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# DRAFT REGULATORY GUIDE DG-3010

(Proposed Revision 1 to Regulatory Guide 3.54)

# SPENT FUEL HEAT GENERATION IN AN INDEPENDENT SPENT FUEL STORAGE INSTALLATION



## A. INTRODUCTION

In 10 CFR Part 72, "Licensing Requirements for the Independent Storage of Spent Nuclear Fuel and High-Level Radioactive Waste," paragraph (h)(1) of Section 72.122, "Overall Requirements," requires that spent fuel cladding be protected during storage against degradation that leads to gross ruptures or the fuel must be otherwise confined such that degradation of the fuel during storage will not pose operational safety problems with respect to its removal from storage. It has been shown that, under certain environmental conditions, high storage temperatures can cause degradation and gross rupture of the fuel rods to occur very rapidly. It is necessary to know what storage temperatures are anticipated during the life of the storage installation and that these temperatures will not significantly degrade the cladding to a point that causes gross ruptures. The temperature in an independent spent fuel storage installation is a function of the heat generated by the stored fuel assemblies. The spent fuel storage system is required by 10 CFR 72.128(a)(4) to be designed with a heat removal capability consistent with its importance to safety.

This regulatory guide presents a method acceptable to the Nuclear Regulatory Commission (NRC) staff for calculating heat generation rates for use as design input for an

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This regulatory guide is being issued in draft form to involve the public in the early stages of the development of a regulatory position in this area. It has not received complete staff review and does not represent an official NRC staff position.

Public comments are being solicited on the draft guide (including any implementation schedule) and its associated regulatory analysis or value/impact statement. Comments should be accompanied by appropriate supporting data. Written comments may be submitted to the Rules and Directives Branch, Division of Administrative Services, Office of Administration, U.S. Nuclear Regulatory Commission, Washington, DC 20555-0001. Copies of comments received may be examined at the NRC Public Document Room, 2120 L Street NW., Washington, DC.

Comments will be most helpful if received by **January 2, 1998.**

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independent spent fuel storage installation. The original guide, issued in September 1984, was based on validated analyses performed for pressurized-water reactors (PWRs), and boiling-water reactors (BWRs) were considered only as a simple conservative extension of the PWR data base. In this revision, the procedure for determining heat generation rates for both PWRs and BWRs is based on analyses of each reactor type using calculational methods that have been validated against measured heat generation data from PWR and BWR assemblies. This revision presents a methodology that is simpler and is therefore expected to be more useful to applicants and reviewers.

Regulatory guides are issued to describe and make available to the public such information as methods acceptable to the NRC staff for implementing specific parts of the Commission's regulations, techniques used by the staff in evaluating specific problems or postulated accidents, and guidance to applicants. Regulatory guides are not substitutes for regulations, and compliance with regulatory guides is not required. Regulatory guides are issued in draft form for public comment to involve the public in the early stages of developing the regulatory positions. Draft regulatory guides have not received complete staff review and do not represent official NRC staff positions.

This regulatory guide contains no information collection requirements and therefore is not subject to the requirements of the Paperwork Reduction Act of 1980 (44 U.S.C. 3501 et seq.).

## B. DISCUSSION

The methodology of NUREG/CR-5625[1] is appropriate for computing the heat generation rates of fuel assemblies from light-water-cooled power reactors as a function of burnup, specific power, and decay time. The computed heat generation results are used in the next section in a procedure for determining heat generation rates for PWR and BWR assemblies.

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[1] *Technical Support for a Proposed Decay Heat Guide Using SAS2H/ORIGEN-S Data,* NUREG/CR-5625 (ORNL-6698), September 1994. Copies are available for inspection or copying for a fee from the NRC Public Document Room at 2120 L Street NW., Washington, DC; the PDR's mailing address is Mail Stop LL-6, Washington, DC 20555; telephone (202)634-3273; fax (202)634-3343. Copies may be purchased at current rates from the U.S. Government Printing Office, P.O. Box 37082, Washington, DC 20402-9328 [telephone (202)512-2249]; or from the National Technical Information Service by writing NTIS at 5285 Port Royal Road, Springfield, VA 22161.

Calculations of decay heat have been verified by comparison with the existing data base of experimentally measured decay heat rates for PWR and BWR spent fuel. The range of parameter values in the procedure is considered to lie in the mainstream of typical burnup, specific power, enrichment, and cooling time. A detailed example is shown in Appendix A.

The following terms and units have been used in this guide.

## TERMS AND UNITS USED IN GUIDE

$B_e$ - burnup in last cycle, MWd/kgU

$B_{e-1}$ - burnup in next-to-last cycle, MWd/kgU

$B_i$ - fuel burnup increase for cycle i, MWd/kgU

$B_{tot}$ - total burnup of discharged fuel, MWd/kgU

$E_s$ - initial fuel enrichment, wt-% $^{235}U$

$P$ - specific power of fuel as in Equations 2 and 3, kW/kgU

$P_{ave}$ - average cumulative specific power during 80% uptime, kW/kgU

$P_{ave,e-1}$ - average cumulative specific power (at 80%) through cycle *e-1*, the next-to-last cycle

$P_e$ - fuel-specific power during the last cycle *e*

$P_{e-1}$ - fuel-specific power during cycle *e-1*, the next-to-last cycle

$S$ - percentage safety factor applied to decay heat rates, $p_{tab}$

$T_c$ - cooling time of an assembly, in years

$T_e$ - cycle time of last cycle before discharge, in days

$T_{e-1}$ - cycle time of next-to-last cycle, in days

$T_i$ - cycle time of *i*th reactor operating cycle, including downtime for all but last cycle of assembly history, in days

$T_{res}$ - reactor residence time of assembly, from first loading to shutdown for discharge, in days

$f_7$ - last-cycle short cooling time modification factor

| | | |
|---|---|---|
| $f'_7$ | - | next-to-last cycle short cooling time factor |
| $f_e$ | - | $^{235}U$ initial enrichment modification factor |
| $f_p$ | - | excess power adjustment factor |
| $p$ | - | heat generation rate of spent fuel assembly, W/kgU |

## C. REGULATORY POSITION

The following method for determining heat generation rates of reactor spent fuel assemblies is acceptable to the NRC staff. There may be fuel assemblies with characteristics that are sufficiently outside the mainstream of typical operations that they need a separate computation of the heat generation rate. A discussion of the characteristics of assumed typical reactor operations is given in Appendix B.

The first part of this section contains the definitions and derivations, as used in this guide, of parameters needed in the determination of the heat generation rate of a fuel assembly. The second part contains the procedure used in deriving the final heat rate of an assembly. Although allowance has been made to use simple adjustment factors for cases that are somewhat atypical, many cases will probably not require any adjustment of the table heat rate other than the safety factor.

Heat generation rate tables for actinides, fission products, and light elements are given in Appendix C for informational purposes only. They are not used directly in this guide's method for determining heat rates.

### 1. DEFINITIONS AND DERIVATIONS OF PARAMETERS

The following definitions and derivations of parameters of the spent fuel assembly are used in the procedure in this guide.

#### 1.1 Heat Generation Rate (p)

The heat generation rate of the spent fuel assembly is the recoverable thermal energy (from radioactive decay) of the assembly per unit time per unit fuel mass. The units for heat generation rate used in this guide are watts per kilogram U (W/kgU), where U is the initial uranium loaded. Heat generation rate has also been referred to as decay heat rate, afterheat, or afterheat power.

### 1.2 Cycle and Cycle Times ($T_i$)

A cycle of the operating history for a fuel assembly is, with one exception, the duration between the time criticality is obtained for the initially loaded or reloaded reactor to the time at which the next reloaded core becomes critical. The exception is for the last cycle, in which the cycle ends with the last reactor shutdown before discharge of the assembly. $T_i$ denotes the elapsed time during cycle $i$ for the assembly. Specifically, the first and last cycles are denoted by $i = s$ (for start) and $i = e$ (for end), respectively. $T_{res}$, the total residence time of the assembly, is the sum of all $T_i$ for $i = s$ through $e$, inclusive. Except for the last cycle for an assembly, the cycle times include the downtimes during reload. Cycle times, in this guide, are in days.

### 1.3 Fuel Burnup of the Assembly ($B_i$ and $B_{tot}$)

The fuel burnup of cycle $i$, $B_i$, is the recoverable thermal energy per unit fuel mass during the cycle in units of megawatt days per metric ton (tonne) initial uranium (MWd/tU), or in the SI units[2] of mass used in this guide, megawatt days per kilogram U (MWd/ kgU). $B_i$ is the best maximum estimate of the fuel assembly burnup during cycle $i$. $B_{tot}$ is the total operating history burnup:

$$B_{tot} = \sum_{i=s}^{e} B_i \qquad \text{(Equation 1)}$$

### 1.4 Specific Power of the Fuel ($P_i$, $P_e$, $P_{ave}$, and $P_{ave,e-1}$)

Specific power has a unique meaning in this guide. The reason for developing this definition is to take into account the differences between the actual operating history of the assembly and that used in the computation of the tabulated heat generation rates. The calculational model applied an uptime (time at power) of 80% of the cycle time in all except the last cycle (of the discharged fuel assembly), which had no downtime. The definition of

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[2]The adopted International System of units.

specific power, used here, has two basic characteristics. First, when the actual uptime experienced by the assembly exceeds the 80% applied in the SAS2H/ORIGEN-S calculations, the heat rate derived by the guide procedure maintains equivalent accuracies within 1%. Second, when the actual uptime experienced is lower than the 80% applied in the calculations, the heat rate is reduced. The technical basis for these characteristics is presented in NUREG/CR-5625.

The specific power of cycle *i*, or *e* (last cycle), in kW/kgU, using burnup in MWd/kgU, is determined by

$$P_i = \frac{1000\,B_i}{0.8\,T_i} \text{ for } i < e$$

$$P_e = \frac{1000\,B_e}{T_e} \text{ for } i = e \qquad \text{(Equation 2)}$$

The average specific power over the entire operating history of a fuel assembly, using the same units as in Equation 2, is determined by:

$$P_{ave} = \frac{1000\ B_{tot}}{T_e + 0.8 \sum_{i=s}^{e-1} T_i} \qquad \text{(Equation 3)}$$

The average specific power through the next-to-last cycle is used in applying the adjustment factor for short cooling time (see Regulatory Position 2.2). This parameter is determined by:

$$P_{ave,e-1} = \frac{1000(B_{tot} - B_e)}{0.8(T_{res} - T_e)} \qquad \text{(Equation 4)}$$

Note that $B_{tot}$ and $P_{ave}$, as derived here, are used in determining the heat generation rate with this guide. Also, for cooling times ≤7 years, $P_e$ is used in an adjustment formula. The method applied here accommodates storage of a fuel assembly outside the reactor during one or two cycles and returning it to the reactor. Then, $B_i = 0$ may be set for all intermediate storage cycles. If the cooling time is short (i.e., <10 years), the results derived here may be excessively high for cases in which the fuel was temporarily discharged. Other evaluation methods that include the incorporation of storage cycles in the power history may be preferable.

### 1.5 Assembly Cooling Time ($T_c$)

The cooling time, $T_c$, of an assembly is the time elapsed from the last downtime of the reactor prior to its discharge (at end of $T_e$) to the time at which the heat generation rate is desired. Cooling times, in this guide, are in years.

### 1.6 Assembly Initial Fuel Enrichment ($E_s$)

The initial enrichment, $E_s$, of the fuel assembly is considered to be the average weight percent $^{235}U$ in the uranium when it is first loaded into the reactor. Heat generation rates vary with initial enrichment for fuel having the same burnup and specific power; the heat rate increases with lower enrichment. If the enrichment is different from that used in the calculations at a given burnup and specific power, a correction factor is applied.

## 2. DETERMINATION OF HEAT GENERATION RATES

Directions for determining the heat generation rates of light-water-reactor (LWR) fuel assemblies from Tables 1 through 8 are given in this section. First, a heat rate, $p_{tab}$, is found by interpolation from Tables 1 through 3 or Tables 5 through 7. Next, a safety factor and all the necessary adjustment factors are applied to determine the final heat generation rate, $p_{final}$. There are three adjustment factors (see Regulatory Positions 2.2 to 2.4) plus a safety factor (see Regulatory Position 2.5) that are applied in computing the final heat generation rate, $p_{final}$, from $p_{tab}$. In many cases, the adjustment factors are unity and thus are not needed. An alternative to these directions is the use of the light-water-reactor afterheat rate calculation (LWRARC) code on a personal computer; the code is referred to in Regulatory Position 2.7. This code evaluates $p_{tab}$ and $p_{final}$ using the data and procedures established in this guide.

