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Spent Fuel Decay Heat Measurements Performed at the Swedish Central Interim Storage Facility

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Prepared by
B.D. Murphy and I.C. Gauld

Oak Ridge National Laboratory
Managed by UT-Battelle, LLC
Oak Ridge, TN 37831-6170

M. Aissa, NRC Project Manager

NRC Job Code Y6517

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ABSTRACT

Calorimeter measurements of full-length spent fuel assemblies have been performed at the Swedish Central Interim Storage Facility for Spent Fuel (CLAB) located in Oskarshamn, Sweden. These measurements provide an important and unique database for the validation of computer code predictions of decay heat for modern fuel types and assembly designs. The measured assemblies include boiling-water reactor 8 × 8, 9 × 9, SVEA-64, and SVEA-100 assemblies, and pressurized-water reactor 15 × 15 and 17 × 17 assemblies. This report compiles the assembly design and fuel data, reactor operating history data, reactor conditions, and the results of the decay heat measurements that have been performed for intact spent fuel assemblies. The data are presented in sufficient detail to allow independent code validation studies to be performed.

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1 INTRODUCTION

The Swedish Nuclear Fuel and Waste Management Company, Svensk Kärnbränslehuntering AB (SKB), has initiated a large experimental program to measure decay heat from boiling-water reactor (BWR) and pressurized-water reactor (PWR) assemblies residing at the Swedish Central Interim Storage Facility for Spent Nuclear Fuel, CLAB, located outside Oskarshamn, Sweden.[1] Oak Ridge National Laboratory (ORNL), under a collaboration agreement with SKB, has provided technical support to the program in the areas of calorimeter design, uncertainty assessment, evaluation of the fuel design data and experimental data, and validation of computational methods using the ORNL SCALE code system[2] to predict assembly decay heat. The decay heat measurements performed at CLAB are being used to extend the validation database, beyond that currently available, to include modern-design assemblies and high burnup fuel. The measurements are being used by ORNL to validate computer code predictions of decay heat for a wide range of fuel designs and support the technical basis for expanding the U.S. Nuclear Regulatory Commission (NRC) Regulatory Guide RG 3.54, Spent Fuel Heat Generation in an Independent Spent Fuel Storage Installation.[3]

This report presents a compilation of the experimental measurements, fuel and assembly design data, fuel irradiation data, and reactor operating information necessary to perform benchmark calculations. A more extensive report on the measurements and assembly data has been published separately by SKB.[4] The assemblies described in this report include 8 × 8, 9 × 9, SVEA-64, SVEA-100, 15 × 15, and 17 × 17 designs. This report is restricted to include only the measurements of intact fuel assemblies. Those assemblies that were rebuilt (fuel rods either removed or reconfigured) are not included at this time because insufficient information was available on the details of the reconstitution to allow the assemblies to be considered for use in code validation. A total of 34 BWR assemblies and 30 PWR assemblies are described in this report. Multiple measurements were performed on some assemblies. All calorimeter measurements documented in this report were performed at the CLAB facility between June 2003 and June 2004.

The fuel data and measurement information documented in this report were supplied by SKB. Reactor operating history data, assembly burnup data by reactor cycle, axial void profiles, and other reactor data is based on information provided by Swedish nuclear power plants. Detailed information was not available for all assemblies at the time this study was performed. For these assemblies, appropriate values were estimated based on the data for similar assemblies with more detailed descriptions. Any information in this report that has been estimated or inferred from other assemblies is indicated.

2 FACILITY DESCRIPTION

All fuel assembly calorimeter measurements described in this report were performed at the Swedish CLAB spent fuel storage facility located near the site of the Oskarshamn Nuclear Power Station owned by OKG, in Sweden. The CLAB facility is operated by OKG for SKB. Spent nuclear fuel from all Swedish reactors is stored at CLAB in pools located 30 m below ground, with a capacity of 5,000 tonnes of uranium (about 20,000 BWR assemblies and 2,500 PWR assemblies).

To support the characterization of the spent fuel inventory at CLAB, SKB has undertaken a project to construct a spent fuel assembly calorimeter and perform measurements for use in validating computer code predictions of decay heat. Measurements will be repeated on selected fuel assemblies at intervals in the future, and additional assemblies may be added as required to validate computer code predictions over the range of fuel inventory at CLAB. The experimental program being conducted by SKB is being used to validate the computer code and data used to support the safety analysis of the final repository for radioactive waste to be constructed in Sweden.

The design of the calorimeter at CLAB is based on the calorimeter design used at GE Morris Operations.[5,6] The calorimeter is 4.9 m long and composed of two concentric pipes separated by polyurethane foam to provide insulation between the interior vessel and the pool water. There is a fixed insert for PWR fuel assemblies and a removable insert for BWR assemblies, used to maintain the fuel assembly centered and vertical in the calorimeter. Temperatures within the calorimeter are measured by 16 PT-100 type sensors: 8 sensors in the water inside the vessel; 2 sensors on the inside and outside surfaces of the calorimeter; and 2 sensors outside the calorimeter to measure the pool water temperature. There are five gamma monitors positioned to measure the radial distribution of gamma radiation that escapes the calorimeter, which is used to correct the calorimeter data for gamma energy loss.

The calorimeter is typically operated in static mode using the rate of water temperature increase to establish the thermal output of the assemblies. The decay heat is evaluated by comparing the temperature increase to a calibration curve established using an electric heated assembly prior to each measurement campaign. The calibration curves are made for a series of power levels that allow the rate of temperature rise to be determined as a function of assembly decay heat. The decay heat established by the measurements is then corrected for the measured energy loss from gamma rays escaping from the calorimeter. The calorimeter is shown at poolside and raised to show the assembly loading hatch of the calorimeter above the water level in Figures 1 and 2. The digital controller and readout monitor are shown in Figure 3.

The design target accuracy for the calorimeter was about ± 2% at the 95% confidence level. The random 95 % error associated with the measurements, based on the final design of the calorimeter, was estimated by SKB as a function of decay heat rate: for a low thermal output of about 50 W, the estimated error is ± 4.5 W, or 9%. For a thermal output of about 300 W, the error is about ± 8 W or 2.7%, decreasing relatively to ± 15.5 W or 1.7% at 900 W of generated heat.

The actual random error was estimated[7] using the results of repeat measurements for six of the BWR assemblies and four of the PWR assemblies. The standard deviation for this group of BWR and PWR assemblies was found to be 3.94 W. For the BWR assemblies only, the value was 1.4 W, and for the PWR assemblies it was 5.8 W. These results are consistent with the random error estimated by SKB; however, the population of assemblies is small in both cases. The uncertainty analysis described includes only random sources of uncertainty and does not address potential sources of systematic bias. A more detailed description of the analysis of measurements and evaluation of measurement uncertainty is documented in Ref. 7.

