Survey of Operating Parameters for Use in Burnup Credit Calculations

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INTRODUCTION

Burnup credit is credit taken for the reduction of reactivity that results from burnup of nuclear fuel in a reactor. The decrease in reactivity is due to the depletion of fissile nuclides and the accumulation of neutron-absorbing nuclides during and after the fuel is used to generate power. The use of burnup credit permits the storage of fuel assemblies with a higher initial enrichment of ^{235}U, or in larger or higher-density arrays, with reduced dependence on neutron absorbers. Safety-related fuel burnup calculations must use bounding conservative assumptions for reactor operating parameters that might unnecessarily reduce burnup credit benefits.[1,2] The impact of variations in the relevant parameters on k_{eff} for spent fuel storage and transport systems is discussed in detail elsewhere.[2,3] In this work, reactor-specific operating data were collected and analyzed for the purpose of developing a better understanding and basis for assigning operating parameters for use in fuel depletion calculations for burnup credit analyses.

DESCRIPTION OF THE ACTUAL WORK

Reactor operating data were collected from a series of Commercial Reactor Critical (CRC) documents.[4] These documents present detailed operating data and fuel characteristics for 25 cycles of 6 pressurized water reactors (PWRs) and 2 boiling water reactors (BWRs). These data were used by the Civilian Radioactive Waste Management System staff to model 66 critical reactor configurations, referred to as statepoints. Table I provides overview data on the 66 CRC statepoints. The CRC data include descriptions of reactor dimensions and materials; time-dependent parameters needed to perform fuel depletion calculations; and axial-dependent data, such as fuel burnup, moderator density, and fuel temperature, for each assembly modeled in each CRC statepoint. These data were used for integral depletion and criticality code validation, and hence are assumed to be accurate.

Axially-dependent burnup, fuel temperatures, and moderator density data were extracted from the CRC documents for each assembly present in the modeled statepoints. Burnup-dependent hot full power (HFP) soluble boron concentration (C_B) information was extracted from the CRC data for each PWR cycle. Results of the analysis of the extracted data are provided in this paper.

RESULTS

Burnup Data

Axial burnup shapes were collected, one for each assembly modeled in each statepoint. The highest burnup values are located near the center of each assembly. The top and bottom of each assembly have a much lower burnup and typically have more ^{235}U left over than the center. Modeling the axial burnup shape, rather than a flat axial profile with the same average burnup, results in a higher reactivity during hypothetical flooded storage or transport configurations.

The fuel assemblies located closer to the center of the core achieve a higher power level and thus accumulate burnup faster during each cycle as the fuel is depleted. It is typical for assemblies to change locations between cycles; therefore, burnup does not always accumulate at a constant rate.

In burnup credit analyses, a conservative axial burnup profile can be used to simplify the calculations for multiple fuel assemblies. The conservative profiles provide a lower-than-actual burnup near the ends of the assembly, which maximizes reactivity.[5] A thorough analysis of the collected axial burnup shapes has not yet been performed.

Maximum Fuel Temperature Data

A conservative fuel temperature for use in fuel burnup calculations should be high, but not excessively high. As the fuel temperature increases, the ^{238}U neutron capture resonances broaden, increasing fast neutron absorption and plutonium generation. Consequently, the reactivity of the fuel is increased, and the benefit of burnup credit is reduced.

Axially dependent fuel temperature data were collected for every assembly in each PWR and BWR reactor at each statepoint and at intermediate depletion points. The PWR maximum fuel temperature data are presented in Fig. 1. The average maximum fuel temperature for PWRs is 923.7 K, with a standard deviation of 120.6 K. BWRs have higher maximum fuel temperatures than PWRs because the coolant at the top of the assembly is less dense due to boiling and cannot remove as much heat from the fuel. The BWR maximum fuel temperature data are presented in Fig. 2. The average maximum fuel temperature for BWRs is 1073.6 K, with a standard deviation of 173.1 K.