Table 1
BWR Spent Fuel Heat Generation Rates, Watts Per Kilogram U, for Specific Power = 12 kW/kgU

| Cooling Time, Years | Fuel Burnup, MWd/kgU | | | | | |
|---|---|---|---|---|---|---|
| | 20 | 25 | 30 | 35 | 40 | 45 |
| 1.0 | 4.147 | 4.676 | 5.121 | 5.609 | 6.064 | 6.531 |
| 1.4 | 3.132 | 3.574 | 3.955 | 4.370 | 4.760 | 5.163 |
| 2.0 | 2.249 | 2.610 | 2.933 | 3.281 | 3.616 | 3.960 |
| 2.8 | 1.592 | 1.893 | 2.174 | 2.472 | 2.764 | 3.065 |
| 4.0 | 1.111 | 1.363 | 1.608 | 1.865 | 2.121 | 2.384 |
| 5.0 | 0.919 | 1.146 | 1.371 | 1.606 | 1.844 | 2.087 |
| 7.0 | 0.745 | 0.943 | 1.142 | 1.349 | 1.562 | 1.778 |
| 10.0 | 0.645 | 0.819 | 0.996 | 1.180 | 1.369 | 1.561 |
| 15.0 | 0.569 | 0.721 | 0.876 | 1.037 | 1.202 | 1.370 |
| 20.0 | 0.518 | 0.656 | 0.795 | 0.940 | 1.088 | 1.240 |
| 25.0 | 0.477 | 0.603 | 0.729 | 0.861 | 0.995 | 1.132 |
| 30.0 | 0.441 | 0.556 | 0.672 | 0.792 | 0.914 | 1.039 |
| 40.0 | 0.380 | 0.478 | 0.576 | 0.678 | 0.781 | 0.886 |
| 50.0 | 0.331 | 0.416 | 0.499 | 0.587 | 0.674 | 0.764 |
| 60.0 | 0.292 | 0.365 | 0.438 | 0.513 | 0.589 | 0.666 |
| 70.0 | 0.259 | 0.324 | 0.387 | 0.454 | 0.520 | 0.587 |
| 80.0 | 0.233 | 0.291 | 0.347 | 0.405 | 0.464 | 0.523 |
| 90.0 | 0.212 | 0.263 | 0.313 | 0.365 | 0.418 | 0.470 |
| 100.0 | 0.194 | 0.241 | 0.286 | 0.333 | 0.380 | 0.427 |
| 110.0 | 0.179 | 0.222 | 0.263 | 0.306 | 0.348 | 0.391 |

Table 2
BWR Spent Fuel Heat Generation Rates, Watts Per Kilogram U, for Specific Power = 20 kW/kgU

| Cooling Time, Years | Fuel Burnup, MWd/kgU | | | | | |
|---|---|---|---|---|---|---|
| | 20 | 25 | 30 | 35 | 40 | 45 |
| 1.0 | 5.548 | 6.266 | 6.841 | 7.455 | 8.000 | 8.571 |
| 1.4 | 4.097 | 4.687 | 5.173 | 5.690 | 6.159 | 6.647 |
| 2.0 | 2.853 | 3.316 | 3.718 | 4.142 | 4.540 | 4.950 |
| 2.8 | 1.929 | 2.296 | 2.631 | 2.982 | 3.324 | 3.673 |
| 4.0 | 1.262 | 1.549 | 1.827 | 2.117 | 2.410 | 2.705 |
| 5.0 | 1.001 | 1.251 | 1.501 | 1.760 | 2.024 | 2.292 |
| 7.0 | 0.776 | 0.985 | 1.199 | 1.420 | 1.650 | 1.882 |
| 10.0 | 0.658 | 0.838 | 1.023 | 1.215 | 1.413 | 1.616 |
| 15.0 | 0.576 | 0.731 | 0.890 | 1.056 | 1.227 | 1.403 |
| 20.0 | 0.523 | 0.663 | 0.805 | 0.954 | 1.107 | 1.263 |
| 25.0 | 0.480 | 0.608 | 0.737 | 0.871 | 1.009 | 1.150 |
| 30.0 | 0.444 | 0.560 | 0.678 | 0.800 | 0.925 | 1.053 |
| 40.0 | 0.382 | 0.481 | 0.579 | 0.682 | 0.786 | 0.893 |
| 50.0 | 0.332 | 0.417 | 0.501 | 0.588 | 0.677 | 0.767 |
| 60.0 | 0.292 | 0.365 | 0.438 | 0.513 | 0.589 | 0.666 |
| 70.0 | 0.259 | 0.324 | 0.386 | 0.452 | 0.518 | 0.585 |
| 80.0 | 0.233 | 0.290 | 0.345 | 0.403 | 0.460 | 0.519 |
| 90.0 | 0.211 | 0.262 | 0.311 | 0.362 | 0.413 | 0.465 |
| 100.0 | 0.193 | 0.239 | 0.283 | 0.329 | 0.375 | 0.421 |
| 110.0 | 0.178 | 0.220 | 0.260 | 0.302 | 0.343 | 0.385 |

Table 3
BWR Spent Fuel Heat Generation Rates, Watts Per Kilogram U, for Specific Power = 30 kW/kgU

| Cooling Time, Years | Fuel Burnup, MWd/kgU | | | | | |
|---|---|---|---|---|---|---|
| | 20 | 25 | 30 | 35 | 40 | 45 |
| 1.0 | 6.809 | 7.786 | 8.551 | 9.337 | 10.010 | 10.706 |
| 1.4 | 4.939 | 5.721 | 6.357 | 7.006 | 7.579 | 8.169 |
| 2.0 | 3.368 | 3.958 | 4.463 | 4.979 | 5.453 | 5.938 |
| 2.8 | 2.211 | 2.651 | 3.050 | 3.460 | 3.855 | 4.256 |
| 4.0 | 1.381 | 1.705 | 2.016 | 2.339 | 2.663 | 2.991 |
| 5.0 | 1.063 | 1.335 | 1.605 | 1.885 | 2.172 | 2.462 |
| 7.0 | 0.797 | 1.015 | 1.239 | 1.471 | 1.713 | 1.958 |
| 10.0 | 0.666 | 0.850 | 1.039 | 1.237 | 1.443 | 1.653 |
| 15.0 | 0.579 | 0.737 | 0.898 | 1.067 | 1.242 | 1.422 |
| 20.0 | 0.525 | 0.667 | 0.811 | 0.962 | 1.117 | 1.276 |
| 25.0 | 0.482 | 0.611 | 0.741 | 0.877 | 1.017 | 1.160 |
| 30.0 | 0.445 | 0.563 | 0.681 | 0.805 | 0.931 | 1.061 |
| 40.0 | 0.382 | 0.482 | 0.581 | 0.685 | 0.790 | 0.898 |
| 50.0 | 0.332 | 0.418 | 0.502 | 0.589 | 0.678 | 0.769 |
| 60.0 | 0.292 | 0.366 | 0.438 | 0.513 | 0.589 | 0.666 |
| 70.0 | 0.259 | 0.323 | 0.386 | 0.451 | 0.517 | 0.584 |
| 80.0 | 0.232 | 0.289 | 0.344 | 0.401 | 0.459 | 0.517 |
| 90.0 | 0.210 | 0.261 | 0.310 | 0.361 | 0.411 | 0.463 |
| 100.0 | 0.192 | 0.238 | 0.282 | 0.327 | 0.372 | 0.418 |
| 110.0 | 0.177 | 0.219 | 0.259 | 0.300 | 0.340 | 0.382 |

Table 4
BWR Enrichments for Burnups in Tables

| Fuel Burnup, MWd/kgU | Average Initial Enrichment, wt-% U-235 |
|---|---|
| 20 | 1.9 |
| 25 | 2.3 |
| 30 | 2.7 |
| 35 | 3.1 |
| 40 | 3.4 |
| 45 | 3.8 |

Table 5
PWR Spent Fuel Heat Generation Rates, Watts Per Kilogram U, for Specific Power = 18 kW/kgU

| Cooling Time, Years | Fuel Burnup, MWd/kgU | | | | | |
|---|---|---|---|---|---|---|
| | 25 | 30 | 35 | 40 | 45 | 50 |
| 1.0 | 5.946 | 6.574 | 7.086 | 7.662 | 8.176 | 8.773 |
| 1.4 | 4.485 | 5.009 | 5.448 | 5.938 | 6.382 | 6.894 |
| 2.0 | 3.208 | 3.632 | 4.004 | 4.411 | 4.793 | 5.223 |
| 2.8 | 2.253 | 2.601 | 2.921 | 3.263 | 3.595 | 3.962 |
| 4.0 | 1.551 | 1.835 | 2.108 | 2.398 | 2.685 | 2.997 |
| 5.0 | 1.268 | 1.520 | 1.769 | 2.030 | 2.294 | 2.576 |
| 7.0 | 1.008 | 1.223 | 1.439 | 1.666 | 1.897 | 2.143 |
| 10.0 | 0.858 | 1.044 | 1.232 | 1.430 | 1.633 | 1.847 |
| 15.0 | 0.744 | 0.905 | 1.068 | 1.239 | 1.414 | 1.599 |
| 20.0 | 0.672 | 0.816 | 0.963 | 1.116 | 1.272 | 1.437 |
| 25.0 | 0.615 | 0.746 | 0.879 | 1.018 | 1.159 | 1.308 |
| 30.0 | 0.566 | 0.686 | 0.808 | 0.934 | 1.063 | 1.197 |
| 40.0 | 0.487 | 0.588 | 0.690 | 0.797 | 0.904 | 1.017 |
| 50.0 | 0.423 | 0.510 | 0.597 | 0.688 | 0.780 | 0.875 |
| 60.0 | 0.372 | 0.447 | 0.522 | 0.601 | 0.680 | 0.762 |
| 70.0 | 0.330 | 0.396 | 0.462 | 0.530 | 0.599 | 0.670 |
| 80.0 | 0.296 | 0.355 | 0.413 | 0.473 | 0.534 | 0.596 |
| 90.0 | 0.268 | 0.321 | 0.372 | 0.426 | 0.480 | 0.536 |
| 100.0 | 0.245 | 0.293 | 0.339 | 0.387 | 0.436 | 0.486 |
| 110.0 | 0.226 | 0.270 | 0.312 | 0.356 | 0.399 | 0.445 |

Table 6
PWR Spent Fuel Heat Generation Rates, Watts Per
Kilogram U, for Specific Power = 28 kW/kgU

| Cooling Time, Years | Fuel Burnup, MWd/kgU | | | | | |
|---|---|---|---|---|---|---|
| | 25 | 30 | 35 | 40 | 45 | 50 |
| 1.0 | 7.559 | 8.390 | 9.055 | 9.776 | 10.400 | 11.120 |
| 1.4 | 5.593 | 6.273 | 6.836 | 7.441 | 7.978 | 8.593 |
| 2.0 | 3.900 | 4.432 | 4.894 | 5.385 | 5.838 | 6.346 |
| 2.8 | 2.641 | 3.054 | 3.435 | 3.835 | 4.220 | 4.642 |
| 4.0 | 1.724 | 2.043 | 2.352 | 2.675 | 2.999 | 3.346 |
| 5.0 | 1.363 | 1.637 | 1.911 | 2.195 | 2.486 | 2.793 |
| 7.0 | 1.045 | 1.271 | 1.500 | 1.740 | 1.987 | 2.248 |
| 10.0 | 0.873 | 1.064 | 1.261 | 1.465 | 1.677 | 1.900 |
| 15.0 | 0.752 | 0.915 | 1.083 | 1.257 | 1.438 | 1.627 |
| 20.0 | 0.677 | 0.823 | 0.973 | 1.128 | 1.289 | 1.457 |
| 25.0 | 0.619 | 0.751 | 0.886 | 1.027 | 1.171 | 1.322 |
| 30.0 | 0.569 | 0.690 | 0.813 | 0.941 | 1.072 | 1.208 |
| 40.0 | 0.488 | 0.590 | 0.693 | 0.800 | 0.909 | 1.023 |
| 50.0 | 0.424 | 0.511 | 0.599 | 0.689 | 0.782 | 0.877 |
| 60.0 | 0.372 | 0.447 | 0.523 | 0.601 | 0.680 | 0.762 |
| 70.0 | 0.330 | 0.396 | 0.461 | 0.529 | 0.598 | 0.668 |
| 80.0 | 0.295 | 0.354 | 0.411 | 0.471 | 0.531 | 0.593 |
| 90.0 | 0.267 | 0.319 | 0.371 | 0.424 | 0.477 | 0.531 |
| 100.0 | 0.244 | 0.291 | 0.337 | 0.385 | 0.432 | 0.481 |
| 110.0 | 0.225 | 0.268 | 0.310 | 0.352 | 0.396 | 0.440 |

Table 7
PWR Spent Fuel Heat Generation Rates, Watts Per Kilogram U, for Specific Power = 40 kW/kgU

| Cooling Time, Years | Fuel Burnup, MWd/kgU | | | | | |
|---|---|---|---|---|---|---|
| | 25 | 30 | 35 | 40 | 45 | 50 |
| 1.0 | 8.946 | 10.050 | 10.900 | 11.820 | 12.580 | 13.466 |
| 1.4 | 6.514 | 7.400 | 8.111 | 8.863 | 9.514 | 10.254 |
| 2.0 | 4.462 | 5.129 | 5.692 | 6.284 | 6.821 | 7.418 |
| 2.8 | 2.947 | 3.441 | 3.884 | 4.346 | 4.787 | 5.267 |
| 4.0 | 1.853 | 2.212 | 2.554 | 2.910 | 3.265 | 3.647 |
| 5.0 | 1.429 | 1.728 | 2.021 | 2.327 | 2.639 | 2.970 |
| 7.0 | 1.067 | 1.304 | 1.543 | 1.793 | 2.052 | 2.325 |
| 10.0 | 0.881 | 1.078 | 1.278 | 1.488 | 1.705 | 1.936 |
| 15.0 | 0.754 | 0.921 | 1.091 | 1.268 | 1.452 | 1.645 |
| 20.0 | 0.678 | 0.827 | 0.978 | 1.136 | 1.298 | 1.469 |
| 25.0 | 0.619 | 0.754 | 0.890 | 1.032 | 1.178 | 1.331 |
| 30.0 | 0.570 | 0.693 | 0.816 | 0.945 | 1.077 | 1.215 |
| 40.0 | 0.488 | 0.592 | 0.695 | 0.803 | 0.912 | 1.026 |
| 50.0 | 0.423 | 0.512 | 0.599 | 0.691 | 0.783 | 0.879 |
| 60.0 | 0.371 | 0.448 | 0.522 | 0.601 | 0.680 | 0.762 |
| 70.0 | 0.329 | 0.396 | 0.461 | 0.529 | 0.597 | 0.668 |
| 80.0 | 0.294 | 0.353 | 0.410 | 0.470 | 0.530 | 0.592 |
| 90.0 | 0.266 | 0.319 | 0.369 | 0.422 | 0.475 | 0.530 |
| 100.0 | 0.243 | 0.290 | 0.336 | 0.383 | 0.430 | 0.479 |
| 110.0 | 0.224 | 0.267 | 0.308 | 0.351 | 0.393 | 0.437 |

Table 8
PWR Enrichments for Burnups in Tables

| Fuel Burnup, MWd/kgU | Average Initial Enrichment, wt-% U-235 |
|---|---|
| 25 | 2.4 |
| 30 | 2.8 |
| 35 | 3.2 |
| 40 | 3.6 |
| 45 | 3.9 |
| 50 | 4.2 |

## 2.1 Computing Heat Rate Provided by Tables

Tables 1 through 3 are for BWR fuel, and Tables 5 through 7 are for PWR fuel. The heat rates in each table pertain to a single average specific power and are listed as a function of total burnup and cooling time. After determining $P_{ave}$, $B_{tot}$, and $T_c$ as above, select the next lower (L-index) and next higher (H-index) heat rate values from the tables so that:

$$P_L \le P_{ave} \le P_H$$

$$B_L \le B_{tot} \le B_H$$

and

$$T_L \le T_c \le T_H$$

Compute $p_{tab}$, the heat generation rate, at $P_{ave}$, $B_{tot}$, and $T_c$, by proper interpolation between the tabulated values of heat rates at the lower and higher parameter limits. A linear interpolation should be used between heat rates for either burnup or specific power interpolations. In computing the heat rate at $T_c$, the interpolation should be logarithmic in heat rate and linear in cooling time. Specifically, the interpolation formulas for interpolating in specific power, burnup, and cooling time are, respectively,

$$p = p_L + \frac{p_H - p_L}{P_H - P_L}(P_{ave} - P_L) \qquad \text{(Equation 5)}$$

$$p = p_L + \frac{p_H - p_L}{B_H - B_L}(B_{tot} - B_L) \quad \text{(Equation 6)}$$

$$p = p_L \exp\left[\frac{\ln(p_H/p_L)}{T_H - T_L}(T_c - T_L)\right]^* \quad \text{(Equation 7)}$$

where $p_L$ and $p_H$ represent the tabulated or interpolated heat rates at the appropriate parameter limits corresponding to the L and H index. If applied in the sequence given above, Equation 5 would need to be used four times to obtain $p$ values that correspond to $B_L$ and $B_H$ at values of $T_L$ and $T_H$. A mini-table of four $p$ values at $P_{ave}$ is now available to interpolate burnup and cooling time. Equation 6 would then be applied to obtain two values of $p$ at $T_L$ and $T_H$. One final interpolation of these two $p$ values (at $P_{ave}$ and $B_{tot}$) using Equation 7 is needed to calculate the final $p_{tab}$ value corresponding to $P_{ave}$, $B_{tot}$, and $T_c$. The optional Lagrangian interpolation scheme offered by the LWRARC code is also considered an acceptable method for interpolating the decay heat data.