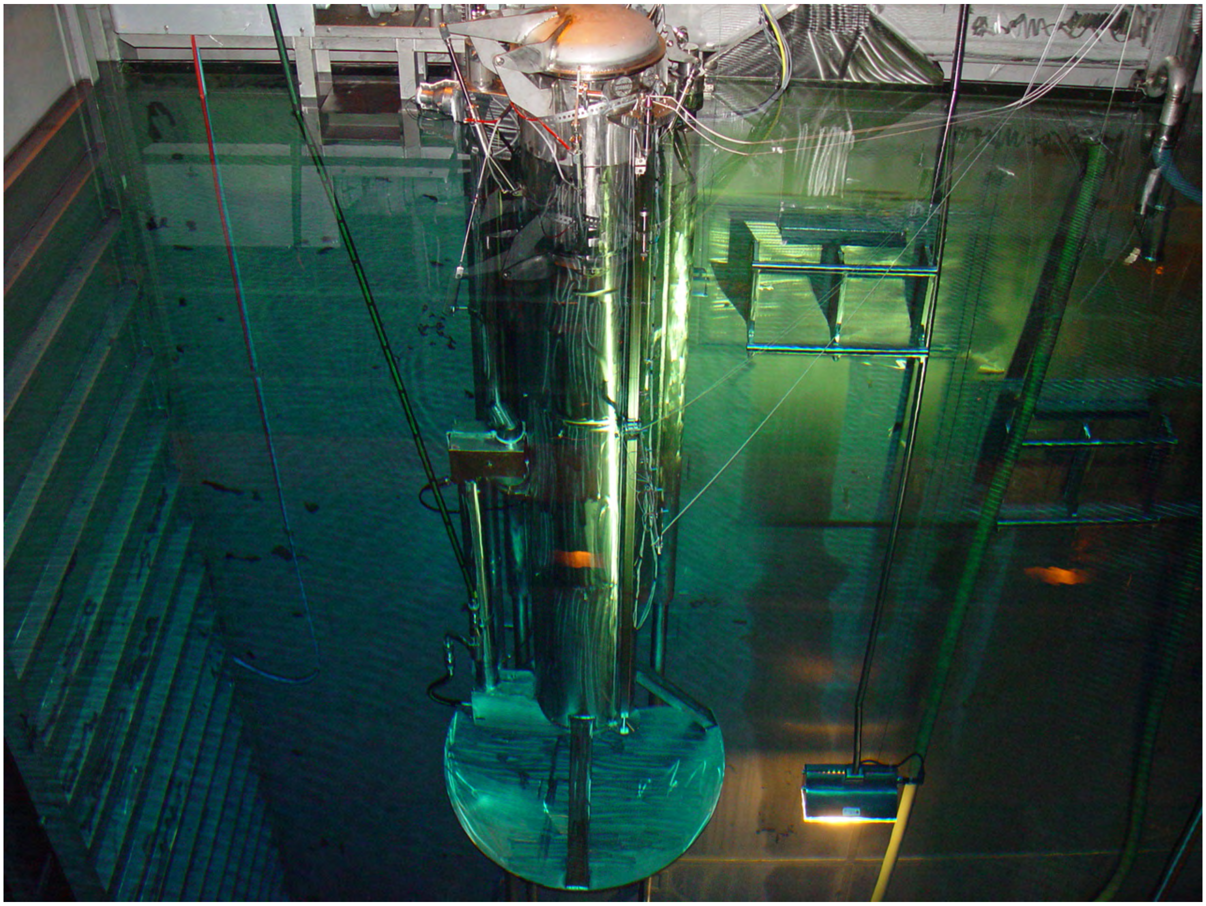

Figure 1 Spent fuel assembly calorimeter at the Swedish CLAB facility

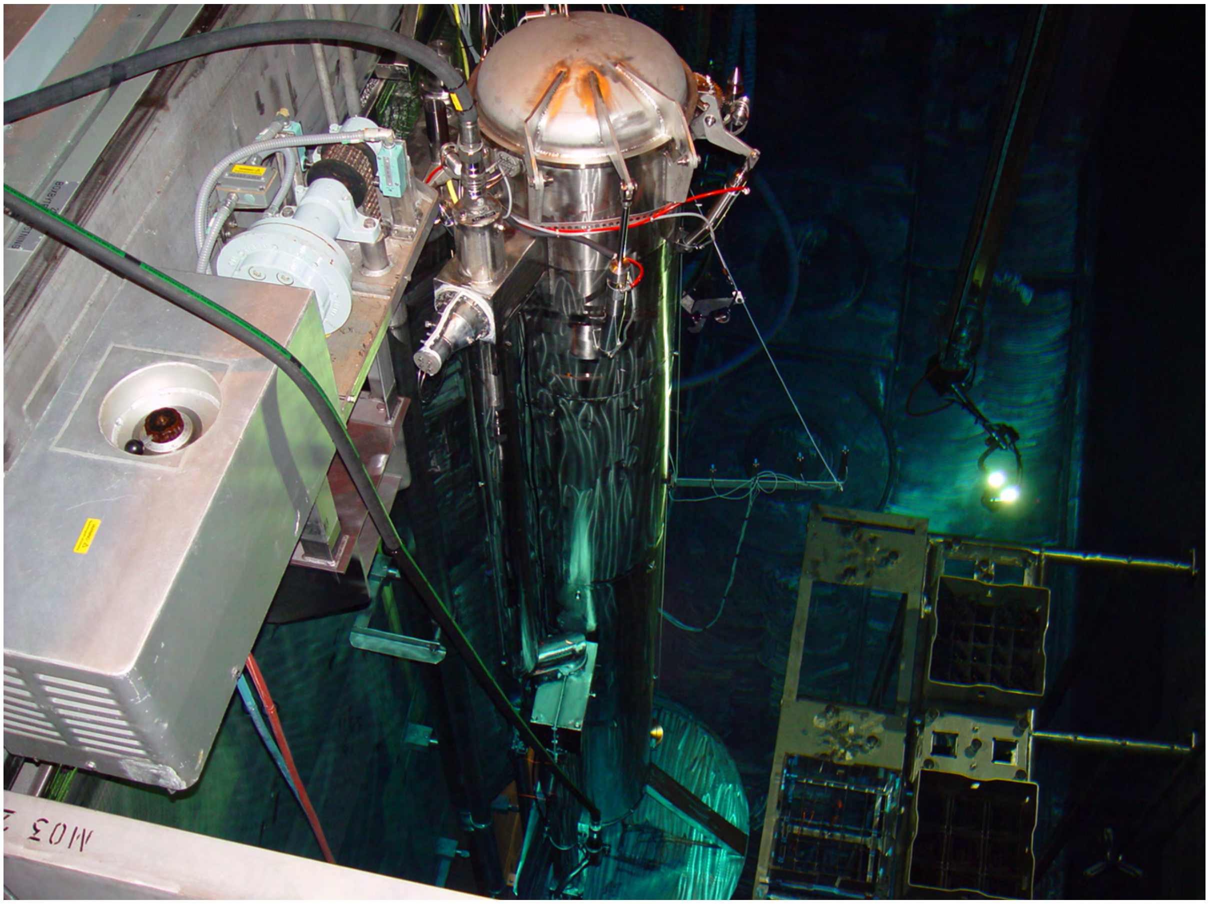

Figure 2 Spent fuel assembly calorimeter (side view)

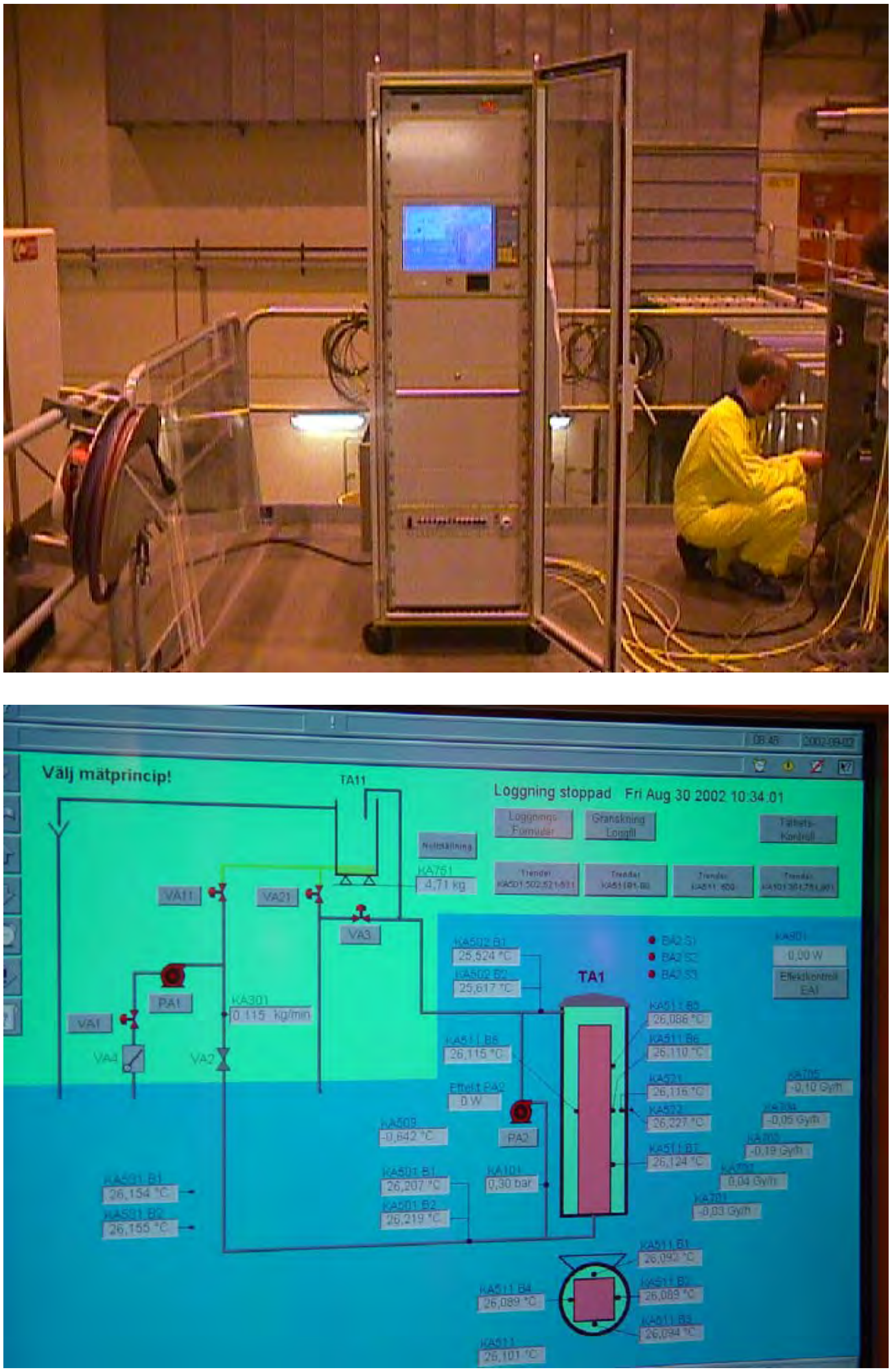

Figure 3 View of calorimeter controller (top) and digital readout monitor (bottom)

3 REACTOR DESCRIPTIONS

The BWR and PWR assemblies that were measured were irradiated in ten different Swedish reactors. Some general reactor information and other data relevant to the decay heat simulations are listed in Table 1. Also listed in the table are the number of assemblies in the core and (where available) the total mass of uranium in the core.

The BWR assemblies described in this report are from the following nuclear power stations:

Barsebäck 1: Two 8 × 8 assemblies.

Barsebäck 2: One 8 × 8 assembly.

Forsmark 1: Two 8 × 8 assemblies and three 9 × 9 assemblies.

Forsmark 2: One 8 × 8 assembly and three SVEA-64 assemblies.

Forsmark 3: Two SVEA-100 assemblies.

Oskarshamn 2: Seven 8 × 8 assemblies and one SVEA-64 assembly.

Oskarshamn 3: One 8 × 8 assembly and two SVEA-100 assemblies.

Ringhals 1: Nine 8 × 8 assemblies.

The PWR assemblies are from the following nuclear power stations:

Ringhals 2: Sixteen 15 × 15 assemblies.

Ringhals 3: Fourteen 17 × 17 assemblies.

Tables 2–11 list the operating data for each reactor. Most important among these are the beginning and ending dates of all cycles of the assemblies in the study. These dates were used to determine the cycle lengths and downtime between cycles.

An important operating parameter for the PWR plants is the soluble boron concentration in the moderator. This information was not provided for either the Ringhals 2 or 3 plants. Based on PWR reactor data compiled in previous validation studies,[7–11] typical cycle-averaged boron levels may be assumed. A parametric study found that the predicted decay heat was not very sensitive to the boron level for the cooling times of interest, indicating that average boron levels are adequate.

Table 1 Reactor operating and design data[a]

Reactor	Type	Pressure (MPa)	Inlet temperature (K)	Outlet temperature (K)	Assembly pitch (cm)	Assemblies in core	U mass in core (MT)
Barsebäck 1	BWR	6.86	545	559	15.30	444	----
Barsebäck 2	BWR	6.86	545	559	15.30	444	----
Forsmark 1	BWR	6.86	547	559	15.38	676	120.6
Forsmark 2	BWR	6.86	547	559	15.40	676	121.5
Forsmark 3	BWR	6.86	551	559	15.45	700	126.1
Oskarshamn 2	BWR	6.86	547	559	15.30	444	80.2
Oskarshamn 3	BWR	6.86	550	561	15.50	700	125.3
Ringhals 1	BWR	6.86	545	559	15.33	648	115.4
Ringhals 2	PWR	15.1	559	595	21.50	157	----
Ringhals 3	PWR	15.3	557	595	21.50	157	----

[a] Data for the reactor operating pressures, inlet and outlet temperatures, and assembly pitch, were obtained from the *World Reactor Handbook*, 2002 (Ref. 12).

