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Research and Development of Environmental Radiation Situation Assessment Procedures and Methods Following Serious Nuclear Accidents

Abstract

The environmental effects of severe nuclear accidents pose a great threat to the environment and to living organisms. Unfortunately, there have been several examples of this over time. In our work, we present development solutions and opportunities which a nuclear power plant or other nuclear facility can implement nuclear environmental monitoring even under extreme conditions. We will discuss systems and tools that can be used to increase the efficiency of the radiation situation assessment, helping decision-makers to make quick and optimal decisions, thus helping to minimise the environmental impact.

Keywords: severe nuclear accident, nuclear environmental monitoring system, radiation situation assessment, radiation detection

Introduction

The scientific achievement that defined the history of mankind was the discovery of radioactivity and its industrial technological application. Nuclear power plants receive enormous emphasis, but not only their usefulness, but also their dangers, which can even lead to a disaster.[4] Unfortunately, there have been examples of such situations in recent decades. That's why we are in parallel with the spread of nuclear power plants, the safety regulations are constantly evolving, so that energy extraction can be realised with the greatest possible nuclear safety and with the least environmental damage. In the following, in light of this, we will describe our research topic, which

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4 Manga–Kátai-Urbán 2016: 120.

includes development proposals and tool systems created in the spirit of environmental control. Our goal is to minimise the burden on the environment in the event of a possible serious nuclear accident and thus protect people's lives and health.

The long-term strategic energy policy was affected by Hungary, but many other countries are also following the extension of the operating time of the current nuclear power plants and the establishment of new nuclear power plants.

Monitoring system developed in the environment of nuclear facilities

First, we will present the Operational Environmental Radiation Protection Control System using the example of the Paks nuclear power plant. To illustrate this, we chose Figure 1 below, as the diversity and complexity of the systems can be seen in the context of this figure.

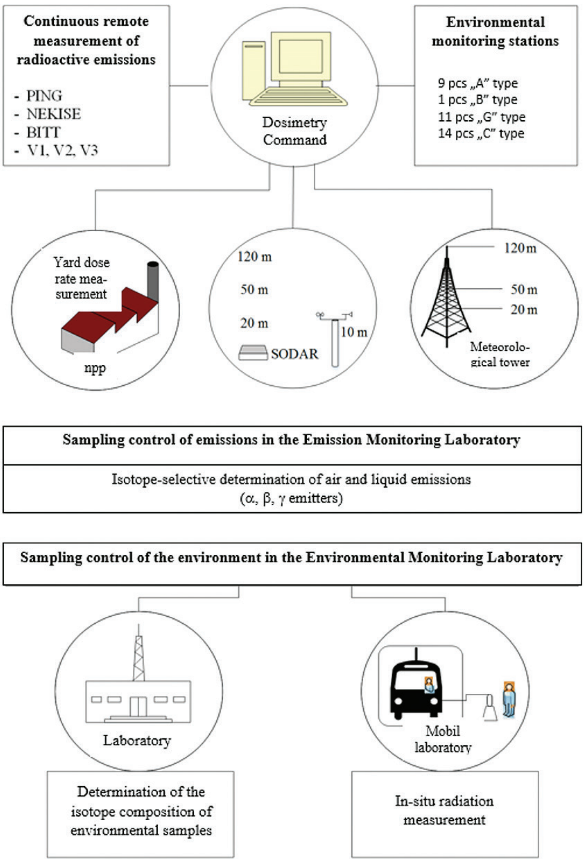

Figure 1: Operational scheme of the Operational Environmental Radiation Protection Control System of the Paks nuclear power plant

