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In-Situ Safeguards Verification of Low Burn-up Pressurized Water Reactor Spent Fuel Assemblies

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ABSTRACT

A novel *in-situ* gross defect verification method for light water reactor spent fuel assemblies was developed and investigated by a Monte Carlo study. This particular method is particularly effective for old pressurized water reactor spent fuel assemblies that have natural uranium in their upper fuel zones. Currently there is no method or instrument that does verification of this type of spent fuel assemblies without moving the spent fuel assemblies from their storage positions. The proposed method uses a tiny neutron detector and a detector guiding system to collect neutron signals inside PWR spent fuel assemblies through guide tubes present in PWR assemblies. The data obtained in such a manner are used for gross defect verification of spent fuel assemblies. The method uses "calibration curves" which show the expected neutron counts inside one of the guide tubes of spent fuel assemblies as a function of fuel burn-up. By examining the measured data in the "calibration curves", the consistency of the operator's declaration is verified.

Key Words: Safeguards, in-situ spent fuel verification, Monte Carlo simulation, pressurized water reactor

INTRODUCTION

A safeguards challenge has been known for sometime in the verification of low burn-up, old light water reactor (LWR) spent fuel assemblies (SFA) that have natural uranium in their upper fuel zones. This type of LWR SFAs cannot be verified using current IAEA instruments without lifting the SFAs from their storage positions. Lifting of SFAs from their storage positions is not only expensive in terms of resources to both IAEA and facilities, but also a safety concern. For example, there have been 30 crane accidents involving either a fuel assembly drop or damage to a fuel assembly during handling in the USA for the period of 1968 through 2002[1]. Another statistic is the 47 below-the-hook events that resulted in many load drops and damaged equipment for the same period[1]. A below-the-hook event is defined as an event where rigging or handling errors resulted in an event. It is apparent that any movement of old PWR spent fuel assemblies should be avoided if possible due to serious safety concerns as well as its intrusive nature to the facilities.

There are currently two instruments at IAEA for in-situ verification of LWR SFAs. One instrument, Improved Cerenkov Viewing Devices (ICVD) is most widely used for *in-situ* verification of PWR spent fuel assemblies by the IAEA and it does spent fuel verification by observing Cerenkov glow from spent fuel. However, ICVD does not work well on old or very low burn-up SFAs or when the water of the spent fuel pool is not clear. The other instrument available to IAEA for *in-situ* verification of PWR spent fuel assemblies is Spent Fuel Attribute Tester (SFAT), which provides a qualitative verification of the spent fuel assemblies by detection of fission product signatures, mostly Cs-137 peak at 661 KeV. Although SFAT has been used in situations where use of ICVD was not possible, it has a fundamental limitation in its verification capability because it obtains fission product signatures only from the top few centimeters of the spent fuel assemblies. Furthermore, prominent Cs-137 peak is not obtainable for fuel assemblies that use natural uranium in their upper portion of the fuel zone[2].

The proposed method will address the verification of this type of SFAs which cannot be verified by the current available instruments. A tiny neutron detector is mechanically inserted into a guide tube hole present in every PWR assemblies using a detector guiding adaptor. Measurement at one position is enough for verification purpose, but vertical scanning can be readily done along the full axial length in a few minutes of data acquisition time. This is a powerful feature that has never been available to IAEA for *in-situ* underwater verification of old spent fuel assemblies.

METHOD DESCRIPTION

The proposed new methodology for *in-situ* verification of old PWR spent fuel assemblies will measure neutrons inside PWR assemblies (see Figure 1). The methodology is based on an idea that the expected neutron signals inside spent fuel would be distinctly higher than the neutron signals inside a dummy fuel which is made out of stainless steel. Unfortunately the "neighbor effect", contribution to the neutron signals to the verification-subject-assembly from the surrounding spending fuel assemblies, makes the evaluation complicated as the degree of the "neighbor effect" varies depending upon various parameters such as initial fuel enrichment of fuel, operating history, cooling time, the amount of burnable poisons in the water, the geometry and material type of storage rack etc.