Table 2 Barsebäck 1 reactor operating history data

Cycle	Start date	Stop date	Cycle length (days)	Downtime (days)
8	8/6/1983[a]	6/28/1984	327	28
9	7/26/1984	8/7/1985	377	26
10	9/2/1985	7/17/1986	318	32
11	8/18/1986	7/1/1987	317	28
12	7/29/1987	9/17/1988	416	

[a] Dates given as month/day/year.

Table 3 Barsebäck 2 reactor operating history data

Cycle	Start date	Stop date	Cycle length (days)	Downtime (days)
9	9/19/1987	7/6/1988	291	32
10	8/7/1988	9/8/1989	397	20
11	9/28/1989	7/11/1990	286	38
12	8/18/1990	9/6/1991	384	16
13	9/22/1991	7/2/1992	284	37

Table 4 Forsmark 1 reactor operating history data

Cycle	Start date	Stop date	Cycle length (days)	Downtime (days)
1A	4/23/1980	6/25/1981	428	52
1B[a]	8/16/1981	6/19/1982	307	67
2	8/25/1982	7/15/1983	324	21
3	8/5/1983	7/13/1984	343	24
4	8/6/1984	5/31/1985	298	38
5	7/8/1985	7/4/1986	361	18
6	7/22/1986	7/31/1987	374	19
7	8/19/1987	6/10/1988	296	30
8	7/10/1988	7/14/1989	369	35
9	8/18/1989	8/17/1990	364	30
10	9/16/1990	5/24/1991	250	27

[a] Reactor cycle simulated in multiple phases.

Table 5 Forsmark 2 reactor operating history data

Cycle	Start date	Stop date	Cycle length (days)	Downtime (days)
1A	12/1/1980	5/1/1982	516	109
1B	8/18/1982	5/20/1983	275	22
2	6/11/1983	5/25/1984	349	49
3	7/13/1984	7/5/1985	357	21
4	7/26/1985	7/25/1986	364	15
5	8/9/1986	5/31/1987	295	20
6	6/20/1987	7/15/1988	391	20
7	8/4/1988	8/18/1989	379	17
8	9/4/1989	5/18/1990	256	25
9	6/12/1990	7/12/1991	395	19

Table 6 Forsmark 3 reactor operating history data

Cycle	Start date	Stop date	Cycle length (days)	Downtime (days)
2	9/2/1986	7/10/1987	311	30
3	8/9/1987	8/12/1988	369	24
4	9/5/1988	6/9/1989	277	34
5	7/13/1989	7/13/1990	365	16

Table 7 Oskarshamn 2 reactor operating history data

Cycle	Start date	Stop date	Cycle length (days)	Downtime (days)
1	10/2/1974	4/16/1976	562	77
2	7/2/1976	5/13/1977	315	86
3	8/7/1977	6/24/1978	321	71
4	9/3/1978	7/20/1979	320	41
5	8/30/1979	7/12/1980	317	39
6	8/20/1980	7/15/1981	329	46
7	8/30/1981	7/23/1982	327	31
8	8/23/1982	8/19/1983	361	31
9	9/19/1983	7/1/1984	286	54
10	8/24/1984	6/7/1985	287	36
11	7/13/1985	8/16/1986	399	42
12	9/27/1986	7/31/1987	307	35
13	9/4/1987	8/20/1988	351	21
14	9/10/1988	8/5/1989	329	27
15	9/1/1989	8/10/1990	343	62
16	10/11/1990	8/2/1991	295	

Table 8 Oskarshamn 3 reactor operating history data

Cycle	Start date	Stop date	Cycle length (days)	Downtime (days)
1	3/18/1985	7/4/1986	473	22
2	7/26/1986	7/3/1987	342	23
3	7/26/1987	7/8/1988	348	37
4	8/14/1988	12/10/1988	118	12
4B	12/22/1988	6/7/1989	167	13
5	6/20/1989	6/23/1990	368	39
6	8/1/1990	6/24/1991	327	

Table 9 Ringhals 1 reactor operating history data

Cycle	Start date	Stop date	Cycle length (days)	Downtime (days)
2	10/13/1978	7/12/1979	272	80
3	9/30/1979	7/3/1980	277	97
4	10/8/1980	7/30/1981	295	99
5	11/6/1981	7/22/1982	258	49
6	9/9/1982	6/18/1983	282	104
7	9/30/1983	7/13/1984	287	46
8	8/28/1984	8/2/1985	339	31
9	9/2/1985	8/15/1986	347	55
10	10/9/1986	8/21/1987	316	34
11	9/24/1987	8/6/1988	317	36
12	9/11/1988	9/15/1989	369	26
13	10/11/1989	8/4/1990	297	26
14	8/30/1990	8/9/1991	344	28

Table 10 Ringhals 2 reactor operating history data

Cycle	Start date	Stop date	Cycle length (days)	Downtime (days)
1	6/19/1974	4/13/1977	1029	85
2	7/7/1977	3/31/1978	267	56
3	5/26/1978	4/3/1979	312	83
4	6/25/1979	4/1/1980	281	78
5	6/18/1980	4/4/1981	290	80
6	6/23/1981	5/6/1982	317	84
7	7/29/1982	4/28/1983	273	91
8	7/28/1983	4/13/1984	260	90
9	7/12/1984	4/4/1985	266	71
10	6/14/1985	4/30/1986	320	63
11	7/2/1986	4/25/1987	297	54
12	6/18/1987	5/12/1988	329	

Table 11 Ringhals 3 reactor operating history data

Cycle	Start date	Stop date	Cycle length (days)	Downtime (days)
1A	7/29/1980	6/2/1983	1038	104
1B	9/14/1983	5/11/1984	240	74
2	7/24/1984	5/25/1985	305	47
3	7/11/1985	5/30/1986	323	49
4	7/18/1986	6/18/1987	335	47
5	8/4/1987	7/7/1988	338	38

4 ASSEMBLY DESIGN DATA

4.1 Overview of Assembly Designs

Swedish nuclear fuel assemblies are manufactured by Westinghouse Nuclear Fuel Operations, located in Västerås, Sweden. The fuel assemblies selected for the decay heat measurements at CLAB included fuels from the Swedish Barsebäck, Forsmark, Oskarshamn, and Ringhals Nuclear Power Stations. The assemblies include a broad range of designs: 8 × 8, 9 × 9, SVEA-64 (8 × 8), SVEA-100 (10 × 10), 15 × 15, and 17 × 17. The total number of BWR and PWR assembly measurements included in this report was 34 and 30, respectively. Multiple decay heat measurements were made on some assemblies. A summary of the measured assemblies described in this report is given in Table 12; this table includes the enrichment range and maximum burnup of the assemblies.

Table 12 Summary of measured Swedish fuel assemblies

Reactor	Assembly design	Enrichments (wt % ^{235}U)	Number of assemblies measured	Maximum burnup (MWd/MTU)
Barsebäck 1	8 × 8	2.922, 2.953	2	41,127
Barsebäck 2	8 × 8	3.154	1	40,010
Forsmark 1	8 × 8	2.090, 2.970	2	34,193
Forsmark 1	9 × 9	2.938	3	37,896
Forsmark 2	8 × 8	2.095	1	19,944
Forsmark 2	SVEA-64	2.850 – 2.920	3	32,837
Forsmark 3	SVEA-100	2.770	2	31,275
Oskarshamn 2	8 × 8	2.201 – 2.875	7	29,978
Oskarshamn 2	SVEA-64	2.902	1	46,648
Oskarshamn 3	8 × 8	2.577	1	25,160
Oskarshamn 3	SVEA-100	2.711	2	40,363
Ringhals 1	8 × 8	2.640, 2.911	9	37,851
Ringhals 2	15 × 15	3.095 – 3.252	16	50,962
Ringhals 3	17 × 17	2.100 – 3.103	14	41,628

The following sections document the assembly design details for each type of assembly measured at CLAB and included in this report. The designs for reconstituted assemblies are not included. In general, more than one set of design data exists for each assembly type. Each type of assembly is listed in a separate table column (identified by *Type*). Many of the assembly geometry design specifications are common to several versions. The fuel description, burnable poison rod exposure, etc. is given separately in Section 5.

4.2 17 × 17 PWR Assemblies

The design data for the 17 × 17 assembly configuration are listed in Table 13. The actual dimensions given for some assemblies were slightly different than those for other assemblies; however these variations were extremely small and were likely within design tolerances and of negligible neutronic importance. Therefore only one set of design dimensions are listed. The layout and basic design dimensions are illustrated in Appendix A.1.

Data in Table 13 also include information on the spacer grid material and mass. The spacer material is one of the structural components of the assembly that contributes to the decay heat. Although not a major contributor, the structural components can be responsible for up to several percent of the decay heat. Essentially all of the decay heat from the structural components comes from activated cobalt in the Inconel spacers.

Table 13 contains data on burnable absorber (poison) rods that are inserted in a fraction of the guide tube locations, typically during the first cycle of assembly irradiation. Some of the measured 17 × 17 assemblies were exposed to burnable absorber rods. The number of guide tubes containing the absorbers was provided and is listed in Section 5. The burnable absorber (BA) material was assumed to be a borosilicate type BA (B_2O_3-SiO_2) rod, typically used in Westinghouse 17 × 17 designs.[13] The quantity of B_2O_3 in the BA rods and the design data for the rods were not provided. Based on a previous study of Westinghouse assembly designs,[13] the BA rods are likely to be stainless steel clad absorbers that are annular in shape. The space internal to this annulus is a gas (not water). The design dimensions for the BA rods are given in Table 13. The presence (and number) of BA rods for individual assemblies is indicated in Section 5.

4.3 15 × 15 PWR Assemblies

There are two different 15 × 15 assembly configurations, listed as Type 1 and 2 in Table 14. As can be seen from the table, the differences are related primarily to the fuel diameter and mass of spacer material. The layout and basic design dimensions are illustrated in Appendix A.1.

The BA rod data are not applicable to the 15 × 15 assemblies. No BA rod exposure was reported for any of the 15 × 15 assemblies considered in this report.