Source: MVM Paks Nuclear Power Plant 2022a: 12.6-3

The upper left side of the Figure 1 shows the transmitter systems for emission control, which include activities, activity concentrations, and dose rates based on gaseous and liquid emissions. On the right side above, you can see the telemetry systems for sampling and measuring gaseous media that have already been emitted from the power plant, which also monitor the aforementioned parameters. For both emission control and environmental control, this is supplemented by sampling-based measurements. The measurements take place in laboratory conditions after sample processing. These precision determinations with a small detection limit also allow us to infer the physicochemical characteristics of the emitted radioactive material, which, where appropriate, helps to delineate abnormal technology. In the event of a serious nuclear accident, however, we can primarily rely on rapid monitoring transmitter systems. From this point of view, the dosimetry controller – at the top of the figure, in the middle – has an important role, where the signals of the transmitter systems run. Here, permanent shift personnel monitor the incoming signals and if an anomaly is experienced or a warning and/or emergency level is generated, the "credibility test" of the measuring channel is carried out, i.e. – among other things – the radiation protection parameter of each technological system is compared, the radiation protection of the emission and environmental control with these measurements. In terms of the load on the environment, courtyard detectors play an important role, and they provide great help in identifying whether we are dealing with chimney or building emissions during a possible accident. In terms of escape routes, they also play an important role in the same way as systems providing meteorological parameters. Moving further down in the diagram, you can see a reference to the Environmental Monitoring Laboratory, which was located in the interior of Paks. In addition, the Emission Monitoring Laboratory performs measurements based on sampling, which is located in the controlled zone. The Environmental Monitoring Laboratory operates another Radiation Protection Measuring Vehicle, which in its current state is prepared for normal operating conditions and can be used for in-situ measurements and sampling.

Development of transmitter systems for nuclear environmental monitoring in the light of serious nuclear accidents

In the following, we will present our study and development proposals in the field of nuclear environmental control, which also takes into account the results of the so-called "stress test" after the severe nuclear accident in Fukushima, which all power plants in the world were required to do. Within this framework, the nuclear power plant of Paks prepared the Targeted Safety Review, which in terms of radiation protection covered the operational safety of radiation protection data provision under extreme conditions (earthquake and total power failure) and within this framework, the system elements that provide vital data in the event of a serious nuclear accident were reviewed. Most of our proposals in the field of nuclear environmental control have already been implemented, which we will describe below.

In connection with emission control, we examined the particle, iodine and noble gas (hereinafter PING) monitoring systems related to airborne emissions, as well as the isotope selective measurements of noble gases (hereinafter NEKISE). BITT probe measuring the dose rate of the air coming out of the twin chimney. Water stations that monitor the incoming and outgoing cooling water (V1, V2) and the so-called "above-balance" and treated wastewater (V3) emitted from the power plant. In connection with the environmental monitoring, the stations that monitor gaseous emissions from the power plant (A1-9, B, G1-11, C1-14). Meteorological systems that play an important role in determining the spread (SODAR, tower). Yard detectors that measure dose rate, measurements related to sampling in connection with emission and environmental control, and the available measuring vehicle.

In light of the above, we came to the conclusion that improvements can be made to the PING and NEKISE systems that measure airborne emissions, primarily by extending their upper measurement limit or in connection with changing the iodine monitor sample, however, taking into account the simplicity and economic aspects, the reinforcement of the BITT probe seemed most reasonable. Building this redundancy is advisable because it has a wide measurement range and has been providing reliable measurements for a long time. Its earthquake resistance and 72-hour protection against total voltage failure can be solved relatively easily. Even activity concentrations can be estimated from the dose rate data provided by the BITT probe. However, it is definitely advisable to supplement this measurement with another high-reliability probe that measures air circulation, from the point of view of determining the source of the emission.[5]

Earthquake resistance and protection against total loss of voltage with a bridging time of at least 72 hours is also necessary for water stations. The latter can be achieved in the case of the V1 and V2 stations by installing an additional pump with a smaller output than the operational one, which can provide even longer water samples that are continuously updated using batteries. As a result, the residence time of the sample in the sample container is longer, but it is still sufficient to maintain representativeness. In the case of the V3 station, the concept is slightly different, since there is no continuous emission here. Here, it is advisable to transform the current measurement technique in such a way that we can measure the emission line itself with a highly sensitive shield detector, which measures the activity of the medium flowing through the pipeline at the time of emission. The container can still be maintained for sampling, but it must be done in coordination with the flow conditions in the pipeline. In the interest of redundancy and diversity, our further development proposal was the establishment of a wireless data connection to the central data collector, the transition to PLC control and instead of many data concentrators and industrial computers, as well as the air conditioning of the container, which further strengthened the availability.[5]

