ZRÍNYI MIKLÓS
NATIONAL DEFENCE UNIVERSITY
Doctorate Council

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Qualification of aerosol and gas purification filters installed into the technological systems of Paks Nuclear Power Plant

Author's summary and official reviews

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Scientific Leader:

Arpad Vincze, PhD

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THE DEFINITION OF SCIENTIFIC PROBLEM

Nuclear facilities (nuclear power plants, reprocessing plants, etc.) discharge radioactive isotopes into their environment even under normal operational conditions. This emission may result in catastrophic consequences in case of accident or terrorist attack, etc. The minimization of the potential discharges, the monitoring of the environment and the provision of controlled fresh air supply to collective protection facilities are a task of primary importance for the radiation protection of the civil population and the military forces involved in the nuclear accident relief work.

The most important aim of the safety measures for a nuclear facility is to ensure that the social risk associated with the discharge of radioactive materials is acceptable both for normal and incidental/accidental conditions. Accordingly, the allowable discharge rate is controlled by rigorous regulatory directives. The assurance of these directives can be achieved with the use of engineering barriers, which provide for the required confinement of the radioactive materials even after the occurrence of an incident/accident. For the facilities used to provide collective protection (shelters, protected emergency response centres, control room of the nuclear power plant, etc.), the aim is to prevent the ingress of contamination into the facility after an accident resulting in the radioactive contamination of the environment, thus to ensure the protection of health and to maintain the ability to work (the fighting efficiency) of those staying in the facility. The engineering barriers used for such cases operate upon similar principles, but with reverse direction of retention.

Various types of filtration equipment have been installed into the process systems of Paks Nuclear Power Plant Ltd, which, functioning as a physical barrier, reduce the release of radioactive aerosol, gaseous and vapours into the environment during normal operational and incidental/accidental events to an acceptable level. With these items of equipment, it is possible to ensure that the dose exposure to the population living in the surroundings of the power plant and the plant operation personnel, resulting from the operation of the nuclear power plant is minimal and even more, in case of normal operation it is below the level of the natural background radiation. In addition, the well functioning engineering barriers used in the nuclear industry provide good example of the design and testing of engineering barriers installed to provide filtered air supply to collective protection facilities.

A part of radioactive medium escaping from the primary loop of a nuclear power plant is released into the atmosphere of the containment in form of vapour, gas or aerosol, The discharge of these materials into the environment is prevented by filters installed into the containment ventilation system. The containment is equipped with fresh air supply and used air exhaust systems, both for operational and maintenance operation mode, providing depression to ensure that any discharge can occur in a controlled manner only. In addition, the containment is also furnished with a recirculation type ventilation system to provide purified air supply to some internal spaces and to reduce the potential of radioactive discharge by pre-cleaning the exhaust air. The ventilation systems are supplied with aerosol filters and iodine filters to remove any form of radioactive contamination from the air discharged into the atmosphere and to ensure that the regulatory limits are observed.

The circulation pumps in the primary loops of Paks Units are not of tight sealed type therefore, maintaining of a constant rate of make-up water supply is necessary. The water taken from the primary loop is subject to thermal degassing, and the removed dissolved gases are transferred, after hydrogen content reduction, into the gas purification system, where the noble gases removed from the gas mixture by an activated carbon adsorber are trapped before discharge into the environment. During this period, the activity of the noble gas isotopes reduces by several orders of magnitude and the gas mixture can be discharged.

It is a factor of primary importance for the filtration equipment, that their design filtration efficiency is continuously maintained. For this purpose, the availability of information on the condition of the equipment is essential, and can be provided by testing and monitoring of the filtration efficiency of the filtration equipment. No such testing work was performed during the initial operation period of the power plant, therefore the development of testing methods for the various items of filtration equipment and tools for the testing work was necessary to allow the completion and evaluation of regular testing in industrial conditions. The actions to be taken to ensure the required filtration efficiency can be identified based on the knowledge of the condition of the equipment.

