COMPARISON OF MODEL PREDICTIONS WITH MEASUREMENTS USING THE IMPROVED SPENT FUEL ATTRIBUTE TESTER*

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ABSTRACT

Design improvements for the International Atomic Energy Agency's Spent Fuel Attribute Tester, recommended on the basis of an optimization study, were incorporated into a new instrument fabricated under the Finnish Support Programme. The new instrument was tested at a spent fuel storage pool on September 8 and 9, 1993. The results of two of the measurements have been compared with calculations. In both cases the calculated and measured pulse height spectra are in good agreement and the ^{137}Cs gamma peak signature from the target spent fuel element is present.

INTRODUCTION

The International Atomic Energy Agency's (IAEA) Spent Fuel Attribute Tester (SFAT) is designed to inspect stored reactor spent fuel assemblies *in situ*. The inspection is accomplished by suspending the SFAT above a target element to detect ^{137}Cs gamma rays. The original instrument was able to detect ^{137}Cs except when long-cooled target elements were located adjacent to short-cooled elements. In this case the background from the surrounding spent fuel assemblies was high and the ^{137}Cs signature was lost.

Previous studies have been conducted by Sandia National Laboratories[1,2,3] (SNL) in which calculations were performed to optimize the SFAT design. These studies resulted in several recommendations for improvement. The modifications recommended were as follows:

1. Shorten the air collimator pipe. Because the optimum length of the pipe was not determined precisely by the analyses, it was recommended that pipes be provided in several lengths: 100, 125, 150, and 200 cm. The 150-cm length was preferred.
2. Make the walls of the pipe as thick as possible within the system weight and handling constraints.
3. Replace the lead gamma-ray filters in the collimator line-of sight with low-Z filters. The filter should be located away fro the detector crystal at the miiddle or bottom of the shield. An iron filter was recommended.
4. Reduce the amount of shielding below the detector crystal.
5. Increase the amount of shielding around the sides of the crystal and the photomultiplier tube.
6. Replace the 2-inch diameter by 2-inch long NaI crystal with a smaller diameter crystal. A 1.5-inch diameter was recommended. The length of the crystal should be no less than 1 inch.

All of these recommendations except the use of multiple pipe lengths were implemented in the new SFAT. The collimator pipe length was fixed at the suggested 150 cm. A 1.5x1.5-inch NaI crystal was used. Figure 1 illustrates the design of the new SFAT.[4]

Facility safety requirements prohibit the use of several possible methods of positioning the pipe close to the target element, but an improvement in positioning was obtained by incorporating a telescoping mechanism in the pipe along with an ultrasonic positioning system. The suggestion for this modification was made by personnel in the Finnish Support Programme. This positioning system allows close, accurate, and reproducible positioning of the SFAT above the target elements. Figure 2 shows the SFAT inside the housing and telescoping mechanism.[4] High-count-rate electronics designed by Los Alamos

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National Laboratory were also added to the SFAT system to reduce dead time and pile-up effects that were evident in some of the measurements made with the original system.