Taking into account the efforts to extend the operating time and the possibility of integration into the future Paks 2 environmental monitoring system, the replacement of the station's power cables and signal cables should also be considered in an earthquake-resistant manner. Another option is to supply the stations with

[5] MTA EK – Kék – ScadaNet Ltd. 2016: 6–86.

aggregators, which requires the purchase of additional aggregators. In connection with A1-9- operational and B- reference station type stations, the protection against earthquakes and the protection of vital measurements against total voltage failure are also generally applicable. Furthermore, in the spirit of greater availability, the data collectors were equipped with air conditioning equipment and PLC control. The battery cells keep the so-called small-volume sampling unit, which is important in the event of an accident, in operation, which performs continuous monitoring of aerosols, elemental and organic iodine, and supplies the BITT probe with a high measurement limit outside the container with voltage with a 72-hour bridging time.

From a measurement technical point of view, replacing the NaI(Tl) heat-stabilised scintillation detector measuring organic iodine with a heat-compensated type has become expedient due to greater availability. Also from a measuring technique point of view, the "gating" of the spectrum of the four iodine isotopes based on previously difficult-to-verify mathematical efficiency calibration has been simplified to refer to the most typical isotope I-131.[5] The A1-9 and B-type stations also contain equipment important for sampling, such as a tritium and radiocarbon sampling unit, a large-volume sampling system, and vessels for dry and wet fallout sampling, but their development is not necessary from the point of view of a serious nuclear accident. Stations C1-14 do not play a role in distance measurement so we will not go into detail about them.

In the case of stations of the G1-11 type, there is no need to expand the solar cells providing autonomous power supply, which ensures the power supply of the dose rate meter with a large measurement limit. From the point of view of earthquake resistance, the support structure is qualified, the inspection of the fixing of the solar panels from the point of view of earthquakes is unnecessary, since the capacity of the batteries has been expanded as part of the development, which far surpasses the 72-hour bridging even in the event of the loss of the solar panel. Another tool under development is the replacement of radios, which was also a basic criterion for more stable communication at all other stations establishing wireless connections.[5] In connection with the 18 courtyard detectors, we also used several development opportunities. Before the development, the detectors only had a wired connection (signal cable, power cable), at our suggestion, they now also have a wireless connection and are capable of autonomous operation with a 72-hour bypass with the help of the local battery. In the framework of preparing for the danger of an earthquake, 5 courtyard detectors were moved outside the ruins, where the earthquake resistance of the surrounding object could not be verified, and a steel scaffolding with the appropriate foundations was provided, which meets the required earthquake resistance requirements.

Meteorological systems play an important role in connection with a possible serious nuclear accident, since the spreading characteristics can be determined with the help of these data. Current systems satisfy the concept of redundancy and diversity. As an advantage of the SODAR system, we would describe its simple structure without moving parts, which means that it can determine the wind profile from the reflection of the ultrasound emitted from the Earth's surface. At the time of its installation, this system already met the earthquake protection criterion system, however, we formulated development proposals regarding the battery capacity, so that it would also be able to provide the required 72-hour bridging, and we proposed the purchase of an additional aggregator to exploit the possibility of aggregator power supply. Regarding its installation location, we also have such insights that the turbulent effect of the buildings around it may gender-distort the values typical of the power plant's environment. From this point of view, the 120 m meteorological tower is in the right place, however, unlike the SODAR system, it has not been tested against an F2 tornado, and the devices placed on it also require more maintenance. All in all, the two systems complement each other well, where prioritised data is provided by SODAR.