If $P_{ave}$ or $B_{tot}$ falls below the minimum table value range, the minimum table-specific power or burnup, respectively, may be used conservatively. If $P_{ave}$ exceeds the maximum table value, the table with the maximum specific power (Table 3 for BWR fuel and Table 7 for PWR fuel) may be used in addition to the adjustment factor, $f_p$, described in Regulatory Position 2.3.

The tables should not be applied if $B_{tot}$ exceeds the maximum burnup in the tables, or if $T_c$ is less than the minimum (1 year). If $T_c$ exceeds the maximum (110 years) cooling time of the tables, the 110-year value is acceptable, although it may be too conservative.

*The user may apply either common logarithms or natural logarithms and consistent antilogarithms.

## 2.2 Short Cooling Time Factors $f_7$ and $f'_7$

The heat rates presented in Tables 1 through 3 and Tables 5 through 7 were computed from operating histories in which a constant specific power and an uptime of 80% of the cycle time were applied. Expected variations from these assumptions cause only minor changes (<1%) in decay heat rates beyond approximately 7 years of cooling. However, if the specific power near the end of the operating history is significantly different from the average specific power, $P_{ave}$, $p_{tab}$ needs to be adjusted if $T_c \leq 7$. The ratios $P_e/P_{ave}$ and $P_{e-1}/P_{ave,e-1}$ are, respectively, used to determine the adjustment factors $f_7$ and $f'_7$. The factors reduce the heat rate $p_{tab}$ if the corresponding ratio is less than 1 and increase the heat rate $p_{tab}$ if the corresponding ratio is greater than 1. The formulas for the factors are below.

$$\begin{aligned}
f_7 &= 1 && \text{when } T_c > 7 \text{ years or } e = s \text{ (i.e., 1 cycle only)} \\
f_7 &= 1 + 0.35R/\sqrt{T_c} && \text{when } 0 \leq R \leq 0.3 \\
f_7 &= 1 + 0.25R/T_c && \text{when } -0.3 \leq R < 0 \\
f_7 &= 1 - 0.075/T_c && \text{when } R < -0.3
\end{aligned} \qquad \text{(Equation 8)}$$

where

$$R = \frac{P_e}{P_{ave}} - 1 \qquad \text{(Equation 9)}$$

$$\begin{aligned}
f_7' &= 1 && \text{when } T_c > 7 \text{ years or } e < 3 \\
f_7' &= 1 + 0.10R'/\sqrt{T_c} && \text{when } 0 \leq R' \leq 0.6 \\
f_7' &= 1 + 0.08R'/T_c && \text{when } -0.5 \leq R' < 0 \\
f_7' &= 1 - 0.04/T_c && \text{when } R' < -0.5
\end{aligned} \qquad \text{(Equation 10)}$$

where

$$R' = \frac{P_{e-1}}{P_{ave,e-1}} - 1 \qquad \text{(Equation 11)}$$

It can be observed that there are upper limits to $R$ and $R'$ in Equations 8 and 10. It is recommended **not** to use the decay heat values of this guide if any of the following conditions occur:

if $T_c \leq$ 10 years and $P_e/P_{ave} > 1.3$,

if 10 years $< T_c \leq$ 15 years and $P_e/P_{ave} > 1.7$, if $T_c \leq 10$ years and $P_{e-1}/P_{ave,e-1} > 1.6$.

Although it is safe to use the procedures in this guide, the heat rate values for $p_{final}$ may be excessively high when

$$T_c \leq 7 \text{ years and } P_e/P_{ave} < 0.6,$$
$$T_c \leq 7 \text{ years and } P_{e-1}/P_{ave,e-1} < 0.4.$$

## 2.3 The Excess Power Adjustment Factor $f_p$

The maximum specific power, $P_{max}$, used to generate the data in Tables 1 through 3 and Tables 5 through 7 is 40 kW/kgU for a PWR and 30 kW/kgU for a BWR. If $P_{ave}$, the average cumulative specific power, is more than 35% higher than $P_{max}$ (i.e., 54 kW/kgU for PWR fuel and 40.5 kW/kgU for BWR fuel), the guide should not be used. When $1 < P_{ave}/P_{max} \leq 1.35$, the guide can still be used, but an excess power adjustment factor, $f_p$, must be applied. The excess power adjustment factor is

$$f_p = \sqrt{P_{ave}/P_{\max}} \qquad \text{(Equation 12)}$$

For $P_{ave} \leq P_{max}$, $\qquad f_p = 1$

## 2.4 The Enrichment Factor $f_e$

The decay heat rates of Tables 1 through 3 and Tables 5 through 7 were calculated using initial enrichments of Tables 4 and 8. The enrichment factor $f_e$ is used to adjust the value $p_{tab}$ for the actual initial enrichment of the assembly $E_s$. To calculate $f_e$, the data in Tables 4 (BWR) or 8 (PWR) should be interpolated linearly to obtain the enrichment value $E_{tab}$ that corresponds to the assembly burnup, $B_{tot}$. If $E_s/E_{tab} < 0.6$, the NRC staff recommends **not** using this guide. When $E_s/E_{tab} \geq 0.6$, set the enrichment factor as follows:

$$f_e = 1 + 0.01[a + b(T_c - d)][1 - E_s/E_{tab}]$$

$$\text{when } E_s/E_{tab} \leq 1.5, \qquad \text{(Equation 13)}$$

$$f_e = 1 - 0.005\,[a + b(T_c - d)]$$

when $E_s/E_{tab} > 1.5$,

where the parameters *a, b,* and *d* vary with reactor type, $E_s$, $E_{tab}$, and $T_c$. These variables are defined in Tables 9 and 10.

**Table 9**
**Enrichment Factor Parameter Values for BWR Assemblies**

| Parameter in Equation 13 | Parameter Value | | | |
|---|---|---|---|---|
| | $E_s/E_{tab} < 1$ | | $E_s/E_{tab} > 1$ | |
| | $1 \le T_c \le 40$ | $T_c > 40$ | $1 \le T_c \le 15$ | $T_c > 15$ |
| *a* | 5.7 | 5.7 | 0.6 | 0.6 |
| *b* | −0.525 | 0.184 | −0.72 | 0.06 |
| *d* | 40 | 40 | 15 | 15 |

**Table 10**
**Enrichment Factor Parameter Values for PWR Assemblies**

| Parameter in Equation 13 | Parameter value | | | |
|---|---|---|---|---|
| | $E_s/E_{tab} < 1$ | | $E_s/E_{tab} > 1$ | |
| | $1 \le T_c \le 40$ | $T_c > 40$ | $1 \le T_c \le 20$ | $T_c > 20$ |
| *a* | 4.8 | 4.8 | 1.8 | 1.8 |
| *b* | −0.6 | 0.133 | −0.51 | 0.033 |
| *d* | 40 | 40 | 20 | 20 |

## 2.5 Safety Factor *S*

Before obtaining the final heat rate $p_{final}$, an appropriate estimate of a percentage safety factor *S* should be determined. Evaluations of uncertainties performed as part of this project indicate that the safety factor should vary with burnup and cooling time.

For BWR assemblies:

$$S = 6.4 + 0.15\,(B_{tot} - 20) + 0.044\,(T_c - 1) \qquad \text{(Equation 14)}$$

For PWR assemblies:

$$S = 6.2 + 0.06\,(B_{tot} - 25) + 0.050\,(T_c - 1) \qquad \text{(Equation 15)}$$

The purpose of deriving spent fuel heat generation rates is usually to apply the heat rates in the computation of the temperatures for storage systems. A preferred engineering practice may be to calculate the temperatures prior to application of a final safety factor. This practice is acceptable if $S$ is accounted for in the more comprehensive safety factors applied to the calculated temperatures.

## 2.6 Final Heat Generation Rate Evaluation

The equation for converting $p_{tab}$, determined in Regulatory Position 2.1, to the final heat generation rate of the assembly, is

$$p_{final} = (1 + 0.01S)\, f_7\, f'_7\, f_p\, f_e\, p_{tab} \qquad \text{(Equation 16)}$$

where $f_7$, $f'_7$, $f_p$, $f_e$, and $S$ are determined by the procedures given in Regulatory Positions 2.2 through 2.5.

## 2.7 Heat Rate Evaluation by LWRARC Code

The LWRARC (light-water-reactor afterheat rate calculation) code is an MS-DOS PC program that performs the calculations in this guide. The only input for cases in which the cooling time exceeds 15 years are $B_{tot}$, $T_{res}$, $E_s$, and $T_c$. Additionally, the short cooling time factors require $B_i$ and $T_i$ of the last and next-to-last cycles. The code features a pull-down menu system with data entry screens containing context-sensitive help messages and verification dialog boxes. The menus may be used with either a keyboard or a mouse. The code printout (one page per case) contains the input data, the computed safety and adjustment factors, and the interpolated and final computed decay heat rates. The output file may be printed, observed on a monitor, or saved. Input cases may be saved, retrieved, duplicated, or stacked in the input file.

The LWRARC code may be requested from either the Radiation Shielding Information Center (RSIC) or the Energy Science and Technology Software Center (ESTSC):

Radiation Shielding Information
Center
Oak Ridge National Laboratory
P.O. Box 2008
Oak Ridge, TN 37831-6362
Telephone: (615)574-6176
FAX: (615)574-6182

Energy Science and Technology Software
Center
Oak Ridge National Laboratory
P.O. Box 1020
Oak Ridge, TN 37831-1020
Telephone: (615)576-2606
FAX: (615)576-2865

# APPENDIX A

## SAMPLE CASE USING HEAT GENERATION RATE TABLES

A BWR fuel assembly with an average fuel enrichment of 2.6 wt-% $^{235}U$ was in the reactor for four cycles. Determine its final heat generation rate with safety factors, using the method in this guide, at 4.2 years cooling time. Adequate details of the operating history associated with the fuel assembly are shown in Table A.1.

**Table A.1**
**Sample Case Operating History**

| Relative Fuel Cycle | Time from Startup of Fuel, Days | | Accumulated Burnup (Best Maximum Estimate), MWd/kgU |
|---|---|---|---|
| | Cycle Startup | Cycle Shutdown | |
| 1 | 0 | 300 | 8.1 |
| 2 | 340 | 590 | 14.7 |
| 3 | 630 | 910 | 20.9 |
| 4 | 940 | 1240 | 26.3 |

Note that the output of the LWRARC code for this case is shown in the first case of Appendix B of NUREG/CR-5625.[1]

[1]*Technical Support for a Proposed Decay Heat Guide Using SAS2H/ORIGEN-S Data*, NUREG/CR-5625 (ORNL-6698), September 1994. Copies are available for inspection or copying for a fee from the NRC Public Document Room at 2120 L Street NW., Washington, DC; the PDR's mailing address is Mail Stop LL-6, Washington, DC 20555; telephone (202)634-3273; fax (202)634-3343. Copies may be purchased at current rates from the U.S. Government Printing Office, P.O. Box 37082, Washington, DC 20402-9328 [telephone (202)512-2249]; or from the National Technical Information Service by writing NTIS at 5285 Port Royal Road, Springfield, VA 22161.

Using Regulatory Position 1:

The following were given in the sample case (see Regulatory Position 1 for definitions):

$T_{res}$ = 1240 d

$B_{tot}$ = 26.30 MWd/kgU

$T_c$ = 4.2 y

$E_s$ = 2.6 wt-% $^{235}U$

Compute $T_e$, $B_e$, $P_e$, $T_{e-1}$, $P_{e-1}$, $P_{ave,e-1}$, and $P_{ave}$ from Regulatory Position 1 and Equations 2 through 4.

