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# Development of a Safeguards Verification Method and Instrument to Detect Pin Diversion from Pressurized Water Reactor (PWR) Spent Fuel Assemblies

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## 1. Introduction

A technical safeguards challenge has remained for decades for the IAEA to identify possible diversion of nuclear fuel pins from Light Water Reactor (LWR) spent fuel assemblies. In fact, as modern nuclear power plants are pushed to higher power levels and longer fuel cycles, fuel failures (i.e., "leakers") as well as the corresponding fuel assembly repairs (i.e., "reconstitutions") are commonplace occurrences within the industry. Fuel vendors have performed hundreds of reconstitutions in the past two decades, thus, an evolved know-how and sophisticated tools exist to disassemble irradiated fuel assemblies and replace damaged pins with dummy stainless steel or other type rods.

Various attempts have been made in the past two decades to develop a technology to identify a possible diversion of pin(s) and to determine whether some pins are missing or replaced with dummy or fresh fuel pins. However, to date, there are no safeguards instruments that can detect a possible pin diversion scenario to the requirements of the IAEA. The FORK detector system [1-2] can characterize spent fuel assemblies using operator declared data, but it is not sensitive enough to detect missing pins from spent fuel assemblies. Likewise, an emission computed tomography system [3] has been used to try to detect missing pins from a spent fuel assembly, which has shown some potential for identifying possible missing pins but this capability has not yet been fully demonstrated. The use of such a device in the future would not be envisaged, especially in an inexpensive, easy to handle setting for field applications.

In this article, we describe a concept and ongoing research to help develop a new safeguards instrument for the detection of pin diversions in a PWR spent fuel assembly. The proposed instrument is based on one or more very thin radiation detectors that could be inserted within the guide tubes of a Pressurized Water Reactor (PWR) assembly. Ultimately, this work could lead to the development of a detector cluster and corresponding high-precision driving system to collect radiation signatures inside PWR spent fuel assemblies. The data obtained would provide the spatial distribution of the neutron and gamma flux fields within the spent fuel assembly, while the data analysis would be used to help identify missing or replaced pins.

Monte Carlo simulations have been performed to help validate this concept using a realistic 17x17 PWR spent fuel assembly [4-5]. The initial results of this study show that neutron profile in the guide tubes, when obtained in the presence of missing pins, can be identifiably different from the profiles obtained without missing pins, Our latest simulations have focused upon a specific type of fission chamber that could be tested for this application.

## 2. Methodology

In order to study the effect on missing or replaced spent fuel pins, simulation studies were done using a Monte Carlo code MCNP5. The fuel assembly modeled was the Takahama-3 17x17 PWR spent fuel assembly [7], which was loaded with 248 $UO_2$ fuel pins, 4.1 w/o U-235 enrichment, 16 $UO_2$-$Gd_2O_3$ pins (2.6% wt U-235 and 6 w/o gadolinium) and 25 water rods The assembly was irradiated for three cycles with a power of 38.6 W/gU, and cooled for 2 years. The depletion of the assembly was achieved using MONTEBURNS [8] to approximate the isotopic distribution after operation at end of cycle (EOC) and after two years of cooling.

Figure 1 below shows a diagram illustrating the 39 independent regions depleted in MONTEBURNS, in which the color red highlights primarily non-depletable regions of water and the guide tubes (larger diameter circles). 1/8 bundle symmetry was used for the depletion process taking advantage of its symmetry. The fuel assembly was also assumed to have reflective boundary conditions surrounding the outer surface of the bundle.

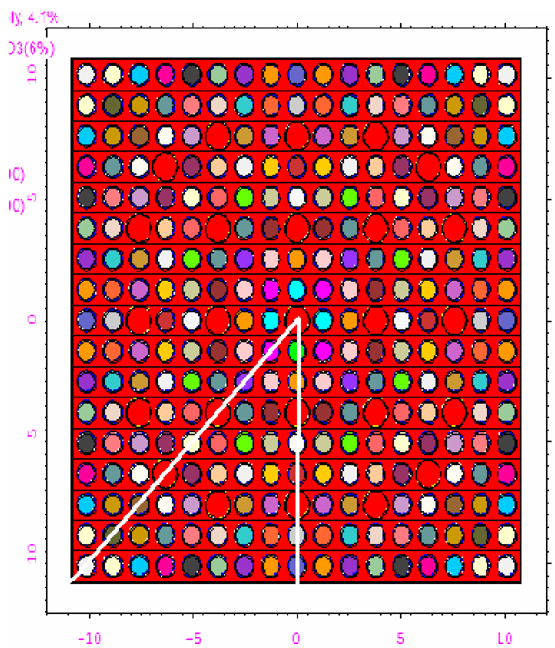


Figure 1. MCNP5 Visual Editor Image of the Takahama-3 17x17 PWR Bundle.
Note that 1/8 of the fuel were used for depletion taking advantage of its symmetry.