In connection with sampling, we have already mentioned that in the case of a serious nuclear accident there is no time or opportunity to determine the data extracted from it, however, there are cases and types of accidents where laboratory processing and the data that can be extracted from them are crucial. Therefore, with Decree 15/2001 (VI. 6.) in accordance with the Emissions and Environmental Control Regulations approved by the authority, we would add sampling and procedures in operating conditions TA2-4 – for expected operational events and planning malfunctions – and TAK1-2 – for complex and serious accidents.[6]

Study of radiation situation assessment tool systems for nuclear accident prevention in the light of serious nuclear accidents

In the following, we will also present the nuclear accident prevention system through the example of the Paks nuclear power plant, and within it, we will review the tasks related to radiation protection, as well as define the areas where we see development opportunities. In accordance with the national provisions, the Paks nuclear power plant operates an Accident Prevention Organisation, the task of which is to manage the contents of the Comprehensive Emergency Response Plan (hereinafter referred to as ÁVIT).

ÁVIT includes, among other things, the Nuclear Accident Prevention Action Plan radiation protection-related tasks are carried out by the Radiation Protection Organisation with slightly more than 50 people. Instead of the Radiation Situation Assessment Section, Radiation Protection Equipment Insurance Section, the Radio-, Biological-, Chemical (hereinafter RBV) Group and the Exemption Group are included within the organisational unit. The Radiation Pollution Measurement Department and the Radiation Detection Department with the three Radiation Detection Squadrons are located within the RBV Group. Taking into account the possible occurrence of a serious nuclear accident, we now mainly examined the means of radiation situation assessment and radiation detection. We are doing all this because, in our opinion, the decision-makers in such a situation, in addition to the technological conditions, should consider this in the first instance in order to protect the environment and people.[7] One of the key tools for beam position assessment is propagation calculation software. In the case of the power plant, this includes two pieces of software. One is the so-called Dose on Lite (simplified online dose rate calculator) software

6 MVM Paks Nuclear Power Plant 2019b: 5–34; MVM Paks Nuclear Power Plant 2022b: 4–30.
7 MVM Paks Nuclear Power Plant 2019a: II. 17–19.

running within the framework of the Radiation Protection Control System, which determines the dose rate values up to a distance of 30 kilometres from the power plant by extrapolation based on the equivalent environmental dose rate of gamma radiation of environmental stations.[8] The other is the so-called TREX (Transport Exchange) program, which, knowing the source member, can calculate the spatial distribution of the emitted radioactive material using a Lagrangian approach, which takes into account propagation, decay and sedimentation.[9]

The calculations are performed for a 30 km area based on predicted AROME (Application of Research to Operations at Mesoscale) data provided by the super computer of the National Meteorological Service[10] or based on the site's meteorological parameters. Our development proposal regarding the software is to feed a complex software with the already available extended radiation protection parameters. In this way, the propagation calculation (with additions of the appropriate models) can be extended not only to the 30 km area of the power plant, but the radiation conditions prevailing inside and in the immediate surroundings of the buildings could be predicted with a real source term, which, updated with further real measurements, would give the most accurate forecasts possible for decision makers.

We mentioned earlier that the power plant has a radiation protection measuring car. This car can be equipped with hand-held sampling devices and hand-held instruments, however, in the event of a major nuclear accident, it is advisable to equip it with greater capabilities. Therefore, our development proposal is that the radiation-shielded – armoured – troop transport car, which can also be found in the power plant and serves as part of accident prevention, equipped with off-road capabilities and external and internal dose performance meters, should be further developed and/or a new acquisition realised by increasing additional capabilities. The capabilities must extend to other radiation measuring devices integrated in the car, covering various radiations – α, β, γ – and measuring ranges, dose meters, route monitoring systems, surface contamination meters, gamma spectrometers, sampling devices, air, liquid, environmental samples. For the placement of marking devices suitable for marking contaminated areas, for the supply of filtered air for collective protection, for the creation of mild compression. The additional task of radiation detectors are chemical and biological detection, so it is advisable to prepare the vehicle for these tasks as well with the appropriate instrumentation, spectrometers, gas meters, pollution meters. In terms of RBV capabilities, the unit that measures meteorological parameters is also an important part of the vehicle. In addition to these, of course, communication and data transfer play a very important role, the construction of which is advisable to be installed in a redundant and diverse manner.

