

Introduction

Safeguards inspections on nuclear material are performed by the IAEA in the framework of the Non-Proliferation Treaty to verify that no nuclear material is diverted from peaceful applications. Almost 75% of the nuclear material inspected by the IAEA consists of spent fuel. Spent fuel verification methods are less precise and accurate due to the high radiation fields of spent fuel.

A candidate for more accurate verification is the FORK detector. The performance of the FORK detector as a so-called partial defect tester (i.e. being able to detect the diversion of 50% of the fuel pins) was investigated experimentally by a joint Finnish, Swedish and Belgian effort. It was concluded then that the FORK detector was not suitable as a partial defect tester, since fuel pin removal could not be detected in an unambiguous way for various possible scenarios.

Later analysis of the results revealed that the measurement results could be interpreted unambiguously, if additional measurements at 90° of the original measurement position are performed. It was decided to perform simulation calculations for the configurations that were investigated during the joint effort by MCNPX for validation of the correctness of the simulation methodology and to investigate by simulation calculations the applicability of the proposed additional measurements for an unambiguous partial defect test. This work was performed under the Belgian Support Programme to the IAEA.

Measurement principles

The FORK detector consists of two arms that can be positioned around a LWR fuel assembly (figure 1). Each arm contains three detectors: one ionisation chamber for measuring gammas and two fission chambers for measuring neutrons (figure 2).

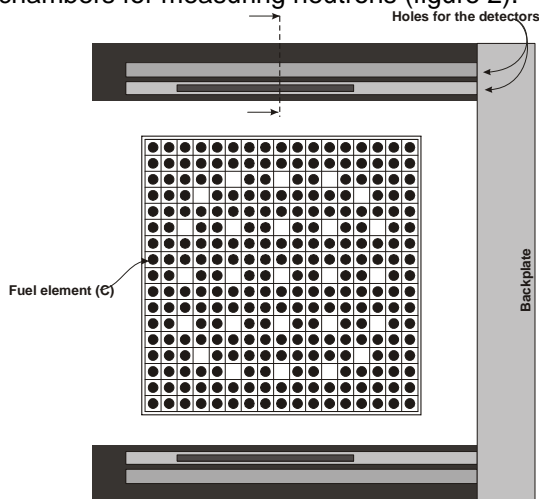


Figure 1. Horizontal cross-section of the FORK detector with a 17x17 PWR fuel assembly

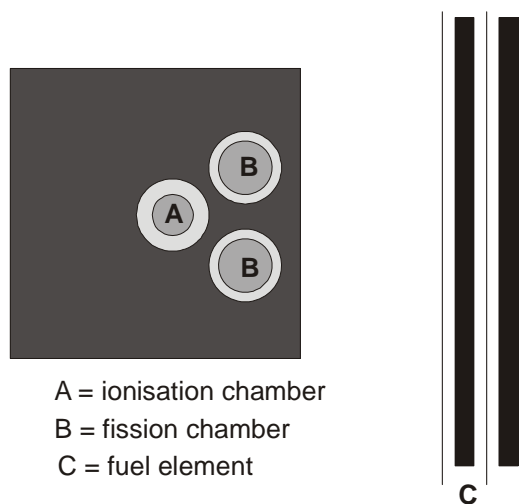


Figure 2. Vertical cross-section of an arm of the FORK detector, showing the position of the three detectors

Whereas the neutron count rate for long cooling times is mainly due to the presence of ^{244}Cm , the gamma count rate is mainly due to the presence of ^{137}Cs . The production of ^{244}Cm is not a linear function of the burn-up, but a higher order power (~ 4) due to the increased formation of mother isotopes with increasing burn-up. The production of ^{137}Cs in the fuel is linearly proportional to the burn-up. This results in a more or less constant ratio between neutron count rate N_c and the fourth power of the gamma count rate G_c ($N_c/G_c^4 = \text{constant}$, where both N_c and G_c are corrected for decay).

In case of a significant diversion of fuel pins this ratio should depart from its constant value.

Results

From a comparison between measured and calculated neutron and gamma count rates, it was concluded that the MCNPX model simulated appropriately the experimental measurement conditions.