### *2.1. The Source Term Distribution*

Separate MCNP5 cases were run for neutron and gamma studies. For the neutron flux source in these assemblies, we targeted the Cm-244 distribution in the assembly. This is because for typical commercial power spent fuel assemblies, the neutron flux inside spent fuel assemblies is expected to be dominated by the spontaneous fission neutrons from Cm-244 after two years of cooling time. Accordingly, the pin-by-pin neutron source strengths were established in the bundle in proportion to the Cm-244 relative accumulation. The neutron source was sampled by the Watt fission spectrum and divided in 23 groups between 1.0E-05 and 20MeV, plus a total count.

## *2.2. Preliminary Results*

Results from pin-diverted cases were compared against cases with all spent fuel pins present, and the absolute difference and percent difference were calculated. Using standard error propagation, relative errors were calculated for both quantities. A key indicator was whether the differences observed were greater than could be accounted by the margin of error of the results. Assuming Maxwell statistics a hypothetical 60-second count was constructed from the MCNP5 flux. The absolute error was calculated as the square root of the count, and the relative error of the difference from the case where all spent fuel pins are present was calculated.

The preliminary Monte Carlo simulation studies showed that indeed two dimensional neutron data, when obtained in the presence of missing pins, have data profiles distinctly different from the profiles obtained without missing pins. Replacing a single spent fuel pin in the assembly resulted in detectable differences in the neutron flux greater than the designated threshold in at least one energy group for most of the guide tubes, as summarized in Table 1. Substitution of a pin by fresh fuel pin or Fe pin can show the difference in neutron measurement up to 2%. Substitution of two pins by fresh fuel pin can show the difference in neutron measurement more than 4.%. Figures 2,3 and 4 illustrate diagrams of the total neutron flux perturbations due to a corner and central pin diversion, providing some evidence of possible detectability.

Table 1: Summary of Neutron Results

| Pin replaced | MCNP5 statistics | Maxwell statistics |
|---|---|---|
| (10,9) | > Threshold in 7 tubes | > Threshold in 13 tubes |
| (17,1) | > Threshold in 3 tubes | > Threshold in 5 tubes |

