Indonesian Journal of Physics and Nuclear Applications
Volume 3, Number 3, October 2018, p. 76-82
e-ISSN 2550-0570, © FSM UKSW Publication

ANALYSIS OF CS-137 TO CS-134 ACTIVITY RATIO FOR FAILED FUEL EXPOSURE ESTIMATION

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Abstract The Cs-134 to Cs-137 activity ratio of the Cs-134 and Cs-137 fission products released from failed fuel rods into primary coolant is very useful to identify the exposure along with the fuel batch of the failed fuel. The calculated and measured Cs-137 to Cs-134 radioactivity ratios of failed BWR and PWR fuels are compared and analyzed for better understanding of their relationship. Moreover, the impacts of power uprate and fuel reload outage on calculated Cs-137 to Cs-134 activity ratios are studied and the physics behind the impacts are provided.

Keywords Cs-137, Cs-134, activity ratio

INTRODUCTION

The Cs-134 to Cs-137 activity ratio of the Cs-134 and Cs-137 fission products released from failed fuel rods into primary coolant has been utilized to estimate the exposure of failed fuel in both BWR and PWR due to their very different half-lives (Cs-134's 2.06 yrs versus Cs-137's 30.17 yrs). This activity ratio is very useful to identify the exposure along with the fuel batch of the failed fuel.

The Cs-137 to Cs-134 activity ratio is calculated from the fission product radioactivity edit of ORIGEN2 (Croff, 1983) output. The Cs-134 and Cs-137 activities are computed as a function of fuel exposure up to 70 GWD/MTU for BWR fuel and PWR fuel with initial enrichments of 2, 3, 4, and 5 weight percent (w%), respectively.

The calculated and measured Cs-137 to Cs-134 radioactivity ratios will be compared and analyzed for better understanding their relationships. Furthermore, the impacts of power uprate and fuel reload outage on calculated Cs-137 to Cs-134 activity ratios will also be studied and the physics behind the impacts will be provided.

1. COMPUTER CODE, NEUTRON CROSS SECTION LIBRARIES AND INPUT FILES

The computer code ORIGEN2 (Croff, 1983) is used for the Cs-134 and Cs-137 radioactivity calculations for BWR and PWR fuels. ORIGEN2 was developed in Oak Ridge National Laboratory and is an acceptable NRC code.

The ORIGEN2 BWRUE and PWRUE neutron cross section libraries for extended burnup are used for nuclear fuel with 4 w% and 5 w% initial enrichments and the ORIGEN2 BWRUS and PWRUS neutron cross section libraries for standard burnup are used for nuclear fuel with 2 w% and 3 w% initial enrichments (Ludwig & Renier, 1989).

The ORIGEN2 input files were set up from the ORIGEN2 input examples, provided together with the ORIGEN2 code, with proper modifications.

The core-average specific power used in this analysis is 25.9 MW/MTU for BWR fuel and 37.5 MW/MTU for PWR fuel (Croff, 1983).

2. ANALYSIS METHODS

The analysis started from fuel depletion with a core-average, fixed specific power. However, since the half-life of Cs-134 (2.06 yrs) is an order of magnitude shorter than that (30.17 yrs) of Cs-137 and since the fuel specific power determines the depletion period required for a given exposure increment, the selection of the fuel depletion specific power affects the values of calculated exposure-dependent Cs-137-to-Cs-134 radioactivity ratios. Consequently, a sequence of simulated, variable specific power levels is selected here for ORIGEN2 fuel depletion in an alternate analysis. The simulated power level sequence is expressed in terms of percentage of the core-average, fixed specific power and is listed in Table 1.

Table 1. Simulated specific power level during fuel life cycle

Exposure, GWD/MTU	0-5	5-10	10-15	15-20	20-25	25-30	30-35
Power Level	90%	100%	110%	120%	110%	100%	90%
Exposure, GWD/MTU	35-40	40-45	45-50	50-55	55-60	60-65	65-70
Power Level	80%	70%	60%	50%	45%	40%	35%

The justification for employing this variable specific power level sequence is given in the following. Since the fresh fuel contains burnable poison, the first segment of depletion (0-5 GWD/MTU) uses 90%, the second segment (5-10 GWD/MTU) uses 100%, the third segment (10-15 GWD/MTU) uses 110%, and the fourth segment (15-20 GWD/MTU) uses 120% of core-average specific power to account for positive reactivity impact in the fuel assembly due to more rapidly burnable poison depletion than fuel depletion in early stages. After the specific power reaching the peak, the subsequent segments of depletion (Exposure > 20 GWD/MTU) use lower specific powers to account for negative reactivity impact in the fuel assembly due to decreasing and eventually no reactivity compensation to fuel depletion from burnable poison depletion.

