

PREDICTION OF DECAY HEAT POWER IN ONTARIO HYDRO CANDU REACTORS DURING PROLONGED OUTAGES

S.D. Arguner and C.A. Morrison
Ontario Hydro
700 University Avenue
Toronto, Ontario, Canada M5G 1X6

ABSTRACT

A standard model has been developed for readily estimating decay heat power as an input to analysis for planning of long duration reactor outages. The model is based on the format of the ANSI/ANS-5.1 standard [1] which, by means of appropriate input data, has been tailored to predict decay heat power in OH reactors utilizing CANDU 37-element fuel.

INTRODUCTION

Information on power produced due to decay heat following shutdown forms a primary input to nuclear safety assessment aspects of the outage planning process at the station, specifically with respect to heat sink availability. Up to this point in time, a variety of methods have been used within OH to generate decay heat data for different cooling times of interest, but no approach has been universally adopted for determining the required information for post-shutdown periods spanning the range from a few hours to a few months. The present work was initiated with the objective of deriving data that is readily reproducible in a standard fashion for the range of operational conditions that may be experienced by CANDU 37-element fuel. A further requirement is to quantify the uncertainty associated with the estimated decay heat power.

The best available means for characterizing the radiation-related properties of irradiated CANDU fuel is considered to be the SCALE4.2 version of the ORIGEN-S code [2], in conjunction with the cross-section libraries specifically developed for 37-element and 28-element fuel. This analysis technique has recently been verified and validated through comparison of calculations against experimental measurements of CANDU reactor fuel [3]. However, this code is not a practical tool to easily determine decay heat powers for operational support purposes. A practical alternative was sought by developing an approach based on the structure of the ANSI/ANS-5.1 standard, but supported by CANDU-specific parameters derived using ORIGEN-S, for the decay time range of interest here.

DECAY HEAT MODEL DEVELOPMENT

Standard Formulation for Decay Heat Power

The ANSI/ANS-5.1-1979 standard [1] provides a calculational framework for predicting the decay heat power from fission products and the associated uncertainty following shutdown of Light Water Reactors (LWR). The formulation has, however, enough flexibility built-in to simulate, via user input options, arbitrary operating power/irradiation histories and to calculate the resultant decay heat powers for other fuel types, such as CANDU fuel, containing U-235, U-238 and Pu-239 as the major fissioning nuclides. A separate procedure for calculating the

additional contribution of actinides to decay heat power is also given, although only the heavy elements U-239 and Np-239 are explicitly included. The treatment for heavy elements as stated in the ANSI/ANS-5.1-1979 standard is less rigorous than that for the fission products, as it does not account for non-uniform irradiation histories.

Data Requirements for CANDU 37 Element Fuel

The approach adopted for developing a standard decay heat model for 37-element CANDU fuel was to (i) implement, initially in the form of a spreadsheet, the algorithm prescribed by the ANSI/ANS-5.1-1979 standard, and (ii) incorporate derived data (user specified as per the standard) relevant to CANDU fuel. The reference data tables specific to CANDU 37-element fuel were derived for a range of fuel burnup from 0 to 200 Mwh/kgU (representative of typical discharge bundle burnup). The derivation of data for three fundamental parameter types using the ORIGEN-S code [2] is briefly described below.

(1) Fractional Fission Rates. The fractional fission rates as a function of burnup were derived from burnup-dependent fission cross sections and nuclide concentrations as calculated by ORIGEN-S for 5 fissionable nuclides (U-235, Pu-239, U-238, Pu-240 and Pu-241). The fission rate fractions derived for Pu-240 and Pu-241 were lumped with the U-235 fraction as per ANS-5.1-1979 methodology, thereby providing a reference fission rate data set composed of 3 major fissionable nuclides (U-235, Pu-239 and U-238).

(2) Energy from Fission. The constant values for recoverable energy directly associated with fission of the above major fissile nuclides were obtained from the library data set used by ORIGEN-S. The additional, indirect source of energy associated with fission is the energy from neutron capture (n,γ) reactions in the fuel, which varies with burnup as the fuel composition changes. Again, this data was obtained from ORIGEN-S simulations of fuel burnup up to 200 Mwh/kg-U.

(3) Actinide Decay Heat Power. Calculation of the actinide contribution to decay heat power is specified through the use of the parameter R, representing the production rate of U-239 relative to overall fission rate. The ANS-5.1 standard prescribes the user-supplied value of R to be evaluated for the reactor composition at the time of shutdown, and the heavy element decay heat to be based on the maximum power during the operating history. Using ORIGEN-S simulations, we have derived a tabulation of R as a function of burnup, and have implemented the algorithm for heavy elements to reflect the histogram representation of irradiation history, in the same way that it is applied for fission product contributions.

