SOME IMPLICATIONS OF BATCH AVERAGE BURNUP CALCULATIONS ON PREDICTED SPENT FUEL COMPOSITIONS*

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ABSTRACT

The accuracy of using batch-averaged burnups to determine spent fuel characteristics (such as isotopic composition, activity, etc.) was examined for a typical pressurized-water reactor (PWR) fuel discharge batch by comparing characteristics computed by (a) performing a single depletion calculation using the average burnup of the spent fuel and (b) performing separate depletion calculations based on the relative amounts of spent fuel in each of twelve burnup ranges and summing the results. The computations were done using ORIGEN2. Procedure (b) showed a significant shift toward a greater quantity of the heavier transuranics, which derive from multiple neutron captures, and a corresponding decrease in the amounts of lower transuranics. Those characteristics which derive primarily from fission products, such as total radioactivity and total thermal power, are essentially identical for the two procedures. Those characteristics that derive primarily from the heavier transuranics, such as spontaneous fission neutrons, are underestimated by procedure (a).

INTRODUCTION

Many back-end fuel cycle and waste management analyses are based on average or standard spent fuel compositions. These spent fuel compositions have often been determined by assuming that the actual batch-average composition is the same as the calculated composition at the batch-average burnup. The resulting data are then used to characterize spent fuel, reprocessing streams, and back-end fuel cycle wastes; they are also used as source terms for fuel cycle facility and process design and risk analyses.

Concerns have recently been expressed as to the validity and accuracy of using standard batch-average burnups to determine spent fuel compositions. As a result, a preliminary analysis of the impact of using standard PWR batch-average burnups has been carried out at Oak Ridge National Laboratory. All analyses were performed using ORIGEN2,[1] a point-depletion code, and its associated PWR reactor model.[2]

PROCEDURE

Two initial ORIGEN2 analyses, in which the compositions determined at 30-GWd/MTIHM burnup were compared with compositions determined by averaging two fuels having burnups of 20 and 40 GWd/MTIHM, respectively, indicated that the accuracy of the batch-average composition was in fact dependent on the distribution of the component fuel burnups. The isotopes most sensitive to the distribution of burnups were those created by multiple neutron capture, primarily the heavier transuranic nuclides.

Since the burnup distribution used in the above calculations were not representative of actual power reactor batch discharges, a similar analysis was undertaken using a burnup distribution from Zion-1.[3] The assembly-averaged burnups in the quarter-core discharge batch (a total of 65 assemblies) varied from 27,889 to 35,853 MWd/MTIHM, with a batch-average burnup of 31,413 MWd/MTIHM.

A breakdown of the specific assembly-averaged burnups is given in Table I and Fig. 1. To account for the effects of axial burnup differences, a generic PWR end-of-cycle axial burnup distribution was assumed for all the assemblies (Fig. 2), since an actual end-of-cycle axial burnup distribution for the Zion-1 discharge batch was not available.

Each fuel assembly was divided into 129 axial segments and the burnup for each segment was determined. The segments from all the assemblies were then aggregated into 12 groups according to their burnups. The relative burnup distribution for the discharge batch is given in Fig. 3. ORIGEN2 calculations were made for each burnup group, the results from all groups were then summed and normalized to 1 MTIHM. Another ORIGEN2 calculation was made using only the batch-average burnup of 31,418 MWd/MTIHM.

RESULTS

A comparison between selected actinides calculated by the two methods is given in Tables II and III. The data for the major fission products are in good agreement because very few of these nuclides involve multiple neutron captures. The differences are large for those actinides formed by multiple neutron capture and are consistently underpredicted by the batch-average burnup calculation. The impact of these differences on spent fuel (or the resulting high-level waste from reprocessing) characteristics are given in Table IV.

In general, the data show that the radioactivity and thermal power of spent fuel (or high-level waste) can be satisfactorily predicted by using a batch-average burnup. The radioactivity and thermal power are nearly identical for both methods, except for distant future times where the longer-lived transuranics exert a greater influence; however, both the relative effect and the absolute magnitude are quite small. As expected, the greatest differences occur in the (α,n) and spontaneous fission neutron source terms where the batch-average burnup calculation has underpredicted the major source terms.

