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# Decay Heat Code Validation Activities at ORNL: Supporting Expansion of NRC Regulatory Guide 3.54


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## INTRODUCTION

Oak Ridge National Laboratory (ORNL) has a long history of involvement in the development and validation of the ORIGEN series of isotope summation codes and nuclear data libraries, widely recognized and used to predict the decay heat for spent nuclear fuel. In particular, the ORIGEN-S code, the depletion/decay module of the SCALE code system,[1] has been extensively validated using experimental isotopic assay data and decay heat measurements for commercial spent fuel. This work was used in the development of the technical basis for NRC Regulatory Guide 3.54 on spent fuel decay heat.[2,3]

The bulk of the experimental data used to validate spent fuel decay heat predictions are from programs of the 1970s and 1980s and consequently involve older-design fuel assemblies with a relatively low enrichment and burnup. This has led to a situation where the spent fuel now being discharged from operating reactors extends well beyond the regime of the experimental data and area of code applicability based on the data. The absence of validation data for modern fuel designs has potentially serious consequences for decay heat predictions in terms of added safety factors to account for larger uncertainties and lower volumetric transport and storage capacities.

## VERIFICATION AND VALIDATION STATUS

Verification studies comparing ORIGEN-S decay heat results with ORIGEN2 and CINDER code results,[4] and comparisons of decay heat calculations against other international codes using a common set of nuclear data,[5,6] have been published. These studies confirm the accuracy of the numerical methods used to solve the depletion/decay equations.

Validation studies for ORIGEN-S include measurements at very short cooling times (2 – 14,000 s) following irradiation of $^{235}$U and $^{239}$Pu samples,[7] comparisons with the ANS-5.1-1979 Decay Heat Standard,[7,8,9] and benchmarking against measured decay heat for spent fuel assemblies.[2,9] A summary of the validation studies and the typical accuracy is given in Table I. In general, decay heat can be predicted by ORIGEN-S with an accuracy of fewer than 5% for a wide range of cooling times.

**TABLE I**

**Summary of ORIGEN-S Decay Heat Validation Results**

| Decay time | Type of Measurement | Accuracy |
|---|---|---|
| ~2 – 100 s | $^{239}$Pu burst fission<br>$^{235}$U burst fission | 2%<br>3% |
| ~100 s – 3 h | $^{239}$Pu burst fission<br>$^{235}$U burst fission | 5%<br>5% |
| 2 – 5 y | 14 PWR fuel assemblies | 4% (avg. dev.) |
| 2 – 7 y | 25 BWR fuel assemblies | 6% (avg. dev.) |

## NRC REGULATORY GUIDE 3.54

The NRC decay heat regulatory guide provides a method for calculating the decay heat for PWR and BWR fuel for burnups up to 50 and 45 GWd/t, respectively, and spans cooling times from 1 to 110 years. The base data used to develop the guide was created using ORIGEN-S. Benchmarking of the ORIGEN-S calculations was performed using measurements for well-characterized fuel assemblies from Point Beach and Turkey Point PWR plants, and the Cooper BWR station. The Point Beach fuel was 3.4 wt % with burnups up to 39 GWd/t, and the Turkey Point fuel was 2.6 wt % and 28 GWd/t. The Cooper BWR fuel was 2.5 wt % and had a maximum burnup of only 27 GWd/t. The decay times of all assemblies were less than 10 years. The regulatory guide applies safety factors to account for the additional uncertainty in extrapolating beyond the range of the validation data. The maximum safety factors are 11% for PWR fuel and 16% for BWR fuel. Safety factors for regimes beyond the range of the regulatory guide would likely be substantially larger.

The current trend towards the use of higher initial $^{235}$U enrichments, burnable poison rods, longer cycles, more efficient fuel management schemes and reactor operating conditions has resulted in routinely higher discharge burnups than considered in Regulatory Guide 3.54. The higher burnups lead to higher actinide content and increased relative importance of actinides in decay heat. The dominant decay heat actinides (e.g., $^{241}$Am, $^{238}$Pu, $^{244}$Cm) have a larger uncertainty than the aggregate fission products, and therefore larger code bias in the predicted decay heat may be expected.

The ANS-5.1-1979 Decay Heat Standard[8] has limited value for high burnup spent fuel due to the inability to accurately treat actinide formation and neutron capture effects, phenomena important to predicting decay heat of high burnup fuel.

The limited range of the regulatory guide and the lack of suitable validation data for high burnup fuel leaves analysts with few options but to use existing methods and data and apply suitably conservative safety factors. The penalty is likely to be large compared to the anticipated accuracy of ORIGEN-S, which has traditionally been capable of predicting decay heat to within about 5% of measurements.

## NEW EXPERIMENTAL PROGRAMS

There are currently no domestic experimental programs being planned to obtain additional decay heat measurements for the inventory of fuel being discharged from U.S. reactors, and the calorimeters used in earlier programs have been decommissioned. The Swedish waste management company (SKB) is planning a series of new measurements at their central interim spent fuel storage facility, CLAB, scheduled to begin in early 2002. This facility stores approximately 1500 spent fuel assemblies from three utilities with a wide range of PWR and BWR assembly designs. The fuel burnups extend up to 51 GWd/t and span a wide range of assembly designs. ORNL is currently collaborating with SKB to provide technical assistance to this project in the areas of assembly selection, generation of code models and nuclear data libraries for the different fuels, and evaluation and publication of the benchmark results. The calorimeter will remain operational for the life of CLAB and will be used to make repeated measurements on the selected assemblies at regular intervals, providing decay heat data for decades into the future. In addition, new fuel designs, reflecting higher enrichments and burnups will be added as they become available to augment the database.

## CONCLUSIONS

ORNL is currently collaborating with SKB to obtain new decay heat measurements for spent fuel in regimes well beyond the existing data used to validate computer codes. It is anticipated that these data will significantly reduce the current uncertainties and level of conservatism for high burnup fuels.

# REFERENCES


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