In the following, we will discuss the applicability of a system of tools that has not yet spread in the environment of nuclear facilities, thus an epoch-making initiative in relation to the Paks nuclear power plant. These are none other than drones. During our studies, it became clear from the beginning that aerial radiation detection can

8 MVM Paks Nuclear Power Plant 2019c: 3–62.
9 Transport Exchange Model Simulator (TREX) 2021: 1–76.
10 See: www.met.hu/idojaras/elorejelzes/modellek/

be used very effectively to identify either extensive radioactive pollution or local hot spots and radiation sources. Many articles have been published under the auspices of the Doctoral School of Military Engineering in connection with helicopter or fixed-wing drone beam reconnaissance methods, which testify to the fact that they have an accuracy comparable to that of pedestrian reconnaissance, all of which can be carried out quickly and with the mapping of large areas. Taking into account the properties of drones that they are relatively cheap, can be deployed quickly, can even be used in formations, the equipment systems that can be installed (detectors, sampling and monitoring devices) are very diverse, their operation and storage are relatively cheap and simple and, last but not least, manpower can be dispensed with, thus in accordance with the ALARA principle, which is essential for the radiation protection of people. Operating on a certain, special principle – e.g. wing flapping principle – with the help of drones, although other beam detection purposes can also be achieved, e.g. inside the building. Through the appropriate communication channels, they can provide additional measurements to radiation situation assessors, which can be crucial in connection with a serious nuclear accident. Of course, in addition to those listed earlier, there are also possibilities for radio detection of large areas, taking into account the efficiency of measurement technology and communication.[11]

Conceptual development and application of complex decision support software

In the case of a nuclear facility, the biggest challenge is the occurrence of a possible serious nuclear accident and its control in such a way that the environment is burdened as little as possible. Decision-makers are in an extremely difficult situation at this time, as they have to take into account and consider a lot of data, factors and other information. That is why we think that a complex decision support software can greatly facilitate this work, because the data of the already available transmitters – supplemented by the data provided by mobile devices – and other databases, modelling and forecasting systems could be available in one place. After that, filters and algorithms can be applied, which would allow only the relevant data to remain, thus making the work of decision makers easier. The primary purpose of the decision support software is to monitor the status of technological systems as well as their radiation parameters. This is the only way to be aware of the extent of the radioactive release and the location(s) of the release. If this information is available, it is easier to make decisions taking into account the minimisation of damage to the environment. The software can also be expanded with other functions. We are thinking here of other emergency management, for example, we could mention the avoidance of dangerous substances or the activities related to fire, which entail the involvement of new specialist areas.[12] The related databases and measurement results are also available. As an additional possibility, we would like to mention that in such situations,

[11] Petrányi et al. 2023. 915–921.

[12] Cimer et al. 2021: 2–16; Érces–Vass 2018: 2–22.

the flow of data and information to the competent national bodies and authorities could be facilitated by setting the appropriate authorisations and permissions with the appropriate links – which are already largely available. In addition to the above, other non-emergency applications are possible, which can be very widely used.[13]

Summary

The spread of the use of nuclear energy is so revolutionary that it is hard to imagine life without it. The specific energy extraction of the heating elements used by nuclear power plants cannot be compared with anything at the moment, and all of this is done in an environmentally friendly way during normal operation. However, some unfortunate events of the past decades have also highlighted the fact that we also have to reckon with the occurrence of a serious nuclear accident. In such situations, reducing the load on the environment is essential. In our article, we make suggestions with this in mind. In light of this, we developed development proposals in the field of nuclear environmental control, most of which have already been implemented. These developments were generally related to protection against earthquakes and total loss of voltage, and the vital measurements were delimited, the reinforcement or replacement of which was necessary in the event of a serious nuclear accident. From the point of view of nuclear accident prevention, we focused primarily on tasks related to radiation protection, including radiation situation assessment and radiation detection tools and methods. As a development direction for the propagation calculation software, which plays an important role in the radiation situation assessment, we have given the integration of the current software and its expansion with other models, which can enable the propagation calculation based on the real source element.