Figure 3 shows results of the N_D/G_c^4 ratio, normalised to the ratio of a full configuration, for several configurations of spent fuel with 50% of the fuel pins missing. It appears that configurations 74 and 76 show an extremely high value for N_D/G_c^4 whereas the other configurations show values that are around or slightly lower than 100%. The high values for the ratio N_D/G_c^4 for configurations 74 and 76 can be explained by the

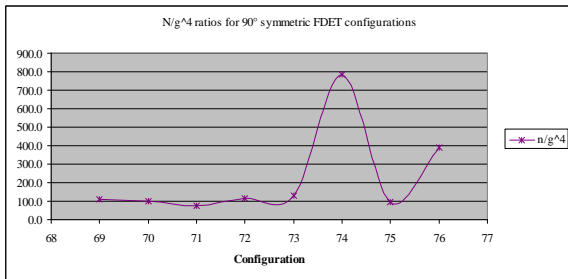


Figure 3. Results of symmetric configurations 69-76 with 50% fuel pins missing

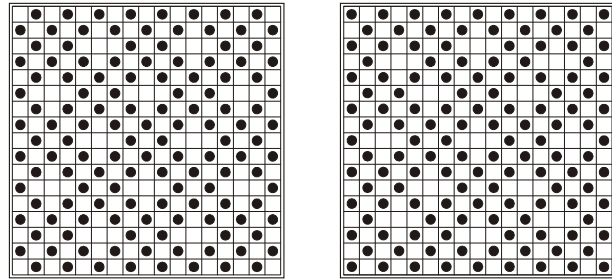


Figure 4. Configuration 69 and 70, where 50% of the fuel pins has been removed in a homogeneous way

fact that only one or a few pins are in the column close to the detectors and that gammas from the pins in the following columns are shielded by the pins in the closer columns. A closer examination of the calculation results confirmed this explanation, showing that taking away a column of fuel pins that is shielded by a closer column does not affect much the observed gamma signal. Shielding by the water is far less effective than shielding by fuel pins. This explains why configurations 74 and 76 show extremely low values for the gamma signal. The influence of these low values is amplified by the fourth power in the expression N_D/G_c^4 . The neutron signal is much less affected by the form of the various configurations and its influence on the ratio N_D/G_c^4 is much less. To conceal a diversion, a diverter should obtain a ratio N_D/G_c^4 of 100% in order to have a signal similar to the full configuration. The results show that configurations with 50% fuel pins missing can be designed that result in a ratio N_D/G_c^4 of 100%. Configurations 69, 70 and 75 could serve directly for this purpose. For the other configurations both configurations with a ratio higher and with a ratio lower than 100% exist, so intermediate configurations will exist resulting in a 100% ratio of N_D/G_c^4 .

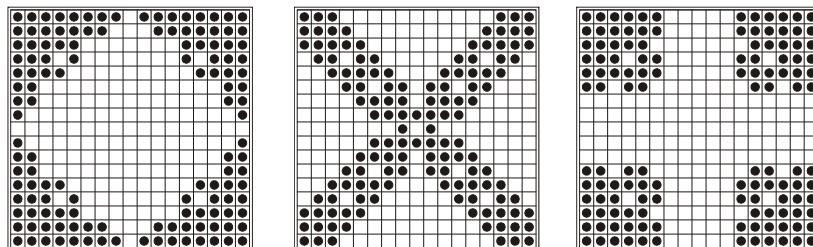


Figure 5. Configuration 71, 72 and 73. 50% of the fuel pins has been removed with the purpose to have pins close to the detectors (71), far from the detectors (72) and an intermediate configuration (73)

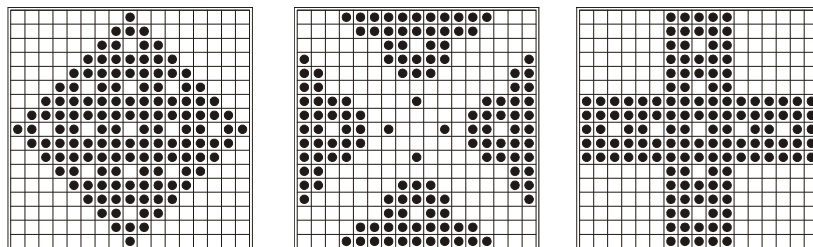


Figure 6. Configuration 74, 75 and 76. 50% of the fuel pins has been removed with the purpose to have pins far from the detectors (74), close to the detectors (75) and an intermediate configuration (76)

Conclusions

Simulations with MCNPX have shown that PWR fuel configurations can be designed so that a twofold FORK detector measurement at the normal measurement position and a position at 90° will not notice a difference between a full assembly and an assembly with 50% fuel pins missing.

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