Physically, the fuel depletion with a sequence of simulated, variable specific powers should be better than the fuel depletion with core-average, fixed specific power, since it incorporates reactivity feedback from earlier burnable poison and fuel depletion and is closer to fuel depletion reality. The comparison of two kinds of calculated Cs-137 to Cs-134 radioactivity ratio curves for PWR fuel with 5 w% initial enrichment against the measured Cs-137 to Cs-134 radioactivity ratio correlation curve from failed PWR fuels (Figure 7-17 of [3]) shown in Figure 1 indeed indicates that the curve with the variable specific power depletion agrees increasingly better to the measured correlation curve than the curve with the fixed specific power depletion after 40 GWD/MTU and confirms the preceding physical reasoning.

Consequently, the Cs-137 to Cs-134 radioactivity ratio is calculated from fission product radioactivity output of ORIGEN2 fuel depletion computation with the simulated, variable specific power carrying reactivity feedback from burnable poison and fuel depletion.

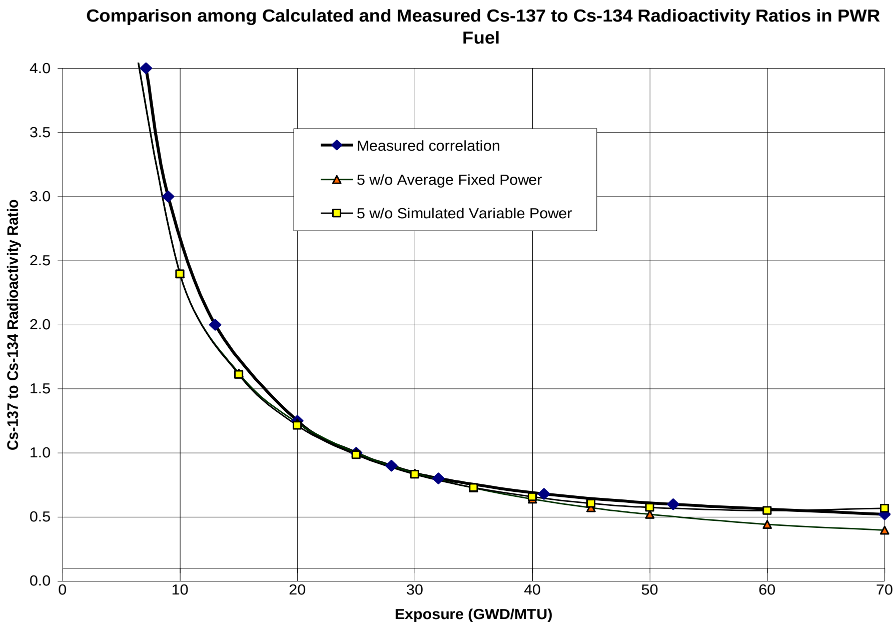

Fig 1. Comparison between calculated and measured Cs-137 to Cs-134 radioactivity ratio curves for PWR Fuel

The result difference of calculated Cs-134 to Cs-137 radioactivity ratios between the cases with variable power depletion and the corresponding cases with fixed power depletion is more noticeable after 45 GWD/MTU.

3. CALCULATED CS-137 TO CS-134 RADIOACTIVITY RATIO RESULTS

The calculated Cs-137 to Cs-134 radioactivity ratios are listed in Table 2 and plotted in Figure 2 as a function of fuel exposure up to 70 GWD/MTU for BWR fuel with initial enrichments of 2, 3, 4, and 5 w%. The measured Cs-137 to Cs-134 radioactivity ratio correlation curve of failed BWR fuels (Figure 4-21 of (Electic Power Research Instute (EPRI), 2003) and (D. L. Smith, 2007) is also plotted in Figure 2 for comparison. The measured Cs-137 to Cs-134 radioactivity ratio correlation curve of failed BWR fuels lies mostly between the calculated ratio curves of BWR fuels with 3 w% and 4 w% initial enrichments. This measured correlation curve validates the calculated Cs-137 to Cs-134 radioactivity ratios for BWR fuel, since typical initial fuel enrichment in BWR fuels varies from 2 w% to 4.95 w%.

