REVIEW OF THE DOCTORAL (PhD) DISSERTATION

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Research and development of intelligent detectors and systems for detection of ionizing radiation for military and disaster management applications

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THE DESCRIPTION OF THE SCIENTIFIC PROBLEM

Since the discovery of X-rays in 1896, measuring ionizing radiation has been a significant challenge for professionals. The measurement of ionizing radiation is almost as old as the discovery of radiation, because we are not able to detect radiation with human senses.

In the early days, ionizing radiation was not considered as dangerous, and it was used in everyday life. E.g., cosmetics and painting for illuminated posters. The danger of ionizing radiation was later realised by scientists and as well the public. Today the use of radiation-emitting materials and equipment in most parts of the world are regulated by law, because the fear of radiation is common in most societies.

After the discovery and application of nuclear weapons, regulatory organizations began to measure radiation in the environment. Nuclear accidents and disasters gave a further boost to the spreading of radiation detectors. Radiation reconnaissance is one of the critical capabilities of Chemical, Biological, Radiological, Nuclear (CBRN) first responders. Nowadays the use of radiation detectors is regular in CBRN accident evaluation, in dangerous goods shipment control process, and in detecting lost or smuggled radioactive sources. Measuring detectors have changed radically since their discovery.

In this dissertation, the applicability of intelligent radiation measuring detectors, algorithms and methods will be investigated in different applications to improve their capabilities. The availability of high-quality information in the right place and time can be an essential factor in disaster management. New measurement methodologies, algorithms can improve the quality of information and can reduce response time to an event.

The tasks of the first measuring devices were limited to measuring and showing results. Instruments used today can alert if the measured value is over a given alarm threshold. The detectors of the future will be able to give suggestions on what the user should do in a given situation and could give a warning before an actual accident occurs. The information available with new technologies can provide a much more accurate picture of the situation. Complicated measurement procedures require well-trained operating personnel. The challenge of the future is to simplify the processes for the operator to perform the necessary tasks and make it possible to use the device without any lengthy and challenging training.

Different radiation measurement technologies are avalible like: ionization chambers, proportional, and GM counters, scintillator and semiconductor detectors.

An intelligent detector is intelligent because: it processes, analyses and interprets the analogue signal coming out of the sensor (GM tube, scintillator crystal); runs various algorithms on it, then generates information relevant to the user; performs tasks and stores data; and communicates with the outside world. A combination of different intelligent detectors can be built together into a system, which can supervise borders, facilities, entire countries or continents. In my research, I focus on two radiation measurement technologies: GM counters and scintillation detectors, because these technologies are available for me, and I found possible development regarding these technologies.

The first technology I investigated is based on GM counters. GM counters can be used in applications where wide measuring range and ruggedness is required. The second technology I investigated deals with applications involving scintillation based detectors. This type of detector can be used when gamma-radiation isotope identification or a high level of sensitivity is required.

The results of this research can be used in the field of on-foot, and onboard radiation reconnaissance, border protection and early warning applications. This dissertation investigates the efficiency of intelligent detectors with different methods and tests and will come to conclusions based on those results. In this context, the intelligent detectors refer to detectros that provide more information than just the analogue measured values, they can also do data analysis and post processes to provide more detailed information for decision-makers..

Improvement of scintillation type detectors

Laboratory type scintillation detectors and GM counters are not suitable for military and disaster management tasks. The environmental resistance of such a devices are weak. Sensitivity to temperature, humidity, vibration and electromagnetic fields makes these units operational only under laboratory conditions . The data available from scintillation detectors is much more complicated than a simple count number coming from a GM counter. However, the information provided by this type of sensor is essential in the field. With the help of a scintillation detector, isotope identification, localisation and radioactive material characterisation tasks can be carried out. I will introduce different solutions on how to modify a scintillation detector to make it field ready. Field ready means endurance to temperature, humidity, dust, rain, pressure, shock, vibration and environmental conditions stated in military standards.

New generation of radiation portal monitors

Scintillation type detectors have been used for radiation portal monitor application for decades. The scientific problem with these systems is that they provide limited information about the events. The information available from such a system are not enough to make the right decisions. If a portal monitor is not sensitive enough or works with an inappropriate algorithm, the system will allow contaminants to pass through a checkpoint, which could lead to a radiological disaster, or in case of smuggling can be used for terrorist attacks. False alarms at these portal monitors can cause severe damage. If the radiation portal monitor system marks a shipment as contaminated in which no radioactive material is present, it is called a false positive alarm. This alarm causes unnecessary panic and financial damage by having to evacuate the facility, suspending work and calling in an expert to clarify the situation. The method I am looking for can reduce the false alarm rate but still has a high level of sensitivity. There are proven technical solutions for the physical protection of radioactive sources that have been available for a long time. However, the algorithm used in the portal monitors can be changed to provide information to a security system, thus further increasing the protection level of the system.