Table 13 17 × 17 PWR assembly design data

Design data	Type 1
Assembly size	17 × 17
Number of fuel rods	264
Number of guide tubes	24
Number of instrument tubes	1
Fuel rod pitch (cm)	1.26
Fuel rod diameter (cm)	0.95
Fuel clad thickness (cm)	0.0572
Fuel pellet diameter (cm)	0.8191
Guide tube outer diameter (cm)	1.224
Guide tube thickness (cm)	0.0406
Instrument tube outer diameter (cm)	1.224
Instrument tube thickness (cm)	0.0406
Fuel clad material	Zircaloy-4
Guide tube material	Zircaloy-4
Instrument tube material	Zircaloy-4
Number of spacers	8
Spacer material	Inconel 718
Spacer mass (grams per spacer)	753
Active fuel length (cm)	365.8
Burnable absorber rod data[a]	
Material	B_2O_3 -SiO_2
B_2O_3 concentration (wt %)	12.5
Density (g/cm^3)	2.299
Outer diameter (cm)	0.85344
Inner diameter (cm)	0.4826
Clad material	304 SS
Outer clad outer diameter (cm)	0.96774
Outer clad inner diameter (cm)	0.87376
Inner clad outer diameter (cm)	0.46101
Inner clad inner diameter (cm)	0.42799

[a] Source: Data from Ref. 13.

Table 14 15 × 15 PWR assembly design data

Design data	Type 1	Type 2
Assembly size	15 × 15	15 × 15
Number of fuel rods	204	204
Number of guide tubes	20	20
Number of instrument tubes	1	1
Fuel rod pitch (cm)	1.43	1.43
Fuel rod diameter (cm)	1.072	1.075
Fuel clad thickness (cm)	0.0618	0.0725
Fuel pellet diameter (cm)	0.929	0.911
Guide tube outer diameter (cm)	1.387	1.389
Guide tube thickness (cm)	0.043	0.043
Instrument tube outer diameter (cm)	1.387	1.389
Instrument tube thickness (cm)	0.043	0.043
Fuel clad material	Zr4	Zr4
Guide tube material	Zr4	Zr4
Instrument tube material	Zr4	Zr4
Number of spacers	7	7
Spacer material	Inconel	Inconel/Zr-4
Spacer mass (grams per spacer)	788	720/160
Active length (cm)	365.8	365.8

4.4 8 × 8 BWR Assemblies

Four different 8 × 8 assembly types are described in Table 15. Three of the four types use corner rods that have a slightly smaller diameter than those internal to the assembly. These assemblies have three corner rods located at each corner of the assembly. The Type 4 assemblies have fuel rods of uniform diameter. Minor differences in dimensions were noted for some of the assemblies. Where such differences were deemed to be inconsequential to the analysis of decay heat, such assemblies were grouped into a single assembly type to minimize the number of unique designs considered.

The BWR assemblies specify inner and outer dimensions for a flow channel that surrounds each assembly, referred to here as a box. The inner diameter (flat-to-flat) of the box is slightly greater than the width of the fuel lattice (based on the pitch of fuel rods), resulting in a region of extra water outside of the fuel rods and inside of the channel box. The water within the box (with the exception of the water rods internal to the assembly) is considered to be in the boiling-water region, whereas the water outside the box is not considered as a boiling region.

The 8 × 8 assemblies generally contain water rods. Water rods are Zircaloy tubes containing water at a higher density (i.e., non-boiling) than that of the boiling region to provide additional moderation in the fuel lattice. The fuel clad material was not provided for most assemblies, and Zircaloy-4 was generally assumed. From the standpoint of the decay heat analysis, it is not important whether the clad is Zircaloy-2 or Zircaloy-4. Similar assumptions apply to the material in the water rods. Some assemblies also contained solid Zircaloy rods; referred to as spacer rods in this report. The diameter of the spacer rods is the same as that for the water rods.

Many of the 8 × 8 assemblies also contained integral burnable poison rods. These poison rods contain gadolinium oxide (Gd_2O_3) mixed with the uranium oxide. These rods are not removed during the irradiation life of the assembly, but rather form an integral part of the assembly. The number of poison rods and the average poison concentration is given in Section 5. The configuration of the poison rods in the assembly was not provided, as this is usually considered proprietary information. A typical configuration for the 8 × 8 assemblies is illustrated in Appendix A.2. The arrangement of any poison rods in these figures is presented for illustrative purposes only, because the actual arrangement will vary for different assemblies. Similar considerations apply for the enrichment zoning shown in the figures.

4.5 9 × 9 BWR Assemblies

All 9 × 9 assemblies described in this report were of the same type (i.e., same physical dimensions). The design data for these assemblies are listed in Table 16. The diameter of the water rods is given as being slightly greater than the rod pitch. The lattice configuration for a 9 × 9 assembly with five water rods is illustrated in Appendix A.2. The assemblies included in this report had 4 water rods and 1 Zircaloy rod. Fuel clad material was assumed to a Zircaloy material.

4.6 SVEA Assemblies

Both SVEA-64 and SVEA-100 design assemblies were measured. The SVEA designs are unique from other 8 × 8 or 10 × 10 designs because the fuel rods are configured in four quadrants, or subassemblies, which are separated by a large region of non-voiding water moderator, often referred to as a water cross. Tables 17 and 18 contain the design data for the SVEA-64 and SVEA-100 assemblies, respectively.

The SVEA-64 assembly contains one water rod and 63 fuel rods. The fuel cladding material was not specified and is assumed to be Zircaloy. The design dimensions for all SVEA-64 assemblies were effectively the same. However, Forsmark 2 assemblies had an Inconel spacer mass given as 35 grams, while the Oskarshamn 2 had a spacer mass of 31 grams. Because of the relatively small contribution of the spacer material to decay heat, the spacer mass listed in Table 17 for the SVEA-64 assembly is 35 grams.

There are no water rods present in any of the SVEA-100 assemblies included in this report (all contain 100 fuel rods). Fuel clad material was not specified and was assumed to be Zircaloy.

Table 15 8 × 8 BWR assembly design data

Design data	Type 1	Type 2	Type 3	Type 4
Assembly size	8 × 8	8 × 8	8 × 8	8 × 8
Number of fuel rods	63	63	63	62
Number of corner rods	12	12	12	0
Number of water rods	1	1	0	1
Number of Zr spacer rods	0	0	1	1
Rod pitch, inner rods (cm)	1.63	1.63	1.63	1.625
Rod pitch, corner rods (cm)	1.58	1.58	1.58	N/A
Rod pitch, corner-inner rods (cm)	1.605	1.605	1.605	N/A
Normal rod diameter (cm)	1.225	1.225	1.225	1.23
Normal rod clad thickness (cm)	0.074	0.08	0.08	0.082
Normal rod pellet diameter (cm)	1.058	1.044	1.044	1.044
Corner rod diameter (cm)	1.175	1.175	1.175	N/A
Corner rod clad thickness (cm)	0.074	0.08	0.08	N/A
Corner rod pellet diameter (cm)	1.008	0.994	0.994	N/A
Fuel clad material[a]	Zircaloy-4	Zircaloy-4	Zircaloy-4	Zircaloy-4
Water rod outer diameter (cm)	1.225[a]	1.225[a]	1.225	1.5
Water rod thickness (cm)	0.08[a]	0.08[a]	0.08[a]	0.08
Water rod material	Zircaloy-2	Zircaloy-2	Zircaloy-2	Zircaloy-2
Box outer flat-to-flat distance (cm)	13.9	13.9	13.9	13.9
Box inner flat-to-flat distance (cm)	13.5	13.44	13.44	13.44
Box wall thickness (cm)	0.2	0.23	0.23	0.23
Box material	Zircaloy-4	Zircaloy-4	Zircaloy-4	Zircaloy-4
Active fuel length (cm)	365.0	368.0	371.2	368.0
Number of spacers	6	6	6	6
Spacer material	Inconel	Inconel	Inconel	Inconel
Spacer mass (grams per spacer)	135	135	135	323

[a] Assumed data.

Table 16 9 × 9 BWR assembly design data

Design data	Type 1
Assembly size	9 × 9
Number of fuel rods	76
Number of water rods	4
Number of Zr spacer rods	1
Fuel rod pitch (cm)	1.445
Fuel rod diameter (cm)	1.1
Fuel clad thickness (cm)	0.0665
Fuel pellet diameter (cm)	0.95
Fuel clad material	Zircaloy-4 [a]
Water rod outer diameter (cm)	1.5
Water rod thickness (cm)	0.08
Water rod material	Zircaloy-2
Box outer flat-to-flat distance (cm)	13.9
Box wall thickness (cm)	0.23
Box material	Zr-4
Active fuel length (cm)	368.0
Number of spacers	6
Spacer material	Zircaloy-4
Spacer mass (grams per spacer)	323

[a] Assumed data.

Table 17 SVEA-64 assembly design data

Design data	Type 1
Assembly size	8 × 8
Number of fuel rods	63
Number of water rods	1
Fuel rod pitch (cm)	1.58
Fuel rod diameter (cm)	1.225
Fuel clad thickness (cm)	0.08
Fuel pellet diameter (cm)	1.044
Water rod outer diameter (cm)	1.225
Water rod thickness (cm)	0.08
Box outer flat-to-flat distance (cm)	14.0
Box wall thickness (cm)	0.11
Box material	Zircaloy-4
Water cross material	Zircaloy-4
Water cross wall thickness (cm)	0.08
Sub-assembly inner measure[b] (cm)	6.59
Active fuel length (cm)	368.0
Fuel clad material	Zircaloy-4[a]
Water rod material	Zircaloy-2
Number of spacers	24 (4 × 6)
Spacer material	Inconel
Spacer mass (grams per spacer)	35

[a] Assumed data.
[b] Flat-to-flat distance across the subassembly box.

Table 18 SVEA-100 assembly design data

Design data	Type 1
Assembly size	10 × 10
Number of fuel rods	100
Number of water rods	0
Fuel rod pitch (cm)	1.24
Fuel rod diameter (cm)	0.962
Fuel clad thickness (cm)	0.063
Fuel pellet diameter (cm)	0.819
Fuel clad material	Zircaloy-4 [a]
Box outer flat-to-flat distance (cm)	13.96
Box wall thickness (cm)	0.11
Box material	Zircaloy-4
Water cross material	Zircaloy-4
Water cross wall thickness (cm)	0.11
Sub-assembly inner dimension[b] (cm)	6.56
Nominal active fuel length (cm)	370.0
Number of spacers	24 (4 × 6)
Spacer material	Inconel
Spacer mass (grams per spacer)	24

[a] Assumed data.
[b] Flat-to-flat distance across the subassembly box.

5 FUEL DATA

This section describes the enrichment levels, fuel density, and burnable poison rod data for the fuel assemblies measured and included in the present report. For most assemblies only ^{235}U and ^{238}U concentrations were available and are listed. For the 15 × 15 assemblies, data on ^{234}U and ^{236}U were also available.