Table 2. Calculated Cs-137 to Cs-134 radioactivity ratios for BWR fuel

	Exposure (GWD/MTU)										
W%	5	10	15	20	25	30	35	40	45	50	60	70
2	2.187	1.263	0.925	0.744	0.643	0.576	0.537	0.515	0.507	0.515	0.568	0.665
3	2.982	1.601	1.127	0.880	0.742	0.651	0.595	0.560	0.541	0.540	0.578	0.663
4	3.915	2.033	1.397	1.070	0.885	0.763	0.683	0.630	0.597	0.584	0.600	0.666
5	4.748	2.431	1.655	1.257	1.030	0.881	0.783	0.714	0.669	0.645	0.643	0.689

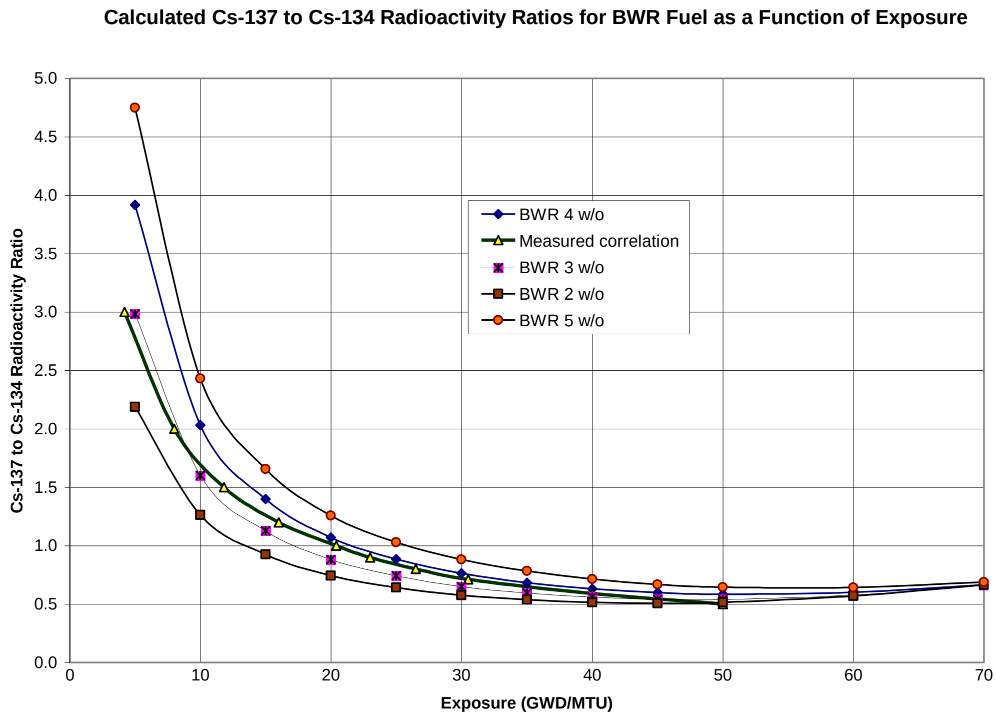

Fig 2. Calculated Cs-137 to Cs-134 radioactivity ratios as a function of fuel exposure for BWR fuel.

The calculated Cs-137 to Cs-134 radioactivity ratios are listed in Table 3 and plotted in Figure 3 as a function of fuel exposure up to 70 GWD/MT for PWR fuel with initial enrichments of 2, 3, 4, and 5 w%. The measured Cs-137 to Cs-134 radioactivity ratio correlation curve of failed PWR fuels (Figure 7-17 of (Electic Power Research Instute (EPRI), 2003) is also plotted in Figure 3 for comparison. The measured Cs-137 to Cs-134 radioactivity ratio correlation curve of failed PWR fuels lies close to the calculated ratio curve of PWR fuel with 5 w% initial enrichment. This measured correlation curve validates the calculated Cs-137 to Cs-134 radioactivity ratios for PWR fuel, since most initial fuel enrichment in PWR fuels is close to 5 w%.