The methodology further uses "calibration curves" or "reference curves" which show the expected neutron counts inside one of the guide tubes of spent fuel as a function of fuel burn-up. The generation and use of "calibration curves" are illustrated by showing a specific example in the following paragraphs. A neutron count is calculated inside one of the guide tubes of the center fuel assembly using MCNP[3] simulation in which identical 14x14 PWR spent fuel assemblies (in terms of initial enrichment, cooling time and burn-up) are arranged in a 3x3 arrangement (see Figure 3.) Altogether 4 different uniform burn-ups are used to generate 4 data points which forms a "calibration curve" for fuel (blue curve): 22.8, 29.0, 33.2 and 39.4 MWD/kg (see Figure 3.) In a similar manner neutron counts are calculated by MCNP simulation in which the center fuel assembly is replaced with a stainless steel dummy assembly. The 4 data points form a "calibration curve" for dummy fuel, represented by a blue curve in the Figure 3. The initial enrichment of 3.8 weight% in ^{235}U was used to generate the isotopics and source spectra at various burnups using ORIGEN-ARP[4]. The MCNP simulation used a cooling time of 10 years and soluble boron of 2000 ppm in the pool. In the development of the "calibration curves" the neighbor effect was assumed to be caused by the immediate 8 surrounding SFAs of the verification-subject-assembly.

Having established "calibration curves" in the uniform burn-up arrangement, the curves can be used to verify whether a spent fuel assembly is a dummy fuel assembly or an actual SFA by correlating neutron measurement data to burn-up data from the curves. This verification is possible not only in a uniform burn-up arrangement but also in a mixed burn-up arrangement. Consider verification activities on the following assembly in an example shown in Figure 4. Note that typically a pond map describing locations and characteristics of SFAs such as burn-ups and cooling times are provided to inspectors by the facility operator. When a measurement is made on the verification-subject-assembly which is the center SFA, a certain measurement datum is obtained. In this example, the measurement datum would be where the horizontal red line starts in the y-axis. Then the corresponding "effective burn-up" point would be approximately 33 MWd/kg, which qualitatively agrees with the operator's claim when the value of the "effective burn-up" is examined with the burn-up distribution of the SFAs in Figure 4. If the verification-subject-assembly was a dummy fuel assembly, the measurement datum would be where the blue horizontal starts in the y-axis. Not knowing whether the verification-subject-assembly is real or a dummy fuel, an inspector uses the red curve to find the "effective burn-up" value of approximately 28 MWd/kg which is clearly contradictory to the operator's claim.

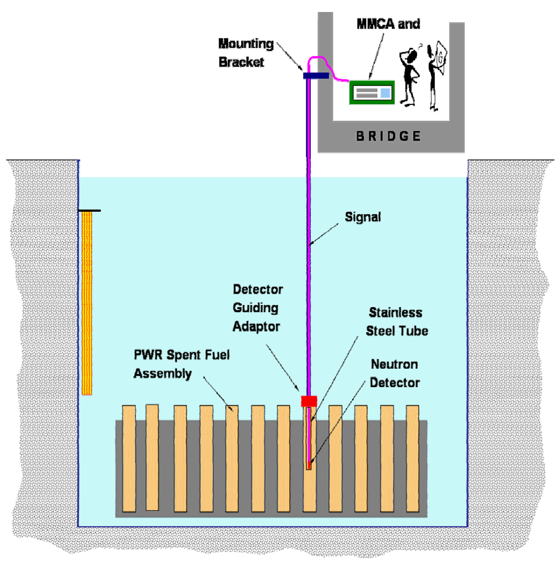

Figure 1: A conceptual diagram for in-situ PWR spent fuel assembly verification system.

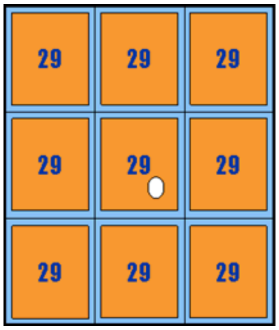

Figure 2: 3x3 arrangement of spent fuel assemblies that have uniform and same burn-up of 29 MWd/kg. The white hole represents a guide tube (measurement) location.

