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Theses of PhD dissertation

Radiation protection planning and performance of removal of damaged fuel elements at Paks Nuclear Power Plant

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Description of the scientific issue

A serious incident occurred at Paks Nuclear Power Plant on 10 April 2003. In the service shaft No. 1 on Unit 2 in the cleaning system of fuel elements located under water the fuel assemblies unloaded from Unit 2 were cleaning. In the cleaning vessel no chain reaction occurred during the incident, but radioactive fission products accumulated in the fuel elements during their operating lifetime inside the reactor generated significant amount of heat. Due to insufficient cooling of the cleaning device the fuel assemblies overheated during some hours, then due to cold water flown in when the cover of the cleaning vessel was opened thermal shock resulted in damage of the fuel assemblies. Due to this event the cladding of fuel elements opened and uranium-dioxide pellets inside them got damaged.

Removal and safe disposal of the damaged fuel assemblies and the nuclear fuel debris had to be resolved. In addition to their technical difficulties these tasks caused also serious radiation protection problems, solution of which was essential to reduce radiation exposure of the personnel and to minimize the radioactive releases into the environment.

The subject of the present dissertation is to research and develop procedures and methods for resolving radiation protection issues of the reconstruction work of the Shaft No. 1 on Unit 2 at Paks NPP and their practical use in order to resolve the set of these irregular radiation protection issues.

In addition to safe reconstruction of the consequences of this incident - which is a unique one in the world – timeliness of the present dissertation is given also by the fact that new and combined procedures have been developed from the activities performed under Hungarian circumstances, which can be well used in the field of domestic radiation protection, environmental protection and emergency preparedness, and they are also useful for military purposes.

During complete elaboration of the topic a radiation protection plan was developed, which enables to perform a complex activity with radiation hazard. During the reconstruction work radiation protection monitoring of the employees and Shaft No. 1, and also monitoring of radioactive releases were possible. During planning and then implementation a lot of data and results were accumulated, which can be used in the future for planning, preparation and implementation of activities with radiation hazard.

Research objectives

1. To estimate radiation conditions of the Shaft No. 1 on Unit 2 at Paks NPP in details with model calculations and on-site measurements.
2. To elaborate radiation protection organisational and technical measures required during recovery of the Shaft No. 1.
3. To plan and design the protective devices and biological shields in accordance with radiation protection and technological requirements.
4. To establish a complex personal dosimetry system for monitoring of internal and external radiation exposure of the workers.
5. To review and develop the requirements concerning establishment and design of installed radiation protection systems.

6. To determine the planned radioactive releases, to compare them with release limits, and to calculate expected radiation exposure of the public with dispersion models.
7. To verify that the recovery work can be performed with acceptable radiation protection measures without radiation exposure of the personnel and public, and also without exceed of radioactive release limits.

Research methods

I studied respective literature and evaluated the possibility of their use for resolving the given concrete or similar problem.
My research-development work meant development of new and complex procedures and methods for resolving the above-mentioned issues, and also their practical use. During the planning phase several usable methods were developed starting from data and results found in the respective literature, but including also the corresponding local experiences. Reliability of the obtained results was proved by comparison with the measured values. Practical usability of the developed procedures is supported by solution of several real problems under both normal and emergency conditions.
I established personal relationships with specialists having significant international experiences in this field. I analysed my previous research achievements and studied new theories and procedures appeared in this topic.
My achievements developed during the research-development work were regularly published; I regularly participated at Hungarian and international research conferences and symposiums. Based on this work and also having the local characteristics and requirements of the recovery work in mind, I could identified radiation protection issues, which have not been resolved so far and on which the theses of the present dissertation are based.