Problems with on-foot reconnaissance

One of the tasks during on-foot radiation reconnaissance is to find hidden, or lost radioactive sources. The task can only be carried out in a very long time in the absence of the appropriate technical equipment and searching technique. The radiation measuring devices used for this purpose are either not sensitive enough or do not have the necessary directional dependence to be able to give guidance to the person using it. By examining the possible measurement configurations, I selected the most effective solution that can provide an answer to this scientific problem.

The control of radioactive shipments can also be significantly improved with the help of intelligent detectors. At present, only simple control measurements are carried out on the outer casing of consignments, using dose rate measuring devices, and the formal requirements of travel documents are checked. The control is easy to circumvent for a professional. For example, artificial radioactive sources can be placed between natural shipments of radiation and the elevated radiation levels can be explained as the effect of natural radioactive materials.

Since most inspections do not allow the consignment to be open, only non-destructive external measurement solutions can be considered to improve the quality of the inspection.
A solution to this problem can be a simple mobile application that calculates the dose rate at the wall of the container from the activity of the source stated in the shipment documentation. The result can be measured with a detector and compared. In addition to the measurable radiation level on the outside of the container, there are additional quantifiable data: mass, height and external shape, that help estimate the activity of the delivered radioactive source. This allows the shipment to be classified without the data from shipment documentation.

Challenges at emission monitoring systems

Activities with certain radioactive materials release gaseous or volatile contamination into the environment. Nuclear power plants, radiopharmaceutical manufacturers and hospitals are typically releasing radioactive contamination into the air. Measurement of emissions is essential if it is to prove that emissions have remained below the officially permitted maximum emission level for a given period. Emissions can be measured in several ways, but the most technology-friendly solution must be found, and several aspects must be taken into account. When choosing a possible solution, it is important that the high gamma background radiation does not affect the measured result, I am looking for a solution to this scientific problem.

RESEARCH OBJECTIVES (RO)

In my research, I set basic conditions for the whole project and research objectives for each topic. Basic conditions:

- To use already existing technologies and results of applied research activities to improve products quality and performance.
- To create all the results of the research in such a way that it can be directly used in the daily work of CBRN first responders.
- Not presenting any company secret which is applied in an existing product or could be used in the future development of the company I work for.

Objectives of my research:

RO1: My goal is to find the new trends and essential requirements of radiation monitoring systems implemented for different applications. To achieve this goal I have to know the relevant regulations, standards and legislation, compare possible solutions and identify the correct method and architecture for such a system. From available algorithms and methodologies, I create new ones to achieve better system performances.

RO2: My research aims to develop new hardware and software solutions that can be integrated into intelligent measuring detectors, which will detect radioactive materials in the field of disaster management and the military. Create a new generation of detectors that are already suitable for field operation.

RO3: My research goal is to develop a selection criteria system for radiation portal monitor applications and to upgrade such system with the additional capability to provide more information for the operator when a radioactive source triggers an alarm, or someone is trying to steal a radioactive source from a supervised area. I prove that a radiation portal monitor is capable of supporting physical protection systems.

RO4: My goal is to create a radioactive source searching algorithm that can be used to find lost or hidden point type sources faster and more efficiently; simplify the qualification of radioactive shipments for the user, while collecting as much information as possible about the shipment and automatically checking the shipment documentation with smart detectors.

RO5: My further goal is to compare different emission control solutions and find the most suitable one for the given task. In addition to the high gamma radiation that often occurs in such systems, the realisation of measuring beta activity concentration.

HYPOTHESES (H)

In harmony with the definition of the research problems, I formulated the following hypotheses:

H1.: The efficacy of radiation monitoring systems can be increased and new capabilities can be added to radiation monitoring systems by using intelligent radiation detectors which compensate for environmental changes, run algorithms to make operation easier and decision making quicker, applies self-checks to be more reliable. (RO1).

H2.: Scintillation detectors can be adapted for field use, disaster management and military purposes by modifying specific hardware and software components of the detector. The modifications cover the scintillator coupling material, the assembly, the fixing of the applied components and the compensation for the environmental effects made possible by the embedded microprocessors. (RO2).