Minimum Moderator Density Data

It is conservative to assume a low moderator density. As moderator density decreases, the neutron flux spectrum is hardened, and ^{238}U absorbs more neutrons, creating more plutonium. Consequently, the reactivity of the fuel is increased, and the benefit of burnup credit is reduced.

Axial-dependent moderator density data were collected for every assembly in each PWR and BWR reactor. The PWR minimum moderator density data are presented in Fig. 3. The average minimum moderator density for PWRs is 0.680 g/cm^3, with a standard deviation of 0.021 g/cm^3. BWRs have a lower minimum moderator density than PWRs because the water boils and becomes less dense at the top of the core. The BWR minimum moderator density data are presented in Fig. 4. The average minimum moderator density for BWRs is 0.233 g/cm^3, with a standard deviation of 0.031 g/cm^3.

Soluble Boron Concentration Data

C_Bs were collected for the six PWRs. The HFP boron concentration was provided at intervals during each operating cycle. Higher C_B values result in a harder neutron flux spectrum, causing plutonium to build up faster in the fuel. Consequently, the reactivity of the fuel is increased and the benefit of burnup credit is reduced.

The cycle average boron concentrations ranged from 317 to 962 parts per million (ppm) B for the 21 PWR cycles described in the CRC data. The average C_Bs for 3 of the 6 PWRs were within 1% of each other. The overall average was 565 ppm B with a standard deviation of 183 ppm B. To calculate the averages, each C_B value was weighted with the width of the burnup interval between the data points.

CONCLUSION

Use of conservative bounding values for plant operating data can reduce the number of calculations required to cover a set of spent nuclear fuel and can provide less complex burnup credit loading criteria. On the other hand, overly conservative values might result in reduced transportation or storage capacities. The work presented in this paper is a survey of operating parameters used in fuel depletion calculations for burnup credit analysis for several PWRs and BWRs. Depending upon the scope of the burnup credit analysis, similar-facility specific or reactor-design-specific operating parameter reviews can be used to reduce conservatism and thus increase the number of assemblies considered acceptable for storage and transportation.

REFERENCES

1. Interim Staff Guidance – 8, Rev. 2, *Burnup Credit in the Criticality Safety Analyses of PWR Spent Fuel in Transport and Storage Casks*, U. S. Nuclear Regulatory Commission, Spent Fuel Project Office, September 2002.
2. J. C. WAGNER, C. E. SANDERS, *Assessment of Reactivity Margins and Loading Curves for PWR Burnup-Credit Cask Designs*, NUREG/CR-6800 (ORNL/TM-2002/6), U. S. Nuclear Regulatory Commission/Oak Ridge National Laboratory, Oak Ridge, TN (2003).
3. M. D. DEHART, *Sensitivity and Parametric Evaluations of Significant Aspects of Burnup Credit for PWR Spent Fuel Packages*, ORNL/TM-12973, Oak Ridge National Laboratory, Oak Ridge, TN (1996).
4. *Summary Report of Commercial Reactor Critical Analyses Performed for Disposal Criticality Analysis Methodology,* B00000000-01717-5705-00075 REV 01, CRWMS M&O, Las Vegas, NV (1998).
5. J. C. WAGNER, M. D. DEHART, *Review of Axial Burnup Distribution Considerations for Burnup Credit Calculations*, ORNL/TM-1999/246, Oak Ridge National Laboratory, Oak Ridge, TN (2000).

Table I. Commercial Reactor Critical Statepoint Information.

Plant	Unit	Plant Type	No. of Statepoints	No. of Cycles	Assy Avg BU Range (GWd/MTU)	Assembly Designs
Crystal River	3	PWR	33	10	0 -> 49	B&W 15x15
McGuire	1	PWR	6	3	0 -> 38	W 17x17STD, W 17x17OFA, B&W 17x17
Sequoya	2	PWR	3	2	0 -> 34	W 17x17
Three Mile Island	1	PWR	3	2	0 -> 28	B&W 15x15
Catawba	1	PWR	3	2	0 -> 39	W 17x17OFA
Davis Besse	1	PWR	7	2	0 -> 44	B&W 15x15
Quad Cities	2	BWR	6	2	0 -> 40	GE 8x8
La Salle	1	BWR	5	2	0 -> 36	GE 8x8