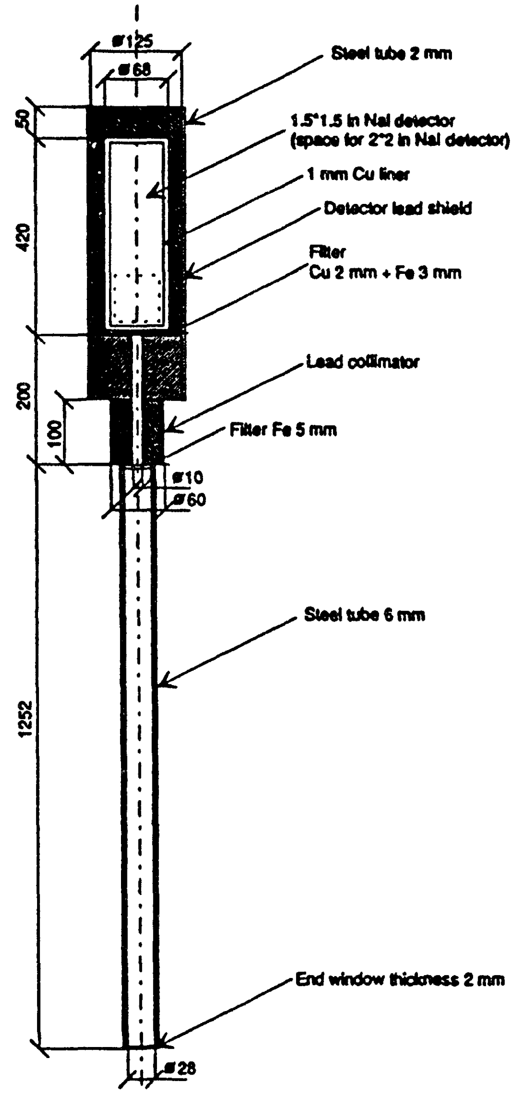

Figure 1. Design of the New SFAT

MODEL OF THE IMPROVED SFAT

The baseline for the SFAT design optimization study was, of course, the original instrument. Measurement results obtained with the original instrument at the Industrial Power Company Ltd. (TVO) intermediate spent fuel storage facility (KPA Store) at Olkiluoto, Finland[5] were provided to SNL through the courtesy and cooperation of the Finnish Centre for Radiation and Nuclear Safety, and the IAEA Safeguards and Security Division. These results served to test the calculational model of the SFAT that was developed. After showing that the model agreed with past measurement results, it was used in a perturbation study to identify design changes to improve the ability of the SFAT to detect ^{137}Cs from long-cooled spent fuel elements adjacent to short-cooled spent fuel elements in a spent fuel storage rack.

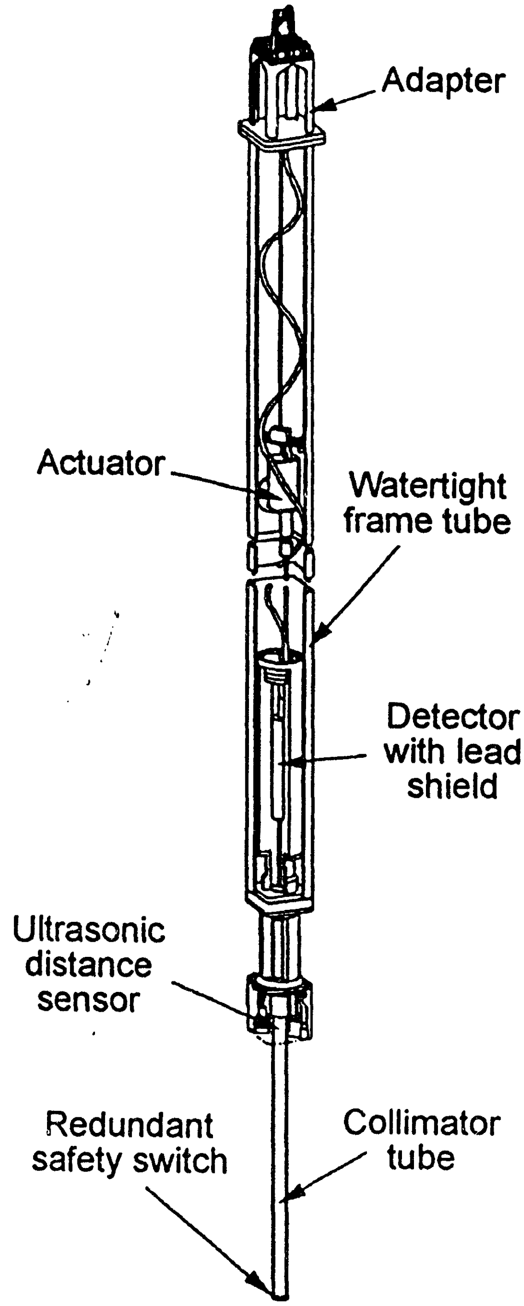

Figure 2. New SFAT inside the housing and telescoping mechanism.

After making final design recommendations, calculations were performed to predict pulse height spectra that could be obtained with the modified SFAT. Predictions were made for 5-year-cooled and 10-year-cooled BWR spent fuel assemblies, with a burnup of 27.5 MWd/kgU, surrounded in the rack by 5-year-cooled assemblies with the same burnup.[2,3] These predictions are reproduced here as Figures 3 and 4. Both spectra show a ^{137}Cs peak. The peak is slightly more prominent in the 10-year-cooled element than in the 5-year-cooled element because of the long half life of ^{137}Cs relative to the other significant gamma ray emitters in the spent fuel elements. This indicates that the contribution to the pulse height spectrum from the adjacent elements is less than that from the target element. Pile up effects, resulting from the high count rate in the detector, are evident because the calculation assumed use of the original SFAT electronics.

