assessing each risk are: frequency, safety (life, natural and built environment, property) and delay.

The determination of likelihood (L) and severity (S) is based on detailed analysis, professional experience, international recommendations and the judgement of the risk assessor. Detailed risk analysis is not an exact science and requires a team of highly skilled professionals.

All works, buildings and structures, including nuclear power plants, have a minimum safety distance within which no or only limited activities can be carried out. In the risk analysis, these protective distances are the boundaries within which each activity must be defined and included. There may be cases where the additional risk of an activity is not significant, but where the new situation resulting from the activity may pose a serious risk.

For each project, it is important to list and define the risks in full, so that no negative circumstances are overlooked. To this end, the team of experts working on the project reviews, interprets and professionally weighs up the plans received as baseline data on the subject project.

In the construction and geotechnical risk analysis, only those activities are identified that arise from construction tasks or anomalies of geotechnical origin. A significant part of the geotechnical risk can be mitigated by further field investigations, engineering calculations and appropriate measures. These investigations, engineering geological surveys or auxiliary technologies are identified in the risk analysis as mitigation measures.

5 - Very likely	Impacts from frequent risk repeatedly experienced during the project, supported by surveys, project and other event statistics.
4 - Likely	Impact likely to occur from a risk that is expected to occur repeatedly during the project, supported by survey, project and other event statistics.
3 - Probable	Ad hoc impact from a risk that is likely to occur during the project, supported by survey, project and other event statistics.
2 - Unlikely	Impact from unlikely risk during the project, supported by survey, project and other event statistics.
1 - Rare	Impact from the unlikely risk during the project, supported by survey, project and other event statistics.

Table 1. Qualitative measures of likelihood [1,4,8]

4 - Catastrophic	Multiple deaths from injury or illness, both immediate and delayed. Release of chemically hazardous or radioactive material outside the facility; an Emergency Management Nuclear Emergency Action Plan is put in place, including an engineered barrier, plus a combination of additional safety systems such as a zoned public evacuation and other health and safety obligations. Loss of production exceeding seven days. Total losses exceed €100 million.
3 - High	For a death, injury or illness, whether immediate or delayed. A risk that modifies the design basis of a nuclear installation, where damage or modification to the design basis of the nuclear installation occurs that could result in localised ionising radiation or radioactive contamination of the site. Loss of production, work or equipment between one day and seven days. Total losses above €20 million but below €100 million.
2 - Significant	Reportable injury, illness or dangerous condition. Absence due to injury is more than one shift but less than 1 working day. Credible scaling accidents that require treatment. Automatic safety systems may be triggered and human intervention may be required. Total losses above €1 million but below €20 million.
1 - Small	Minor damage. No time loss due to injury or the injured person returns to work in the same shift after treatment. No significant damage to the work or equipment causing delay. Total loss, damage max. €1 million.

Table 2. Qualitative measures of impact [1,4,8]

Severity / Probability	1	2	3	4
1	1	2	3	4
2	2	4	6	8
3	3	6	9	12
4	4	8	12	16
5	5	10	15	20

Table 3. Risk matrix [1,4,8]

Risk Index	Risk classification	Sign
15-29	Very high	V
10-14	High	H
5-9	Medium	M
1-4	Small	L

Table 4. Risk matrix [1,4,8]

After determining the probability and severity of the risk, we obtain the risk index using the assessment matrix.

Risk index (RI) =
Probability of occurrence (L) x Severity of risk (S)
RI = L x S

The risk index is determined for both "initial risk" and "residual risk" after mitigation measures.

The aim is to keep risks to an acceptable, minimum level in all project cases.

6. CONCLUSIONS

The aim of the risk analysis is to identify precisely all the work phases that could affect the operation of the plant to be protected at any level.

The risk analysis provides an accurate picture of the risk index of the identified work phases.

The risk index is an objective index on the basis of which the necessary tasks and interventions can be constructed.

The risk analysis should include a precise description of the auxiliary technologies, proposals and other tools that can be used to mitigate the risks. In many cases, at the level of the permit plan, in preparation for the event that their use becomes necessary.

This is of particular importance in a power plant environment where any technological change or additional construction intervention is only possible with the approval of IAEA.

In the nuclear power plant environment, it is essential to define the precise auxiliary technologies and to submit them at the licensing level to the licensing authorities, in the case of nuclear power plants to the local IAEA.

In today's world, where an energy crisis is emerging, with some nuclear power plants being shut down and others being built or upgraded, converted or undergoing an extension of their operating life, accurate risk assessment is essential to ensure safe operation.

New power plants are being built, often in the immediate vicinity of operating power plants that are nearing the end of their useful life. The construction of new power plant units increases the risk to the safe operation of an operating plant to an unprecedented extent.

What is the objective? The objective is to ensure that the overall construction of new power plant units is carried out by work activities with an acceptable low (L) risk rating. Where this cannot be achieved, technological options, construction schedule changes and auxiliary technologies that allow a high level of risk reduction should be identified.