H3.: High-reliability detection of transported radioactive materials can be achieved with radiation portal monitor systems if the systems are used in the appropriate assembly, configuration and with the right operating algorithm. The further development of the algorithm implemented in the radiation portal monitors allows the generation of an alarm signal to the direction of the physical protection system if the supervised radioactive source is located in an unauthorised position. (RO3)

H4.: The process of on-foot radiation reconnaissance can be made more efficient with the help of an intelligent radiation detector and the appropriate search method. The localisation time of lost or hidden sources can be minimised. The control of radioactive shipments can be made more accurate by measuring the radiation levels on the surface of the transport container and the external physical parameters of the container, and calculating the activity of the delivered radioactive source. (RO4)

H5.: The selection of the appropriate system for the measurement of released radioactive material can be optimised with the available information and technology. In emission monitoring systems, the measurement of beta volume activity is possible at high, dynamically changing gamma dose rates, using the appropriate algorithm and intelligent detector assembly. (RO5).

RESEARCH METHODOLOGIES

I conducted a literature search on publications, standards, and international recommendations from a freely available source relevant to the topic, in order to learn about solutions, their structure and operation from other similar systems. By looking at the many detectors and early warning systems built around the world, I observed the trends of development and examined the pros and cons.

Based on the known requirements, regulations and available technology and trends, I created hypotheses and suggestions that are expected to characterize the future monitoring systems. In order to verify my ideas, I implemented several solution algorithms and performed experiments and measurements, with the help of which I verified my assumptions. I analysed the obtained results and the collected data and information in order to move in the right direction. I figured out how to determine the activity of the radioactive material in a transport container. For this, I created the measurement assembly with the necessary electronic and mechanical components and I made the operating software. I recorded the data measured by the equipment and then created various tests using radioactive sources with known activity. I compared the measurement results with the known data and based on the deviations, I qualified the operation of the whole system.

In the course of the research, I made several incorrect assumptions, I managed to identify the faults and was able to avoid following the wrong path. One such incorrect assumption was when I wanted to search for a radioactive source using two scintillator crystals coupled next to each other. The behaviour of the two scintillators under different temperature conditions gave a false result, so I decided not to use this scintillator assembly anymore.

I made conclusions from the results, which helped to verify my hypotheses. The computing capacity that can be integrated into intelligent detectors has increased recently, so general and up-to-date electrical engineering knowledge was required to achieve my goal. During the research, I designed electronic equipment and printed circuit boards. I integrated two ultrasonic distance sensors and one radiation detector, a robotic arm, a turntable and a scale into one system. This assembly can provide a measurement process for radioactive transport container checking, which was not published before. In addition to electrical engineering knowledge, the task also required mechanical design knowledge to develop physical/thermal protection and housing for detectors. During the development, I designed experimental pieces and printed out prototypes with a 3D printer.

THE CONCISE DESCRIPTION OF THE EXAMINATION CONDUCTED

Disaster management professionals need technical tools that enable the detection and monitoring of radiation threats. The source of information can either be early warning systems that allow continuous measurement of a parameter which can indicate a potential threat, or CBRN reconnaissance units with the support of mobile and fixed laboratories, which are deployed in emergencies.

The task of these technical devices is to measure ionizing radiation, to determine the concentration of toxic industrial substances or chemical warfare agents and to detect the presence of biological warfare agents.

Detectors used for disaster management purposes are different from conventional detectors in that they have to operate in extreme environments (wide temperature range [-30 °C … + 50 °C], high humidity [>90%], dust, rain [> IP66], pressure [500 … 1200 hPa], shock [0 …1600 m/s^2], vibration [5 … 500 Hz]), where other equipment has long gone faulty. The detectors used for such purposes are characterized by environmental resistance, wide measuring range, protection against mechanical impact, explosion-proof and radiation-resistant design.

The detectors used today digitize the analogue signal of the sensor and transmit it digitally to higher informatics levels. The unit containing the sensor and the electrical signal processor is called a transmitter or detector. The difference between a transmitter and a detector is that transmitters have no display and only serve as a source for measuring information. Detectors can have more features than just measuring environmental parameters i.e. audiovisual signals, display, battery. All transmitters are detectors, but not all detectors are a transmitter. Microcontrollers can be equipped with custom software, allowing the execution of many algorithms in a detector.

The goal of this research is to examine the optimal use of measuring tools with state-of-the-art technology for disaster management purposes and develop new methodologies that can make the right decisions at a given level on time, helping to speed up the process of disaster recovery. Applying the right technology can save considerable human and material resources.

The availability of the necessary information in the right place, time and form can be crucial in the event of a disaster. The role of a measuring device was previously limited to measuring and displaying the measured value and creating an alarm signal at certain alarm levels.

