Correct Implementation of a Depletion Uncertainty

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Outline

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Background

- 5% of the delta k of depletion is used as the depletion uncertainty for USA spent fuel pool analysis.
- This value is a conservative engineering approximation.
- The approximation is based on fuel management code performance against commercial reactor measured data.
- There is no documentation in support of this engineering approximation.

Background

- Historical applications validated using fresh UO_2 critical experiments and the depletion uncertainty.
- This approach assumes that the depletion uncertainty is to account for the uncertainty in all changes from the fresh UO_2 condition to the burned condition (changes in atom densities and cross sections).
- This paper will show how to determine such an uncertainty using power reactor data.

Definition of Terms

- ANSI/ANS-8.27 gives the following equation:

$$k_p + \Delta k_p + \Delta k_i + \Delta k_x + \Delta k_b \quad \leq \quad k_c - \Delta k_c \; - \Delta k_m$$

- This equation breaks down the depletion uncertainty into an uncertainty in the isotopic content, Δk_i, and an uncertainty due to the cross sections of isotopes that are not in k_c (Δk_x).
- Section 5.2 of ANSI/ANS-8.27 allows for a combined approach to validation that eliminates the need for Δk_i and Δk_x

Definition of Terms

- The following equation is the correct form with Δk_d, the depletion bias and uncertainty, replacing Δk_i and Δk_x.

$$k_p + \Delta k_p + \Delta k_d + \Delta k_b \quad \leq \quad k_c - \Delta k_c - \Delta k_m$$

- k_c is derived from fresh UO2 critical experiments and addresses the geometric and material concerns not related to burnup.
- Δk_c is the uncertainty in the method derived from the fresh UO2 criticals
- Δk_m is the administrative margin (typically 5%)
- k_p is the system k that has the appropriate modeling of the axial and horizontal burnup variations.
- Δk_p is the uncertainty in the system model (eg manufacturing uncert.)
- Δk_b is an allowance for uncertainty in k_p due to uncertainty in the assigned burnup value.
- Δk_d is the depletion uncertainty covering all non-spatial changes from the initial UO2 criticals.

How do you determine Δk_d

- To determine Δk_d you must measure the change in reactivity with burnup and determine the accuracy of your codes to reproduce this reactivity change.
- The reactivity change with burnup is required for power plant operation.
- Predictions are compared to measurements on a routine basis.
- Since the spatial distribution of burnup is handled conservatively in the calculation of k_p the Δk_d is not spatial and can be determined from lattice or point codes.

Proposed Approach

- Use fuel management tools to convert power reactor data to simple benchmarks to be calculated by criticality tools.
- The benchmarks will contain the bias and uncertainty in the fuel management tools.
- The deviation between the benchmarks and the criticality tools analysis is a bias to be added to the the fuel management tools bias to obtain the final value of Δk_d.

Two Steps to Make the Benchmarks

1. Determine the burnup bias and uncertainty of the fuel management tools at full power conditions using the power distributions.
2. Using the fuel management tools create lattice benchmarks at cold conditions. These benchmarks will have to include a bias and uncertainty from step 1 plus additional bias and uncertainty for the conversion to the benchmarks

Example Benchmark Analysis

- The benchmark uncertainty has not been established yet but the following slides show analysis of benchmarks and the criticality codes analysis.
- The benchmarks were made with an actual commonly used fuel management tool and the criticality analysis was done with current criticality tools.

Example Benchmark Analysis

Burnup GWD/MTU	Benchmark k	Δk burnup benchmark	Criticality Codes k	Δk burnup Crit. Codes	difference in Δk
1.8 wt% U-235, 0 ppm					
0	1.2279		1.2258		
10	1.1021	.1258	1.1064	.1194	-.0064
20	1.0142	.2137	1.0170	.2088	-.0049
30	.9498	.2781	.9516	.2742	-.0038
1.8 wt% U-235, 500 ppm					
0	1.1283		1.1251		
10	1.0287	.0996	1.0314	.0937	-.0059
20	.9496	.1787	.9513	.1738	-.0049
30	.8905	.2378	.8911	.2340	-.0038
1.8 wt% U-235, 1000 ppm					
0	1.0451		1.0411		
10	.9660	.0791	.9677	.0734	-.0056
20	.8942	.1509	.8948	.1463	-.0045
30	.8397	.2054	.8395	.2017	-.0038

Example Benchmark Analysis

Burnup GWD/MTU	Benchmark k	Δk burnup benchmark	Criticality Codes k	Δk burnup Crit. Codes	difference in Δk
5.0 wt% U-235, 0 ppm					
0	1.4546		1.4582		
40	1.1132	.3415	1.1201	.3382	-.0033
50	1.0526	.4021	1.0586	.3996	-.0024
60	.9966	.4580	1.0025	.4557	-.0023
5.0 wt% U-235, 500 ppm					
0	1.3955		1.3980		
40	1.0695	.3260	1.0754	.3226	-.0034
50	1.0096	.3859	1.0149	.3831	-.0028
60	.9543	.4412	.9596	.4384	-.0028
5.0 wt% U-235, 1000 ppm					
0	1.3417		1.3432		
40	1.0299	.3118	1.0351	.3081	-.0037
50	.9709	.3708	.9754	.3678	-.0030
60	.9163	.4254	.9208	.4223	-.0031

Results of the Example Case

- The criticality codes always under predicted the delta k of depletion.
- No credit will be allowed for the under predictions.
- The uncertainty for the delta k of depletion is the uncertainty claimed for the benchmarks (uncertainty of the fuel management codes).