Another advantage is that they can provide forecasts not only for a 30 km area, but also for the buildings and their immediate surroundings, both in the short and long term. In connection with radiation detection, we propose the development of a radiation protection measuring car and a new tool system for the applicability of drones. In connection with the radiation protection measuring car, we have listed the aspects that must be met in connection with a possible serious nuclear accident. Drones are well suited for radiation protection and economy. Both fixed-wing and rotary-wing models can be proven to have a right to exist, and they are even suitable for performing more complex tasks in combination or by using several types together. By developing a complex decision support system, the work of decision makers can be made easier, so that they can make the most optimal decision as quickly as possible. With the help of the software, you can track the technology status as well as its radiation parameters and their emission routes. By applying the appropriate algorithm and supplementing the appropriate forecasting models, the data could be filtered so that only the relevant data are available. The software can provide additional opportunities for communication and data provision to the national bodies involved in accident prevention and the authorities. Taking everything into account, thanks to our development and

[13] Csurgai et al. 2018: 171–183; Solymosi et al. 2023: 843–848.

innovation proposals, the radiation conditions can be continuously monitored and modeled, allowing decisions to be made that protect the safety of our environment, minimize its burden and protect people's lives and health.

References

Cimer, Zsolt et al. (2021): Application of Chemical Monitoring and Public Alarm Systems to Reduce Public Vulnerability to Major Accidents Involving Dangerous Substances. *Symmetry,* 13(8), 1528. Online: https://doi.org/10.3390/sym13081528

Csurgai, József et al. (2018): Dividing of Controlled Area in Nuclear Power Plants. *Hadmérnök,* 13(4), 171–183.

Érces, Gergő – Vass, Gyula (2018): Veszélyes ipari üzemek tűzvédelme ipari üzemek fenntartható tűzbiztonságának fejlesztési lehetőségei a komplex tűzvédelem tekintetében. *Műszaki Katonai Közlöny,* 28(4), 2–22.

Manga, László – Kátai-Urbán, Lajos (2016): Nukleáris balesetkből levonható tanulságok – a tudomány állása I. rész. *Bolyai Szemle,* 4(E-szám), 120–136. Online: www.uni-nke.hu/document/uni-nke-hu/bolyai-szemle-2016-04.original.pdf

MVM Paks Nuclear Power Plant (2019a): *Átfogó Veszélyhelyzet-kezelési és Intézkedési Terv* I-V m. Paks: MVM PA Zrt.

MVM Paks Nuclear Power Plant (2019b): *Kibocsátás Ellenőrzési Szabályzat V04*. Paks: MVM PA Zrt.

MVM Paks Nuclear Power Plant (2019c): *SER KK rendszer, Terjedésszámítás a Dose on Lite program algoritmusa.* Paks: MVM PA Zrt.

MVM Paks Nuclear Power Plant (2022a): *1–4. blokk Végleges Biztonsági Jelentés.* Paks: MVM PA Zrt.

MVM Paks Nuclear Power Plant (2022b): *Környezetellenőrzési Szabályzat V4*. Paks: MVM PA Zrt.

MTA EK – Kék – ScadaNet Ltd. (2016): *A sugárvédelmi ellenőrző rendszer kibocsátás- és környezetellenőrzésének felújítása, műszaki leírás V.1.2*. Budapest: EK.

Petrányi, János et al. (2023): Assessing the Radiation Contamination of Large Areas Using Advanced Technologies. *Radiation Protection Dosimetry,* 199(8–9), 915–921. Online: https://doi.org/10.1093/rpd/ncad092

Solymosi, Máté et al. (2023): Monitoring System of the Fuel-Casette-Free STATE of the Control Rod Sleeves on the PAKS NPP. *Radiation Protection Dosimetry,* 199(8–9), 843–848. Online: https://doi.org/10.1093/rpd/ncad116

TREX – Terjedési-Ülepedési Modell Szimulátor (2021). Veszprém: Radioökológiai Tisztaságért Társadalmi Szervezet.

Legal sources

15/2001 (6.VI.) KöM Decree on radioactive discharges into air and water from the use of nuclear energy and their control

Act CXXVIII of 2011 on disaster management and amending certain related acts