

CHARACTERISATION OF NUCLEAR POWER PLANT SPENT FUELS FOR SAFEGUARDS USING IN-SITU GAMMA SPECTROMETRY

PhD thesis summary

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The Nuclear Security Department of the HUN-REN Centre for Energy Research has been studying the spent fuel assemblies of Paks Nuclear Power Plant (NPP) Ltd. in Hungary over the last two decades. The purpose of the gamma-ray spectrometry measurements of spent fuels was to verify their burnup level, which allows the quantification of the operator-calculated burnup uncertainty. The objective of my PhD thesis is to develop methods of VVER-440 reactor type spent fuel parameter calculation based on gamma-ray spectrometric measurements. The parameters in question are the fuel burnup, cooling time, initial enrichment, remaining fissile material content, and the activities of detectable fission products. The primary motivation of my research is to improve established nuclear safeguards verification methods; however, the nuclear forensic analysis perspective was also placed in focus. Another important motivation linked to the original aim of the spent fuel measurements is to reduce the burnup engineering factor by determining the calculation uncertainty of the NPP. The applied methods include gamma-ray spectrometric measurement and evaluation, non-linear regression, parameter prediction by machine learning algorithms, and Monte Carlo particle transport simulation.

I summarise my results in four thesis statements, of which the most important achievements are presented here. I showed, using regression with power functions, that the fuel burnup can be predicted from the $^{134}\text{Cs}^2/(^{106}\text{Ru}^{137}\text{Cs})$ activity ratio with an error almost a fifth of the error that results from the $^{134}\text{Cs}/^{137}\text{Cs}$ activity ratio. The $^{134}\text{Cs}^2/(^{106}\text{Ru}^{137}\text{Cs})$ activity ratio can be measured in spent fuels of up to 9 years of cooling time and can be successfully used without cooling time information. When predicting the cooling time, I obtained the smallest errors from the $^{110\text{m}}\text{Ag}/^{134}\text{Cs}$ activity ratio for fuels of up to 5 years of cooling time; for fuel assemblies cooled longer than that, the $^{134}\text{Cs}/^{154}\text{Eu}$ activity ratio yielded the most reliable results. In spent fuels that were cooled for less than half a year, the shortness of the cooling period is indicated by the presence of ^{136}Cs , ^{140}Ba , and ^{156}Eu . Applying machine learning algorithms, I achieved a slight improvement in burnup prediction accuracy and a significant improvement in cooling time prediction accuracy. The machine learning models, including artificial neural networks, were capable of successfully predicting the initial enrichment and the remaining ^{239}Pu concentration. With convolutional neural networks, I was able to predict fuel parameters without the need for spectrum evaluation. I conducted the absolute full-energy peak efficiency calibration using Monte Carlo simulations. Applying X-ray radiography and determining the germanium dead layer thickness led to an improved simulation model, which I validated using experimental relative efficiency curves and data of spent fuels from other VVER-440 type reactors.