Table 3. Calculated Cs-137 to Cs-134 radioactivity ratios for PWR fuel

	Exposure (GWD/MTU)											
W%	5	10	15	20	25	30	35	40	45	50	60	70
2	2.208	1.245	0.902	0.721	0.617	0.547	0.504	0.477	0.462	0.460	0.486	0.548
3	2.998	1.575	1.097	0.852	0.711	0.618	0.558	0.518	0.493	0.483	0.497	0.548
4	3.945	2.004	1.362	1.036	0.847	0.722	0.639	0.581	0.541	0.520	0.513	0.547
5	4.778	2.395	1.611	1.214	0.984	0.832	0.730	0.657	0.606	0.574	0.550	0.568

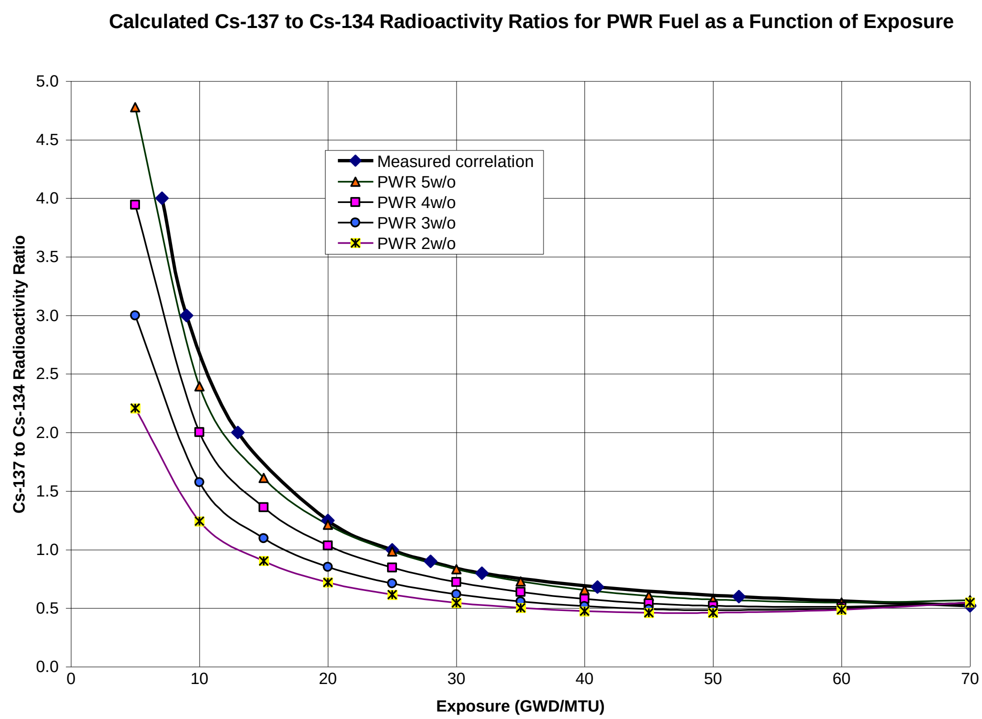

Fig 3. Calculated Cs-137 to Cs-134 radioactivity ratios as a function of fuel exposure for PWR fuel.

4. IMPACT OF POWER UPRATE AND FUEL RELOAD OUTAGE ON CALCULATED CS-137 TO CS-134 RADIOACTIVITY RATIOS

To evaluate power uprate and fuel reload outage impact, the Cs-137 to Cs-134 radioactivity ratios are calculated from fuel depletion with the fixed specific power. Comparison of calculated Cs-137 to Cs-134 radioactivity ratios of original, 20%-power uprate, and 60 days fuel reload outage after 330 days of cycle exposure for PWR fuel with 5 w% initial enrichments is shown in Figure 4. The power uprate is normally no higher than 20% and the current fuel reload outage period is normally no longer than 60 days.