An alarming device does not provide enough information to make the right decision in the shortest time at a stressful situation. Because these types of alarms are not very common, operating personnels in such a situation are often unable to act appropriately, may panic, may forget to take the necessary steps, or may make incorrect decisions due to lack of routine or under-training.

As a result of this research, detectors and systems will be able to obtain additional information that will improve decision-making and, in some respects, take over responsibility from the operator. The final decision will still be made by the operator, but it will be much more comfortable and will be based on more data. The task of a measuring device does not end by alerting the user with the alarm, it should also assist in the handling of the alarm. From the start until the end of an event, different situation-dependent actions should be carried out. Measuring systems can be used not only for alarming purposes. It can also check whether a particular facility is exceeding its annual emissions quota or that its technology is undergoing changes that could lead to disaster. Officials can also be supported by special measuring equipments to inspect the compliance with radiation protection regulations and to avoid unnecessary exposure of workers or population. Intelligent measuring devices can also improve safety and security capabilities. An intelligent system can track the location and use of dangerous goods, log all activities, and create a security alert for unauthorized use or theft.

This area of research is relatively new because there were not enough resources (memory, processor speed) in a measuring unit to conduct further tasks. Performing additional functions while conducting the measurement requires a high speed embedded microcontroller with the capability of running concurrent tasks.

Intelligent measuring devices and systems can be used not only for disaster management purposes but also for monitoring the regular operation of nuclear facilities. Alternatively, security applications and counter-terrorism tasks may arise when it comes to detecting warfare agents or nuclear materials.

In the first chapter, I dealt with the development of scintillation detectors. In this context, I had to get to know the solutions that already exist and the technologies available that can help in the development of technology.

During the design of the new generation of detectors, I examined the various environmental parameters and impacts in order to compensate for their impact. I systematized the radiation measurement and detection systems that are currently used for military and disaster management tasks.

Relevant domestic regulations, international recommendations and standards give the fundamental design of these systems. Among other things, I examined the current state of on-foot radiation reconnaissance, extended this activity to on-board and aerial radiation detection, and then studied the application of radiation portal monitors through several application examples. After that, I studied the CBRN early warning systems, many of which also serve in Hungary, supporting the home and law enforcement agencies. Examining the existing CBRN early warning systems, I managed to identify their basic structure, starting from the measuring devices to the data centers. I investigated the mechanisms of these systems to find patterns and possible new features. I was looking for the answer to which system organization architecture ensures the best availability of critical information in the shortest possible time. Starting from the simplest system architecture to high-availability multiple redundant systems, I analysed their potential. Based on these, I formed conclusions and suggestions for the further development of existing systems. The first generation of intelligent detectors is already serving military and disaster management systems. Among the capabilities of the detectors, the accuracy of the measured data is of primary importance, the speed of data processing and transmission is almost equally important, so authentic, essential data can reach the decision-makers and then the CBRN reconnaissance units as soon as possible. In this chapter, I have presented the structure and operation of several similar monitoring and alarm systems operating abroad. I examined the operational logics and algorithms implemented in existing systems. In the relevant publications, I looked for references that can be guidelines for building such a system. In this chapter, I sought synergies between radiation measurement systems and other chemical and meteorological monitoring networks used in CBRN defence. I examined in details the capabilities of these monitoring stations, with particular regard to the measuring ranges, the operating environmental parameters, and the response time of the system following a possible accident situation.

In the second chapter, I focused specifically on the development of scintillation detectors in order to make these detectors usable for military and disaster management tasks. I had to modify some components of the detector to reach this goal. The effectiveness of modification was verified experimentally. During the developments, I made a change in, among other things, the scintillation crystal coupling material.

The conventionally available coupling materials are able to operate in laboratory conditions only. I tested different coupling materials with a climate chamber to check the behaviour at different temperatures.

The coupling material I found was able to withstand temperatures from -30 °C to + 50 °C. With the new technology, the detector became applicable to a wider temperature range than before. In addition to the coupling material, I investigated the production technology of scintillation crystals in order to improve the quality of the crystals under extreme conditions. The resistance of a conventional scintillation detector to drops and vibration is weak, but with the modifications I proposed, the detector can also be used in onboard vehicle reconnaissance systems. The scintillation detector is sensitive to electromagnetic radiation, and this radiation can significantly affect the measurement. The design of electromagnetic shielding is essential during the construction of such equipment. Scintillation detectors are strongly temperature-dependent, the change of this environmental parameter must be compensated, for which I have performed experiments and formulated modification proposals. Scintillation detectors are not able to function correctly at high dose rates (>100 mSv/h). In order to widen the measuring range, I measured with different scintillation detector materials at a high dose rates and investigated possible solutions for different signal processing methods. In addition to the traditional NaI(Tl) scintillator, I also examined BGO (bismuth germanate) crystals. I paid particular attention to the correction of the disunion errors of scintillation crystals, and I was looking for a solution to prevent the disunion, which can be caused, among other things, by a sudden temperature change. During the research, I tried to improve the quality of the scintillator, i.e. to keep the full width at half of the maximum value of the gamma spectrum peak to a given radiation source as small as possible.