The fuel enrichment in PWR assemblies is typically the same for all non-poison rods in the assembly. However, BWR assemblies typically reduce the enrichment of the outermost rods of the assembly (where thermal flux is larger) relative to the rods internal to the assembly to achieve a more uniform power distribution. Assembly enrichment zoning patterns vary widely and are typically proprietary fuel vendor information. The assembly enrichment zoning was not provided for the Swedish assemblies. All enrichment data provided in the tables of this section represent assembly-average values. The enrichment zoning patterns shown for the BWR assemblies in Appendix A.2 is for illustrative purposes only.

5.1 PWR 15 × 15 Assemblies

Table 19 shows fuel data for the 15 × 15 assemblies. Reactor, assembly, and assembly type are noted. The complete design and fuel data for each assembly type can be obtained by cross-referencing the type with the design data given in Section 4. The effective fuel (UO_2) density accounts for porosity and dishing of the fuel pellets. The initial composition of the uranium is listed by the isotopic vector for ^{234}U, ^{235}U, ^{236}U, and ^{238}U, and also by mass in the assembly. There was no burnable absorber rod exposure indicated for any of the measured 15 × 15 assemblies.

5.2 PWR 17 × 17 Assemblies

Table 20 shows fuel data for the 17 × 17 assemblies. Reactor, assembly, and assembly type are noted. The effective fuel density and uranium isotopic mass values are listed for ^{235}U and ^{238}U. The initial concentrations of ^{234}U and ^{236}U were not provided.

Four of the measured 17 × 17 assemblies were identified as having burnable absorber rods during irradiation. However, the duration of the BA rod insertion was not provided. Based on typical PWR operational practice,[13] the BA rods are typically inserted in the assemblies during the first cycle of reactor exposure, after which they are withdrawn. Although the boron levels in the poison rods are significantly depleted after the first cycle, the BA rods are not always withdrawn after one cycle, and continued presence of the rods will reduce the moderation in the guide tubes.

5.3 BWR 8 × 8 Assemblies

Table 21 shows fuel data for the 8 × 8 assemblies. Isotopic data for uranium are listed for the ^{235}U and ^{238}U isotopes. The number of integral burnable poison rods and the concentration of burnable poison (Gd_2O_3) in the fuel pellets that contain poison are also listed. The burnable poison rods are an integral part of the assembly, unlike the BA rods used in the PWR assemblies that can be inserted or withdrawn from the guide tubes of the assembly. The table also lists the relative poison, a term that refers to the fraction of fuel pellets in the fuel rod that contain Gd_2O_3. Therefore, a value of 1.0 indicates that all of the pellets in the poison rods contain gadolinium.

5.4 BWR 9 × 9 Assemblies

The 9 × 9 assembly data are listed in Table 22. These data are of similar type to those for the 8 × 8 assemblies.

5.5 SVEA Assemblies

Data for SVEA-64 and SVEA-100 assemblies are listed in Tables 23 and 24, respectively. For the SVEA-64 assemblies, only the ^{235}U and total uranium concentrations were provided. The initial concentrations for ^{234}U and ^{236}U may be estimated using the uranium isotopic vectors provided for the 15 × 15 assemblies in Table 19 by assuming that ^{234}U and ^{236}U scale proportionately with the initial ^{235}U concentration.

Table 19 Fuel data for PWR 15 × 15 assemblies

Reactor	Assembly ID	Type	Fuel density (g/cm^3)	Eff. fuel density (g/cm^3)	Initial U (g)	Initial ^{238}U (g)	Initial ^{235}U (g)	Initial ^{236}U (g)	Initial ^{234}U (g)	Initial ^{238}U (wt %)	Initial ^{235}U (wt %)	Initial ^{236}U (wt %)	Initial ^{234}U (wt %)	Number of BA rods
Ringhals 2	C01	1	10.41	10.23	455,789	441,485	14,107	69	128	96.862	3.095	0.015	0.028	0
Ringhals 2	C12	1	10.41	10.18	453,736	439,496	14,043	69	128	96.862	3.095	0.015	0.028	0
Ringhals 2	C20	1	10.41	10.21	454,758	440,486	14,075	69	128	96.862	3.095	0.015	0.028	0
Ringhals 2	D27	2	10.41	10.10	432,589	418,326	14,066	69	128	96.703	3.252	0.016	0.030	0
Ringhals 2	D38	2	10.41	10.13	434,214	419,898	14,119	69	128	96.703	3.252	0.016	0.029	0
Ringhals 2	E38	2	10.41	10.12	433,593	419,527	13,869	69	128	96.756	3.199	0.016	0.030	0
Ringhals 2	E40	2	10.41	10.13	434,244	420,157	13,890	69	128	96.756	3.199	0.016	0.029	0
Ringhals 2	F14	2	10.41	10.18	436,382	422,232	13,953	69	128	96.757	3.197	0.016	0.029	0
Ringhals 2	F21	2	10.41	10.17	435,939	421,803	13,939	69	128	96.757	3.197	0.016	0.029	0
Ringhals 2	F25	2	10.41	10.21	437,286	423,107	13,982	69	128	96.757	3.197	0.016	0.029	0
Ringhals 2	F32	2	10.41	10.20	436,993	422,824	13,972	69	128	96.758	3.197	0.016	0.029	0
Ringhals 2	G11	2	10.41	10.18	436,180	422,077	13,906	69	128	96.767	3.188	0.016	0.029	0
Ringhals 2	G23	2	10.41	10.18	436,125	421,947	13,981	69	128	96.749	3.206	0.016	0.029	0
Ringhals 2	I09	2	10.41	10.21	437,353	423,149	14,007	69	128	96.752	3.203	0.016	0.029	0
Ringhals 2	I24	2	10.41	10.03	429,597	415,641	13,759	69	128	96.751	3.203	0.016	0.030	0
Ringhals 2	I25	2	10.41	10.11	433,062	418,995	13,870	69	128	96.752	3.203	0.016	0.030	0

Table 20 Fuel data for PWR 17 × 17 assemblies

Reactor	Assembly ID	Type	Fuel density (g/cm^3)	Eff. fuel density (g/cm^3)	Initial U (g)	Initial ^{238}U (g)	Initial ^{235}U (g)	Initial ^{238}U (wt %)	Initial ^{235}U (wt %)	Number of BA rods
Ringhals 3	2A5	1	10.45	10.31	462,026	452,284	9,742	97.900	2.100	0
Ringhals 3	5A3	1	10.45	10.3	461,477	451,787	9,690	97.900	2.100	0
Ringhals 3	0C9	1	10.45	10.21	457,639	443,448	14,191	96.899	3.101	12
Ringhals 3	1C2	1	10.45	10.24	459,050	444,815	14,235	96.899	3.101	0
Ringhals 3	1C5	1	10.45	10.22	457,992	443,790	14,202	96.899	3.101	12
Ringhals 3	2C2	1	10.45	10.25	459,490	445,241	14,249	96.899	3.101	0
Ringhals 3	3C1	1	10.45	10.23	458,433	444,217	14,216	96.9	3.101	0
Ringhals 3	3C5	1	10.45	10.24	458,873	444,643	14,230	96.899	3.101	12
Ringhals 3	3C9	1	10.45	10.25	459,138	444,900	14,238	96.899	3.101	0
Ringhals 3	4C4	1	10.45	10.24	459,050	444,815	14,235	96.899	3.101	0
Ringhals 3	4C7	1	10.45	10.23	458,256	444,045	14,211	96.899	3.101	12
Ringhals 3	0E2	1	10.45	10.35	463,598	449,111	14,487	96.897	3.103	0
Ringhals 3	0E6	1	10.45	10.31	461,769	447,453	14,316	96.897	3.103	0
Ringhals 3	1E5	1	10.45	10.35	463,898	449,506	14,392	96.897	3.103	0

Table 21 Fuel data for BWR 8 × 8 assemblies

Reactor	Assembly ID	Type	Fuel density (g/cm^3)	Eff. fuel density (g/cm^3)	Initial U (g)	Initial ^{238}U (g)	Initial ^{235}U (g)	Initial ^{235}U (wt %)	Number of poison rods	Gd_2O_3 (wt %)	Relative poison
Ringhals 1	1177	1	10.26	10.16	180,587	175,816	4,771	2.642	3	2	1
Ringhals 1	1186	1	10.43	10.32	180,515	175,750	4,765	2.640	3	2	1
Ringhals 1	6423	2	10.46	10.35	177,701	172,547	5,154	2.900	4	2	1
Ringhals 1	6432	2	10.45	10.34	177,520	172,382	5,138	2.894	4	2	1
Ringhals 1	6454	2	10.46	10.35	177,683	172,534	5,149	2.898	4	2	1
Ringhals 1	8327	2	10.45	10.34	177,544	172,389	5,155	2.904	4	2	1
Ringhals 1	8331	2	10.46	10.35	177,690	172,520	5,170	2.910	4	2	1
Ringhals 1	8332	2	10.45	10.34	177,519	172,380	5,139	2.895	4	2	1
Ringhals 1	8338	2	10.45	10.35	177,596	172,426	5,170	2.911	4	2	1
Oskarshamn 3	12078	2	10.44	10.33	177,358	172,787	4,571	2.577	3	5.5	1
Forsmark 2	5535	2	10.50	10.35	177,689	173,966	3,723	2.095	0	N/A	N/A
Forsmark 1	3838	2	10.50	10.36	177,903	174,192	3,711	2.090	3	3.95	1
Barsebäck 1	9329	3	10.50	10.32	178,771	173,548	5,223	2.922	5	2.55	1
Barsebäck 1	10288	3	10.50	10.34	179,159	173,868	5,291	2.953	5	2.55	1
Barsebäck 2	14076	3	10.50	10.37	179,571	173,906	5,665	3.154	4	2	1
Oskarshamn 2	1377	3	10.71	10.60	183,575	179,535	4,040	2.201	0	N/A	N/A
Oskarshamn 2	1389	3	10.72	10.61	183,650	179,608	4,042	2.201	0	N/A	N/A
Oskarshamn 2	1546	3	10.73	10.63	183,968	179,919	4,049	2.201	0	N/A	N/A
Oskarshamn 2	1696	3	10.75	10.64	184,253	180,198	4,055	2.201	0	N/A	N/A
Oskarshamn 2	1704	3	10.74	10.63	184,022	179,972	4,050	2.201	0	N/A	N/A
Oskarshamn 2	2995	3	10.47	10.36	179,382	174,540	4,842	2.699	4	2	1
Oskarshamn 2	6350	3	10.44	10.34	179,003	173,857	5,146	2.875	6	3.2	1
Forsmark 1	KU0100	4	10.30	10.17	174,920	169,730	5,190	2.970	4	2.5	1