Short description of the tasks completed

1. Status survey of the Shaft No. 1 by model calculations and field measurements

After the incident the most important task was to survey the status of radiation in order to ensure protection of the personnel and to plan protective measures. I performed the radiation protection status survey of the Shaft No. 1 and evaluation of the results. Starting from isotope composition of the damaged fuel elements and on the basis of model calculations the expected values of gamma dose rates around the cleaning vessel was determined. Then based on radionuclide composition of contaminated water inside the Shaft No. 1 the dose rates emerging above the water was determined. The model calculations were validated by dose rate measurements. During decontamination a new procedure was used for determination of surface beta contamination occurring in high gamma background.
Detailed understanding of radiation conditions inside the Shaft No. 1 and its environment enabled to take adequate organisational and technical measures during the planning phase of recovery.

2. Radiation protection planning of the work platform and associated technologies

During the planning phase of recovery new and unique technologies and tools had to be planned, which required solution of several and serious radiation protection issues. The most important task was to design a work platform that provided suitable protection for workers

during removal of the damaged fuel elements. On the work platform the warning level of gamma dose rate was 40 μSv/h. Consequently, the water level inside the Shaft No. 1, wall thickness of the bottom and sidewall of the work platform had to be design so that people on the work platform could work in a lower dose rate than the warning level.
Shielding of the damaged fuel elements had to be ensured with a water layer of sufficient thickness. Based on the monitoring level of dose rate this thickness of the water layer was 250 cm. 100 mm thickness of the steel floor of the work platform with a service hole and lead glass of the inspection hole ensured required shielding against the contaminated water inside the Shaft No. 1 and damaged fuel elements in the cleaning vessel. In the Shaft No. 1 iron shielding of 8 mm (top) and 45 mm (on the workplace until the height of 2 m) of the sidewall of the work platform could sufficiently reduce radiation effects from the wall.
Sufficient shielding of the pipelines and assemblies of the independent cooling system transporting the water from Shaft No. 1 was also an outstanding task. Thickness of shielding was determined by model calculations, which was verified also by on-site measurements. Practical measurements proved the suitability of shielding size, since dose monitoring device around the independent cooling system and barriers around the podium never indicated higher value than 14 μSv/h, which was in accordance with the class of room.
Storage cases of the damaged fuel elements were transported outside water, so their shielding was not provided during their transfer. This new type of transfer required calculation of each expected dose rates, on the basis of which it could be determined which rooms had to be locked during transfer and which measurements had to be taken on the surrounding locations.

3. Personal dosimetry

During removal of the damaged fuel elements one of the most important tasks for radiation protection was to perform personal dosimetry tasks, such as to determine exact radiation exposure of the workers. Consequently, radiation exposure monitoring levels were determined, dose calculations were performed for determination of expected radiation exposure of the workers, a detailed dose plan was developed for each work phase and a monitoring instruction of radiation exposure was elaborated.
The dose plan establishes time requirement of each task in a systematic and analytical way, and provides dose estimation for the work, considering working place of the workers, duration of the work and radiation conditions of the workplaces. According to the dose plan and on the basis of conservative calculations the maximal individual exposure was 5.8 mSv, which was significantly below both the monitoring level and dose limit.
From radiation protection aspect one of the most important objectives during the recovery work was to keep radiation exposure of the workers below the dose limits. The planned technical and organisational measures ensured suitable protection of the personnel and compliance with the radiation protection limits was also ensured.

4. Auxiliary Radiation Protection Monitoring System

In order to understand the condition of the Shaft No. 1 and its environment in details it was essential to perform installed on-line radiation protection monitoring systems. During preparation for the recovery a new and special monitoring system was designed and installed, by which continuous monitoring of the Shaft No. 1 and its environment was ensured.
The Auxiliary Radiation Protection Monitoring System (KISER in Hungarian) ensured continuous monitoring concerning the following parameters:

- on the work platform:
  - dose rate of gamma radiation,
  - activity concentration of alpha, beta and gamma aerosols in the air,
  - activity concentration of radioactive iodine and noble gases;
- dose rate of gamma radiation on the podium of the reactor hall,
- total gamma activity concentration in the water of the Shaft No. 1,
- in the air ventilated from under the work platform and filtered:
  - activity concentration of alpha, beta and gamma aerosols in the air,
  - activity concentration of radioactive iodine and noble gases.