$T_e$ = 1240 − 940 = 300 d

$B_e$ = 26,300 − 20,900 = 5,400 kWd/kgU

$P_e$ = (26,300 − 20,900)/300 = 18.00 kW/kgU

$T_{e-1}$ = 940 − 630 = 310 d

$B_{e-1}$ = 20,900 − 14,700 = 6,200 kWd/kgU

$P_{e-1}$ = 6,200/[0.8(310)] = 25.0 kW/kgU

$P_{ave,e-1}$ = 20,900/[0.8(940)] = 27.793 kW/kgU

$P_{ave}$ = 26,300/[300 + 0.8 (940)] = 25.00 kW/kgU

## Using Regulatory Position 2

$P_{tab}$ should be determined from $P_{ave}$, $B_{tot}$, and $T_c$, as described in Regulatory Position 2.1. First, select the nearest heat rate values in Tables 2 and 3 for the following limits:

$$P_L = 20 \le P_{ave} \le P_H = 30$$
$$B_L = 25 \le B_{tot} \le B_H = 30$$
$$T_L = 4 \le T_c \le T_H = 5$$

Next, use the prescribed interpolation procedure for computing $p_{tab}$ from the tabular data. Although the order is optional, the example here interpolates between specific powers, burnups, and then cooling times. Denote the heat rate, $p$, as a function of specific power, burnup, and cooling time by $p(P,B,T)$. The table values at $P_L$ and $P_H$ for $B_L$ and $T_L$ are

$$p(P_L, B_L, T_L) = p(20,25,4) = 1.549$$

$$p(P_H, B_L, T_L) = p(30,25,4) = 1.705$$

First, interpolate the above heat rates to $P_{ave}$ using

$$p(P_{ave},25,4) = p(20,25,4) + F_p\,[p(30,25,4) - p(20,25,4)]$$

where

$$F_p = (P_{ave} - P_L)/(P_H - P_L) = 0.5$$

The result at $p(P_{ave},25,4)$ is

$$p(P_{ave},25,4) = 1.549 + 0.5\,(1.705 - 1.549) = 1.627$$

The other three values at $P_{ave}$ are computed with a similar method:

$$p(P_{ave},30,4) = 1.827 + 0.5\,(2.016 - 1.827) = 1.9215$$

$$p(P_{ave},25,5) = 1.293$$

$$p(P_{ave},30,5) = 1.553$$

These are heat rates at the burnup and time limits.

Second, interpolate each of the above pairs of heat rates to $B_{tot}$ from the values at $B_L$ and $B_H$:

$$F_B = (B_{tot} - B_L)/(B_H - B_L) = 0.26$$

$$p(P_{ave}, B_{tot}, 4) = 1.627 + 0.26\ (1.9215 - 1.627) = 1.7036$$

$$p(P_{ave}, B_{tot}, 5) = 1.3606$$

Third, compute the heat rate at $T_c$ from the above values at $T_L$ and $T_H$ by an interpolation that is logarithmic in heat rate and linear in time:

$$F_T = (T_c - T_L)/(T_H - T_L) = 0.2$$

$$log[p(P_{ave}, B_{tot}, T_c)] = log\ 1.7036 + 0.2\ (log\ 1.3606 - log\ 1.7036) = 0.2118$$

$$p_{tab} = p(P_{ave}, B_{tot}, T_c) = 10^{0.2118} = 1.629 \text{ W/kgU}$$

With the value for $p_{tab}$, the formulas of Regulatory Positions 2.2 through 2.6 can be used to determine $p_{final}$. Since $T_c < 7$ y, use Equations 8 through 11 to calculate the short cooling time factors:

$$R = P_e/P_{ave} - 1 = (18/25) - 1 = -0.28$$

$$f_7 = 1 + [0.25(-0.28)]/4.2 = 0.983$$

$$R' = P_{e-1}/P_{ave,e-1} - 1 = -0.1005$$

$$f'_7 = 1 + [0.08(-0.1005)]/4.2 = 0.998$$

Since $P_{ave} < P_H = P_{max}$, the excess power factor, $f_p$, is unity. Interpolating Table 4 enrichments to obtain the enrichment associated with the burnup yields

$$E_{tab} = 2.3 + (2.7 - 2.3)(26.3 - 25)/(30 - 25) = 2.404$$

The enrichment factor, $f_e$, is then calculated using Equation 13:

$$f_e = 1 + 0.01\ (8.376)(1 - 2.6/2.404) = 0.993$$

because $E_s > E_{tab}$

The safety factor, $S$, for a BWR is given in Equation 14:

$$S = 6.4 + 0.15\,(26.3 - 20) + 0.044\,(4.2 - 1)$$
$$= 7.49\%$$

Then, using Equation 16,

$$p_{final} = (1 + 0.01\,S)\, f_7 f'_7 f_p f_e p_{tab}$$

with the above adjustment factors and $p_{tab}$ yields

$$p_{final} = 1.0749 \times 0.983 \times 0.998 \times 1 \times 0.993 \times 1.629$$

$$= 1.0749 \times 1.587 = 1.706 \text{ W/kgU}$$

Thus, the final heat generation rate, including the safety factor, of the given fuel assembly is 1.706 W/kgU.

# APPENDIX B

## ACCEPTABILITY AND LIMITS OF THE GUIDE

Inherent difficulties arise in attempting to prepare a heat rate guide that has appropriate safety factors, is not excessively conservative, is easy to use, and applies to all commercial reactor spent fuel assemblies. In the endeavor to increase the value of the guide to licensees, the NRC staff made an effort to ensure that safe but not overly conservative heat rates were computed. The procedures and data recommended in the guide should be appropriate for most power reactor operations with only minor limitations in applicability.

In general, the guide should not be applied outside the parameters of Tables 1 through 8. These restrictions, in addition to certain limits on adjustment factors, are given in the text. The major table limits are summarized in Table B.1.

**Table B.1**
**Parameter Range for Applicability of the Regulatory Guide**

| Parameter | BWR | PWR |
|---|---|---|
| $T_c$(year) | 1–110 | 1–110 |
| $B_{tot}$ (MWd/kgU) | 20–45 | 25–50 |
| $P_{ave}$ (kW/kgU) | 12–30 | 18–40 |

In using the guide, the lower limit on cooling time, $T_c$, and the upper limit on burnup, $B_{tot}$, should never be extended. An adjustment factor, $f_p$, can be applied if the specific power, $P_{ave}$, does not exceed the maximum value of the tables by more than 35%. Thus, if $P_{ave}$ is greater than 54 kW/gU for PWR fuel or 40.5 kW/kgU for BWR fuel, the guide should not be applied. The minimum table value of specific power or burnup can be used for values below the table range; however, if the real value is considerably less than the table minimum, the heat rate derived can be excessively conservative. Also, the upper cooling time limit is conservative for longer cooling times.

In preparing generic depletion/decay analyses for specific applications, the most difficult condition to model is the power operating history of the assembly.

Although a power history variation (other than the most extreme) does not significantly change the decay heat rate after a cooling time of approximately 7 years, it can have significant influence on the results in the first few years. Cooling time adjustment factors, $f_7$ and $f'_7$, are applied to correct for variations in power history that differ from those used in the generation of the tables. For example, the heat rate at 1 year is increased substantially if the power in the last cycle is twice the average power of the assembly. The limits on the conditions in Regulatory Position 2.2 on ratios of cycle to average specific power are needed; first, to derive cooling time adjustment factors that are valid, and second, to exclude cases that are extremely atypical. Although these limits were determined so that the factors are safe, a reasonable degree of discretion should be used in the considerations of atypical assemblies— particularly with regard to their power histories.

Another variable that requires attention is the $^{59}$Co content of the clad and structural materials. Cobalt-59 is partly transformed to $^{60}$Co in the reactor and subsequently contributes to the decay heat rate. The $^{59}$Co content used in deriving the tables here should apply only to assemblies containing Zircaloy-clad fuel pins. The $^{60}$Co contribution can become excessive for $^{59}$Co contents found in stainless-steel-clad fuel pins. Thus, the use of the guide for stainless-steel-clad assemblies should be limited to cooling times that exceed 20 years. Because $^{60}$Co has a 5.27-year half-life, the heat rate contribution from $^{60}$Co is reduced by the factor of 13.9 in 20 years.

In addition to the parameters used here, decay heat rates are a function of other variables to a lesser degree. Variations in moderator density (coolant pressure, temperature) can change decay heat rates, although calculations indicated that the expected differences (approximately 0.2% heat rate change per 1% change in water density, during any of the first 30-year decay times) are not sufficient to require additional corrections. The PWR decay heat rates in the tables were calculated for fuel assemblies containing water holes. Computed decay heat rates for assemblies containing burnable poison rods (BPRs) did not change significantly (<1% during the first 30-year decay) from fuel assemblies containing water holes.

Several conditions were considered in deriving the safety factors (Equations 14 and 15) that were developed for use in the guide. Partial uncertainties in the heat generation rates were computed for selected cases by applying the known standard deviations of half-lives, Q-values, and fission yields of all the fission product nuclides that make a significant contribution to decay heat rates. This calculation did not account for uncertainties in contributions produced by the neutron absorption in nuclides in the reactor flux, or from variations in other parameters. In addition to the standard deviations in neutron cross sections, much of the uncertainty from neutron absorption arose from approximations in the model used in the depletion analysis. In developing the safety factors, these more indirect uncertainties were determined from comparisons of the calculated total or individual nuclide decay heat rates with those determined by independent computational methods, as well as comparisons of heat rate measurements obtained for a variety of reactor spent fuel assemblies. Note from the equations that the safety factors increase with both burnup and cooling time. This increase in the safety factor is a result of the increased importance of the actinides to the decay heat with increased burnup and cooling time together with the larger uncertainty in actinide predictions caused by model approximations and limited experimental data.

Whenever there is a unique difference in either the design or operating conditions of a spent fuel assembly that is more extreme than that accepted here, another well-qualified method of analysis that accounts for the difference should be used.

## CONTRIBUTIONS TO DECAY HEAT RATES BY ACTINIDES, FISSION PRODUCTS, AND LIGHT ELEMENTS

The decay heat rates determined by the methods recommended in this guide are totals resulting from all sources of radioactive decay. In the tables of this Appendix C, the contributions to these totals from actinides, fission products, and light elements are listed separately. These values were used to construct the totals given in Tables 1-7. The values in this Appendix C represent some of the many results available from the codes described in NUREG/CR-5625.

Table C.1 BWR decay heat rates (W/kgU) of light elements, actinides, and fission products, for specific power = 12 kW/kgU, Set 1

| Burnup = 20 MWd/kgU | | | Cooling Time, years | Burnup = 25 MWd/kgU | | |
|---|---|---|---|---|---|---|
| Light El | Actinides | Fis Prod | | Light El | Actinides | Fis Prod |
| 4.747E-02 | 3.[illegible]74E-01 | 3.762E+00 | 1.0 | 4.993E-02 | 4.850E-01 | 4.141E+00 |
| 3.410E-02 | 2.293E-01 | 2.869E+00 | 1.4 | 3.642E-02 | 3.323E-01 | 3.205E+00 |
| 2.841E-02 | 1.542E-01 | 2.066E+00 | 2.0 | 3.054E-02 | 2.257E-01 | 2.354E+00 |
| 2.480E-02 | 1.210E-01 | 1.446E+00 | 2.8 | 2.670E-02 | 1.779E-01 | 1.688E+00 |
| 2.077E-02 | 1.123E-01 | 9.784E-01 | 4.0 | 2.239E-02 | 1.641E-01 | 1.177E+00 |
| 1.804E-02 | 1.132E-01 | 7.879E-01 | 5.0 | 1.946E-02 | 1.642E-01 | 9.626E-01 |
| 1.370E-02 | 1.178E-01 | 6.135E-01 | 7.0 | 1.480E-02 | 1.683E-01 | 7.595E-01 |
| 9.134E-03 | 1.243E-01 | 5.118E-01 | 10.0 | 9.896E-03 | 1.744E-01 | 6.349E-01 |
| 4.701E-03 | 1.328E-01 | 4.312E-01 | 15.0 | 5.121E-03 | 1.820E-01 | 5.340E-01 |
| 2.443E-03 | 1.390E-01 | 3.768E-01 | 20.0 | 2.680E-03 | 1.873E-01 | 4.660E-01 |
| 1.280E-03 | 1.433E-01 | 3.321E-01 | 25.0 | 1.417E-03 | 1.906E-01 | 4.105E-01 |
| 6.770E-04 | 1.463E-01 | 2.938E-01 | 30.0 | 7.571E-04 | 1.925E-01 | 3.629E-01 |
| 1.971E-04 | 1.491E-01 | 2.308E-01 | 40.0 | 2.266E-04 | 1.933E-01 | 2.849E-01 |
| 6.381E-05 | 1.493E-01 | 1.819E-01 | 50.0 | 7.571E-05 | 1.914E-01 | 2.245E-01 |
| 2.566E-05 | 1.480E-01 | 1.437E-01 | 60.0 | 3.099E-05 | 1.882E-01 | 1.772E-01 |
| 1.409E-05 | 1.459E-01 | 1.136E-01 | 70.0 | 1.681E-05 | 1.843E-01 | 1.401E-01 |
| 1.014E-05 | 1.432E-01 | 8.983E-02 | 80.0 | 1.176E-05 | 1.800E-01 | 1.108E-01 |
| 8.483E-06 | 1.404E-01 | 7.108E-02 | 90.0 | 9.603E-06 | 1.756E-01 | 8.767E-02 |
| 7.573E-06 | 1.375E-01 | 5.626E-02 | 100.0 | 8.447E-06 | 1.713E-01 | 6.939E-02 |
| 6.926E-06 | 1.345E-01 | 4.453E-02 | 110.0 | 7.666E-06 | 1.671E-01 | 5.493E-02 |