Table 22 Fuel data for BWR 9 × 9 assemblies

Reactor	Assembly ID	Type	Fuel density (g/cm^3)	Eff. fuel density (g/cm^3)	Initial U (g)	Initial ^{235}U (g)	Initial ^{235}U (wt %)	Number of poison rods	Gd_2O_3 (wt %)	Relative poison
Forsmark 1	KU0269	1	10.30	10.14	177,020	5,201	2.938	6	2.5	1
Forsmark 1	KU0278	1	10.30	10.15	177,133	5,206	2.938	6	2.5	1
Forsmark 1	KU0282	1	10.30	10.15	177,097	5,204	2.938	6	2.5	1

Table 23 Fuel data for SVEA-64 assemblies

Reactor	Assembly ID	Type	Fuel density (g/cm^3)	Eff. fuel density (g/cm^3)	Initial U (g)	Initial ^{235}U (g)	Initial ^{235}U (wt %)	Number of poison rods	Gd_2O_3 (wt %)	Relative poison
Forsmark 2	11494	1	10.50	10.36	181,088	5,287	2.920	4	2.55	0.82
Forsmark 2	11495	1	10.50	10.36	181,070	5,287	2.910	4	2.55	0.82
Forsmark 2	13775	1	10.50	10.38	181,340	5,175	2.850	5	2.55	1
Oskarshamn 2	12684	1	10.45	10.34	182,320	5,291	2.902	6	3.15	1

Table 24 Fuel data for SVEA-100 assemblies

Reactor	Assembly ID	Type	Fuel density (g/cm^3)	Eff. fuel density (g/cm^3)	Initial U (g)	Initial ^{238}U (g)	Initial ^{235}U (g)	Initial ^{235}U (wt %)	Number of poison rods	Gd_2O_3 (wt %)	Relative poison
Oskarshamn 3	13628	1	10.50	10.39	180,774	175,873	4,901	2.711	8	4.4	1
Oskarshamn 3	13630	1	10.50	10.39	180,775	175,874	4,901	2.711	8	4.4	1
Forsmark 3	13847	1	10.70	10.58	180,669	175,667[a]	5,002	2.770	5	2.55	0.8
Forsmark 3	13848	1	10.70	10.58	180,667	175,665[a]	5,002	2.770	5	2.55	0.8

[a] Values derived from ^{235}U values. Note that the derived values exclude contributions from ^{234}U and ^{236}U.

6 POWER HISTORY DATA

6.1 Assembly Burnup Data

The power history data for the measured assemblies are detailed in Tables 25–34. There is one table for each reactor. For each assembly, the assembly design and the assembly identifier are listed. The exposure history information is listed as burnup per cycle together with cycle length in days. The total burnup for the assembly, obtained from the sum of cycle burnups for each cycle exposed, is also provided in the tables. The down time is the time between consecutive cycles, generally for the purposes of refueling. The average assembly specific power (MW/MTU) for a cycle can be derived from the cycle burnup (MWd/MTU) divided by the cycle length (days). The cycle-average power on an assembly basis (MW/assembly) can be obtained using the assembly initial uranium mass values listed in Section 5. Note that some cycles are subdivided to account for significant periods of low and zero operating power during a cycle.

Table 25 Barsebäck 1 assembly irradiation history

Operational data type		Cycle 8	Cycle 9	Cycle 10	Cycle 11	Cycle 12
Startup date		8/6/1983	7/26/1984	9/2/1985	8/18/1986	7/29/1987
Shutdown date		6/28/1984	8/7/1985	7/17/1986	7/1/1987	9/17/1988
Operating days		327	377	318	317	416
Downtime days		28	26	32	28	---
Assembly ID	Design	Assembly Burnup (MWd/MTU)				
9329	8 × 8	8,219	17,727	25,034	31,958	41,127
10288	8 × 8		9,726	17,440	25,587	35,218

Table 26 Barsebäck 2 assembly irradiation history

Operational data type		Cycle 9	Cycle 10	Cycle 11	Cycle 12	Cycle 13
Startup date		9/19/1987	8/7/1988	9/28/1989	8/18/1990	9/22/1991
Shutdown date		7/6/1988	9/8/1989	7/11/1990	9/6/1991	7/2/1992
Operating days		291	397	286	384	284
Downtime days		32	20	38	16	--
Assembly ID	Design	Assembly Burnup (MWd/MTU)				
14076	8 × 8	8,398	18,616	24,130	34,126	40,010

Table 27 Forsmark 1 assembly irradiation history

Operational data type		Cycle 1A	Cycle 1B	Cycle 2	Cycle 3	Cycle 4	Cycle 5	Cycle 6	Cycle 7	Cycle 8	Cycle 9	Cycle 10
Startup date		4/23/1980	8/16/1981	8/25/1982	8/5/1983	8/6/1984	7/8/1985	7/22/1986	8/19/1987	7/10/1988	8/18/1989	9/16/1990
Shutdown date		6/25/1981	6/19/1982	7/15/1983	7/13/1984	5/31/1985	7/4/1986	7/31/1987	6/10/1988	7/14/1989	8/17/1990	5/24/1991
Operating days		428	307	324	343	298	361	374	296	369	364	250
Downtime days		52	67	21	24	38	18	19	30	35	30	---
Assembly ID	Design	Assembly Burnup (MWd/MTU)										
3838	8 × 8	6,160	13,092	15,990	19,053						21,839	25,669
KU0100	8 × 8						10,643	18,706	26,630	34,193		
KU0269	9 × 9						10,158	18,787	27,153	35,113		
KU0278	9 × 9						10,414	17,685	24,764	29,413	35,323	
KU0282	9 × 9						10,122	18,800	25,844	32,112	37,896	

Table 28 Forsmark 2 assembly irradiation history

Operational data type		Cycle 1A	Cycle 1B	Cycle 2	Cycle 3	Cycle 4	Cycle 5	Cycle 6	Cycle 7	Cycle 8	Cycle 9
Startup date		12/1/1980	8/18/1982	6/11/1983	7/13/1984	7/26/1985	8/9/1986	6/20/1987	8/4/1988	9/4/1989	6/12/1990
Shutdown date		5/1/1982	5/20/1983	5/25/1984	7/5/1985	7/25/1986	5/31/1987	7/15/1988	8/18/1989	5/18/1990	7/12/1991
Operating days		516	275	349	357	364	295	391	379	256	395
Downtime days		109	22	49	21	15	20	20	17	25	---
Assembly ID	Design	Assembly Burnup (MWd/MTU)									
5535	8 × 8	8,850	10,758	12,862	14,982	16,665	18,115	19,944			
11494	SVEA-64				9,098	16,676	24,136	32,431			
11495	SVEA-64				9,098	16,676	24,136	32,431			
13775	SVEA-64						8,801	18,300	23,975	27,498	32,837

Table 29 Forsmark 3 assembly irradiation history

Operational data type		Cycle 2	Cycle 3	Cycle 4	Cycle 5
Startup date		9/2/1986	8/9/1987	9/5/1988	7/13/1989
Shutdown date		7/10/1987	8/12/1988	6/9/1989	7/13/1990
Operating days		311	369	277	365
Downtime days		30	24	34	---
Assembly ID	Design	Assembly Burnup (MWd/MTU)			
13847	SVEA-100	7,857	17,217	23,779	31,275
13848	SVEA-100	7,857	17,217	23,779	31,275

Table 30 Oskarshamn 2 assembly irradiation history

Operational data type		Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5	Cycle 6	Cycle 7	Cycle 8	Cycle 9	Cycle 10
Startup date		10/2/1974	7/2/1976	8/7/1977	9/3/1978	8/30/1979	8/20/1980	8/30/1981	8/23/1982	9/19/1983	8/24/1984
Shutdown date		4/16/1976	5/13/1977	6/24/1978	7/20/1979	7/12/1980	7/15/1981	7/23/1982	8/19/1983	7/1/1984	6/7/1985
Operating days		562	315	321	320	317	329	327	361	286	287
Downtime days		77	86	71	41	39	46	31	31	54	36
Assembly ID	Design	Assembly Burnup (MWd/MTU)									
1377	8 × 8	8,982	14,546								
1389	8 × 8	4,315	7,300	11,829	14,539	16,933	19,481				
1546	8 × 8	6,961					13,840	21,032	24,470		
1696	8 × 8	4,492	7,904	13,258	16,319			18,502	20,870		
1704	8 × 8	4,587	8,031	13,384	16,638			19,437			
2995	8 × 8		6,143	13,359	19,705	23,577	29,978				
6350	8 × 8						7,113	14,909	24,019		27,675

Table 30 Oskarshamn 2 assembly irradiation history (cont.)