The aim of the installed radiation protection monitoring system was to evaluate the radiation protection condition in an operative way and inform the personnel. By installing the system KISER a complex installed radiation protection monitoring system was operated around the Shaft No. 1, which was suitable for continuous monitoring of the radiation condition at the workplace, for displaying and storing the measuring results, and comparing them with warning and emergency levels, and also for signalling on the displaying units.
The measurements of the system KISER were supplemented by the gamma dose rate measurements, activity concentration measurements of beta and gamma aerosols and radioactive noble gases.
Operative supervision of the recovery work and continuous radiation protection monitoring could be implemented on high level using these systems.

5. Release and environment monitoring

During preparation and implementation of recovery of the Shaft No. 1 on Unit 2 at Paks NPP in addition to personal dosimetry issues one of the most important tasks from radiation protection aspect was to minimize radioactive releases into the environment and monitoring of radioactive releases and the environment.
Preliminary treatment of liquid radioactive wastes generating during preparation and implementation of recovery was performed by the available process systems. Releases could occur on the available releasing pathways after inspections performed in checking vessels, by which compliance with release limits could be ensured.
Concerning gaseous radioactive releases during the preparation work radiation exposure of the public increased by $4{,}30 \cdot 10^{-5}$ μSv, which is $4{,}8 \cdot 10^{-5}$ % of the dose restriction value of 90 μSv/year.
In relation to removing activities it had to be taken into consideration that during the work the fuel elements could be further damaged. Gaseous activity to be released due to damage is practically resulted from the isotope Kr-85. Assuming destruction of all the fuel elements, in accordance with the calculations performed, radiation exposure of the public would increase by $5{,}58 \cdot 10^{-4}$ μSv, which is $6{,}2 \cdot 10^{-4}$ % of the dose restriction value of 90 μSv/year.
Considering the above described planned radioactive releases and consequent extra radiation impact of the public it can be stated that the preparation work and the recovery work itself was implemented with high level of safety for environmental releases and complying with the

relevant limits of liquid and gaseous releases. The released radioactive isotopes had negligible effect on the environment.

6. Radiation protection evaluation of removal of the damaged fuel elements

After the incident occurred on 10 April 2003 the plant started preparing for removal of the damaged fuel elements. By the autumn of 2006 all the required technical tools and licence from the regulatory body were available and on 15 October 2006 actual removal of the fuel elements in the Shaft No. 1 on Unit 2 was started.
During the removing work of the damaged fuel elements the radiation conditions were very good. Accordingly, radiation exposure of the personnel was low; the rate of both collective and individual maximal radiation exposure was acceptable.
Also the radioactive releases were low and it could be stated that the consequent extra radiation exposure of the public (lower than 1 nSv) was negligible.

New scientific achievements (theses)

1. During the serious incident occurred on 10 April 2003 at Paks NPP safe removal and disposal of 30 pieces of significant damaged fuel assemblies in a cleaning vessel located in the Shaft No. 1 on Unit 2 and released, also damaged uranium-dioxide pellets required completely new radiation protection issues, which had never been experienced in the practice of nuclear power plants. Solution of these issues made essential to perform status evaluation of the Shaft No. 1 by model calculations and on-site measurements in order to minimize radiation exposure of the working personnel and amount of radioactive materials released into the environment. Accordingly, **regarding the given emergency case a complete radiation protection status evaluation was performed and the results were assessed**, including the following:

- from the isotope composition of the damaged fuel elements, on the basis of model calculations the expected values of gamma dose rates around the cleaning vessel was determined;
- similarly to the damaged fuel elements, on the basis of radionuclide composition of radioactive contaminated water in the Shaft No. 1 the dose rates above the water was determined;
- the model calculations were validated by on-site dose rate measurements;
- a new method was used for determining surface beta contamination in intensive gamma background.

Detailed understanding of the condition of the Shaft No. 1 and its environment enabled to take suitable organisational and technical measures during the planning phase of recovery and to design required radiation protective devices.