In the third chapter, I examined the possible uses and assemblies of radiation portal monitors. To do this, I had to be sufficiently familiar with these systems. I had to identify the differences in each application and then make recommendations as to which components are best suited for what purposes. While searching for the best solution, new features and ideas emerged that I had to explore one by one. One such idea was born that I can introduce an additional feature to the monitoring system: generating an alarm to the physical protection system if the radioactive source has been stolen.

After a thorough understanding of radiation portal monitors structure and operation, I examined the algorithms implemented in such systems while looking for development opportunities. I researched the history of the radiation portal monitors and their implementations in Hungary.

I found that the essential operation of the radiation portals can be expanded with additional devices (speedometer, license plate recognition), which make the detection process of radioactive sources more efficient. I made further investigations about using different intelligent detectors for different applications. As I expected, detectors should be modified if it is used as a mobile, or as a fixed-installed or as a vehicle-mounted measuring system. The applicability of intelligent detectors for use in the radiation portal monitors depends on the mechanical design, the physical size, which affects the sensitivity, and the algorithm, which mainly determines the logic of generating alarm signals, background compensation, and acknowledgement of alarms by users. To further develop radiation portal monitors, I was looking for features that became available as technology advances, such as online isotope identification and alarm suppression functionalities caused by natural radiating materials. I studied different types of portal monitors and created a selection system based on their areas of application, which can help to find the right radiation portal monitors. I have developed an algorithm that allows the alarm logic applied in radiation portal monitors to be used to provide additional signals to the physical protection system of radioactive sources.

In the fourth chapter, I analysed the efficiency of searching methods of lost and hidden orphan sources. To improve such methods, I had to be familiar with the existing methods. I proposed the modification of the detector assembly and algorithm. I made tests to check the efficiency of the change. I also collected information about inspection methods of the control of radioactive shipments. I realised that the information available at the site can help to determine the estimated activity of the delivered radioactive source. This information opens new perspectives in shipment control.

In this chapter, I compared on-foot radioactive source search methods. As a first step, I identified the existing procedures, then created new ones, selected the appropriate intelligent detectors, tested them under different conditions, and then drew conclusions based on the obtained measurement data, to determine the most efficient search method. I found that the measurement assemblies I studied, the lead ring-collimated, high-sensitivity scintillation detector is the best choice. If this detector is combined with the alarm algorithm used at portal monitors, the device will guide the user, after a few turns, in the right direction. It identifies a point source in the shortest possible time, even if there are several point type sources nearby. I examined the control of properly transported radioactive materials and made proposals for its modernization. I have also developed two procedures; one simple procedure allows the shipment documentation to be checked using the data contained in the documentation.

The other method is a complex method that does not rely on shipment documents, it only forms a picture of the shipment from measurement data and gives the result of the examination. The measuring device I have built estimates the activity of a radioactive point source in a cylindrical transport container by measuring the external radiation level, the weight and size of the container and conducts mathematic calculations. Based on the measurement, the transport container can be visualized, thus filtering out the inhomogeneity of the transport container, which may have been caused by hidden damage or an air bubble caused by a manufacturing defect. Through thinner shielding, those working near the container may suffer unreasonably high radiation exposures. The measurement can be further refined by isotope identification and smears sampling procedures. A complex set of specific analytics gives an accurate picture of a radioactive shipment, which helps the inspection process.

In the fifth chapter, I investigated the radioactive emission monitoring systems and created new methods and recommendations to implement the right assembly for the technology. I had to identify all the available monitoring methods for radioactive material releases. I realised that the gamma background radiation at these facilities is changing several orders of magnitude and affecting the measured values. Beta surface contamination measurement at high, dynamically changing gamma dose rates is a task that I had to investigate in detail, with actual experiments and a special detector assembly. In emission control systems and on-foot reconnaissance, this method is probably applicable to prove that I conducted many tests.

In this chapter, I presented radioactive material release control systems. After learning about the relevant regulations and finding all known monitoring configurations, I made a comparison and justified which applications to each solution can be used, what are their advantages and disadvantages. These systems, for example, are strongly affected if other radiation-emitting activities are performed in the area of the measurement, which adds to the emission value, falsifying it. With the assembly and operation, I developed, online surface contamination can be measured even with high (1 μSv/h … 100 mSv/h), fluctuating gamma background radiation. This method compensates the effects of nearby technologies releasing radiation and provides valid emission data.