MODEL TESTING

The decay heat powers predicted by this proposed standard model were then benchmarked against the ORIGEN-S predicted values over a range of irradiation conditions and decay times, to confirm the robustness of the method. The nominal case presented for comparison below is the decay power transient following constant power irradiation of a 37 element fuel bundle under conditions typically encountered in operating OH reactors.

Using the proposed standard model to simulate an average power fuel bundle operating at a constant power up to a core-average burnup of 110 MWh/kgU, the decay heat powers and associated 1-sigma uncertainties were calculated for various decay times spanning the range of hours to months. The results showed good agreement, well within the +/- 1-sigma uncertainties as illustrated in Figure 1, with the corresponding results obtained from the calculations using the ORIGEN-S code.

The degree of agreement was preserved when the above set of calculations were performed for two significantly different fuel burnup levels of 70 and 200 MWh/kgU, representing different stages in the irradiation history of individual fuel bundles. The results of these calculations are given in Table 1 along with the nominal case.

Table 1
Comparison of Decay Heat Powers Predicted
Standard Model (Best Estimate) vs. ORIGEN-S Code

% Difference in Decay Power $[(P_{\text{standard}}/P_{\text{ORIGEN-S}})-1]*100$			
Fuel Decay Time (seconds)	Burnup 70	(MWh/kg U)	
		110	200
1.00E+04	2.0	2.1	2.3
1.00E+05	-0.6	-0.4	-1.0
1.00E+06	-0.7	-0.4	-0.4
1.00E+07	1.6	2.1	1.1

APPLICATIONS

Full Power Equilibrium Fuelling Operation

In its typical application mode, the proposed standard model is used to produce the decay heat power for the whole core at input decay times of interest following shutdown from full reactor power under equilibrium fuelling conditions. For the large collection of bundles present in the whole core, it can be assumed that irradiation of all the fuel in the core can be represented by core-average parameters. From the output data, a "best estimate" decay heat power curve with associated uncertainties can be quickly constructed and used for engineering judgment decisions and sensitivity analysis purposes. This information also provides the basis for assigning a

conservative upper limit to the decay power curve, by incorporating an appropriate margin based on the estimated uncertainty.

Power History Simulation

The proposed standard model can also be used to simulate an arbitrary operating power history. In addition to decay times of interest for this mode of application, the only inputs required are operating powers and durations (currently up to 20 consecutive periods) in order to synthesize the fuel burnup history. In a recent application, the fuel burnup histories of bundles in selected core channels were derived from a station database of bundle power/burnup information preceding a station outage. The channel decay heat power profiles pertaining to a certain cooling time during the outage were then constructed from the individual bundle powers calculated using the standard model, and the results provided as input to the station's analysis of instrumented channel data from that period of the outage. Predicted decay heat powers for these cases, which tracked the time-varying power history of individual bundles as they underwent fuelling shifts along the channel, again showed excellent agreement between the proposed standard model, as implemented in the spreadsheet, and explicit calculations using ORIGEN-S.

FUTURE DEVELOPMENT

As a primary objective for possible future development work, it is expected that the OH standard decay heat model developed for 37-element CANDU fuel will be extended to include a model for 28-element CANDU fuel. In the next iteration of the model, it is also our intent to address the revisions made in the ANSI/ANS-5.1-1994 version of the reference standard [1].

REFERENCES

- [1] ANSI/ANS5.1 - 1979, "American National Standard for Decay Heat Power in Light Water Reactors", published by American Nuclear Society, 1979.
- [2] O.W. Hermann and R.M. Westfall, "ORIGEN-S; SCALE system module to calculate fuel depletion, actinide transmutation, fission product buildup and decay, and associated radiation source terms", Section F7 of SCALE: A Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluations, NUREG / CR-0200 (ORNL/NUREG/CSD-2/V2/R4) Volume 2, Revision 4, April 1995.
- [3] I.C. Gould, K.A. Litwin, "Verification and Validation of the ORIGEN-S Code and Nuclear Data Libraries", AECL Report RC-1442 also COG Working Party 25 Report COG-I-95-200, October 1995.

Figure 1
Comparison of Decay Heat Powers Predicted for 110 MWh/kgU Equilibrium Fuelling
Standard Model vs. ORIGEN-S Code