2. During planning phase of the recovery work of the Shaft No. 1 on Unit 2 of Paks NPP **completely new and special technologies and tools had to be designed** in order to evaluate the work platform providing protection for the workers and dose spaces occurring during transport of the damage fuel elements:

- Contamination conditions of the walls and water in the Shaft No. 1 and radiation effects of the fuel elements were analysed. Accordingly, **I determined** the thickness of radiation protection shielding layers of the work platform, which could provide adequate protection for the workers during removal of the damaged fuel elements.
- By model calculations **I determined the thickness of shielding**, which was later proved by on-site measurements.

- The special method of transferring the loaded cases required calculation of expected doses, on the basis of which **I determined** which rooms had to be locked during transfers and which calculations had to be performed on the surrounding locations.

3. During removal of the damaged fuel elements from radiation protection aspect one of the most important tasks was performance of personal dosimetry tasks and exact determination of radiation exposure of the workers. Accordingly, in order to resolve this radiation protection issue - which is a unique one in the world -:

- On the basis of the Hungarian and Russian radiation health regulations **I determined the monitoring levels of radiation exposure** for the whole duration of the reconstruction work, **for both external and internal radiation exposure**.
- Simultaneously with the design of protective devices **I performed dose calculations** in order to determine expected radiation exposure of the workers.
- In order to reduce radiation exposure of the workers **I introduced organisational and technical measures** and specified individual protective devices.
- I determined the tools and order of personal dosimetry for monitoring of both external and internal radiation protection.

4. In order to understand the status of the Shaft No. 1 and its environment in details it is essential to implement installed on-line radiation protection monitoring systems. During preparation for the recovery work a new monitoring system was designed and installed, by which continuous monitoring of the Shaft No. 1 and its environment was ensured. During the designing phase of this new Auxiliary Radiation Protection Monitoring System (KISER in Hungarian):

- **I determined the design basis of the new system.**
- By detailed calculations **I determined** the required specification of the installed measuring devices and sampling locations.
- **I calculated the warning and emergency levels** of the measuring devices.

5. During preparation and implementation of the recovery work of the Shaft No. 1 on Unit 2 at Paks NPP in order to minimize the amount of radioactive materials released into the environment and to monitor radioactive releases and the environment:

- By complex radiation protection calculations **I determined the planned radioactive releases** and compared them with the corresponding release limits.
- It was the first time that **I compiled** and systematized **the measuring methods of the actual releases** during the recovery work.
- On the basis of the planned releases **I calculated the radiation impacts of the public by model calculations.**

Conclusions

1. Detailed understanding of the condition of the Shaft No. 1 and its environment enabled to take suitable organisational and technical measures during the planning phase of recovery and to design required radiation protective devices.
2. From radiation protection aspect during the recovery work one of the most important objectives was to keep radiation exposure of the workers below the dose limits. The planned biological protection, establishment of a ventilation system, measures taken during half-wet transfer and individual protective devices ensured adequate protection of

the personnel against external and internal doses. Compliance with the radiation protection limits was also ensured.

3. During preparation for the recovery work a new monitoring system was designed and installed, by which continuous monitoring of the Shaft No. 1 and its environment was ensured.
4. Considering the planned radioactive releases and consequent extra radiation exposure of the public it can be declared that the preparation work and the recovery work itself was implemented with high level of safety for environmental releases and complying with the relevant limits of liquid and gaseous releases. The released radioactive isotopes had negligible effect on the environment.

Recommendations

1. Model calculations can be widely used for various maintenance and modification activities at a nuclear power plant, during emergency practices and for dose and shielding calculations on military field.
2. My achievements can be well utilised also in education for training of specialists in the field of radiation protection and nuclear emergency preparedness.
3. During planning and then implementation a lot of data and results were accumulated, which can be used for planning, preparation and implementation of future radiation protection activities.
4. **During complete elaboration of the topic a radiation protection plan was developed, which enables successful performance of a complex and special activity with radiation hazard.**