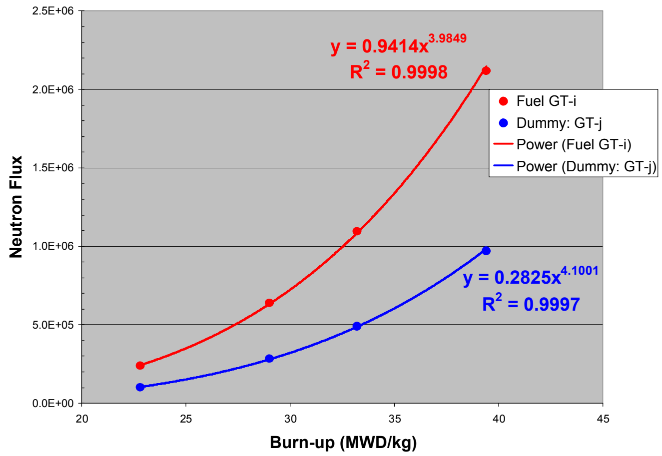

Figure 3: Calibration curves in uniform burn-up arrangement.

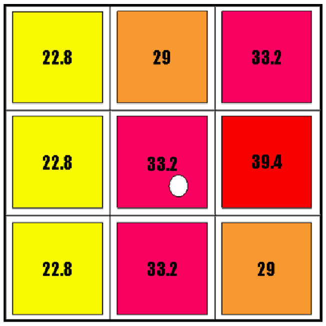

Figure 4: 3x3 arrangement of spent fuel assemblies that have mixed burn-up. The white hole represents a guide tube (measurement) location.

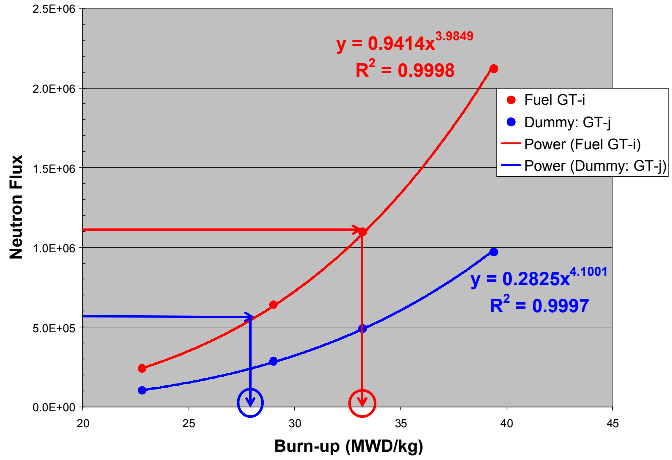

Figure 5: An example of gross-defect verification of a PWR in a mixed burn-up environment. Simulated measurements were done at the guide tube position shown in Figure 4.

EXPERIMENTS

Fabrication of a Measurement System

A neutron measurement system was fabricated in order to measure neutron signals inside guide tubes of a PWR spent fuel assembly. The system has two detachable parts: a Detector Rod (RD) and Detector Guide Adaptor (DGA). The DR consists of a tiny Centronic fission chamber (6.3 mm diameter) with 14 meter cable placed inside a 1.5 meter long water proof stainless steel tube (See Figure 6) and a larger cylinder. The stainless steel tube is connected to the larger cylinder which would sit on the top of the DGA when the tube of the DR is inserted into a guide tube of SFA. There is a cable fastener on the top of the larger cylinder to make the DR water proof. The DGA is designed and fabricated in order to facilitate the insertion of the tube of DR. The DGA is made out of aluminum, has two legs and four funnel shaped openings where the bottoms of the openings are lined up with the guide tube holes (See Figure 7). The DGA is first placed on the top of the SFA using two legs, and then the DR is inserted using the DGA. The system is designed to be used with MMCA (Mini Multi-Channel Analyzer), the standard IAEA MCA, and WinMCS, one of the standard pieces of software for neutron measurement at IAEA. The main advantage of taking this strategy is that there would be no training required for IAEA inspectors as the electronics and the software are already being widely used at IAEA.