Regulatory limits and requirements are specified for controlling the airborne discharges from the nuclear power plant and the filtration efficiency of various filtration units.

The subject of the first part of this paper is the development of a method, with the adaptation of international procedures, for measuring the efficiency of the C-500 type aerosol filters installed into the ventilation systems, and the completion and evaluation of measurements in industrial environment.

The second research area addressed in my paper is the work performed in relation to the testing of activated carbon filled adsorbers used in the gas purification systems. For the adsorbers, regulatory criteria have been specified, for Kr and Xe isotopes, in form of retention time for a given air flow rate. A retention measuring method had to be developed for all criteria, and then, the inspection had to be carried out for all adsorbers. Upon knowing the inspection results, the actions required for ensuring the acceptable filtration efficiency had to be identified and performed.

RESEARCH AIMS

1. To review the operation mechanisms, major types and known qualification methods of aerosol filters.
2. To check the conditions for the application of known qualification methods for the qualification of real (industrial) systems.
3. To develop a qualification method for the C-500 type aerosol filters used in the process systems of Paks Nuclear Power Plant, and to establish a measuring configuration required for the qualification of the aerosol filters.
4. To perform the testing of the qualification procedure under modelled and real operational conditions.
5. To carry out the periodic qualification of the C-500 type aerosol filters.
6. To evaluate the qualification results and to identify the actions required for maintaining the qualified status.

7. To review the operation mechanism of the activated carbon adsorbers.
8. To develop a method for the qualification, against all specified criteria, of activated carbon adsorbers used in the process systems of Paks Nuclear Power Plant.
9. To establish a measuring configuration, for testing the qualification procedure in modelled and actual operational conditions.
10. To carry out the periodic qualification of the activated carbon adsorbers, to evaluate the qualification results and to identify the actions required for maintaining the qualified status.
11. Upon the experience obtained, to examine the possibility of combining the single procedures in order to simplify the qualification of combined filtration units used for collective protection purposes.

METHODS OF RESEARCH

I studied the international and national literature available in the subject matter, and I assessed the possibilities for the application of these sources for the qualification of the filters.

I analysed the results of my research work carried out to date and studied the new theories and procedures published in this subject.

I regularly published the results of my research work, and I attended and scientific conferences and symposia, where I presented papers.

I endeavoured to improve the already applied qualification procedures and to use the available set of tools.

I built model devices for experimental purposes, for the validation of the qualification procedures and for the selection of the appropriate procedures.

I carried out experimental measurements of process system filters with the aim to improve the developed qualification methods.

The applicability of the developed procedures in the practice is demonstrated by the fact that they have been introduced for use in the periodic testing of the filtration units.

THE EXECUTED RESEARCHES

The research work I completed clearly resulted in new achievements that can be directly applied in the practice and are now summarised as follows:

1. Periodic filtration efficiency measurements on C-500 type aerosol filters

First, I will present the ventilation and gas purification systems and the filtration units used in these systems, which play a role in the reduction of the airborne radioactive discharges.

I will also describe the principles of aerosol filtration and then the various types of filtration and the filtration efficiency testing methods.

I will introduce the measuring method and measuring configuration selected, in consideration of the local conditions and circumstances, for site efficiency testing of the C-500 type aerosol filters used in the ventilation systems.

In the nuclear practice, aerosol filters are generally tested with the use of liquid aerosols, because the filters are exposed to such load in accident conditions. Di-Ethyl-Hexyl-Sebacat (DEHS) has been selected for use as test aerosol.

The addition of the test aerosol and the concentration measurement upstream and downstream of the filters takes place through injection points.

The SN-10 aerosol generator of NUCON International Inc. has been selected for preparation of the test aerosol. The maximum output capacity of the aerosol generator is 3 g aerosol/min. The devices are operated from the 6 bar compressed air system through a connection hose.

A Royco Model 3313 type laser particle counter has been selected for the determination of the aerosol concentration, which provides a linear response within a measuring range covering seven orders of magnitude, thus being suitable for measuring the filter inlet and outlet concentration.