The impact of power uprate on calculated Cs-137 to Cs-134 activity ratios is shown negligible. This is due to the fact that both Cs-137 and Cs-134 concentrations in depleted fuel depend on the total fission rate, which is approximately proportional to power, and that these common fission-rate-dependent factors cancel out each other in the activity ratio.

The impact of fuel reload outage on calculated Cs-137 to Cs-134 activity ratio is shown small for short outage but should be significant for long outage. This is due to the fact that the Cs-134 half-life (2.06 yrs) is much shorter than the Cs-137 half-life (30.17 yrs).

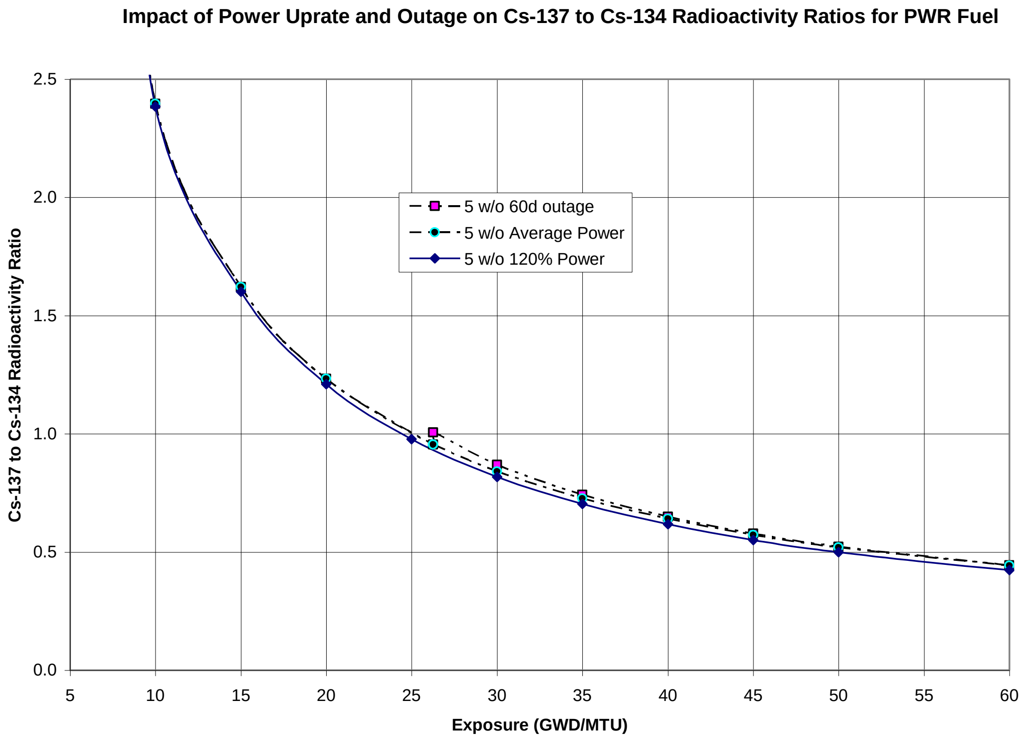

Fig 4. Impact of power uprate and outage on Cs-137 to Cs-134 radioactivity ratios for PWR fuel.

5. CONCLUSION

A sequence of simulated, variable specific power levels has been selected for ORIGEN2 fuel depletion computation. This simulated power level sequence incorporates reactivity feedback from earlier burnable poison and fuel depletion.

The measured Cs-137 to Cs-134 radioactivity ratio correlation curve of failed BWR fuels lies mostly between the calculated ratio curves of BWR fuels with 3 w% and 4 w% initial enrichments. This measured correlation curve validates the calculated Cs-137 to Cs-134 radioactivity ratios for BWR fuel, since typical initial fuel enrichment in BWR fuels varies from 2 w% to 4.95 w%.

The measured Cs-137 to Cs-134 radioactivity ratio correlation curve of failed PWR fuels lies close to the calculated ratio curve of PWR fuel with 5 w% initial enrichment. This measured correlation curve validates the calculated Cs-137 to Cs-134 radioactivity ratios for PWR fuel, since most initial fuel enrichment in PWR fuels is close to 5 w%.

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