Table C.2 BWR decay heat rates (W/kgU) of light elements, actinides, and fission products, for specific power = 12 kW/kgU, Set 2

| Burnup = 30 MWd/kgU | | | Cooling Time, years | Burnup = 35 MWd/kgU | | |
|---|---|---|---|---|---|---|
| Light El | Actinides | Fis Prod | | Light El | Actinides | Fis Prod |
| 5.162E-02 | 6.440E-01 | 4.425E+00 | 1.0 | 5.315E-02 | 8.103E-01 | 4.746E+00 |
| 3.790E-02 | 4.462E-01 | 3.471E+00 | 1.4 | 3.918E-02 | 5.694E-01 | 3.761E+00 |
| 3.187E-02 | 3.076E-01 | 2.594E+00 | 2.0 | 3.299E-02 | 4.003E-01 | 2.848E+00 |
| 2.790E-02 | 2.448E-01 | 1.901E+00 | 2.8 | 2.889E-02 | 3.229E-01 | 2.120E+00 |
| 2.343E-02 | 2.253E-01 | 1.359E+00 | 4.0 | 2.428E-02 | 2.976E-01 | 1.543E+00 |
| 2.037E-02 | 2.241E-01 | 1.127E+00 | 5.0 | 2.112E-02 | 2.950E-01 | 1.290E+00 |
| 1.551E-02 | 2.270E-01 | 8.994E-01 | 7.0 | 1.610E-02 | 2.962E-01 | 1.037E+00 |
| 1.039E-02 | 2.316E-01 | 7.538E-01 | 10.0 | 1.080E-02 | 2.985E-01 | 8.704E-01 |
| 5.400E-03 | 2.369E-01 | 6.334E-01 | 15.0 | 5.625E-03 | 3.005E-01 | 7.306E-01 |
| 2.841E-03 | 2.399E-01 | 5.523E-01 | 20.0 | 2.969E-03 | 3.004E-01 | 6.367E-01 |
| 1.511E-03 | 2.412E-01 | 4.863E-01 | 25.0 | 1.586E-03 | 2.989E-01 | 5.603E-01 |
| 8.140E-04 | 2.412E-01 | 4.297E-01 | 30.0 | 8.587E-04 | 2.964E-01 | 4.949E-01 |
| 2.484E-04 | 2.385E-01 | 3.372E-01 | 40.0 | 2.654E-04 | 2.893E-01 | 3.882E-01 |
| 8.490E-05 | 2.338E-01 | 2.656E-01 | 50.0 | 9.202E-05 | 2.808E-01 | 3.057E-01 |
| 3.528E-05 | 2.280E-01 | 2.096E-01 | 60.0 | 3.864E-05 | 2.719E-01 | 2.412E-01 |
| 1.908E-05 | 2.218E-01 | 1.657E-01 | 70.0 | 2.091E-05 | 2.630E-01 | 1.906E-01 |
| 1.316E-05 | 2.156E-01 | 1.310E-01 | 80.0 | 1.432E-05 | 2.543E-01 | 1.508E-01 |
| 1.061E-05 | 2.094E-01 | 1.037E-01 | 90.0 | 1.145E-05 | 2.460E-01 | 1.193E-01 |
| 9.240E-06 | 2.035E-01 | 8.206E-02 | 100.0 | 9.930E-06 | 2.382E-01 | 9.441E-02 |
| 8.344E-06 | 1.978E-01 | 6.495E-02 | 110.0 | 8.941E-06 | 2.309E-01 | 7.473E-02 |

Table C.3 BWR decay heat rates (W/kgU) of light elements, actinides, and fission products, for specific power = 12 kW/kgU, Set 3

| Burnup = 40 MWd/kgU | | | Cooling Time, years | Burnup = 45 MWd/kgU | | |
|---|---|---|---|---|---|---|
| Light El | Actinides | Fis Prod | | Light El | Actinides | Fis Prod |
| 5.467E-02 | 1.008E+00 | 5.001E+00 | 1.0 | 5.559E-02 | 1.186E+00 | 5.289E+00 |
| 4.027E-02 | 7.180E-01 | 4.002E+00 | 1.4 | 4.089E-02 | 8.574E-01 | 4.265E+00 |
| 3.390E-02 | 5.141E-01 | 3.068E+00 | 2.0 | 3.439E-02 | 6.255E-01 | 3.300E+00 |
| 2.970E-02 | 4.198E-01 | 2.315E+00 | 2.8 | 3.013E-02 | 5.175E-01 | 2.517E+00 |
| 2.497E-02 | 3.875E-01 | 1.709E+00 | 4.0 | 2.533E-02 | 4.791E-01 | 1.880E+00 |
| 2.173E-02 | 3.827E-01 | 1.440E+00 | 5.0 | 2.205E-02 | 4.723E-01 | 1.593E+00 |
| 1.657E-02 | 3.810E-01 | 1.164E+00 | 7.0 | 1.681E-02 | 4.678E-01 | 1.293E+00 |
| 1.112E-02 | 3.797E-01 | 9.777E-01 | 10.0 | 1.129E-02 | 4.626E-01 | 1.087E+00 |
| 5.800E-03 | 3.760E-01 | 8.199E-01 | 15.0 | 5.892E-03 | 4.533E-01 | 9.110E-01 |
| 3.066E-03 | 3.711E-01 | 7.139E-01 | 20.0 | 3.118E-03 | 4.434E-01 | 7.930E-01 |
| 1.641E-03 | 3.653E-01 | 6.280E-01 | 25.0 | 1.671E-03 | 4.332E-01 | 6.973E-01 |
| 8.905E-04 | 3.590E-01 | 5.545E-01 | 30.0 | 9.086E-04 | 4.229E-01 | 6.155E-01 |
| 2.771E-04 | 3.456E-01 | 4.347E-01 | 40.0 | 2.841E-04 | 4.029E-01 | 4.824E-01 |
| 9.697E-05 | 3.320E-01 | 3.422E-01 | 50.0 | 1.001E-04 | 3.840E-01 | 3.797E-01 |
| 4.118E-05 | 3.188E-01 | 2.701E-01 | 60.0 | 4.286E-05 | 3.666E-01 | 2.996E-01 |
| 2.250E-05 | 3.064E-01 | 2.134E-01 | 70.0 | 2.357E-05 | 3.505E-01 | 2.367E-01 |
| 1.550E-05 | 2.948E-01 | 1.688E-01 | 80.0 | 1.629E-05 | 3.358E-01 | 1.872E-01 |
| 1.242E-05 | 2.840E-01 | 1.335E-01 | 90.0 | 1.307E-05 | 3.223E-01 | 1.481E-01 |
| 1.078E-05 | 2.739E-01 | 1.057E-01 | 100.0 | 1.135E-05 | 3.099E-01 | 1.172E-01 |
| 9.704E-06 | 2.646E-01 | 8.365E-02 | 110.0 | 1.022E-05 | 2.985E-01 | 9.279E-02 |

Table C.4 BWR decay heat rates (W/kgU) of light elements, actinides, and fission products, for specific power = 20 kW/kgU, Set 1

| Burnup = 20 MWd/kgU | | | Cooling Time, years | Burnup = 25 MWd/kgU | | |
|---|---|---|---|---|---|---|
| Light El | Actinides | Fis Prod | | Light El | Actinides | Fis Prod |
| 6.181E-02 | 2.957E-01 | 5.190E+00 | 1.0 | 6.573E-02 | 4.366E-01 | 5.764E+00 |
| 4.084E-02 | 2.036E-01 | 3.853E+00 | 1.4 | 4.447E-02 | 3.012E-01 | 4.341E+00 |
| 3.278E-02 | 1.398E-01 | 2.680E+00 | 2.0 | 3.605E-02 | 2.068E-01 | 3.073E+00 |
| 2.832E-02 | 1.119E-01 | 1.789E+00 | 2.8 | 3.123E-02 | 1.648E-01 | 2.100E+00 |
| 2.362E-02 | 1.051E-01 | 1.133E+00 | 4.0 | 2.608E-02 | 1.531E-01 | 1.370E+00 |
| 2.047E-02 | 1.064E-01 | 8.744E-01 | 5.0 | 2.262E-02 | 1.536E-01 | 1.075E+00 |
| 1.551E-02 | 1.113E-01 | 6.493E-01 | 7.0 | 1.716E-02 | 1.582E-01 | 8.101E-01 |
| 1.032E-02 | 1.181E-01 | 5.298E-01 | 10.0 | 1.145E-02 | 1.646E-01 | 6.620E-01 |
| 5.299E-03 | 1.271E-01 | 4.431E-01 | 15.0 | 5.905E-03 | 1.730E-01 | 5.521E-01 |
| 2.748E-03 | 1.337E-01 | 3.866E-01 | 20.0 | 3.081E-03 | 1.788E-01 | 4.810E-01 |
| 1.436E-03 | 1.384E-01 | 3.406E-01 | 25.0 | 1.623E-03 | 1.826E-01 | 4.235E-01 |
| 7.570E-04 | 1.416E-01 | 3.012E-01 | 30.0 | 8.640E-04 | 1.849E-01 | 3.743E-01 |
| 2.182E-04 | 1.450E-01 | 2.366E-01 | 40.0 | 2.554E-04 | 1.865E-01 | 2.939E-01 |
| 6.936E-05 | 1.456E-01 | 1.865E-01 | 50.0 | 8.361E-05 | 1.853E-01 | 2.315E-01 |
| 2.712E-05 | 1.447E-01 | 1.473E-01 | 60.0 | 3.322E-05 | 1.826E-01 | 1.828E-01 |
| 1.449E-05 | 1.428E-01 | 1.164E-01 | 70.0 | 1.748E-05 | 1.791E-01 | 1.445E-01 |
| 1.027E-05 | 1.404E-01 | 9.208E-02 | 80.0 | 1.200E-05 | 1.753E-01 | 1.143E-01 |
| 8.551E-06 | 1.378E-01 | 7.286E-02 | 90.0 | 9.719E-06 | 1.713E-01 | 9.040E-02 |
| 7.618E-06 | 1.351E-01 | 5.767E-02 | 100.0 | 8.519E-06 | 1.673E-01 | 7.155E-02 |
| 6.966E-06 | 1.324E-01 | 4.565E-02 | 110.0 | 7.722E-06 | 1.635E-01 | 5.664E-02 |

Table C.5 BWR decay heat rates (W/kgU) of light elements, actinides, and fission products, for specific power = 20 kW/kgU, Set 2

| Burnup = 30 MWd/kgU | | | Cooling Time, years | Burnup = 35 MWd/kgU | | |
|---|---|---|---|---|---|---|
| Light El | Actinides | Fis Prod | | Light El | Actinides | Fis Prod |
| 6.880E-02 | 5.899E-01 | 6.182E+00 | 1.0 | 7.175E-02 | 7.543E-01 | 6.629E+00 |
| 4.724E-02 | 4.101E-01 | 4.716E+00 | 1.4 | 4.971E-02 | 5.303E-01 | 5.110E+00 |
| 3.856E-02 | 2.844E-01 | 3.395E+00 | 2.0 | 4.074E-02 | 3.731E-01 | 3.728E+00 |
| 3.348E-02 | 2.276E-01 | 2.370E+00 | 2.8 | 3.541E-02 | 3.014E-01 | 2.645E+00 |
| 2.799E-02 | 2.103E-01 | 1.589E+00 | 4.0 | 2.964E-02 | 2.783E-01 | 1.809E+00 |
| 2.430E-02 | 2.097E-01 | 1.267E+00 | 5.0 | 2.574E-02 | 2.762E-01 | 1.458E+00 |
| 1.846E-02 | 2.130E-01 | 9.671E-01 | 7.0 | 1.956E-02 | 2.779E-01 | 1.123E+00 |
| 1.233E-02 | 2.181E-01 | 7.921E-01 | 10.0 | 1.309E-02 | 2.809E-01 | 9.207E-01 |
| 6.386E-03 | 2.243E-01 | 6.595E-01 | 15.0 | 6.794E-03 | 2.838E-01 | 7.654E-01 |
| 3.348E-03 | 2.280E-01 | 5.740E-01 | 20.0 | 3.574E-03 | 2.846E-01 | 6.656E-01 |
| 1.775E-03 | 2.299E-01 | 5.051E-01 | 25.0 | 1.902E-03 | 2.839E-01 | 5.855E-01 |
| 9.518E-04 | 2.305E-01 | 4.462E-01 | 30.0 | 1.025E-03 | 2.821E-01 | 5.170E-01 |
| 2.868E-04 | 2.289E-01 | 3.501E-01 | 40.0 | 3.127E-04 | 2.763E-01 | 4.055E-01 |
| 9.588E-05 | 2.250E-01 | 2.757E-01 | 50.0 | 1.060E-04 | 2.689E-01 | 3.193E-01 |
| 3.858E-05 | 2.200E-01 | 2.176E-01 | 60.0 | 4.300E-05 | 2.609E-01 | 2.520E-01 |
| 2.016E-05 | 2.144E-01 | 1.720E-01 | 70.0 | 2.240E-05 | 2.529E-01 | 1.991E-01 |
| 1.357E-05 | 2.087E-01 | 1.360E-01 | 80.0 | 1.490E-05 | 2.450E-01 | 1.575E-01 |
| 1.079E-05 | 2.031E-01 | 1.076E-01 | 90.0 | 1.172E-05 | 2.375E-01 | 1.246E-01 |
| 9.353E-06 | 1.977E-01 | 8.518E-02 | 100.0 | 1.009E-05 | 2.303E-01 | 9.859E-02 |
| 8.426E-06 | 1.925E-01 | 6.742E-02 | 110.0 | 9.049E-06 | 2.236E-01 | 7.804E-02 |

Table C.6 BWR decay heat rates (W/kgU) of light elements, actinides, and fission products, for specific power = 20 kW/kgU, Set 3

| Burnup = 40 MWd/kgU | | | Cooling Time, years | Burnup = 45 MWd/kgU | | |
|---|---|---|---|---|---|---|
| Light El | Actinides | Fis Prod | | Light El | Actinides | Fis Prod |
| 7.481E-02 | 9.488E-01 | 6.976E+00 | 1.0 | 7.701E-02 | 1.129E+00 | 7.365E+00 |
| 5.211E-02 | 6.752E-01 | 5.432E+00 | 1.4 | 5.376E-02 | 8.133E-01 | 5.780E+00 |
| 4.281E-02 | 4.826E-01 | 4.015E+00 | 2.0 | 4.420E-02 | 5.908E-01 | 4.315E+00 |
| 3.726E-02 | 3.937E-01 | 2.893E+00 | 2.8 | 3.848E-02 | 4.873E-01 | 3.147E+00 |
| 3.120E-02 | 3.635E-01 | 2.015E+00 | 4.0 | 3.224E-02 | 4.507E-01 | 2.222E+00 |
| 2.711E-02 | 3.593E-01 | 1.638E+00 | 5.0 | 2.801E-02 | 4.444E-01 | 1.820E+00 |
| 2.062E-02 | 3.582E-01 | 1.271E+00 | 7.0 | 2.131E-02 | 4.405E-01 | 1.420E+00 |
| 1.380E-02 | 3.575E-01 | 1.042E+00 | 10.0 | 1.427E-02 | 4.351E-01 | 1.166E+00 |
| 7.174E-03 | 3.550E-01 | 8.652E-01 | 15.0 | 7.422E-03 | 4.280E-01 | 9.673E-01 |
| 3.780E-03 | 3.511E-01 | 7.517E-01 | 20.0 | 3.914E-03 | 4.191E-01 | 8.400E-01 |
| 2.016E-03 | 3.462E-01 | 6.608E-01 | 25.0 | 2.090E-03 | 4.099E-01 | 7.382E-01 |
| 1.089E-03 | 3.407E-01 | 5.834E-01 | 30.0 | 1.131E-03 | 4.006E-01 | 6.515E-01 |
| 3.342E-04 | 3.288E-01 | 4.573E-01 | 40.0 | 3.486E-04 | 3.823E-01 | 5.105E-01 |
| 1.142E-04 | 3.165E-01 | 3.600E-01 | 50.0 | 1.197E-04 | 3.650E-01 | 4.018E-01 |
| 4.668E-05 | 3.046E-01 | 2.840E-01 | 60.0 | 4.921E-05 | 3.490E-01 | 3.170E-01 |
| 2.442E-05 | 2.932E-01 | 2.244E-01 | 70.0 | 2.583E-05 | 3.342E-01 | 2.505E-01 |
| 1.626E-05 | 2.826E-01 | 1.775E-01 | 80.0 | 1.720E-05 | 3.207E-01 | 1.981E-01 |
| 1.278E-05 | 2.727E-01 | 1.404E-01 | 90.0 | 1.350E-05 | 3.084E-01 | 1.567E-01 |
| 1.098E-05 | 2.635E-01 | 1.111E-01 | 100.0 | 1.159E-05 | 2.970E-01 | 1.240E-01 |
| 9.843E-06 | 2.550E-01 | 8.796E-02 | 110.0 | 1.038E-05 | 2.866E-01 | 9.817E-02 |