This method can be used not only for emission measurement systems, but also for the detection of alpha and beta sources in a contaminated area, or in a reactor environment, to check the effectiveness of the decontamination.

SUMMARISED CONCLUSIONS

The radiation monitoring systems for disaster management and military purposes are already using intelligent detectors, with the improvement of the capabilities of these detectors can open new possibilities in decision support systems. The processes that have been used in these intelligent detectors can be improved to achieve more information on the shortest time. As a consequence of applying new intelligent detectors, the time between the first sign of a disaster and the first response of preventing the disaster has been significantly reduced. The tendency I observed that the results are more accurate, measuring ranges getting wider, and usage has become more comfortable in extreme conditions as it was in the past.

I investigated different monitoring systems, focusing on the capabilities and their measurement techniques. I proofed that scintillation detectors can improve significantly the capability of environmental monitoring systems. (H1)

Scintillation technology is advantageous due to the high sensitivity but requires the use of various engineering solutions customised to extreme field conditions.

I collected all the effects should be considered to build a detector should be used for military and disaster management purposes. The coupling materials and light barrier help to prevent the ambient light from affecting the measurement. Detectors can withstand vibration and dropping using external and internal absorber techniques. External and internal electromagnetic radiation should be handled at the detector level. Electrical components, shields, and grounding can prevent the detector from interfering with external electromagnetic radiation or the detector from interfering with other electrical equipment. Changes in temperature lead to significant errors in measurement results, so it is worthwhile to use temperature compensation, which is based on temperature measurement and automatic calibration with the help of etalon sources. Adequate insulation can protect against sudden changes in temperature.

After extremely high dose rate (>100 mSv/h) irradiation the NaI(Tl) and CsI(Na) scintillators only return to their original values within hours and over a given dose rate they are no longer capable of measuring radiation. These problems can be solved by the BGO scintillator, which is capable of continuously measuring the intensity of radiation without any after glowing effect, or the anode current measurement can also be useful at high dose rates.

The result of this development is the extension of a lifetime, the increase of vibration resistant and widening the operating temperature range of NaI(Tl) scintillators to be able to fulfil military standers i.e. MIL-STD-810. I solved the separation issue of NaI(Tl) by using a unique coupling material. I created a new testing process to prove the quality of NaI(Tl) scintillation crystal quality. Scintillation crystals produced by this new process are already used in multiple detectors like in the onboard radiation reconnaissance system. I proved that modified scintillation detectors can be used for military and disaster management purposes. (H2)

Several factors influence the operation of a radiation portal monitor, which can, in many cases, determine whether or not it can detect a hidden radioactive source. I identified different configurations for various application regarding gamma and neutron radiation detection. In addition to fixed portal monitors, there are mobile, onboard, and even handheld variants. I proofed that high-reliability detection of transported radioactive materials can be achieved with radiation portal monitor systems if the systems are used in the appropriate assembly, configuration and with the right operating algorithm. (H3)

I examined the currently available radiation protection monitoring systems and developed an additional algorithm, similar to the radiation portal monitor algorithm that allows radiation measuring detectors to support physical protection systems. I made theoretical analysis, and with that, I proofed that the radiation portal monitor algorithm allows the generation of an alarm signal to the direction of the physical protection system if the supervised radioactive source is removed. (H3)

I tested many search methods and measurement configurations for finding hidden orphan sources. I concluded that the detachable ring collimated scintillation detector configuration is the most efficient.

The most suitable search method for finding a source consists of the following steps:

1. Detection with a multi-directional, high sensitive scintillation detector using in radiation portal mode.
2. After detection, the actual localisation should be started with the lead collimator should be placed on the detector, and the searching should be started with the method of “rotation”. In a few steps, the source should be localized.
3. The searching method may be continued with isotope identification for gamma radiation nuclides and activity determination.

I developed different inspection methods of radioactive transports. Only a mobile phone is needed to conduct the necessary inspection.

The advanced inspection method relays only on measured parameters, and not trusting the transportation documents. The prototype I created work in laboratory conditions and only with cylindrical isotope holder. In order to achieve more accuracy, the model should be modified. To improve the result of the algorithm more tests should be conducted at different distances with different isotopes (Cs-137 and Co-60) and with different containers (lead, tungsten, steel), the algorithm should be able to handle more container types (e.g., rectangular). The advanced inspection method can be improved with multiple collimated radiation detectors.