The measuring method and the test configuration selected have been adopted at Paks Nuclear Power Plant Ltd as a tool for in-site filtration efficiency testing of aerosol filters. At the end of the section, I will provide a summary of the measurement results. My measurements demonstrated that the aerosol filters are unable to achieve the specified filtration efficiency and, therefore, actions will need to be taken to reinstate the required efficiency.

2. Improvement of the retention measuring method on the activated carbon adsorbers

I will present the theory of the retention of noble gases and assess the factors affecting the retention.

Budapest University for the Technology and Economy (BUTE) has developed a measuring procedure, which is based on monitoring the activity concentration of noble gas isotopes at the adsorber inlet and outlet. The monitoring is performed by gamma spectroscopic measurement systems using semiconductor detectors. For the adsorbers, regulatory criteria, i.e. retention period has been specified for Kr and Xe isotopes, however, the measurement method of BUTE does not allow the measurement of retention properties for Xe isotopes.

I have improved the measuring method, which, now allows the completion of tests for all retention criteria by using the benefits offered by the structure of the adsorber. This method includes the measurement of the activity concentration at intermediate locations in addition to the outlet of the adsorber. By presenting the measurement results, I will illustrate the differences between the two methods, the adequacy and the higher reliability of the improved method.

The improved method has been adopted for practical use at Paks Nuclear Power Plant, as a measuring procedure for annual testing of the activated carbon adsorbers.

3. Construction of a model and testing the retention properties

The results of the tests performed demonstrated that the retention capacity of the adsorbers is not acceptable. It was therefore required to improve the capacity of the adsorbers and to reveal the reasons for the loss of capacity.

As a first step, I elaborated a procedure for sampling the adsorbers, to allow the assessment of the physical and chemical properties by analysing the samples taken of the carbon charge. The results of the analysis demonstrated that the physical and chemical properties of the activated carbon charge were not worse than those of the fresh activated carbon.

Following this, I built a model equipment to allow, on the one hand, the determination of the retention properties of any kind of activated carbon for application at Paks and, on the other hand, the comparison and validation of various methods used for measuring the retention factors. The use of the model also allows checking what retention properties the adsorbers would have with the use of various activated carbon charges and of different physical conditions.

The validation of the results obtained with the use of the model has taken place by completion of measurements in parallel connection with the operating adsorber and with identical carbon charge.

The measurement results demonstrated that the reduced retention capacity is attributable to the higher moisture content of the adsorber charge and, on the other hand, they revealed that the specified retention capacity could be achieved theoretically with fully dried activated carbon only, which, however, can not be guaranteed in industrial circumstances.

4. Drying of the activated carbon adsorber

It became clear as a result of the model experiments that the most economical way of increasing the capacity of the adsorbers is the drying of the activated carbon charge. This is not a simple work in industrial circumstances, therefore an appropriate drying method had to be selected. For this aim, I modified the model to allow the identification of the method among several other theoretically practicable methods, which can effectively be used for the adsorbers. After completion and evaluation of the tests, I selected the effective way of drying the adsorbers, which is drying by dry air in vacuum. After providing the conditions for the drying operations in industrial environment in large scale, I completed the drying of all adsorbers. As a result of the drying, I managed to achieve a significant improvement in the capacity of the adsorbers.

5. Review of the retention capacity criteria

It was also demonstrated by the retention tests carried out using the model that the capacity of the adsorbers can not be increased to the level specified in the criteria, and the replacement of the adsorber charge would not even result in such an increase. It was, therefore, necessary to review the capacity criteria specified for the activated carbon adsorbers of gas purifier systems to allow the theoretical substantiation of the required retention criteria.

I performed a review of the criteria specified for the activated carbon adsorbers. First, I calculated the maximum possible load to the adsorbers, by considering the operational requirements applied for the gas purifier in the main building and the maximum allowed activity values of the primary coolant. Subsequently, I identified the theoretically required retention factors, by considering the limits specified for the airborne discharges and the isotope inventory of the gas to be purified.