Operational data type		Cycle 11	Cycle 12	Cycle 13	Cycle 14	Cycle 15	Cycle 16
Startup date		7/13/1985	9/27/1986	9/4/1987	9/10/1988	9/1/1989	10/11/1990
Shutdown date		8/16/1986	7/31/1987	8/20/1988	8/5/1989	8/10/1990	8/2/1991
Operating days		399	307	351	329	343	295
Downtime days		42	35	21	27	62	---
Assembly ID	Design	Assembly Burnup (MWd/MTU)					
12684	SVEA-64	11,134	20,032	28,184	35,495	43,084	46,648

Table 31 Oskarshamn 3 assembly irradiation history

Operational data type		Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 4B	Cycle 5	Cycle 6
Startup date		3/18/1985	7/26/1986	7/26/1987	8/14/1988	12/22/1988	6/20/1989	8/1/1990
Shutdown date		7/4/1986	7/3/1987	7/8/1988	12/10/1988	6/7/1989	6/23/1990	6/24/1991
Operating days		473	342	348	118	167	368	327
Downtime days		22	23	37	12	13	39	---
Assembly ID	Design	Assembly Burnup (MWd/MTU)						
12078	8 × 8	8,690	16,948	25,160				
13628	SVEA-100		9,171	18,613	20,910	24,673	32,885	35,619
13630	SVEA-100		9,328	18,984	21,970	25,793	32,866	40,363

Table 32 Ringhals 1 assembly irradiation history

Operational data type		Cycle 2	Cycle 3	Cycle 4	Cycle 5	Cycle 6	Cycle 7	Cycle 8	Cycle 9	Cycle 10	Cycle 11	Cycle 12	Cycle 13	Cycle 14
Startup date		10/13/1978	9/30/1979	10/8/1980	11/6/1981	9/9/1982	9/30/1983	8/28/1984	9/2/1985	10/9/1986	9/24/1987	9/11/1988	10/11/1989	8/30/1990
Shutdown date		7/12/1979	7/3/1980	7/30/1981	7/22/1982	6/18/1983	7/13/1984	8/2/1985	8/15/1986	8/21/1987	8/6/1988	9/15/1989	8/4/1990	8/9/1991
Operating days		272	277	295	258	282	287	339	347	316	317	369	297	344
Downtime days		80	97	99	49	104	46	31	55	34	36	26	26	---
Assembly ID	Design	Assembly Burnup (MWd/MTU)												
1177	8 × 8	4,486	9,369	16,334	20,430	25,484	30,320	36,242						
1186	8 × 8	4,554	9,614	15,459	19,967	24,592	28,020	30,498						
6423	8 × 8					5,401	12,064	19,440	26,198	31,635	35,109			
6432	8 × 8				5,502	10,444	16,181	23,266	30,079	34,746	36,861			
6454	8 × 8			7,120	13,000	18,936	24,831	30,918	37,236					
8327	8 × 8						3,212	9,482	15,956	21,578	28,065	34,820	36,141	37,851
8331	8 × 8						6,974	15,132	22,493	26,648	33,319	35,903		
8332	8 × 8				5,755	11,468	16,558	23,407	29,963	32,651	34,977			
8338	8 × 8				5,660	11,130	16,282	23,202	29,963	32,634	34,830			

Table 33 Ringhals 2 assembly irradiation history

Operational data type		Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5	Cycle 6	Cycle 7	Cycle 8	Cycle 9	Cycle 10	Cycle 11	Cycle 12
Startup date		6/19/1974	7/7/1977	5/26/1978	6/25/1979	6/18/1980	6/23/1981	7/29/1982	7/28/1983	7/12/1984	6/14/1985	7/2/1986	6/18/1987
Shutdown date		4/13/1977	3/31/1978	4/3/1979	4/1/1980	4/4/1981	5/6/1982	4/28/1983	4/13/1984	4/4/1985	4/30/1986	4/25/1987	5/12/1988
Operating days		1029	267	312	281	290	317	273	260	266	320	297	329
Downtime days		85	56	83	78	80	84	91	90	71	63	54	---
Assembly ID	Design	Assembly Burnup (MWd/MTU)											
C01	15 × 15	11,247	20,650	28,219		36,688							
C12	15 × 15	11,247	20,565	27,955		36,385							
C20	15 × 15	11,247	20,624	28,078						35,720			
D27	15 × 15			9,510	22,399	31,666		39,676					
D38	15 × 15		6,367	15,698	23,056	31,757	39,403						
E38	15 × 15			7,568	16,026	25,905	33,973						
E40	15 × 15			7,705	14,954	25,609	34,339						
F14	15 × 15				5,069	15,824	25,722	34,009					
F21	15 × 15				4,767	11,084	21,130	29,385	36,273				
F25	15 × 15				8,307	19,056	27,372	35,352					
F32	15 × 15					10,553	21,162	29,553			37,314	43,943	50,962
G11	15 × 15					6,890	17,312	25,180	32,123	35,463			
G23	15 × 15						10,268	20,303	27,921	35,633			
I09	15 × 15								6,727	15,677	24,742	32,310	40,188
I24	15 × 15							8,245	17,212	26,356	34,294		
I25	15 × 15							5,207	10,198	20,001	28,999	36,859	

Table 34 Ringhals 3 assembly irradiation history

Operational data type		Cycle 1A	Cycle 1B	Cycle 2	Cycle 3	Cycle 4	Cycle 5
Startup date		7/29/1980	9/14/1983	7/24/1984	7/11/1985	7/18/1986	8/4/1987
Shutdown date		6/2/1983	5/11/1984	5/25/1985	5/30/1986	6/18/1987	7/7/1988
Operating days		1038	240	305	323	335	338
Downtime days		104	74	47	49	47	---
Assembly ID	Design	Assembly Burnup (MWd/MTU)					
2A5	17 × 17	12,228	20,107				
5A3	17 × 17	11,696	19,699				
0C9	17 × 17	9,884	18,076	28,426	38,442		
1C2	17 × 17	6,249	11,268	22,777	33,318		
1C5	17 × 17	9,884	17,986	28,397	38,484		
2C2	17 × 17	7,783	16,128	26,060	36,577		
3C1	17 × 17	7,783	16,124	26,055	36,572		
3C5	17 × 17	9,884	17,997	28,340	38,373		
3C9	17 × 17	7,783	16,160	26,036	36,560		
4C4	17 × 17	6,249	11,240	22,270	33,333		
4C7	17 × 17	9,884	17,985	28,332	38,370		
0E2	17 × 17			7,496	20,530	31,838	41,628
0E6	17 × 17				12,490	25,521	35,993
1E5	17 × 17				10,556	23,690	34,638

6.2 Assembly Burnup Profile Data

Assembly axial burnup profiles were available for some but not all of the assemblies. The profiles are described in terms of the burnup in discrete axial zones of the assembly. Each zone has the same axial height. In the case of PWR assemblies, there were 24 axial zones, and for BWR assemblies there were 25 zones. The local zone burnup data are given in units of megawatt days per metric ton of uranium (MWd/MTU) for each axial zone. The burnup values are those reported by the utilities. Note that values for the Barsebäck and Oskarshamn assemblies are reported to the nearest 100 MWd/MTU.

Axial burnup profile data were available for all measured PWR assemblies. All of the 15 × 15 assemblies came from the Ringhals 2 reactor, and all of the 17 × 17 assemblies were from the Ringhals 3 reactor. The corresponding axial profiles are listed in Tables 35 and 36, respectively. The axial burnup profiles for the 8 × 8, 9 × 9, SVEA-64, and SVEA-100 assemblies are listed in Tables 37–40. Those assemblies for which profiles were not available are not listed in the tables. The only assemblies for which axial profile data were not available were Ringhals-1 8 × 8 assemblies 6423, 6432, 6454, 8327, 8331, 8332, and 8338.

If burnup profiles are desired for assemblies for which data are not available, it may be possible to derive representative profiles by evaluating similar assemblies that have listed profiles. Following the axial burnup profile tables, there is an evaluation and discussion of the profile data.

Table 35 PWR 15 × 15 assembly burnup profile data

Reactor	Ringhals 2						
Assembly ID	**C01**	**C12**	**C20**	**D27**	**D38**	**E38**	**E40**
Axial level	Discharge burnup (MWd/MTU)						
1 (bottom)	20938	20894	20317	22790	22420	17154	20163
2	30055	29982	29205	33099	32169	26466	28758
3	35077	34977	34139	38570	37501	31559	33332
4	37367	37245	36428	40893	39961	34119	35324
5	38321	38185	37414	41811	41053	35407	36117
6	38677	38530	37799	42151	41538	36139	36402
7	38786	38631	37930	42290	41767	36518	36488
8	38808	38647	37966	42307	41887	36706	36505
9	38807	38641	37975	42295	41961	36829	36503
10	38808	38636	37983	42286	42020	36929	36501
11	38815	38640	37996	42284	42076	37019	36502
12	38829	38651	38016	42290	42132	37110	36512
13	38850	38669	38042	42303	42187	37202	36529
14	38877	38694	38074	42309	42239	37292	36541
15	38912	38726	38111	42317	42288	37379	36555
16	38957	38769	38158	42331	42336	37462	36574
17	39015	38824	38215	42357	42379	37535	36598
18	39077	38884	38272	42390	42403	37577	36622
19	39105	38910	38288	42400	42364	37537	36618
20	38981	38785	38147	42279	42142	37286	36495
21	38400	38206	37548	41722	41430	36525	35994
22	36639	36455	35788	39964	39490	34576	34452
23	32133	31973	31350	35286	34684	30023	30358
24 (top)	23157	23042	22574	25664	25094	21354	21966

Table 35 PWR 15 × 15 assembly burnup profile data (continued)

Reactor	Ringhals 2								
Assembly ID	**F14**	**F21**	**F25**	**F32**	**G11**	**G23**	**I09**	**I24**	**I25**
Axial level	Discharge burnup (MWd/MTU)								
1 (bottom)	19083	21231	19894	32227	19843	21047	24212	19588	22731
2	27514	30092	28531	44459	28645	29748	34163	28041	31982
3	32196	34781	33299	50497	33541	34367	39284	32689	36682
4	34384	36861	35525	52964	35865	36409	41482	34872	38617
5	35380	37765	36544	53879	36946	37275	42380	35886	39334
6	35845	38151	37020	54165	37455	37635	42703	36356	39552
7	36065	38306	37253	54214	37706	37782	42790	36576	39577
8	36174	38368	37378	54181	37840	37842	42793	36684	39539
9	36238	38394	37457	54125	37925	37870	42771	36745	39487
10	36287	38407	37518	54067	37988	37887	42748	36787	39438
11	36330	38416	37572	54012	38044	37903	42729	36822	39396
12	36373	38424	37624	53963	38098	37920	42715	36855	39360
13	36416	38432	37675	53917	38152	37936	42705	36889	39330
14	36461	38440	37726	53876	38206	37954	42699	36922	39303
15	36506	38450	37775	53839	38261	37974	42697	36956	39282
16	36551	38459	37821	53808	38314	37996	42699	36987	39266
17	36592	38466	37859	53781	38359	38017	42703	37011	39257
18	36616	38459	37871	53749	38376	38028	42700	37010	39247
19	36584	38406	37817	53676	38319	37997	42658	36944	39210
20	36391	38212	37587	53452	38071	37832	42478	36710	39056
21	35772	37619	36916	52759	37349	37279	41888	36046	38526
22	34084	35970	35152	50752	35486	35690	40178	34320	36949
23	29887	31731	30832	45373	31015	31546	35655	30099	32731
24 (top)	21550	23080	22276	33752	22295	23035	26135	21747	23917