The method I invented will speed up the inspection time, and with collimation, the source localisation process can be more accurate. The detector can be a useful tool to prevent a significant industrial accident. Integration of spectrometric detectors to the system could give more information, and it can be used in other application, like radioactive waste measurements. (H4)

I investigated the radioactive emission measurement methods. The result of my investigation was that there is no perfectly suited configuration for every technology releasing contamination. I declared basic guidelines for different measurement tasks. The guideline considers it the development level of the technology, the resources available, other activities in the environment.

If the response time is not essential and the released isotopes have long half-life, the offline-measurement based sample taking method is ideal and has the lowest detection limit and the most insensitivity to environmental radiation.

The technology can be observed the most closely with the monitoring system installed directly on the technology air filters. The fastest detection time is achieved by direct measurement in the pipe system. Sampling Online Emission Measurement, with a rapid alert, allows for energy selective activity concentration measurement.

Measuring methods and related technical solutions can provide more and more accurate information as technology advances. However, the best results can be achieved if several of the above methods are integrated into the monitoring system. Redundant measurement assemblies based on various technologies increase the reliability and availability of the entire system.

Beta surface contamination monitoring at high gamma dose rate method can be used in several applications where on-line gamma background compensation is needed for beta measurement.

Gamma compensation algorithm also works in total beta measuring systems, where the goal is to determine the beta activity of a sample rather than calculate surface contamination.

Another application of this type of beta measurement algorithm with a fluctuating gamma background is radioactive emission control. Surface contamination algorithms are used in many applications, making them well suited primarily for detection of contamination. The measurement setup could gain additional accuracy by performing calibration with etalon sources before each measurement. (H5)

CONCISE DESCRIPTION OF NEW SCIENTIFIC ACHIEVEMENTS

T1.: **I proved** that applications and different processes have been implemented within intelligent detectors installed in the radiation monitoring system. With the help of such systems, the time between the first sign of a disaster and the first reaction to prevent it has been significantly reduced. I proved that the already existing application should be updated to increase accuracy, to widen the measuring ranges and to use in field conditions. (H1).

T2.: **I proved** that NaI(Tl) type scintillation detectors are usable for disaster management and military purposes if the detector is protected against temperature changes, mechanical shocks, electromagnetic radiation, and errors due to sudden temperature fluctuations, extreme high ionizing radiation. I created a hardware and software recommendation for scintillation detectors which can optimise the feature of the detector to use in extreme condition. (H2).

T3.: **I developed** a system of criteria for radiation portal monitor systems to have the most suitable assembly, configuration and operation procedure, which can improve the efficiency of detection of hidden transported radioactive materials. I integrated the radiation monitoring software into the physical protection system of irradiators to make an alarm if the supervised radioactive source has been removed. (H3)

T4.: **I developed** a search method to make the on-foot radiation reconnaissance process more efficient with the help of narrow collimated scintillation detectors and with time optimised searching strategy. I defined basic and advanced inspection methods to improve the control of radioactive shipments by measuring the external physical parameters and radiation level of the container. (H4)

T5.: **I developed** a system of criteria for radioactive emission monitoring systems to find the ideal measurement assembly for different technologies. I integrated an intelligent detector assembly into emission control systems, to measure beta surface contamination at high, dynamically varying gamma dose rates. (H5)

RECOMMENDATIONS

Based on the conclusions formulated in the individual chapters of my dissertation further scientific research can be started.

I recommend further studies to improve the efficiency of radiation reconnaissance on the field. More tests should be conducted which can give additional feedbacks for developments of such devices, or processes. I am sure that all measurements assembly I investigated can be changed to get quick and more accurate results. With the improvements of technology sooner or later new ideas and solutions will surface that will revolutionise the methodology for radiation measurements. The computing capacity and speed of a handheld device will increase in the future, opening doors for endless possibilities.

The newest equipment which is releasing radiation only for a short time generating pulsed type radiation fields will give a lot of challenges for professionals, to measure these fields correctly.

Terrorists trying to use radioactive materials for creating dirty bombs, getting more and more educated. They know exactly how to transport illegal radioactive material unnoticed, or cover the presence of artificer radioactive material with naturally occurring materials, at borders, to smuggles goods.

Fulfilling the requirements for radiation monitoring equipment is challenging, because the end-users are used to technologies, and they are expecting that all detectors should be handled easily.

The education cost of well trained CBRN expert is very high, and it took years of training. In case of emergency, there will be not enough experts to handle the situation, that is why the technology makes it possible to handle enormous events security with a small group of professional.

My research answered some of the questions regarding radiation measurements but also created new questions, which could be the base of a new PhD dissertation.