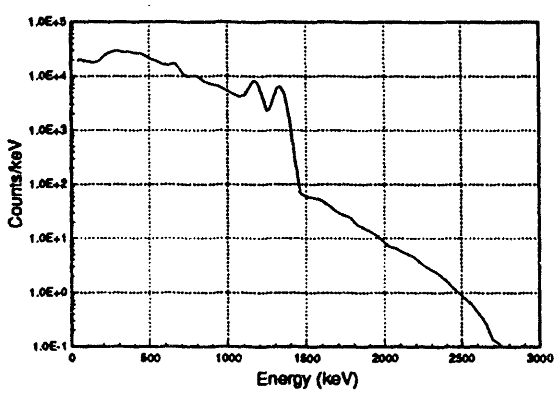

Figure 3. Predicted pulse-height spectrum for a 5-year-old, 27.5-GWd/kgU target assembly surrounded by 5-year-old, 27.5-GWd/kgU background assemblies.

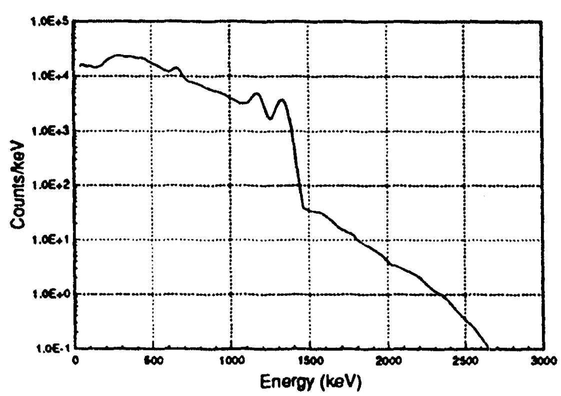

Figure 4. Predicted pulse-height spectrum for a 10-year-old, 27.5-GWd/kgU target assembly surrounded by 5-year-old, 27.5-GWd/kgU background assemblies.

On September 8 and 9, 1993, the modified SFAT was tested at the TVO KPA Store in Olkiluoto, Finland.[4] The tests were performed by one of the authors (Rolf Arlt), Matti Tarvainen of the Finnish Centre for Radiation and Nuclear Safety, and Antero Tiitta of the Finnish Technical Research Centre of Finland Reactor Laboratory. TVO personnel assisted by providing access to the KPA Store and by operating facility machinery.

Measurements were made of both ^{137}Cs and ^{60}Co radiation sources to calibrate the system. Using these calibration measurements, a revised GADRAS[6] response model for the SFAT was developed that closely matches the actual instrument. Figure 5 shows a comparison between the calibration source measurement and the calculated pulse height. The differences between the two curves is everywhere less than 10%. The revised response model was applied to the previous calculated results to predict a pulse height spectrum for comparison with the measurements.

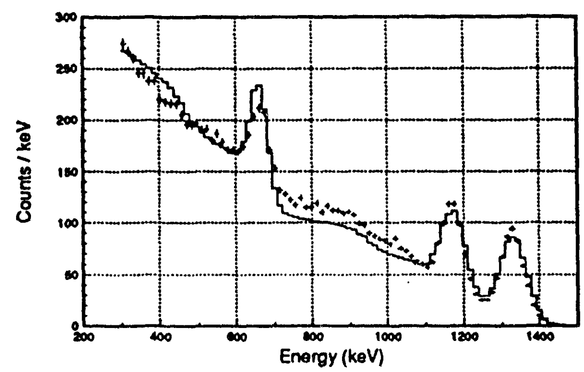

Figure 5. Comparison of measured calibration source pulse-height spectrum with one calculated using the detector response function. Error bars are the measured data.

About 60 measurements were taken on spent fuel elements. In all of these measurements a low-level discriminator was used at about 400 keV. Measurements were selected for comparison with the calculations on the basis of the burnups, cooling times, and background environments available.