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Table I. Assembly-Averaged Burnups

Number of assemblies	Burnup (MWd/MTIHM)
1	35,853
2	31,714
2	30,404
2	35,009
4	28,627
4	31,313
2	31,710
4	27,889
4	30,422
4	34,982
4	28,600
4	28,232
4	31,385
4	33,162
2	30,402
4	31,294
4	30,414
4	33,158
2	35,009
4	34,980

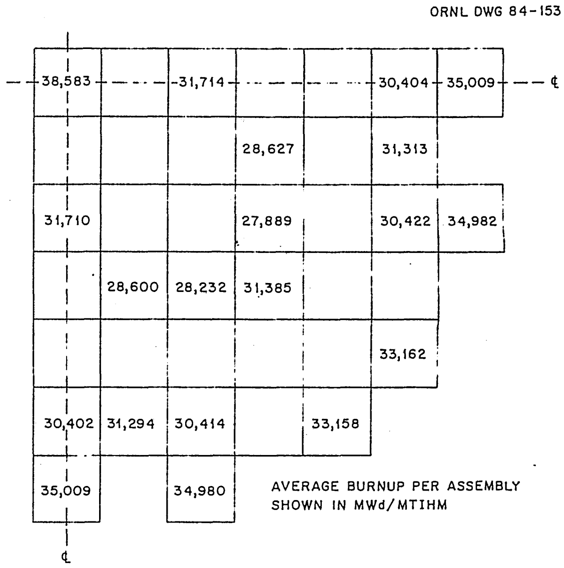

Fig. 1. Quarter-Core Discharge Batch (Top View).

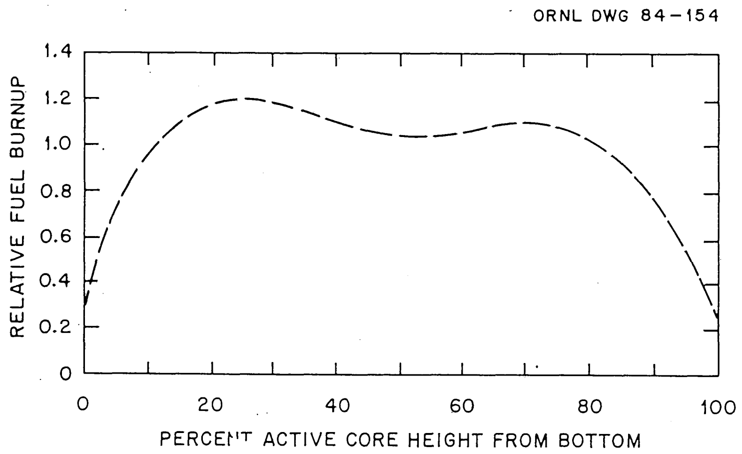

Fig. 2. Axial End-of-Cycle Burnup Distribution.

Table II. Gram-Atoms of Selected PWR Actinides at Discharge[a]

Isotope	Sum of groups[b]	Batch average[c]	Percent difference[d]
^{236}Pu	4.84×10^{-6}	4.47×10^{-6}	-7.6
^{238}Pu	5.15×10^{-1}	4.79×10^{-1}	-7.0
^{239}Pu	2.01×10^{1}	2.06×10^{1}	2.5
^{240}Pu	8.97×10^{0}	9.25×10^{0}	3.1
^{241}Pu	4.75×10^{0}	4.81×10^{0}	1.3
^{242}Pu	1.78×10^{0}	1.68×10^{0}	-5.6
^{241}Am	1.10×10^{-1}	1.17×10^{-1}	6.4
^{242m}Am	2.38×10^{-3}	2.53×10^{-3}	6.3
^{243}Am	3.54×10^{-1}	2.97×10^{-1}	-16.1
^{242}Cm	4.65×10^{-2}	4.53×10^{-2}	- 2.6
^{243}Cm	1.32×10^{-3}	1.17×10^{-3}	-11.4
^{244}Cm	1.09×10^{-1}	7.75×10^{-2}	-28.9
^{245}Cm	4.13×10^{-3}	2.65×10^{-3}	-36.6
^{246}Cm	5.72×10^{-4}	2.93×10^{-4}	-48.8

[a]Based on 1 MTIHM.
[b]Composition was determined by summing the individual compositions for each burnup group.
[c]Batch-average burnup is 31,418 MWd/MTIHM.

[d]Percent difference $= \frac{\text{(batch average)} - \text{(sum of groups)}}{\text{(sum of groups)}} \times 100.$

Table III. Gram-Atoms of Major Transuranic Elements at Discharge (per MTIHM)

Element	Sum of groups	Batch average	Percent difference[a]
Plutonium	36.115	36.819	1.95
Americium	0.466	0.417	-10.5
Curium	0.162	0.127	-21.6
Total	36.743	37.363	1.69

[a]Percent difference $= \frac{\text{(batch average)} - \text{(sum of groups)}}{\text{(sum of groups)}} \times 100.$

Table IV. Comparison of Spent Fuel and High-Level Waste Characteristics[a]

