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## SNF Calculations of Spent Fuel Source Terms for Fuel Pools and Storage Casks

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## INTRODUCTION

Efficient analysis of spent fuel source terms is a task of growing importance for many utilities. As the on-site fuel pool storage capacity becomes exhausted, it is necessary to utilize dry storage casks for additional, on-site storage.

Since the first release in 2004, the SNF program [1] has been extended with e.g. more detailed isotopic decay chains and new user features, such as a general restart capability. The most important new validation was the completion of a benchmark using measured decay heat data of spent fuel assemblies.

SNF has been successfully applied for calculation of gamma- and neutron radiation parameters relevant to cask loading criteria. Other applications, besides traditional back-end calculations include 'on-line' core- and fuel pool decay heat calculations using a special decay heat module (DHM) that may be executed by the reactor engineer.

## SNF METHOD AND VALIDATION

SNF is based on the isotopic summation method using nodal, isotopic concentrations from standard 2-D/3-D CASMO/SIMULATE [2,3] or HELIOS/PRESTO-2 [4] core-tracking calculations. Thus, this program extends the 'state-of-the-art' in-core fuel management (ICFM) methods with a consistent back-end capability. The required 2-D/3-D calculations are performed as part of the normal ICFM activity and thus very little additional effort and quality assurance is involved. Isotopic decay data were obtained from the ENDF/B-VI decay data file.

SNF has been validated both by direct experimental measurement comparisons and by comparisons with ORIGEN-ARP [5] decay and source terms calculations. An example of comparisons with ORIGEN-ARP is shown in Table I. Note that in these comparisons the initial isotopic concentrations of ORIGEN-ARP were utilized in SNF, thus eliminating the fuel depletion part of the calculation from the comparison. The agreement is within 0.1% for cooling times up to 10,000 years. This is an improvement relative to earlier results [1], due to the implementation of the complete U-233 and U-235 decay chains in the current SNF program version.

TABLE I. SNF %-deviations of activity, decay heat and total neutron source relative to ORIGEN-ARP-2.0 for BWR fuel at 55 GWd/t burnup vs. cooling time (Cool.t.).

Cool. t. (years)	Activity (%)	Decay heat (%)	Neutron source (%)
0.3	0.0	0.0	0.0
1.0	0.0	0.0	-0.1
3.0	0.0	0.0	-0.1
10	0.0	0.0	0.0
30	0.0	0.0	0.0
100	0.0	0.0	0.0
300	-0.1	-0.1	0.0
1000	-0.1	0.0	0.0
3000	-0.1	-0.1	0.0
10000	-0.1	0.0	0.0

Comparisons with calorimetric decay heat measurements of spent fuel assemblies from Swedish reactors have shown very good agreement. A total of 16 BWR fuel assemblies (8x8, 9x9 and SVEA-watercross designs) and 33 PWR fuel assemblies (15x15 and 17x17 designs) were analyzed. Preliminary results for the 16 BWR assemblies [6] had shown a systematic under prediction of about 3 %. New analysis, using the final, corrected experimental data and including also 33 PWR assemblies shows, on average, only 0.6 % under prediction. The average calculation-to-experiment ratios (C/E) per fuel type and for all the 49 fuel assemblies are shown in Table II. As may be seen, the average C/E-values of the different fuel types are quite consistent. The larger standard deviation of the older BWR-8x8 and -9x9 fuel as compared with the BWR-watercross and the PWR fuel types is probably due to inaccuracies in the applied power histories.

TABLE II. SNF vs. measured decay heat of BWR and PWR fuel assemblies. Average C/E-ratio per fuel type.

Fuel assembly type	Number of assemblies	C/E average and std.deviation
BWR-8x8/9x9	8	0.991 ± 0.041
BWR-watercross	8	0.989 ± 0.015
PWR-15x15	17	0.993 ± 0.011
PWR-17x17	16	1.000 ± 0.010
Total	49	0.994 ± 0.019

## CASK LOADING CALCULATIONS

SNF has been applied to cask loading calculations of discharged fuel assemblies from Kernkraftwerk Brunsbüttel (KKB) and Kernkraftwerk Krümmel (KKK). ICFM calculations using HELIOS/PRESTO-2 were supplied by the utility, Vattenfall Europe Nuclear Energy (VE NE). The loading criteria for a given type of storage/transport cask were based on limiting values on certain radiation parameters defined as functions of the photon spectrum and neutron source rates, as well as on burnup, activity and decay heat.

A total of 201 KKB fuel assemblies and 320 KKK fuel assemblies were analyzed to determine acceptability for cask loading at specified dates. The SNF results were compared with reference loading calculations provided by the cask vendor using plant burnup data and traditional spent fuel calculation methods. On average, the activity and decay heat predictions by SNF were lower (10-20%) than the reference and thus more assemblies could be loaded at the specified dates. The differences are probably caused by the multi-dimensional fuel depletion method of SNF compared with the reference method that also has a built-in conservatism to account for uncertainties.

To optimize the utilization of cask capacities, two years cycle projection including subsequent SNF calculations will be done on a routine basis from now on. The goal for the utility is to avoid partial loading of casks.

## CORE AND FUEL POOL DECAY HEAT CALCULATIONS

The SNF/DHM calculation module has been implemented at KKB. Data is automatically retrieved from the online core monitoring system. DHM keeps track of the decay heat of all fuel assemblies in the core as well as those in the fuel pool. It may be used to calculate the actual core decay heat in the case of a scram and to calculate the decay heat of all fuel assemblies in the fuel pool to plan the activities during outages.

## CONCLUSION

Based on the validation of SNF against experimental data and ORIGEN-ARP decay calculations, it is concluded that the characteristics of spent fuel assemblies are calculated with high accuracy. Experimental decay heat comparisons with a total of 49 BWR and PWR fuel assemblies have shown an average C/E-ratio of  $0.994 \pm 0.019$ . Routine applications include cask loading analyses and core- and fuel pool decay heat calculations.

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