Table C.7 BWR decay heat rates (W/kgU) of light elements, actinides, and fission products, for specific power = 30 kW/kgU, Set 1

| Burnup = 20 MWd/kgU | | | Cooling Time, years | Burnup = 25 MWd/kgU | | |
|---|---|---|---|---|---|---|
| Light El | Actinides | Fis Prod | | Light El | Actinides | Fis Prod |
| 7.591E-02 | 2.580E-01 | 6.475E+00 | 1.0 | 8.104E-02 | 3.892E-01 | 7.316E+00 |
| 4.621E-02 | 1.816E-01 | 4.711E+00 | 1.4 | 5.080E-02 | 2.731E-01 | 5.397E+00 |
| 3.561E-02 | 1.289E-01 | 3.203E+00 | 2.0 | 3.970E-02 | 1.924E-01 | 3.726E+00 |
| 3.046E-02 | 1.062E-01 | 2.074E+00 | 2.8 | 3.405E-02 | 1.567E-01 | 2.460E+00 |
| 2.529E-02 | 1.012E-01 | 1.255E+00 | 4.0 | 2.830E-02 | 1.472E-01 | 1.529E+00 |
| 2.188E-02 | 1.028E-01 | 9.384E-01 | 5.0 | 2.450E-02 | 1.482E-01 | 1.162E+00 |
| 1.655E-02 | 1.079E-01 | 6.725E-01 | 7.0 | 1.855E-02 | 1.530E-01 | 8.438E-01 |
| 1.100E-02 | 1.148E-01 | 5.398E-01 | 10.0 | 1.235E-02 | 1.597E-01 | 6.776E-01 |
| 5.638E-03 | 1.241E-01 | 4.492E-01 | 15.0 | 6.356E-03 | 1.684E-01 | 5.619E-01 |
| 2.918E-03 | 1.308E-01 | 3.916E-01 | 20.0 | 3.309E-03 | 1.745E-01 | 4.890E-01 |
| 1.522E-03 | 1.357E-01 | 3.450E-01 | 25.0 | 1.738E-03 | 1.786E-01 | 4.304E-01 |
| 8.003E-04 | 1.391E-01 | [illegible] | 30.0 | 9.222E-04 | 1.812E-01 | 3.804E-01 |
| 2.290E-04 | 1.427E-01 | 2.396E-01 | 40.0 | 2.701E-04 | 1.831E-01 | 2.986E-01 |
| 7.194E-05 | 1.436E-01 | 1.888E-01 | 50.0 | 8.718E-05 | 1.823E-01 | 2.352E-01 |
| 2.769E-05 | 1.428E-01 | 1.491E-01 | 60.0 | 3.402E-05 | 1.799E-01 | 1.857E-01 |
| 1.459E-05 | 1.411E-01 | 1.179E-01 | 70.0 | 1.764E-05 | 1.767E-01 | 1.468E-01 |
| 1.029E-05 | 1.389E-01 | 9.322E-02 | 80.0 | 1.203E-05 | 1.730E-01 | 1.161E-01 |
| 8.564E-06 | 1.364E-01 | 7.376E-02 | 90.0 | 9.736E-06 | 1.693E-01 | 9.185E-02 |
| 7.635E-06 | 1.338E-01 | 5.838E-02 | 100.0 | 8.539E-06 | 1.655E-01 | 7.269E-02 |
| 6.986E-06 | 1.312E-01 | 4.621E-02 | 110.0 | 7.745E-06 | 1.618E-01 | 5.754E-02 |

Table C.8 BWR decay heat rates (W/kgU) of light elements, actinides, and fission products, for specific power = 30 kW/kgU, Set 2

| Burnup = 30 MWd/kgU | | | Cooling Time, years | Burnup = 35 MWd/kgU | | |
|---|---|---|---|---|---|---|
| Light El | Actinides | Fis Prod | | Light El | Actinides | Fis Prod |
| 8.512E-02 | 5.349E-01 | 7.931E+00 | 1.0 | 8.934E-02 | 6.945E-01 | 8.553E+00 |
| 5.454E-02 | 3.770E-01 | 5.925E+00 | 1.4 | 5.801E-02 | 4.935E-01 | 6.454E+00 |
| 4.307E-02 | 2.666E-01 | 4.153E+00 | 2.0 | 4.609E-02 | 3.525E-01 | 4.580E+00 |
| 3.704E-02 | 2.170E-01 | 2.796E+00 | 2.8 | 3.971E-02 | 2.883E-01 | 3.132E+00 |
| 3.084E-02 | 2.023E-01 | 1.783E+00 | 4.0 | 3.309E-02 | 2.680E-01 | 2.038E+00 |
| 2.672E-02 | 2.021E-01 | 1.376E+00 | 5.0 | 2.868E-02 | 2.664E-01 | 1.590E+00 |
| 2.025E-02 | 2.058E-01 | 1.013E+00 | 7.0 | 2.176E-02 | 2.685E-01 | 1.181E+00 |
| 1.351E-02 | 2.112E-01 | 8.144E-01 | 10.0 | 1.453E-02 | 2.718E-01 | 9.504E-01 |
| 6.976E-03 | 2.178E-01 | 6.736E-01 | 15.0 | 7.523E-03 | 2.753E-01 | 7.844E-01 |
| 3.648E-03 | 2.219E-01 | 5.855E-01 | 20.0 | 3.948E-03 | 2.766E-01 | 6.811E-01 |
| 1.928E-03 | 2.242E-01 | 5.151E-01 | 25.0 | 2.096E-03 | 2.763E-01 | 5.988E-01 |
| 1.031E-03 | 2.251E-01 | 4.550E-01 | 30.0 | 1.126E-03 | 2.749E-01 | 5.288E-01 |
| 3.076E-04 | 2.240E-01 | 3.569E-01 | 40.0 | 3.404E-04 | 2.697E-01 | 4.146E-01 |
| 1.014E-04 | 2.206E-01 | 2.811E-01 | 50.0 | 1.138E-04 | 2.629E-01 | 3.264E-01 |
| 4.003E-05 | 2.159E-01 | 2.219E-01 | 60.0 | 4.528E-05 | 2.555E-01 | 2.576E-01 |
| 2.056E-05 | 2.108E-01 | 1.753E-01 | 70.0 | 2.311E-05 | 2.479E-01 | 2.036E-01 |
| 1.369E-05 | 2.054E-01 | 1.387E-01 | 80.0 | 1.516E-05 | 2.404E-01 | 1.610E-01 |
| 1.085E-05 | 2.001E-01 | 1.097E-01 | 90.0 | 1.184E-05 | 2.332E-01 | 1.274E-01 |
| 9.393E-06 | 1.949E-01 | 8.682E-02 | 100.0 | 1.015E-05 | 2.264E-01 | 1.008E-01 |
| 8.461E-06 | 1.900E-01 | 6.873E-02 | 110.0 | 9.099E-06 | 2.200E-01 | 7.979E-02 |

Table C.9 BWR decay heat rates (W/kgU) of light elements, actinides, and fission products, for specific power = 30 kW/kgU, Set 3

| Burnup = 40 MWd/kgU | | | Cooling Time, years | Burnup = 45 MWd/kgU | | |
|---|---|---|---|---|---|---|
| Light El | Actinides | Fis Prod | | Light El | Actinides | Fis Prod |
| 9.371E-02 | 8.840E-01 | 9.029E+00 | 1.0 | 9.716E-02 | 1.063E+00 | 9.546E+00 |
| 6.150E-02 | 6.345E-01 | 6.883E+00 | 1.4 | 6.410E-02 | 7.709E-01 | 7.334E+00 |
| 4.912E-02 | 4.590E-01 | 4.945E+00 | 2.0 | 5.132E-02 | 5.651E-01 | 5.322E+00 |
| 4.241E-02 | 3.780E-01 | 3.435E+00 | 2.8 | 4.435E-02 | 4.694E-01 | 3.742E+00 |
| 3.538E-02 | 3.507E-01 | 2.277E+00 | 4.0 | 3.701E-02 | 4.357E-01 | 2.518E+00 |
| 3.068E-02 | 3.470E-01 | 1.794E+00 | 5.0 | 3.211E-02 | 4.299E-01 | 2.000E+00 |
| 2.329E-02 | 3.463E-01 | 1.343E+00 | 7.0 | 2.438E-02 | 4.264E-01 | 1.507E+00 |
| 1.556E-02 | 3.460E-01 | 1.081E+00 | 10.0 | 1.629E-02 | 4.224E-01 | 1.214E+00 |
| 8.070E-03 | 3.441E-01 | 8.899E-01 | 15.0 | 8.457E-03 | 4.149E-01 | 9.982E-01 |
| 4.243E-03 | 3.407E-01 | 7.719E-01 | 20.0 | 4.451E-03 | 4.067E-01 | 8.653E-01 |
| 2.258E-03 | 3.363E-01 | 6.783E-01 | 25.0 | 2.372E-03 | 3.980E-01 | 7.600E-01 |
| 1.216E-03 | 3.313E-01 | 5.987E-01 | 30.0 | 1.281E-03 | 3.892E-01 | 6.707E-01 |
| 3.703E-04 | 3.202E-01 | 4.692E-01 | 40.0 | 3.919E-04 | 3.718E-01 | 5.255E-01 |
| 1.248E-04 | 3.086E-01 | 3.693E-01 | 50.0 | 1.328E-04 | 3.553E-01 | 4.136E-01 |
| 5.001E-05 | 2.973E-01 | 2.914E-01 | 60.0 | 5.343E-05 | 3.400E-01 | 3.263E-01 |
| 2.555E-05 | 2.866E-01 | 2.303E-01 | 70.0 | 2.730E-05 | 3.260E-01 | 2.578E-01 |
| 1.669E-05 | 2.765E-01 | 1.821E-01 | 80.0 | 1.777E-05 | 3.131E-01 | 2.039E-01 |
| 1.297E-05 | 2.671E-01 | 1.441E-01 | 90.0 | 1.376E-05 | 3.014E-01 | 1.613E-01 |
| 1.108E-05 | 2.583E-01 | 1.140E-01 | 100.0 | 1.173E-05 | 2.906E-01 | 1.276E-01 |
| 9.913E-06 | 2.501E-01 | 9.024E-02 | 110.0 | 1.047E-05 | 2.806E-01 | 1.010E-01 |

Table C.10 PWR decay heat rates (W/kgU) of light elements, actinides, and fission products, for specific power = 18 kW/kgU, Set 1

| Burnup = 25 MWd/kgU | | | Cooling Time, years | Burnup = 30 MWd/kgU | | |
|---|---|---|---|---|---|---|
| Light El | Actinides | Fis Prod | | Light El | Actinides | Fis Prod |
| 1.198E-01 | 4.377E-01 | 5.389E+00 | 1.0 | 1.269E-01 | 5.918E-01 | 5.855E+00 |
| 1.062E-01 | 3.002E-01 | 4.079E+00 | 1.4 | 1.130E-01 | 4.091E-01 | 4.487E+00 |
| 9.579E-02 | 2.045E-01 | 2.908E+00 | 2.0 | 1.021E-01 | 2.814E-01 | 3.249E+00 |
| 8.550E-02 | 1.620E-01 | 2.006E+00 | 2.8 | 9.113E-02 | 2.241E-01 | 2.286E+00 |
| 7.262E-02 | 1.505E-01 | 1.328E+00 | 4.0 | 7.742E-02 | 2.072E-01 | 1.550E+00 |
| 6.351E-02 | 1.515E-01 | 1.053E+00 | 5.0 | 6.771E-02 | 2.071E-01 | 1.245E+00 |
| 4.369E-02 | 1.567E-01 | 8.031E-01 | 7.0 | 5.191E-02 | 2.116E-01 | 9.597E-01 |
| 3.275E-02 | 1.642E-01 | 6.609E-01 | 10.0 | 3.492E-02 | 2.182E-01 | 7.935E-01 |
| 1.696E-02 | 1.739E-01 | 5.530E-01 | 15.0 | 1.808E-02 | 2.264E-01 | 6.600E-01 |
| 8.806E-03 | 1.807E-01 | 4.822E-01 | 20.0 | 9.389E-03 | 2.318E-01 | 5.749E-01 |
| 4.589E-03 | 1.855E-01 | 4.247E-01 | 25.0 | 4.894E-03 | 2.351E-01 | 5.060E-01 |
| 2.406E-03 | 1.885E-01 | 3.755E-01 | 30.0 | 2.566E-03 | 2.367E-01 | 4.471E-01 |
| 6.872E-04 | 1.910E-01 | 2.948E-01 | 40.0 | 7.342E-04 | 2.366E-01 | 3.509E-01 |
| 2.235E-04 | 1.905E-01 | 2.323E-01 | 50.0 | 2.399E-04 | 2.336E-01 | 2.764E-01 |
| 9.681E-05 | 1.882E-01 | 1.834E-01 | 60.0 | 1.047E-04 | 2.290E-01 | 2.182E-01 |
| 6.071E-05 | 1.849E-01 | 1.450E-01 | 70.0 | 6.620E-05 | 2.238E-01 | 1.724E-01 |
| 4.912E-05 | 1.812E-01 | 1.147E-01 | 80.0 | 5.379E-05 | 2.183E-01 | 1.364E-01 |
| 4.425E-05 | 1.772E-01 | 9.072E-02 | 90.0 | 4.856E-05 | 2.127E-01 | 1.079E-01 |
| 4.133E-05 | 1.733E-01 | 7.180E-02 | 100.0 | 4.541E-05 | 2.072E-01 | 8.539E-02 |
| 3.904E-05 | 1.693E-01 | 5.684E-02 | 110.0 | 4.293E-05 | 2.019E-01 | 6.759E-02 |