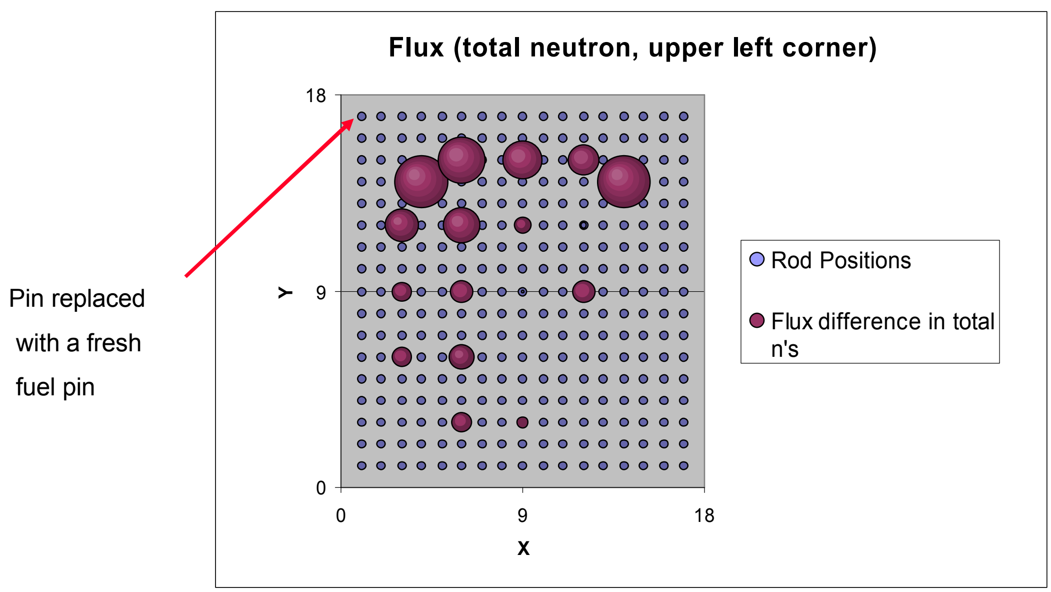


Figure 2. Neutron Flux Perturbation in Guide Tubes due to a Corner Pin Diversion

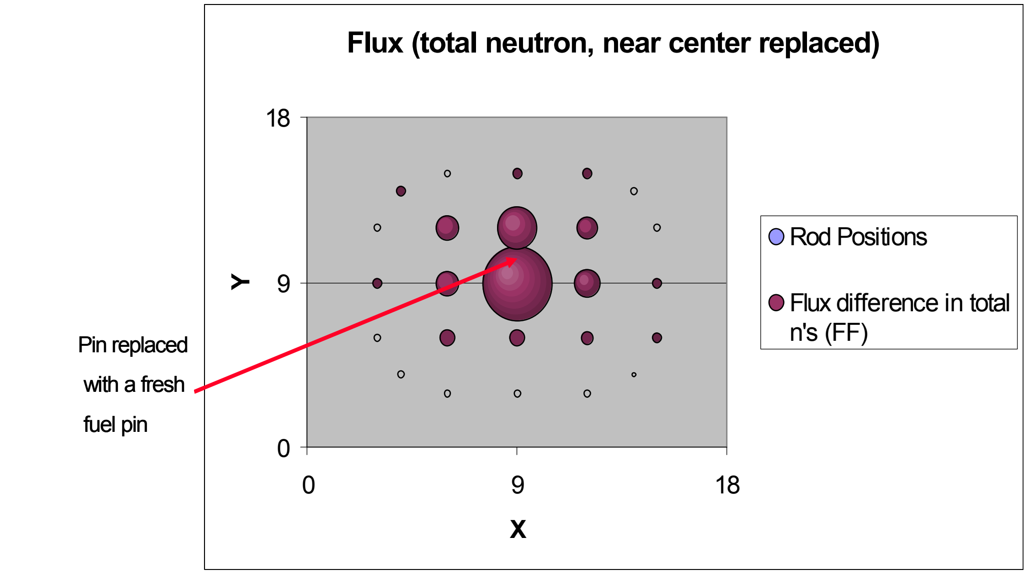


Figure 3. Neutron Flux Perturbation in Guide Tubes due to a Central Pin Diversion