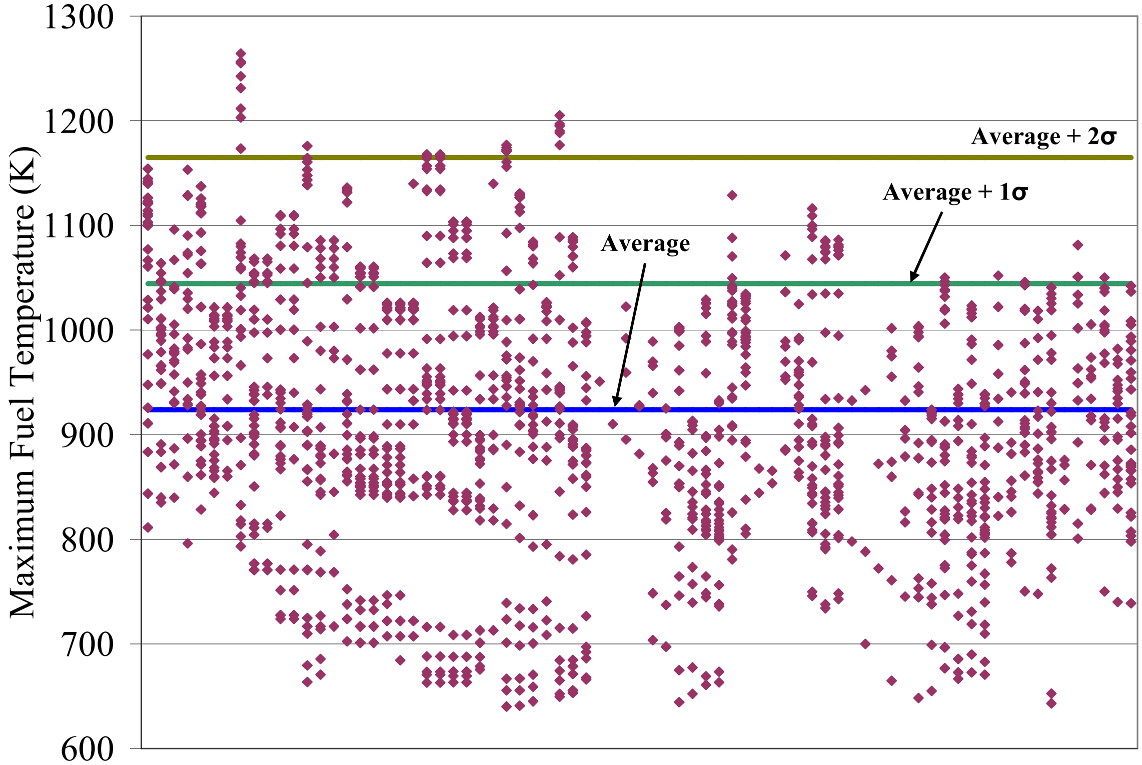

Fig. 1. Distribution of maximum hot full power fuel temperatures for 21 cycles of 6 PWRs.