	Age of spent fuel (yr)					
	Discharge	1.0	10	10^2	10^3	10^4
			Radioactivity, Ci			
Sum of groups[b]	2.10×10^8	2.39×10^6	3.74×10^5	3.89×10^4	1.65×10^3	4.49×10^2
Batch-average[c]	2.10×10^8	2.38×10^6	3.76×10^5	3.91×10^4	1.67×10^3	4.56×10^2
			Thermal power, W			
Sum of groups	2.09×10^6	9.98×10^3	1.10×10^3	2.69×10^2	5.16×10^1	1.29×10^1
Batch-average	2.09×10^6	9.87×10^3	1.08×10^3	2.69×10^2	5.25×10^1	1.32×10^1
			(α,n) neutrons/sec			
Sum of groups	5.51×10^7	1.61×10^7	5.86×10^6	5.04×10^6	1.38×10^6	3.09×10^5
Batch-average	5.30×10^7	1.50×10^7	5.28×10^6	5.01×10^6	1.40×10^6	3.14×10^5
			Spontaneous fission, neutrons/sec			
Sum of groups	5.42×10^8	3.40×10^8	2.06×10^8	1.05×10^7	3.51×10^6	1.71×10^6
Batch-average	4.50×10^8	2.57×10^8	1.47×10^8	8.10×10^6	3.09×10^6	1.54×10^6
	Age of high-level waste (yr)[d]					
	Reprocessing	10	10^2	10^3	10^4	10^6
			Radioactivity, Ci			
Sum of groups	2.25×10^6	2.77×10^5	3.18×10^4	1.20×10^2	3.88×10^1	5.97×10^0
Batch-average	2.24×10^6	2.78×10^5	3.20×10^4	1.15×10^2	3.58×10^1	5.99×10^0
			Thermal power, W			
Sum of groups	9.75×10^3	8.75×10^2	1.00×10^2	2.85×10^0	4.78×10^{-1}	7.33×10^{-2}
Batch-average	9.64×10^3	8.62×10^2	1.00×10^2	2.77×10^0	4.09×10^{-1}	7.32×10^{-2}
			(α,n) neutrons/sec			
Sum of groups	1.33×10^7	1.96×10^6	3.44×10^5	7.80×10^4	1.12×10^4	2.55×10^3
Batch-average	1.24×10^7	1.50×10^6	3.32×10^5	7.62×10^4	9.51×10^3	2.55×10^3
			Spontaneous fission, neutrons/sec			
Sum of groups	3.37×10^8	1.95×10^8	7.47×10^6	1.12×10^6	3.08×10^5	1.21×10^3
Batch-average	2.54×10^8	1.39×10^8	5.09×10^6	5.83×10^5	1.62×10^5	8.35×10^2

[a]Based on 1 MTIHM.
[b]Composition was determined by summing the individual compositions for each burnup group.
[c]Batch-average burnup is 31,418 MWd/MTIHM.
[d]Reprocessed at 1 yr.

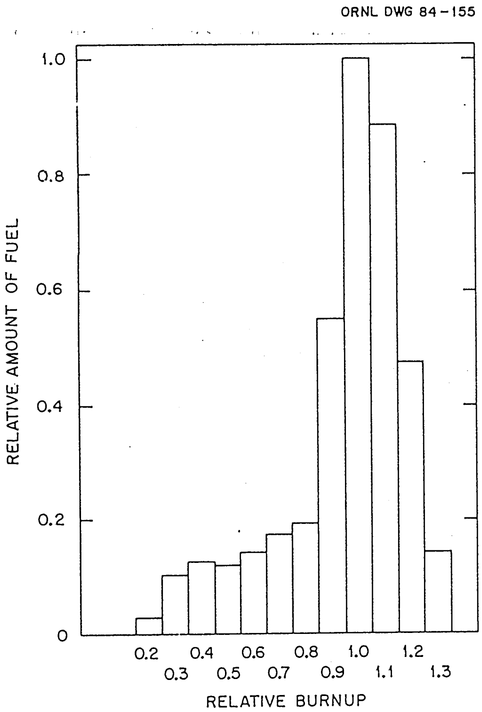

Fig. 3. Relative Spent Fuel Burnup Distribution.

CONCLUSIONS

These conclusions can be drawn from this preliminary analysis:

1. The accuracy of using a batch-average burnup is dependent on the distribution of burnup in the discharge batch, and on the parameter being calculated.

2. Reasonably accurate values for the total radioactivity, thermal power, and fission products are obtained using a batch-average burnup.

3. Batch-average burnup calculations are nonconservative in the prediction of those nuclides formed by multiple neutron capture (i.e., the higher transuranics) and in the prediction of some neutron source terms.

4. The nonconservative errors will probably be greater in higher burnup LWR fuels.

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