Table C.11 PWR decay heat rates (W/kgU) of light elements, actinides, and fission products, for specific power = 18 kW/kgU, Set 2

| Burnup = 35 MWd/kgU | | | Cooling Time, | Burnup = 40 MWd/kgU | | |
|---|---|---|---|---|---|---|
| Light El | Actinides | Fis Prod | years | Light El | Actinides | Fis Prod |
| 1.319E-01 | 7.602E-01 | 6.194E+00 | 1.0 | 1.365E-01 | 9.352E-01 | 6.590E+00 |
| 1.177E-01 | 5.305E-01 | 4.800E+00 | 1.4 | 1.221E-01 | 6.608E-01 | 5.155E+00 |
| 1.064E-01 | 3.696E-01 | 3.528E+00 | 2.0 | 1.105E-01 | 4.680E-01 | 3.833E+00 |
| 9.506E-02 | 2.965E-01 | 2.529E+00 | 2.8 | 9.870E-02 | 3.797E-01 | 2.785E+00 |
| 8.077E-02 | 2.736E-01 | 1.754E+00 | 4.0 | 8.386E-02 | 3.507E-01 | 1.963E+00 |
| 7.064E-02 | 2.721E-01 | 1.426E+00 | 5.0 | 7.335E-02 | 3.476E-01 | 1.609E+00 |
| 5.416E-02 | 2.751E-01 | 1.110E+00 | 7.0 | 5.623E-02 | 3.486E-01 | 1.261E+00 |
| 3.643E-02 | 2.798E-01 | 9.162E-01 | 10.0 | 3.783E-02 | 3.508E-01 | 1.041E+00 |
| 1.887E-02 | 2.852E-01 | 7.640E-01 | 15.0 | 1.959E-02 | 3.522E-01 | 8.670E-01 |
| 9.797E-03 | 2.879E-01 | 6.649E-01 | 20.0 | 1.017E-02 | 3.515E-01 | 7.540E-01 |
| 5.108E-03 | 2.888E-01 | 5.850E-01 | 25.0 | 5.305E-03 | 3.492E-01 | 6.630E-01 |
| 2.680E-03 | 2.882E-01 | 5.167E-01 | 30.0 | 2.784E-03 | 3.457E-01 | 5.854E-01 |
| 7.683E-04 | 2.841E-01 | 4.052E-01 | 40.0 | 7.997E-04 | 3.367E-01 | 4.590E-01 |
| 2.525E-04 | 2.778E-01 | 3.191E-01 | 50.0 | 2.641E-04 | 3.264E-01 | 3.614E-01 |
| 1.114E-04 | 2.705E-01 | 2.518E-01 | 60.0 | 1.175E-04 | 3.156E-01 | 2.852E-01 |
| 7.106E-05 | 2.628E-01 | 1.990E-01 | 70.0 | 7.559E-05 | 3.049E-01 | 2.253E-01 |
| 5.804E-05 | 2.551E-01 | 1.574E-01 | 80.0 | 6.201E-05 | 2.947E-01 | 1.782E-01 |
| 5.251E-05 | 2.476E-01 | 1.245E-01 | 90.0 | 5.621E-05 | 2.849E-01 | 1.410E-01 |
| 4.916E-05 | 2.404E-01 | 9.855E-02 | 100.0 | 5.267E-05 | 2.758E-01 | 1.116E-01 |
| 4.652E-05 | 2.335E-01 | 7.801E-02 | 110.0 | 4.989E-05 | 2.672E-01 | 8.831E-02 |

Table C.12 PWR decay heat rates (W/kgU) of light elements, actinides, and fission products, for specific power = 18 kW/kgU, Set 3

| Burnup = 45 MWd/kgU | | | Cooling Time, | Burnup = 50 MWd/kgU | | |
|---|---|---|---|---|---|---|
| Light El | Actinides | Fis Prod | years | Light El | Actinides | Fis Prod |
| 1.410E-01 | 1.144E+00 | 6.891E+00 | 1.0 | 1.458E-01 | 1.354E+00 | 7.273E+00 |
| 1.264E-01 | 8.180E-01 | 5.438E+00 | 1.4 | 1.308E-01 | 9.824E-01 | 5.781E+00 |
| 1.144E-01 | 5.883E-01 | 4.090E+00 | 2.0 | 1.185E-01 | 7.198E-01 | 4.385E+00 |
| 1.022E-01 | 4.820E-01 | 3.311E+00 | 2.8 | 1.059E-01 | 5.973E-01 | 3.259E+00 |
| 8.685E-02 | 4.454E-01 | 2.153E+00 | 4.0 | 8.996E-02 | 5.533E-01 | 2.354E+00 |
| 7.597E-02 | 4.399E-01 | 1.778E+00 | 5.0 | 7.869E-02 | 5.452E-01 | 1.952E+00 |
| 5.824E-02 | 4.378E-01 | 1.401E+00 | 7.0 | 6.033E-02 | 5.393E-01 | 1.543E+00 |
| 3.918E-02 | 4.358E-01 | 1.158E+00 | 10.0 | 4.059E-02 | 5.322E-01 | 1.274E+00 |
| 2.029E-02 | 4.312E-01 | 9.[illegible]28E-01 | 15.0 | 2.102E-02 | 5.200E-01 | 1.058E+00 |
| 1.054E-02 | 4.251E-01 | 8.367E-01 | 20.0 | 1.092E-02 | 5.074E-01 | 9.187E-01 |
| 5.498E-03 | 4.181E-01 | 7.354E-01 | 25.0 | 5.698E-03 | 4.947E-01 | 8.072E-01 |
| 2.887E-03 | 4.106E-01 | 6.491E-01 | 30.0 | 2.993E-03 | 4.821E-01 | 7.122E-01 |
| 8.315E-04 | 3.947E-01 | 5.087E-01 | 40.0 | 8.641E-04 | 4.580E-01 | 5.579E-01 |
| 2.766E-04 | 3.789E-01 | 4.004E-01 | 50.0 | 2.891E-04 | 4.356E-01 | 4.391E-01 |
| 1.246E-04 | 3.636E-01 | 3.159E-01 | 60.0 | 1.315E-04 | 4.152E-01 | 3.464E-01 |
| 8.104E-05 | 3.493E-01 | 2.496E-01 | 70.0 | 8.632E-05 | 3.966E-01 | 2.737E-01 |
| 6.684E-05 | 3.360E-01 | 1.974E-01 | 80.0 | 7.150E-05 | 3.797E-01 | 2.164E-01 |
| 6.072E-05 | 3.236E-01 | 1.562E-01 | 90.0 | 6.507E-05 | 3.643E-01 | 1.712E-01 |
| 5.696E-05 | 3.121E-01 | 1.236E-01 | 100.0 | 6.108E-05 | 3.502E-01 | 1.355E-01 |
| 5.398E-05 | 3.014E-01 | 9.783E-02 | 110.0 | 5.792E-05 | 3.373E-01 | 1.073E-01 |

Table C.13 PWR decay heat rates (W/kgU) of light elements, actinides, and fission products, for specific power = 28 kW/kgU, Set 1

| Burnup = 25 MWd/kgU | | | Cooling Time, years | Burnup = 30 MWd/kgU | | |
|---|---|---|---|---|---|---|
| Light El | Actinides | Fis Prod | | Light El | Actinides | Fis Prod |
| 1.361E-01 | 3.874E-01 | 7.036E+00 | 1.0 | 1.461E-01 | 5.340E-01 | 7.710E+00 |
| 1.181E-01 | 2.700E-01 | 5.205E+00 | 1.4 | 1.275E-01 | 3.734E-01 | 5.772E+00 |
| 1.058E-01 | 1.885E-01 | 3.606E+00 | 2.0 | 1.144E-01 | 2.615E-01 | 4.056E+00 |
| 9.420E-02 | 1.527E-01 | 2.394E+00 | 2.8 | 1.020E-01 | 2.115E-01 | 2.741E+00 |
| 7.992E-02 | 1.436E-01 | 1.500E+00 | 4.0 | 8.653E-02 | 1.973E-01 | 1.759E+00 |
| 6.986E-02 | 1.450E-01 | 1.148E+00 | 5.0 | 7.564E-02 | 1.977E-01 | 1.364E+00 |
| 5.353E-02 | 1.506E-01 | 8.410E-01 | 7.0 | 5.796E-02 | 2.026E-01 | 1.010E+00 |
| 3.609E-02 | 1.583E-01 | 6.791E-01 | 10.0 | 3.898E-02 | 2.096E-01 | 8.159E-01 |
| 1.864E-02 | 1.685E-01 | 5.645E-01 | 15.0 | 2.018E-02 | 2.184E-01 | 6.764E-01 |
| 9.672E-03 | 1.757E-01 | 4.916E-01 | 20.0 | 1.047E-02 | 2.243E-01 | 5.883E-01 |
| 5.038E-03 | 1.808E-01 | 4.329E-01 | 25.0 | 5.454E-03 | 2.280E-01 | 5.176E-01 |
| 2.638E-03 | 1.841E-01 | 3.826E-01 | 30.0 | 2.857E-03 | 2.300E-01 | 4.573E-01 |
| 7.497E-04 | 1.871E-01 | 3.004E-01 | 40.0 | 8.124E-04 | 2.306E-01 | 3.588E-01 |
| 2.405E-04 | 1.870E-01 | 2.367E-01 | 50.0 | 2.611E-04 | 2.281E-01 | 2.826E-01 |
| 1.015E-04 | 1.850E-01 | 1.869E-01 | 60.0 | 1.106E-04 | 2.241E-01 | 2.231E-01 |
| 6.210E-05 | 1.820E-01 | 1.477E-01 | 70.0 | 6.793E-05 | 2.193E-01 | 1.763E-01 |
| 4.961E-05 | 1.786E-01 | 1.168E-01 | 80.0 | 5.440E-05 | 2.141E-01 | 1.394E-01 |
| 4.450E-05 | 1.749E-01 | 9.243E-02 | 90.0 | 4.886E-05 | 2.089E-01 | 1.103E-01 |
| 4.150E-05 | 1.711E-01 | 7.315E-02 | 100.0 | 4.561E-05 | 2.038E-01 | 8.730E-02 |
| 3.919E-05 | 1.674E-01 | 5.791E-02 | 110.0 | 4.311E-05 | 1.988E-01 | 6.911E-02 |

Table C.14 PWR decay heat rates (W/kgU) of light elements, actinides, and fission products, for specific power = 28 kW/kgU, Set 2

| Burnup = 35 MWd/kgU | | | Cooling Time, years | Burnup = 40 MWd/kgU | | |
|---|---|---|---|---|---|---|
| Light El | Actinides | Fis Prod | | Light El | Actinides | Fis Prod |
| 1.539E-01 | 6.960E-01 | 8.205E+00 | 1.0 | 1.613E-01 | 8.674E-01 | 8.747E+00 |
| 1.351E-01 | 4.903E-01 | 6.211E+00 | 1.4 | 1.420E-01 | 6.170E-01 | 6.682E+00 |
| 1.214E-01 | 3.464E-01 | 4.426E+00 | 2.0 | 1.278E-01 | 4.412E-01 | 4.816E+00 |
| 1.082E-01 | 2.812E-01 | 3.046E+00 | 2.8 | 1.139E-01 | 3.609E-01 | 3.360E+00 |
| 9.182E-02 | 2.612E-01 | 1.999E+00 | 4.0 | 9.670E-02 | 3.348E-01 | 2.244E+00 |
| 8.028E-02 | 2.603E-01 | 1.570E+00 | 5.0 | 8.455E-02 | 3.322E-01 | 1.778E+00 |
| 6.151E-02 | 2.637E-01 | 1.175E+00 | 7.0 | 6.479E-02 | 3.338E-01 | 1.341E+00 |
| 4.137E-02 | 2.689E-01 | 9.505E-01 | 10.0 | 4.357E-02 | 3.365E-01 | 1.085E+00 |
| 2.141E-02 | 2.749E-01 | 7.863E-01 | 15.0 | 2.255E-02 | 3.387E-01 | 8.958E-01 |
| 1.111E-02 | 2.783E-01 | 6.832E-01 | 20.0 | 1.171E-02 | 3.387E-01 | 7.776E-01 |
| 5.789E-03 | 2.797E-01 | 6.008E-01 | 25.0 | 6.098E-03 | 3.371E-01 | 6.835E-01 |
| 3.033E-03 | 2.796E-01 | 5.306E-01 | 30.0 | 3.195E-03 | 3.342E-01 | 6.034E-01 |
| 8.632E-04 | 2.763E-01 | 4.161E-01 | 40.0 | 9.102E-04 | 3.263E-01 | 4.730E-01 |
| 2.782E-04 | 2.707E-01 | 3.276E-01 | 50.0 | 2.940E-04 | 3.168E-01 | 3.723E-01 |
| 1.185E-04 | 2.640E-01 | 2.586E-01 | 60.0 | 1.258E-04 | 3.068E-01 | 2.938E-01 |
| 7.314E-05 | 2.568E-01 | 2.043E-01 | 70.0 | 7.803E-05 | 2.969E-01 | 2.322E-01 |
| 5.877E-05 | 2.496E-01 | 1.616E-01 | 80.0 | 6.286E-05 | 2.873E-01 | 1.836E-01 |
| 5.287E-05 | 2.426E-01 | 1.278E-01 | 90.0 | 5.663E-05 | 2.782E-01 | 1.452E-01 |
| 4.940E-05 | 2.359E-01 | 1.012E-01 | 100.0 | 5.295E-05 | 2.695E-01 | 1.149E-01 |
| 4.673E-05 | 2.294E-01 | 8.008E-02 | 110.0 | 5.012E-05 | 2.614E-01 | 9.096E-02 |