POTENTIAL PRACTICAL USE OF THE RESEARCH FINDINGS

The results achieved in this synopsis can help to develop the following capabilities for military and disaster management applications:

Early warning monitoring, On-foot, onboard, aerial reconnaissance, Searching for orphan isotopes, Inspection of isotope transports, Uknown isotope identification, Command and decision support, Integrated building management.

All of the theses I created can be used for the direct implementation of different products; some of these are already in use.

A lot of engineering task should be done to put these concepts into a product, and validation processes need to be conducted. With the help of this research, a new generation of scintillation detectors can be created, which can be used in field conditions. With the capability of outdoor use, the detector will be used for disaster management and military purposes.

Following the system of criteria for selecting a radiation portal monitor equipped with the appropriate assembly, configuration and operation algorithm can provide higher reliability as in the past and can realise addition feature to the monitoring system, i.e., generating an alarm to the physical protection system if the radioactive source has been stolen.

Searching methods of lost and hidden orphan sources can be improved by adapting the detector assembly and algorithm I proposed. Different level of modification can be made at the inspection methods of the control of radioactive shipments. With the estimated activity of the delivered radioactive source, the deliveries of radioactive materials can be more secure.

The release of radioactive materials at different artificial technology is a serious threat to the environment. The measuring of these levels is challenging because the background radiation at these measurements is affected by work with isotopes. The system of criteria, I established, for selecting an emission control system can support different technology, and can lead to a more accurate measurement of emission and with that lower the environmental damage.

Beta surface contamination measurement at high, dynamically varying gamma dose rates in emission control systems and on-foot reconnaissance could be a useful tool. It can be applied at normal and emergency conditions. Among realtime methods, this is the most precise one if the goal is to measure surface contamination at high gamma dose-rate.

MY PUBLICATIONS IN THE SUBJECT

Articles reviewed and selected from professional periodicals published in English:

- Petrányi, János: In Situ, Rapid Inspection Methods for Radioactive Material Transportation MŰSZAKI KATONAI KÖZLÖNY 29: 4 pp. 33-42., 10 p. (2020)

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- Petrányi, János: Nagy gamma-dózisteljesítmény mellett történő felületi szennyezettség mérése intelligens detektorokkal SUGÁRVÉDELEM IX : 1 pp. 17-24. , 8 p. (2016)
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- Petrányi, János: Nuclear measurement solutions of gamma technical corporation. In: International Conference on Radioanalytical and Nuclear Chemistry (RANC-2016) Budapest, Magyarország : Akadémiai Kiadó, (2016) pp. 145-145., 1 p.
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PROFESSIONAL-SCIENTIFIC CURRICULUM VITAE OF THE CANDIDATE

Name: János Tamás Petrányi

Place and date of birth: Budapest, 30.08.1979.

Studies: Petrányi János Tamás a Budapesti Műszaki és Gazdaságtudományi Egyetemen végzett okleveles villamosmérnökként, később a Budapesti Műszaki Főiskolán manager szakmérnök diplomát is szerzett. A munkája során bővített és átfogó fokozatú sugárvédelmi képesítést kapott. Az atomenergia alkalmazása körében eljáró sugárvédelmi szakértő, valamint független műszaki szakértőként a Magyar Mérnöki Kamara rendes tagja.

Language skills: He has an intermediate "C" type language exam in English and German.

Professional career: He started his professional career at the Technical University of Munich in 2002 as a programmer, and after a stay abroad for almost a year, he worked at GAMMA Zrt. as a development engineer. He has been working for the same company ever since, in different positions. He served in the positions of technical director, head of nuclear division and eventually director of R&D.

2002-2002	Technical University of Munich, programmer
2003-2010	GAMMA Zrt., development engineer
2010-2015	GAMMA Zrt., technical director
2015-2018	GAMMA Zrt., head of nuclear division and director of R&D
2018-	GAMMA Zrt., director of R&D

Scientific activity:

- In recognition of his professional work, in 2015 he was elected to the management board of the Radiation Protection Section of the Eötvös Loránd Physical Society.
- He has been a member of the editorial board of the online magazine "RADIATION PROTECTION" ever since.
- In 2016, he won the Radiation Protection Award for Excellence.
- He has been invited to be the congress president of the sixth European International Radiation Protection Association (IRPA) Congress in 2022.He regularly publishes in domestic and foreign professional journals, participates and gives lectures at conferences and congresses. As an industry consultant, he was involved in the creation of several MSc and BSc dissertations, as well as reviewing several dissertations. Thanks to his work, several disaster management and military equipment and devices were created, which are still actively used.

János Tamás Petrányi Budapest, November 07, 2020