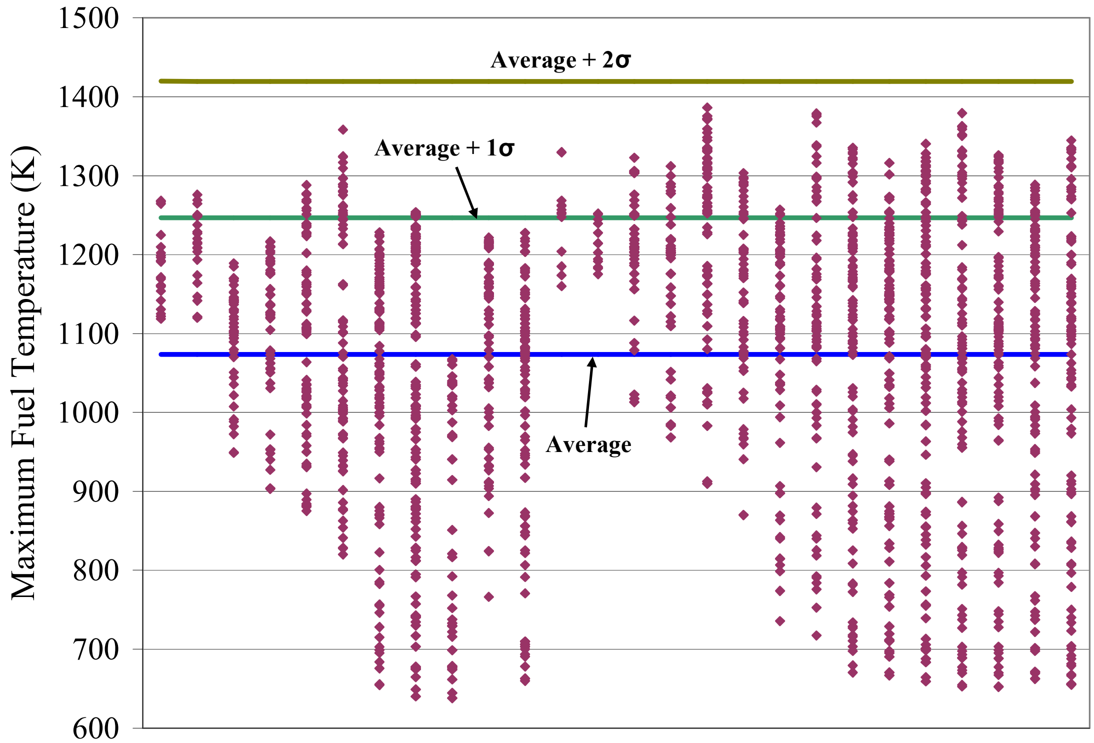

Fig. 2. Distribution of maximum hot full power fuel temperatures for 4 cycles of 2 BWRs.