As a result of the review, the nuclear authority has modified the criteria. The retention factors, increased by drying the adsorbers, achieve the values modified as a consequence of the review, which means that the work performed resulted in harmony between the regulations and the process system.

CONCLUSIONS

1. The development of a method for testing the retention capacity of activated carbon adsorbers for all specified retention criteria allows the completion of the periodic testing of the adsorbers.
2. Model experiments were carried out and resulted in the identification of reasons for the loss of capacity of the adsorbers, which was the wetting of the carbon charge. It was demonstrated by the experiments that the retention capacity of the adsorbers could not be remarkably increased even with the installation of fresh carbon charge. As a result of my experiments, it was possible to save the costs of a carbon charge replacement that would not even have brought an improvement in quality.
3. With the drying procedure, it became possible to reinstate the capacity of adsorbers that became reduced due to carbon charge moistening. I demonstrated with the completion of the carbon charge drying operations that the drying procedure can be successfully applied in large scale in industrial environment.
4. I demonstrated with the review of the adsorber capacity criteria that the criteria are too rigorous. As a result of the review, the nuclear authority modified the criteria. With this action it was possible to create harmony between the regulations and the achievable capacity with regard to the activated carbon adsorbers.
5. The measuring method and test configuration selected have been adopted as a tool for the site efficiency testing of the aerosol filters at Paks Nuclear Power Plant. My measurements demonstrated that the aerosol filters are not capable of achieving the specified efficiency therefore, actions will need to be taken to reinstate the filtration capacity to the acceptable level.

NEW SCIENTIFIC RESULTS

1. **I reviewed the retention criteria specified for activated carbon adsorbers,** and in theoretical way, I identified the required value of the retention criteria. The Hungarian nuclear authority, by adopting the results of my review for practical application, modified the regulatory criteria for the retention capacity of adsorbers.
2. **I improved the method for testing the retention factor of activated carbon adsorbers,** to make it suitable for testing the retention factors for Xe isotopes. The improved testing method has been adopted at Paks Nuclear Power Plant for practical use as a tool of annual testing the activated carbon adsorbers. The tests performed demonstrate the adequacy and reliability of the new method.
3. **I built a model** to allow, on the one hand, to determine the retention properties of any kind of activated carbon applied at Paks and, on the other hand, to compare and validate various methods used for measuring the retention factors. The model was successfully

used in the practice for site testing of different activated carbons and various physical conditions. **With my measurement results, I demonstrated** that the reduced retention capacity is due to the high moisture content of the adsorber charge.

4. **I modified the model developed for testing the activated carbon adsorbers** used in gas purifiers. I performed measurements in the model, as a result **a method for the effective drying of the activated carbon adsorbers was selected.** I developed the configuration required for the completion of the drying process in industrial scale. **I successfully completed, in industrial environment, the drying of activated carbon adsorbers used in the process systems of Paks Nuclear Power Plant.** The drying resulted in a significant increase in the capacity of the adsorbers.

5. Based on international practice and national experience, **I selected a measuring method and a test configuration for site efficiency testing of the aerosol filters** with the use of test aerosol, which takes account of the site specific requirements specified for the aerosol filters used in the process systems of Paks Nuclear Power Plant. The measurement method has been adopted for practical use at the power plant as a measuring procedure for annual testing of the activated carbon adsorbers. With an adequate test aerosol the method is applicable for testing the efficiency of other filter types (aerosol filters of defence facilities and shelters, and respirators).