Results of the Example Case

- The benchmarks uncertainties have not been produced yet.
- Based on HZP critical measurements and HFP end of cycle predictions there is no bias with burnup. The deviation around the mean is about 0.4 % in k (2 sigma).
- If the creation of the benchmarks confirm this then Δk_d would be 0.4% in k since the criticality codes produce a lower change in k with depletion.
- Note that since the Δk_d is not a function of burnup its magnitude is 5% of the delta k of depletion at 8 GWD/MTU and 2% at 20 GWD/MTU.

Future Plans

- The approach outlined in this presentation has received support from the utilities through EPRI.
- A Request-for-Proposal has been issued by EPRI with responses requested by March 29, 2010.

Comment

- This approach is **not a code to code comparison**.
- Codes are used to extract the relevant data from the actual measurements to allow measured biases and uncertainty.
- There is manipulation of the data but within the range of actual experience at power plants.

Conclusions

- It is possible to make benchmarks for validation of the delta k of depletion using power reactor data.
- The benchmarks contain the bias and uncertainty from measured data.
- Calculation of these benchmarks with criticality tools establish a bias with the criticality tools.
- Any positive bias from the criticality tools needs to be added to the benchmark bias and uncertainty.

Conclusions

- Preliminary analysis suggest that the depletion bias in fuel management tools is negligible and the uncertainty in the delta k of depletion is less than 2% for burnups greater than 20 GWD/MTU.

Additional Slides

Historical Approaches - CRCs

- Historically, a limited set of state points from commercial reactors have been analyzed with criticality codes.
- Due to the limited number of state points it was difficult to determine accuracy as a function of burnup so the critical state points were added to the k_c set and various corrections attempted.
- The analysis of the state points contains the error in calculation of UO_2 cores as well as the error in calculating depletion (atom densities and cross sections).

Step 1: Fuel Management Tool Accuracy at HFP

1. For selected core locations with incore measurements increase the burnup a small amount (Δbu) in the core model.
2. Record the change in power distribution (Δp).
3. Use the Δbu/Δp to convert the measured error in power to a Δbu.
4. Initially assume the fuel management codes calculated Δk/Δbu is correct (no bias)
5. Use this Δk/Δbu to convert to a Δk deviation.

Step 1: Fuel Management Tool Accuracy at HFP

6. Using the predicted to measured power distributions create more than 4000 data points (Δk of measured to predicted as a function of burnup, enrichment, depletion parameters …).
7. Each monthly flux map produces more than 50 data points. Each ten-month cycle could produce 500 data points.
8. Data should be collected over multiple cycles and multiple plants.
9. Analyze the data to establish any trend in Δk deviation as a function of burnup. If there is a statistically significant trend this is a bias in the Δk of depletion. The deviation about the mean is the uncertainty.

Step 1: Fuel Management Tool Accuracy at HFP

10. If a statistically significant trend is observed, adjust the Δk/Δbu used in step 5 (slide 19) and redo steps 5, 6 and 9.
11. If the bias determined in step 9 is the same you are done. Otherwise repeat with new bias until converged.
12. Use this data to determine the depletion bias and uncertainty as a function of burnup.
13. Check to see if the error is also a function of other parameters such as burnable absorber loading, etc.

Step 2: Determine Uncertainty in Benchmarks

- The benchmarks will be at cold conditions.
- Additional bias and uncertainty is needed to cover the conversion from HFP to cold conditions.
- This additional uncertainty can be obtained from measured power coefficients, measured HZP critical conditions, and sensitivity analysis.

Example Benchmark Analysis

Burnup GWD/MTU	Benchmark k	Δk burnup benchmark	Criticality Codes k	Δk burnup Crit. Codes	difference in Δk
3.0 wt% U-235, 0 ppm					
0	1.3620		1.3617		
20	1.1334	.2286	1.1392	.2226	-.0061
30	1.0518	.3102	1.0563	.3054	-.0048
40	.9831	.3789	.9869	.3748	-.0041
3.0 wt% U-235, 500 ppm					
0	1.2817		1.2804		
20	1.0755	.2062	1.0798	.2005	-.0057
30	.9968	.2849	1.0004	.2800	-.0049
40	.9305	.3512	.9334	.3470	-.0042
3.0 wt% U-235, 1000 ppm					
0	1.2114		1.2092		
20	1.0244	.1870	1.0276	.1815	-.0055
30	.9485	.2629	.9511	.2581	-.0048
40	.8845	.3269	.8868	.3224	-.0045

Example Benchmark Analysis

Burnup GWD/MTU	Benchmark k	Δk burnup benchmark	Criticality Codes k	Δk burnup Crit. Codes	difference in Δk
			4.0 wt% U-235, 0 ppm		
0	1.4199		1.4216		
30	1.1213	.2987	1.1278	.2938	-.0049
40	1.0501	.3698	1.0559	.3657	-.0042
50	.9866	.4333	.9922	.4294	-.0039
			4.0 wt% U-235, 500 ppm		
0	1.3511		1.3516		
30	1.0704	.2807	1.0760	.2756	-.0051
40	1.0007	.3503	1.0057	.3459	-.0045
50	.9385	.4126	.9430	.4085	-.0040
			4.0 wt% U-235, 1000 ppm		
0	1.2894		1.2889		
30	1.0249	.2645	1.0295	.2594	-.0051
40	.9568	.3326	.9610	.3279	-.0048
50	.8959	.3936	.8999	.3890	-.0046