Table C.15 PWR decay heat rates (W/kgU) of light elements, actinides, and fission products, for specific power = 28 kW/kgU, Set 3

| Burnup = 45 MWd/kgU | | | Cooling Time, years | Burnup = 50 MWd/kgU | | |
|---|---|---|---|---|---|---|
| Light El | Actinides | Fis Prod | | Light El | Actinides | Fis Prod |
| 1.690E-01 | 1.073E+00 | 9.156E+00 | 1.0 | 1.767E-01 | 1.282E+00 | 9.661E+00 |
| 1.493E-01 | 7.710E-01 | 7.058E+00 | 1.4 | 1.565E-01 | 9.334E-01 | 7.503E+00 |
| 1.344E-01 | 5.585E-01 | 5.145E+00 | 2.0 | 1.410E-01 | 6.870E-01 | 5.518E+00 |
| 1.199E-01 | 4.603E-01 | 3.640E+00 | 2.8 | 1.258E-01 | 5.721E-01 | 3.944E+00 |
| 1.018E-01 | 4.267E-01 | 2.471E+00 | 4.0 | 1.068E-01 | 5.310E-01 | 2.708E+00 |
| 8.901E-02 | 4.218E-01 | 1.975E+00 | 5.0 | 9.341E-02 | 5.234E-01 | 2.176E+00 |
| 6.821E-02 | 4.202E-01 | 1.499E+00 | 7.0 | 7.158E-02 | 5.180E-01 | 1.658E+00 |
| 4.587E-02 | 4.189E-01 | 1.212E+00 | 10.0 | 4.814E-02 | 5.116E-01 | 1.340E+00 |
| 2.374E-02 | 4.151E-01 | 9.993E-01 | 15.0 | 2.492E-02 | 5.003E-01 | 1.102E+00 |
| 1.233E-02 | 4.098E-01 | 8.666E-01 | 20.0 | 1.294E-02 | 4.886E-01 | 9.552E-01 |
| 6.422E-03 | 4.036E-01 | 7.613E-01 | 25.0 | 6.741E-03 | 4.766E-01 | 8.387E-01 |
| 3.366E-03 | 3.967E-01 | 6.719E-01 | 30.0 | 3.534E-03 | 4.648E-01 | 7.400E-01 |
| 9.603E-04 | 3.820E-01 | 5.264E-01 | 40.0 | 1.009E-03 | 4.420E-01 | 5.796E-01 |
| 3.114E-04 | 3.672E-01 | 4.143E-01 | 50.0 | 3.285E-04 | 4.209E-01 | 4.560E-01 |
| 1.342E-04 | 3.529E-01 | 3.269E-01 | 60.0 | 1.424E-04 | 4.016E-01 | 3.598E-01 |
| 8.388E-05 | 3.394E-01 | 2.583E-01 | 70.0 | 8.954E-05 | 3.841E-01 | 2.842E-01 |
| 6.784E-05 | 3.269E-01 | 2.042E-01 | 80.0 | 7.264E-05 | 3.681E-01 | 2.247E-01 |
| 6.121E-05 | 3.152E-01 | 1.616E-01 | 90.0 | 6.563E-05 | 3.536E-01 | 1.778E-01 |
| 5.729E-05 | 3.044E-01 | 1.279E-01 | 100.0 | 6.146E-05 | 3.404E-01 | 1.407E-01 |
| 5.425E-05 | 2.943E-01 | 1.012E-01 | 110.0 | 5.823E-05 | 3.282E-01 | 1.114E-01 |

Table C.16 PWR decay heat rates (W/kgU) of light elements, actinides, and fission products, for specific power = 40 kW/kgU, Set 1

| Burnup = 25 MWd/kgU | | | Cooling Time, years | Burnup = 30 MWd/kgU | | |
|---|---|---|---|---|---|---|
| Light El | Actinides | Fis Prod | | Light El | Actinides | Fis Prod |
| 1.485E-01 | 3.419E-01 | 8.456E+00 | 1.0 | 1.607E-01 | 4.800E-01 | 9.412E+00 |
| 1.259E-01 | 2.435E-01 | 6.145E+00 | 1.4 | 1.374E-01 | 3.420E-01 | 6.921E+00 |
| 1.119E-01 | 1.754E-01 | 4.175E+00 | 2.0 | 1.224E-01 | 2.459E-01 | 4.761E+00 |
| 9.944E-02 | 1.458E-01 | 2.702E+00 | 2.8 | 1.088E-01 | 2.033E-01 | 3.129E+00 |
| 8.428E-02 | 1.389E-01 | 1.630E+00 | 4.0 | 9.225E-02 | 1.917E-01 | 1.928E+00 |
| 7.365E-02 | 1.406E-01 | 1.215E+00 | 5.0 | 8.061E-02 | 1.926E-01 | 1.455E+00 |
| 5.641E-02 | 1.463E-01 | 8.646E-01 | 7.0 | 6.175E-02 | 1.977E-01 | 1.045E+00 |
| 3.793E-02 | 1.543E-01 | 6.886E-01 | 10.0 | 4.152E-02 | 2.049E-01 | 8.315E-01 |
| 1.963E-02 | 1.646E-01 | 5.700E-01 | 15.0 | 2.148E-02 | 2.140E-01 | 6.859E-01 |
| 1.019E-02 | 1.721E-01 | 4.960E-01 | 20.0 | 1.115E-02 | 2.203E-01 | 5.960E-01 |
| 5.304E-03 | 1.773E-01 | 4.367E-01 | 25.0 | 5.805E-03 | 2.242E-01 | 5.243E-01 |
| 2.776E-03 | 1.808E-01 | 3.859E-01 | 30.0 | 3.038E-03 | 2.265E-01 | 4.631E-01 |
| 7.867E-04 | 1.841E-01 | 3.030E-01 | 40.0 | 8.612E-04 | 2.274E-01 | 3.633E-01 |
| 2.505E-04 | 1.842E-01 | 2.387E-01 | 50.0 | 2.743E-04 | 2.253E-01 | 2.862E-01 |
| 1.042E-04 | 1.825E-01 | 1.884E-01 | 60.0 | 1.143E-04 | 2.216E-01 | 2.259E-01 |
| 6.287E-05 | 1.797E-01 | 1.489E-01 | 70.0 | 6.902E-05 | 2.170E-01 | 1.785E-01 |
| 4.985E-05 | 1.764E-01 | 1.178E-01 | 80.0 | 5.479E-05 | 2.120E-01 | 1.412E-01 |
| 4.459E-05 | 1.728E-01 | 9.320E-02 | 90.0 | 4.905E-05 | 2.070E-01 | 1.117E-01 |
| 4.155E-05 | 1.692E-01 | 7.376E-02 | 100.0 | 4.574E-05 | 2.020E-01 | 8.839E-02 |
| 3.923E-05 | 1.656E-01 | 5.839E-02 | 110.0 | 4.322E-05 | 1.972E-01 | 6.997E-02 |

Table C.17 PWR decay heat rates (W/kgU) of light elements, actinides, and fission products, for specific power = 40 kW/kgU, Set 2

| Burnup = 35 MWd/kgU | | | Cooling Time, years | Burnup = 40 MWd/kgU | | |
|---|---|---|---|---|---|---|
| Light El | Actinides | Fis Prod | | Light El | Actinides | Fis Prod |
| 1.706E-01 | 6.341E-01 | 1.010E+01 | 1.0 | 1.800E-01 | 7.998E-01 | 1.084E+01 |
| 1.469E-01 | 4.538E-01 | 7.510E+00 | 1.4 | 1.557E-01 | 5.766E-01 | 8.131E+00 |
| 1.311E-01 | 3.277E-01 | 5.233E+00 | 2.0 | 1.393E-01 | 4.201E-01 | 5.725E+00 |
| 1.167E-01 | 2.709E-01 | 3.496E+00 | 2.8 | 1.239E-01 | 3.487E-01 | 3.873E+00 |
| 9.891E-02 | 2.538E-01 | 2.201E+00 | 4.0 | 1.051E-01 | 3.258E-01 | 2.479E+00 |
| 8.644E-02 | 2.534E-01 | 1.681E+00 | 5.0 | 9.183E-02 | 3.238E-01 | 1.911E+00 |
| 6.621E-02 | 2.571E-01 | 1.220E+00 | 7.0 | 7.034E-02 | 3.257E-01 | 1.397E+00 |
| 4.452E-02 | 2.626E-01 | 9.713E-01 | 10.0 | 4.729E-02 | 3.287E-01 | 1.112E+00 |
| 2.304E-02 | 2.689E-01 | 7.990E-01 | 15.0 | 2.447E-02 | 3.314E-01 | 9.125E-01 |
| 1.195E-02 | 2.726E-01 | 6.934E-01 | 20.0 | 1.270E-02 | 3.318E-01 | 7.911E-01 |
| 6.224E-03 | 2.743E-01 | 6.096E-01 | 25.0 | 6.612E-03 | 3.306E-01 | 6.951E-01 |
| 3.258E-03 | 2.745E-01 | 5.382E-01 | 30.0 | 3.461E-03 | 3.281E-01 | 6.136E-01 |
| 9.238E-04 | 2.717E-01 | 4.220E-01 | 40.0 | 9.818E-04 | 3.207E-01 | 4.809E-01 |
| 2.946E-04 | 2.665E-01 | 3.323E-01 | 50.0 | 3.134E-04 | 3.117E-01 | 3.786E-01 |
| 1.230E-04 | 2.601E-01 | 2.622E-01 | 60.0 | 1.311E-04 | 3.022E-01 | 2.987E-01 |
| 7.449E-05 | 2.533E-01 | 2.072E-01 | 70.0 | 7.960E-05 | 2.927E-01 | 2.360E-01 |
| 5.924E-05 | 2.464E-01 | 1.639E-01 | 80.0 | 6.340E-05 | 2.834E-01 | 1.866E-01 |
| 5.310E-05 | 2.396E-01 | 1.296E-01 | 90.0 | 5.688E-05 | 2.746E-01 | 1.477E-01 |
| 4.956E-05 | 2.331E-01 | 1.026E-01 | 100.0 | 5.313E-05 | 2.663E-01 | 1.169E-01 |
| 4.686E-05 | 2.268E-01 | 8.121E-02 | 110.0 | 5.027E-05 | 2.585E-01 | 9.249E-02 |

Table C.18 PWR decay heat rates (W/kgU) of light elements, actinides, and fission products, for specific power = 40 kW/kgU, Set 3

| Burnup = 45 MWd/kgU | | | Cooling Time, years | Burnup = 50 MWd/kgU | | |
|---|---|---|---|---|---|---|
| Light El | Actinides | Fis Prod | | Light El | Actinides | Fis Prod |
| 1.901E-01 | 9.994E-01 | 1.139E+01 | 1.0 | 2.001E-01 | 1.206E+00 | 1.206E+01 |
| 1.652E-01 | 7.266E-01 | 8.622E+00 | 1.4 | 1.746E-01 | 8.867E-01 | 9.193E+00 |
| 1.480E-01 | 5.346E-01 | 6.138E+00 | 2.0 | 1.565E-01 | 6.612E-01 | 6.600E+00 |
| 1.318E-01 | 4.460E-01 | 4.209E+00 | 2.8 | 1.394E-01 | 5.560E-01 | 4.572E+00 |
| 1.118E-01 | 4.157E-01 | 2.738E+00 | 4.0 | 1.182E-01 | 5.184E-01 | 3.010E+00 |
| 9.767E-02 | 4.114E-01 | 2.130E+00 | 5.0 | 1.033E-01 | 5.114E-01 | 2.355E+00 |
| 7.482E-02 | 4.102E-01 | 1.567E+00 | 7.0 | 7.917E-02 | 5.064E-01 | 1.739E+00 |
| 5.030E-02 | 4.092E-01 | 1.246E+00 | 10.0 | 5.323E-02 | 5.003E-01 | 1.382E+00 |
| 2.603E-02 | 4.059E-01 | 1.020E+00 | 15.0 | 2.754E-02 | 4.896E-01 | 1.128E+00 |
| 1.351E-02 | 4.010E-01 | 8.835E-01 | 20.0 | 1.429E-02 | 4.783E-01 | 9.761E-01 |
| 7.034E-03 | 3.951E-01 | 7.759E-01 | 25.0 | 7.443E-03 | 4.668E-01 | 8.568E-01 |
| 3.682E-03 | 3.886E-01 | 6.846E-01 | 30.0 | 3.897E-03 | 4.554E-01 | 7.557E-01 |
| 1.045E-03 | 3.746E-01 | 5.363E-01 | 40.0 | 1.107E-03 | 4.334E-01 | 5.918E-01 |
| 3.345E-04 | 3.604E-01 | 4.221E-01 | 50.0 | 3.549E-04 | 4.130E-01 | 4.657E-01 |
| 1.406E-04 | 3.466E-01 | 3.330E-01 | 60.0 | 1.497E-04 | 3.943E-01 | 3.673E-01 |
| 8.574E-05 | 3.336E-01 | 2.631E-01 | 70.0 | 9.166E-05 | 3.773E-01 | 2.902E-01 |
| 6.848E-05 | 3.215E-01 | 2.080E-01 | 80.0 | 7.336E-05 | 3.620E-01 | 2.295E-01 |
| 6.151E-05 | 3.103E-01 | 1.646E-01 | 90.0 | 6.596E-05 | 3.480E-01 | 1.815E-01 |
| 5.749E-05 | 2.998E-01 | 1.302E-01 | 100.0 | 6.166E-05 | 3.351E-01 | 1.437E-01 |
| 5.442E-05 | 2.902E-01 | 1.031E-01 | 110.0 | 5.841E-05 | 3.234E-01 | 1.137E-01 |

## VALUE/IMPACT STATEMENT

A Value/Impact Statement was published with Regulatory Guide 3.54 when it was issued in September 1994. No changes are necessary, so a separate value/impact statement for this proposed Revision 1 has not been prepared. A copy of the value/impact statement is available for inspection or copying for a fee in the Commission's Public Document Room at 2120 L Street NW., Washington, DC, under Regulatory Guide 3.54. The PDR's mailing address is Mail Stop LL-6, Washington, DC 20555; telephone (202)634-3273; fax (202)634-3343.