Measurements

The system was field tested on 17x17 Westinghouse type SFAs in a commercial PWR spent fuel pond. The expected most difficult challenge in this measurement campaign, the insertion of a fission chamber into the tiny guide tube from the spent fuel pond bridge, worked out very well using the DGA and DR. On the average it took about 3-4 minutes for placement of DGA and insertion of DR and additional 5 minutes for single position data acquisition. A limited number of data points were acquired due to insufficient available time at the spent fuel pond. Figure 8 shows a picture as the Detector Rod was about to be inserted into a guide tube of a PWR spent fuel assembly. One can observe a shining DGA already placed on the top of an assembly. Any visual aid such as underwater camera was not necessary in order to either place DGA or insert the tube of DR into the opening of the DGA.

Two measurements were performed when a verification-subject-assembly was fully surrounded by 8 SFAs as shown in Figure 9 . Subsequently the verification-subject-assembly was lifted and moved out of its position to a new location where there were no surrounding SFAs. A measurement was carried out at this location. A stainless steel dummy assembly was placed into the position where the verification-subject-assembly was moved out. Measurements were performed at the 4 guide tube positions.

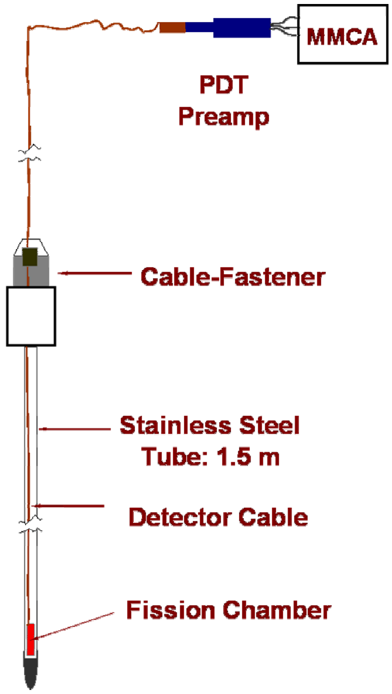

Figure 6: A diagram of the detector rod with electronics.

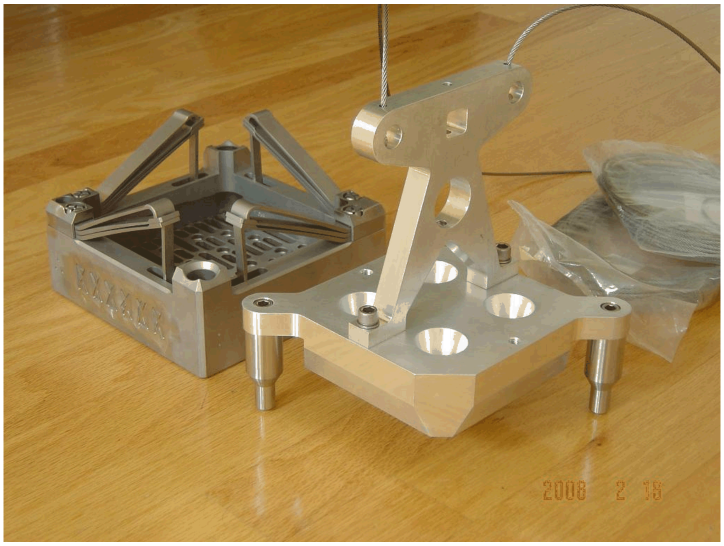

Figure 7: A picture of the Detector Guiding Adaptor along with a top nozzle of Westinghouse 17x17. The Detector Guiding Adaptor is used to facilitate the insertion of the Detector Rod.