RECOMMENDATIONS

1. The efficiency testing of filtration equipment in the nuclear power plant will need to be regularly performed, and the applied procedures and methods will need to be improved and simplified, in the future.
2. For items of the filtration equipment that failed in the test, actions will need to be taken for reinstating the filtration capacity and the research and development work performed in this field will need to be continued in the future too.
3. The efficiency measuring methods and test configuration used for the aerosol filters can be applied for testing the aerosol filters of military facilities and shelters. For such an application, it shall be ensured that the selected test aerosol complies with the specific requirements of the given filtration unit.
4. The methods developed for retention testing of the adsorbers and for the drying of wet carbon charges in industrial environment can be applied for testing and conditioning of large size activated carbon filled filtration units in other industrial facilities. Of course, the testing method can only be used if the function of the filtration unit is similar to those used in nuclear facilities.
5. I consider that it would be practicable to assess the generation and composition of aerosols in Paks NPP. The results of this assessment could be used for the more precise identification of the composition of the test aerosol used for qualification of the filters and for the simulation of the accidental conditions.

PUBLICATIONS' LIST

A.) Published papers

1. **Eigemann Gábor**: Jódszűrők vizsgálata. Diplomaterv, Budapesti Műszaki Egyetem, Hő- és Rendszertechnikai Intézet, 1989.

2. **Eigemann Gábor**: Atomerőművi gáztisztító rendszerek adszorberei aktív szén töltetének módosítása és minősítése. A SOMOS Alapítvány által doktoranduszok számára meghirdetett "Pro Patria et Scientia" országos pályázat 1. díja 2003-ban.

3. Á. Vincze, **G. Eigemann**, J. Solymosi: Filtration of radioaerosols in Nuclear Power Plant Paks, Hungary. AARMS Vol. 5, No. 3 (2006) 335-344.

4. **Eigemann Gábor**, Gimesi Ottó, Zsille Ottó, Vincze Árpád, Solymosi József: Gáztisztító rendszerben üzemelő adszorber retenció mérési módszerének továbbfejlesztése a Paksi Atomerűben. Sugárvédelmi Nívódíj Pályázaton 2008-ban Sugárvédelmi Nívódíj felnőtt kategóriában

5. **Eigemann Gábor**: Radioaeroszolok szűrése a Paksi Atomerőműben. Fiatal kutatók írják: http://www.zmne.hu/tanszekek/vegyi/forum.htm

B.) Conference presentations

1. Vincze Árpád, Barnabás István, Bodnár Róbert, **Eigemann Gábor**, Volent Gábor, Solymosi József: Gáztisztító rendszerek retenciós állapotának folyamatos ellenőrzése. XXIII. Sugárvédelmi Továbbképző Tanfolyam, Balatonkenese, 1998. május.

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9. **Eigemann Gábor**, Vincze Árpád, Solymosi József, Gimesi Ottó, Zsille Ottó, Csurgai József: Radioaktív aeroszolszűrők ellenőrzése a Paksi Atomerőműben. XXXI. Sugárvédelmi Továbbképző Tanfolyam, Keszthely, 2006. május.

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C.) Work in progress

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2. **Eigemann Gábor**, Gimesi Ottó, Zsille Ottó, Vincze Árpád, Solymosi József: Gáztisztító rendszerben üzemelő adszorber retenció mérési módszerének továbbfejlesztése a Paksi Atomerőműben. Megjelenik: Sugárvédelem on-line folyóirat (received and accepted)

PROFESSIONAL CV

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2002-2006	Zrínyi Miklós National defence University PhD Institute in Military Technology PhD student
1984-1989:	Technical University of Budapest Faculty of Mechanical Engineering M.Sc. in Mechanical Engineering, in the field of Process Engineering

Professional Experience:

2004-	Head of the Mechanical Engineering Section at Paks NPP
2003-2004	Head of the System Technological Section at Paks NPP
2000-2003	Group leader of the System Technological Section at Paks NPP
1997-2000	Group leader of the Mechanical Technology Section at Paks NPP
1995-1997	Group leader of the Reactor Section at Paks NPP
1993-1995	Mechanical technologist of the Reactor Section at Paks NPP
1989-1993	Mechanic, chief mechanic, reactor operator at Paks NPP

Languages:

German:	Intermediate state examination in 1995 (type C)
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Paks, 05. June, 2008.

Gabor J. Eigemann