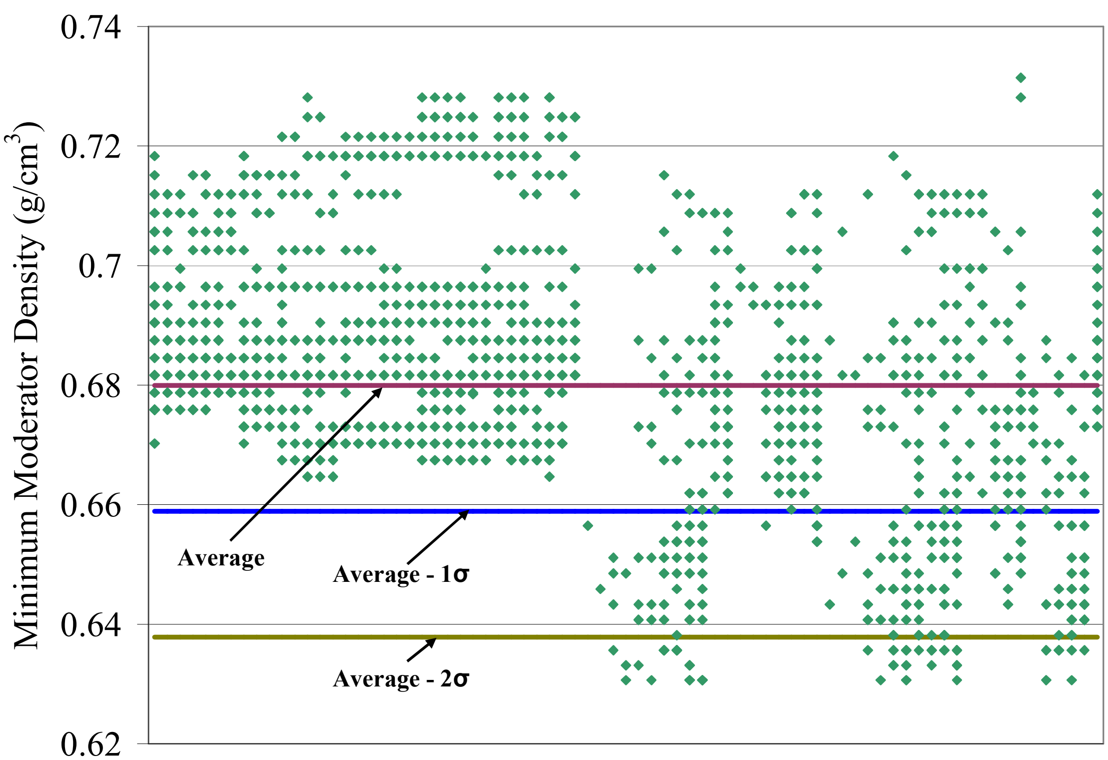

Fig. 3. Distribution of minimum hot full power water densities for 21 cycles of 6 PWRs.

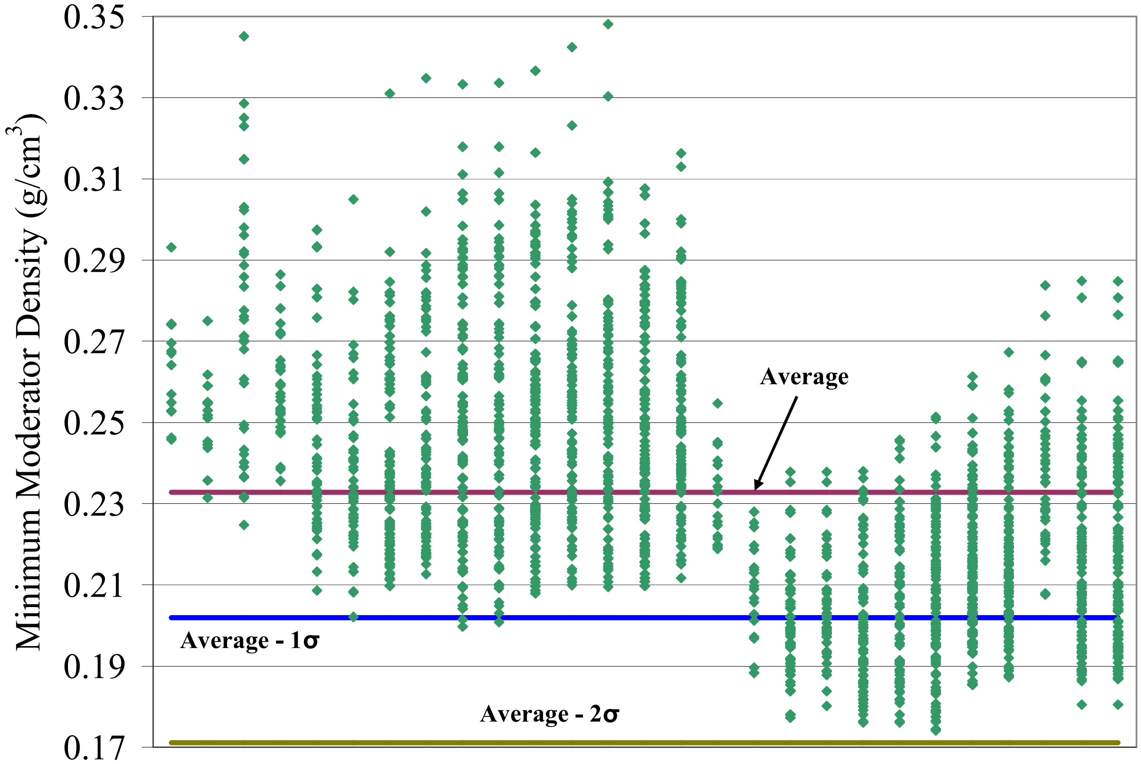

Fig. 4. Distribution of minimum hot full power water densities for 4 cycles of 2 BWRs.