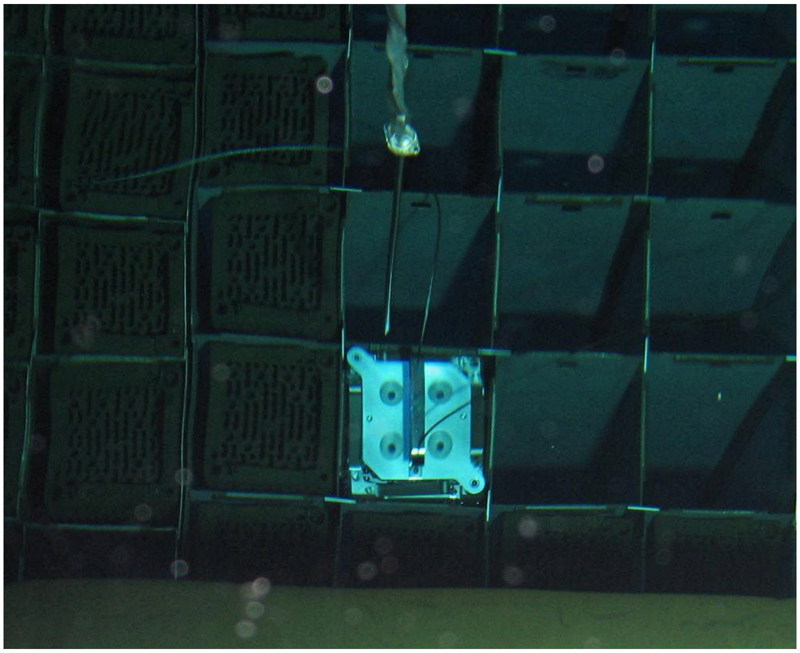

Figure 8: A picture of a Detector Rod about to be inserted through an opening in Detector Guiding Adaptor which is already placed on the top of a PWR spent fuel assembly.

RESULTS AND DISCUSSION

The left table of the Figure 9 shows distribution of burn-ups and discharge dates of the verification-subject-assembly and its surrounding 8 SFAs. The right two tables show raw data and cooling time corrected neutron data obtained at the four guide tube locations using the measurement system. The numbers in the parenthesis are neutron counts per second when the center assembly is a real fuel assembly whereas the numbers below are neutron counts per second when the center assembly was replaced with a dummy fuel assembly. The data point of 1.5 CPS was obtained when the verification-subject-assembly was isolated where there were no surrounding SFAs. One can observe that approximately half of the neutron counts at this measurement position are due to the effects from the surrounding SFAs.

As "calibration curves" that can be used for gross defect verification are not established yet for this facility, the data obtained at the dummy fuel assembly could not be verified using the methodology described. However, the data trend shown in the measurement agrees quite well with the results shown in the simulation study.

Now the real challenge is how to create "calibration curves" which can be used in real field applications. Use of Monte Carlo simulation is one way, considering all parameters involved in different spent fuels and pond configuration. However, validation measurements of the Monte Carlo generated 'calibration curves" may still be needed for each spent fuel pond in order to ensure its applicability. It would be ideal if the "calibration curves" can be created by actual measurements in the facility. However, this would be a challenge unless SFAs with same (or very similar) burn-ups and cooling time are arranged in a way that "calibration curves" can be generated. A clever, experimental and practical way to create "calibration curves" still needs to be developed using a combination of measurement and computer simulation.

21.0 11/12/87	32.0 1/16/92	31.6 1/02/93
21.0 11/12/87	**32.8 12/1/89**	38.4 1/02/93
20.5 11/12/87	32.1 12/1/89	32.6 1/02/93

(--) 1.3	(3.0) 2.2 ***1.5***
(--) 1.5	(2.90) 2.3

(Raw Data)

(--) 2.7	(5.9) 4.5 ***3.0***
(--) 3.0	(5.8) 4.6

(Cooling time corrected data)

Figure 9: The left table shows burn-up and discharge date for a SFA that is subject to verification and its surrounding SFAs. The right table shows raw data and cooling time corrected neutron data obtained using the measurement system. The numbers in the parenthesis are neutron counts per second when the center assembly is a real fuel assembly whereas the numbers below are neutron counts per second when the center assembly was replaced with a dummy fuel assembly. The data point of 1.5 CPS was obtained when the verification-subject-assembly was isolated where there were no surrounding SFAs.

CONCLUSIONS

A novel *in-situ* gross defect verification method for light water reactor spent fuel assemblies was developed and investigated by a Monte Carlo study. The method is applicable to those light water reactor spent fuel assemblies that cannot be verified by the current existing methods or instruments. A neutron measurement system was built and demonstrated that it was not only possible to measure neutron signals inside guide tubes of PWR spent fuel assemblies, but also practical to be field-deployable. A practical method of creating "calibration curves" still needs to be developed in the future.

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