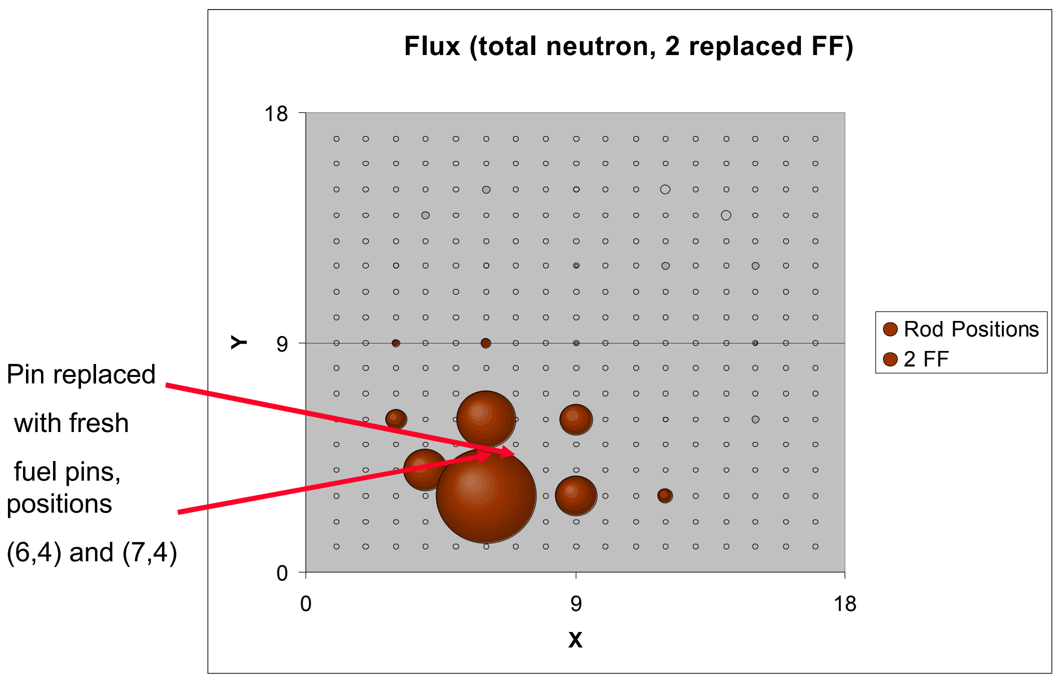


Figure 4. Neutron Flux Perturbation in Guide Tubes due to Two-Pin Diversion

## 3. Recent Results with Fission Chamber Model

Our early simulations focused primarily on MCNP tallies of neutron and gamma flux profiles within the guide tubes, and in assessing whether distinguishable differences could be detected in the gamma or neutron flux at each of the energy groups or bins selected. However, in practice, available radiation measurement tools do not usually have the luxury of finely divided energy tallies. Thus, we proceeded to model a typical fission chamber such as the LND 30753 shown in Figure 5 as a diagram and as an MCNP model, side-by-side, with the general specifications provided in Table 2.

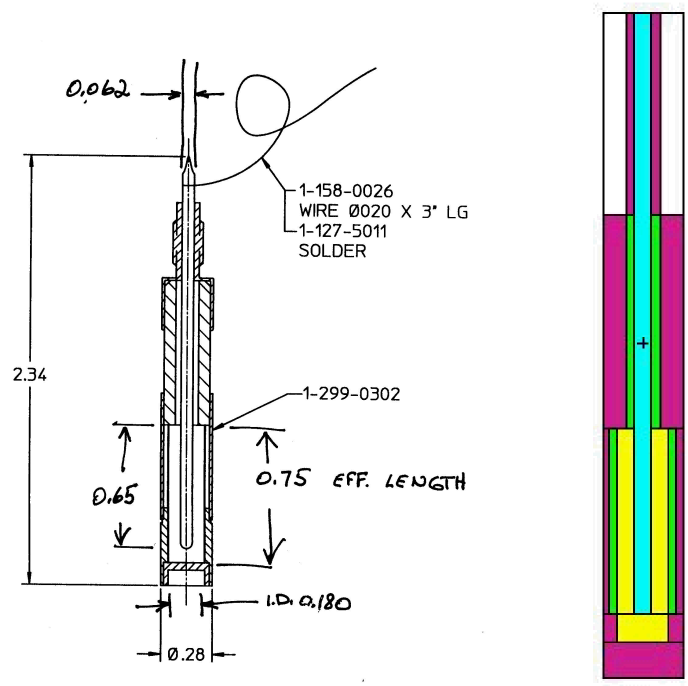


Figure 5. LND 30753 Fission Counter [10]

Table 2. General Specifications of LND 30753 Fission Counter

| | |
|---|---|
| Maximum Diameter (inch/mm) | 0.28 / 7.1 |
| Effective Diameter (inch/mm) | 0.18 / 4.6 |
| Maximum Length (inch/mm) | 2.34 / 59.4 |
| Sensitive Length (inch/mm) | 0.75 / 19.1 |
| Cathode Material | Nickel |
| Fill Gas | Argon |
| Fill Pressure (Torr) | 760 |
| Connector | Flying Lead |

Figure 6, below, Shows cross-sectional views of the MCNP model of this fission chamber inserted into the central guide tube of the assembly previously described.