The risk analysis should itemise each construction phase, each of which should be assigned a risk index. For activities classified as medium, high and very high risk, a proposal for risk reduction should be made. In the selection of risk mitigation options, feasibility and the extent of risk mitigation are the primary considerations.

In the case of nuclear power plants, economic efficiency cannot be the objective, there is only one option, and that is maximum safety. Achieving this is also essential if the nuclear power plant in operation is to be involved in a construction project. This is the way to minimise the level of risk to nuclear power plants

REFERENCES

[1] **BAECHER G. B., CHRISTIAN J.T.**, "Reliability and Statistics in Geotechnical Engineering", John Wiley & Sons Ltd., 2003, ISBN: 0-471-49833-5

[2] **BASSETT, R.**, "A Guide to Field Instrumentation in Geotechnics: Principles, Installation and Reading", CRC Press, 2011.(1st ed.) https://doi.org/10.1201/b15432

[3] **LEROUEIL S., LOCAT J**., "Slope movements - Geotechnical characterization, risk assessment and mitigation", In: Proceedings of the sixth Danube- Europaen Conference on Soil Mechanics and Geotechnical Engineering, Porec, Croatia, 25-29 May 1998, pp. 95-106. ISBN: 90-5410-957-2 https://doi.org/10.1201/9781003078173-6

[4] **HORVATH T.**, "Geotechnical Investigation and Risk Assessment at Budapest Metro Line 4", In: 1 st International Congress on Tunnels and Underground Structures in South – East Europe „USING UNDERGROUND SPACE" Croatia, 2011.

[5] National Atomic Energy Office, "Safeguards supervision of nuclear facilities, nuclear and other radioactive materials, ionizing radiation generating equipment", [online] Available at: https://www.haea.gov.hu/web/v3/oahportal.nsf/web?openagent&menu=02&submenu=2_3 [Accessed: 4th May 2023;

[6] International Atomic Energy Agency, "Guidelines for integrated risk assessment and management in large industrial areas", Inter-Agency programme on the assessment and management of health and environmental risks from energy and other complex industrial systems (IAEA-TECDOC--994), 1998.

[7] **FABER MH**. "Risk and safety in civil, environmental and geomatic engineering", Lecture notes, Swiss Federal Institute of Technology, ETH Zurich, Switzerland, 2008.

[8] **WHITMAN R. V.** "Evaluating calculated risk in geotechnical engineering", Journal of Geotechnical Engineering, 110-2, pp. 145-188, 1984. https://doi.org/10.1061/(ASCE)0733-9410(1984)110:2(143)

[9] **BRIAUD J-L**, "Failure has consequences", Geostrata Magazine, 24(1), pp.18-20, 2022. https://doi.org/10.1061/geosek.0000047

[10] **SEBESTYÉN, Z., TÓTH, T.**, "A Revised Interpretation of Risk in Project Management", Periodica Polytechnica Social and Management Sciences, 22(2), pp. 119–128., 2014. https://doi.org/10.3311/PPso.7740

[11] **RAUL B. REBAK,** "Iron-chrome-aluminum alloy cladding for increasing safety in nuclear power plants", EPJ Nuclear Sciences Technologies, 3(34), 2017 https://doi.org/10.1051/epjn/2017029

[12] **KAROLYI GY.**, "Architectural and civil engineering aspects of nuclear safety requirements", BME, Web lecture, Budapest, Hungary

[13] International Atomic Energy Agency, "Assessment of Defence in Depth for Nuclear Power Plants", Safety Reports Series No. 46, IAEA, Vienna, 2005. ISBN: 92-0-114004-5

[14] **WAN W.**, "Nuclear Risk Reduction: A Framework for Analysis", UNIDIR, Geneva, Switzerland, 2019. https://doi.org/10.37559/WMD/19/NRR01.

[15] **KÖHLER J.**, "Risk and Safety in Engineering", Web lectures, Swiss Federal Institute of Technology, ETH Zurich, Switzerland

[16] **CRETU O., STEWART R., BERENDS T.**, "Risk Management for Design and Construction", John Wiley & Sons Ltd., 2011. ISBN: 978-0-470-63538-4 https://doi.org/10.1002/9781118984017

[17] **PAP, M., MAHLER, A**. "Comparison of Different Empirical Correlations to Estimate Permeability Coefficient of Quaternary Danube Soils", Periodica Polytechnica Civil Engineering, 63(1), pp. 25–29, 2019 https://doi.org/10.3311/PPci.13108

[18] **KÁPOLNAINÉ NAGY-GÖDE, F., TÖRÖK AKOS** "Types of Landslides along Lake Balaton Hungary", Periodica Polytechnica Civil Engineering, 66(2), pp. 411-420, 2022, https://doi.org/10.3311/PPci.18615