Figure 6 shows a comparison between the calculated SFAT pulse height spectrum for a 5-year-cooled, 27.5 MWd/kgU BWR spent fuel element surrounded by a rack of identical background elements, and the measurement of a 5-year-cooled, 28 MWd/kgU spent fuel element surrounded by similar elements. In this Figure, the ^{60}Co peaks, which arise from activation of the structural materials of the element, are in excellent agreement. The predicted ^{137}Cs peak is slightly more pronounced than the measured peak. Below the ^{137}Cs peak the measurement shows more scattered photons than are accounted for in the calculation. This difference may be the result of errors in the detector response function. However, the difference between the curves above the 400 keV cutoff is everywhere less than 10%.

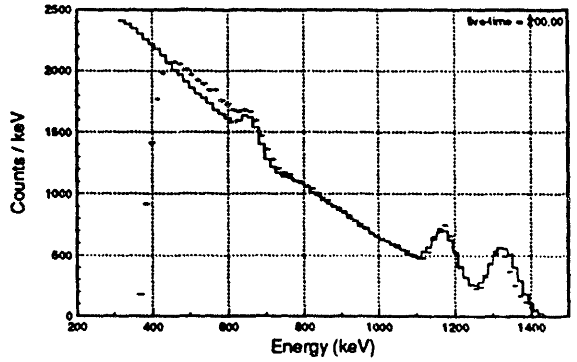

Figure 6. Comparison of a measured pulse-height spectrum from a 28-GWd/kgU, 5-years-cooled spent fuel assembly with one predicted for a 27.5-GWd/kgU, 5-years-cooled spent fuel assembly. Error bars are the measured data.

The oldest reactor contributing spent fuel to KPA Store is 12 years old. Therefore no long-cooled, high-burnup spent fuel assemblies were available to be measured. The closest measurement available for comparison with the 10-year-cooled, 27.5 MWd/kgU calculation was an 8-year-cooled, 18 MWd/kgU burnup element surrounded by similar short-cooled, high-burnup elements. The spectra for these two cases are compared in Figure 7. Again the ^{60}Co peaks are in good agreement. In addition the shape and magnitude of the ^{137}Cs peaks agree well although the effect of multiply scattered photons is underestimated in the calculation. Given the discrepancy between the burnups and cooling times for the two curves, the overall agreement is good.

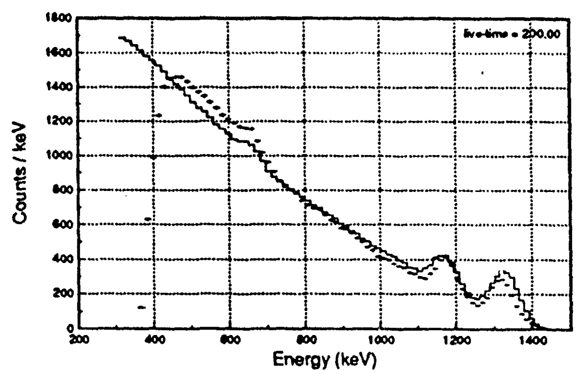

Figure 7. Comparison of a measured pulse-height spectrum from an 18-GWd/kgU, 8-years-cooled spent fuel assembly with one predicted for a 27.5 GWd/kgU, 10-years-cooled spent fuel assembly. Error bars are the measured data.

CONCLUSIONS

Calculations performed for the optimization of the SFAT have been combined with characterization measurements to predict pulse height spectra obtained by the instrument as ultimately fabricated. Only two relevant measurements are available for the comparison, and the burnup, cooling times, and backgrounds of these measurements do not exactly match the calculation parameters. Nevertheless, the calculated results compare well with the measurements. This lends additional credibility to the optimization study and confirms the predictions made in that study.

The new SFAT device shows significant improvement over the original instrument. In measurement situations similar to the two cases considered here, the original SFAT failed to detect a ^{137}Cs peak in a 10-minute measurement. In the new measurements, the improved device detected ^{137}Cs in less than 200 seconds. The new instrument positioning system allows repeatibility of measurements and significantly reduces the measurement time required per assembly. It also improves the accuracy of positioning the instrument to ensure optimum peak detection in cases where a fuel channel is present.

ACKNOWLEDGMENTS

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