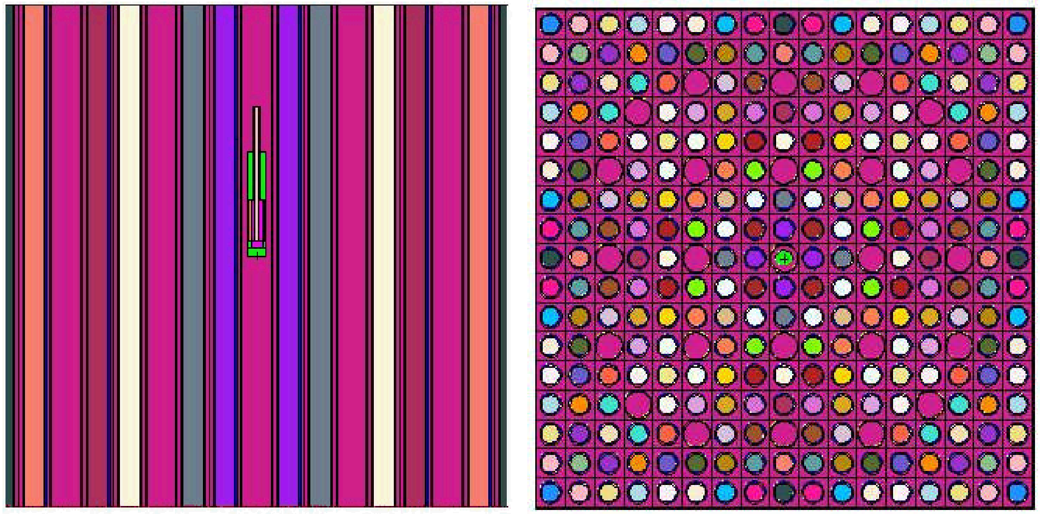

Figure 6. Cross-Sectional View of LND 307 Fission Counter in Central Guide Tube

Likewise, Figure 7, illustrates the expected impact of the detector's presence within the guidetube upon the measurements.

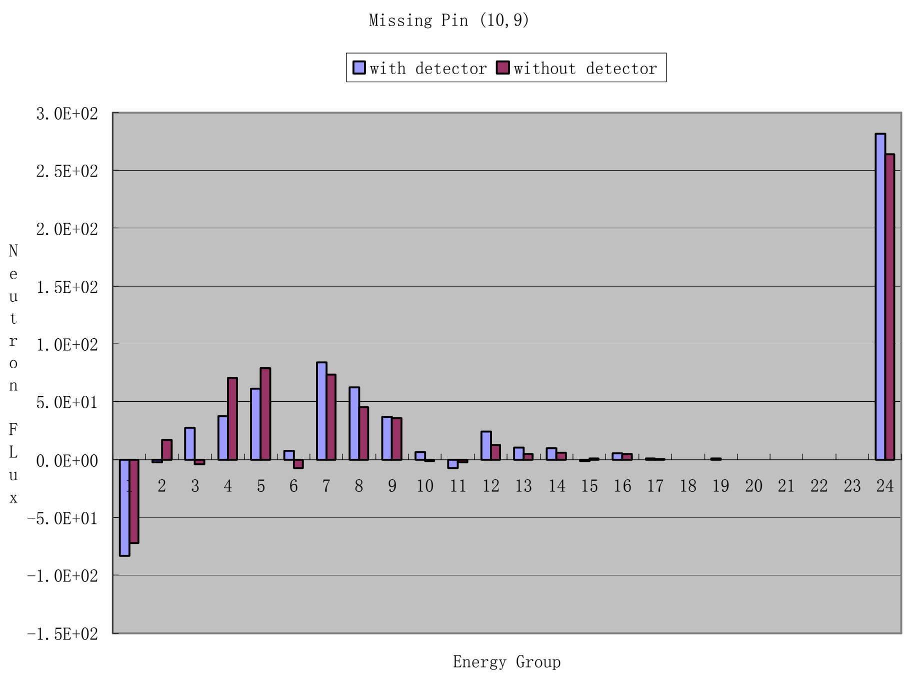


Figure 7. Neutron Flux Spectrum with and without Fission Chamber

## 4. Conclusions and Future Work

Monte Carlo simulations have been performed to help validate this concept using a realistic 17x17 PWR spent fuel assembly. The preliminary results of this study show that neutron profiles in the guide tubes, when obtained in the presence of missing pins, can be identifiably different from the profiles obtained without missing pins.

There is still much work to be done in this area to establish a real experimental test. Ongoing activities include:

- Uncertainty analysis related to the operational and cooling history, and the type of PWR assembly (15x15 or vintage models), in particular, assessment of asymmetric depletion upon detection ability.

- Assembly depletion in 3D using TRITON and/or MCNPX/CINDER'90

- Monte Carlo analyses performed in 3D

- Study of detector design and efficiencies associated, such as study of thin fission chamber position within guide tube, and axial displacement of chamber, multiple detectors (cluster).

## 5. Acknowledgement

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