Table 36 PWR 17 × 17 assembly burnup profile data

Reactor	Ringhals 3								
Assembly ID	**2A5**	**5A3**	**0C9**	**1C2**	**1C5**	**2C2**	**3C1**	**3C5**	**3C9**
Axial level	Discharge burnup (MWd/MTU)								
1 (bottom)	9653	8661	21140	18077	21160	20091	20090	21119	20088
2	14880	14073	30635	26607	30666	29186	29185	30603	29181
3	18290	17624	36170	31538	36208	34451	34449	36127	34443
4	20213	19664	38931	33882	38970	37025	37022	38877	37014
5	21233	20897	40254	34933	40291	38210	38206	40193	38196
6	21734	21421	40852	35372	40886	38723	38719	40784	38707
7	21953	21617	41103	35579	41136	38939	38935	41031	38922
8	22029	21669	41204	35656	41236	39023	39019	41129	39005
9	22038	21660	41248	35691	41280	39055	39051	41171	39035
10	22025	21633	41275	35719	41307	39077	39072	41197	39057
11	22012	21612	41302	35749	41335	39107	39102	41222	39086
12	22010	21605	41334	35781	41368	39148	39143	41254	39128
13	22023	21616	41373	35817	41409	39202	39197	41292	39182
14	22052	21645	41419	35855	41457	39269	39263	41338	39248
15	22096	21690	41472	35897	41512	39348	39342	41390	39327
16	22150	21748	41530	35942	41573	39440	39433	41448	39419
17	22200	21805	41585	35988	41630	39541	39533	41502	39520
18	22219	21836	41612	36019	41662	39630	39622	41529	39610
19	22145	21781	41551	35990	41605	39654	39644	41467	39633
20	21854	21520	41251	35778	41311	39468	39458	41168	39447
21	21112	20821	40373	35088	40440	38741	38730	40293	38719
22	19488	19256	38178	33252	38247	36739	36728	38103	36718
23	16251	16092	33136	28872	33201	31955	31946	33073	31936
24 (top)	10915	10834	23686	20553	23733	22837	22831	23640	22823

Table 36 PWR 17 × 17 assembly burnup profile data (continued)

Reactor	Ringhals 3				
Assembly ID	**4C4**	**4C7**	**0E2**	**0E6**	**1E5**
Axial level	Discharge burnup (MWd/MTU)				
1 (bottom)	18075	21118	24593	20541	18931
2	26607	30601	34686	29342	27564
3	31541	36124	40170	34267	32452
4	33888	38874	42652	36574	34844
5	34942	40189	43723	37597	36023
6	35383	40780	44169	38045	36563
7	35591	41027	44347	38248	36844
8	35670	41125	44413	38347	36985
9	35706	41167	44435	38405	37072
10	35735	41193	44438	38446	37136
11	35765	41219	44435	38482	37193
12	35798	41250	44428	38516	37246
13	35834	41289	44419	38550	37298
14	35873	41335	44410	38584	37350
15	35915	41387	44400	38619	37403
16	35961	41445	44391	38657	37454
17	36007	41499	44381	38696	37499
18	36039	41527	44361	38729	37522
19	36011	41466	44294	38712	37478
20	35800	41167	44065	38507	37257
21	35111	40292	43366	37827	36565
22	33273	38103	41416	35990	34713
23	28892	33073	36490	31481	30256
24 (top)	20567	23641	26583	22679	21673

Table 37 BWR 8 × 8 assembly burnup profile data

Reactor	Ringhals 1	Ringhals 1	Oskarshamn 3	Forsmark 1	Forsmark 2	Barsebäck 1	Barsebäck 1	Barsebäck 2
Assembly ID	**1177**	**1186**	**12078**	**3838**	**5535**	**9329**	**10288**	**14076**
Axial level	Discharge burnup (MWd/MTU)							
1 (bottom)	20521	17481	11300	10899	9028	30200	18300	21600
2	30692	26029	19500	19258	15826	31900	29600	34500
3	35545	30230	23600	23070	18445	37700	35100	40500
4	37745	32082	25400	24864	19467	40300	37300	42800
5	39059	33061	27000	26611	20513	42600	39200	44700
6	39836	33591	27700	27703	21028	43900	40000	45600
7	40202	33899	27900	28282	21157	44700	40200	45700
8	40412	34072	27700	28538	20993	44700	39700	45200
9	40658	34225	28300	29705	21543	45800	40300	45600
10	40701	34303	28600	30180	21826	46200	40400	45500
11	40725	34310	28600	30167	21923	46500	40300	45100
12	40538	34151	28300	29904	21944	46200	39600	44400
13	40498	34141	28900	30323	22558	46700	39900	44600
14	40380	34057	29300	30356	22882	46800	37700	44300
15	40276	33908	29200	30116	22953	46500	39200	43700
16	39922	33607	28700	29719	22965	45800	38200	42700
17	39672	33376	28900	29633	23121	46000	38100	42600
18	39220	32891	28600	29031	22802	45700	37600	42000
19	38483	32336	27900	27866	21956	44900	36700	41000
20	37499	31411	26600	26758	21263	43500	35100	39300
21	36039	30197	25700	25237	20175	42400	33900	38000
22	33892	28417	23900	22794	18347	39900	31600	35600
23	30267	25316	21000	19043	15429	35700	28000	31700
24	24808	20626	16700	14381	11730	22900	23300	26500
25 (top)	17579	14378	9400	10623	8835	22400	17600	20400

Table 37 BWR 8 × 8 assembly burnup profile data (continued)

Reactor	Oskarshamn 2	Oskarsham 2	Oskarshamn 2	Oskarshamn 2	Oskarshamn 2	Oskarshamn 2	Oskarshamn 2	Forsmark 1
Assembly ID	**1377**	**1389**	**1546**	**1696**	**1704**	**2995**	**6350**	**KU0100**
Axial level	Discharge burnup (MWd/MTU)							
1 (bottom)	7600	11000	13000	12100	11100	19500	16300	14695
2	12100	16700	19800	18400	17000	27900	24700	25639
3	14800	20000	23600	21700	20300	32100	29000	31737
4	16300	21700	25600	23400	22100	34100	30800	34452
5	17400	22700	26800	24200	23000	34900	31600	36630
6	17600	23200	27300	24600	23500	35100	31800	37682
7	17400	23400	27400	24800	23600	35000	31800	38189
8	17000	23500	27600	24800	23500	34900	31600	38104
9	16800	23400	27600	24700	23300	34600	31600	38914
10	16600	23300	27500	24600	23100	34200	31400	39261
11	16400	23000	27600	24400	22800	33900	31500	39433
12	16300	22700	28000	24100	22400	33400	31200	39183
13	16200	22400	28200	23800	22100	33000	31000	39757
14	16100	22100	28100	23400	21700	32600	30700	39802
15	16000	21700	28000	23100	21300	32200	30300	39562
16	15800	21300	27900	22700	21000	31900	29800	39217
17	15600	20800	27800	22300	20600	31400	29500	39376
18	15300	20300	27400	21800	20100	30900	29000	38974
19	15000	19600	26600	21100	19400	30200	28400	37977
20	14500	18700	25500	20300	18700	29400	27400	37096
21	13800	17600	24000	19100	17500	28100	26200	35556
22	12800	16100	22000	17500	16000	26100	24400	32677
23	11300	13900	19100	15200	13800	23100	21700	27764
24	8900	10900	15100	12000	10800	18500	17600	21395
25 (top)	5900	6900	10200	7700	7000	12600	12500	16482

Table 38 BWR 9 × 9 assembly burnup profile data

Reactor	Forsmark 1		
Assembly ID	**KU0269**	**KU0278**	**KU0282**
Axial level	Discharge burnup (MWd/MTU)		
1 (bottom)	8603	7943	9352
2	28322	25901	29564
3	35731	32745	37022
4	38495	35584	39994
5	40365	37733	42134
6	40905	38658	42902
7	40872	39039	43014
8	40206	38705	42388
9	40887	39496	42954
10	41093	39734	43000
11	41171	39840	43023
12	40924	39567	42633
13	41606	40261	43280
14	41500	40282	43214
15	40976	40025	42853
16	40235	39637	42287
17	40117	40025	42500
18	39361	39897	42154
19	37909	39247	41216
20	36592	38879	40570
21	34472	37657	39121
22	31013	34810	36152
23	25572	29326	30726
24	16313	18760	19973
25 (top)	8830	10314	11201

Table 39 SVEA-64 assembly burnup profile data

Reactor	Oskarshamn 2	Forsmark 2	Forsmark 2	Forsmark 2
Assembly ID	**12684**	**11494**	**11495**	**13775**
Axial level	Discharge burnup (MWd/MTU)			
1 (bottom)	23300	16962	16962	16247
2	37600	27585	27585	26650
3	44300	32280	32280	31970
4	47000	33996	33996	34198
5	49400	35386	35386	36158
6	50700	36003	36003	37084
7	51300	36061	36061	37443
8	51200	35683	35683	37216
9	52300	36114	36114	37871
10	52800	36279	36279	38056
11	53000	36234	36234	38058
12	52400	35980	35980	37486
13	53000	36329	36329	37776
14	53100	36322	36322	37614
15	52700	35997	35997	37182
16	51800	35791	35791	36356
17	51900	35831	35831	36336
18	51400	35446	35446	35843
19	50400	34534	34534	34978
20	48500	33710	33710	33511
21	47100	32281	32281	32378
22	44300	29702	29702	30207
23	39600	25442	25442	26735
24	32300	19667	19667	21538
25 (top)	24700	16170	16170	12047

Table 40 SVEA-100 assembly burnup profile data

Reactor	Oskarshamn 3	Oskarshamn 3	Forsmark 3	Forsmark 3
Assembly ID	**13628**	**13630**	**13847**	**13848**
Axial level	Discharge burnup (MWd/MTU)			
1 (bottom)	7800	9400	9053	9053
2	27300	31800	26749	26749
3	34100	39200	32086	32086
4	37000	42300	34240	34240
5	39100	44700	35674	35674
6	40100	45700	36261	36261
7	40400	46200	36329	36329
8	40200	46000	36073	36073
9	40900	46700	36565	36565
10	41200	47000	36809	36809
11	41200	46900	36798	36798
12	40700	46300	36625	36625
13	41100	46700	36875	36875
14	41100	46600	36784	36784
15	40900	46200	36451	36451
16	40400	45500	36363	36363
17	40800	45700	36474	36474
18	40600	45300	36262	36262
19	40100	44500	35592	35592
20	38700	42900	34934	34934
21	37500	41500	33500	33500
22	34800	38700	30676	30676
23	30500	34100	25833	25833
24	24100	27700	19696	19696
25 (top)	9800	11500	7910	7910

6.3 Burnup-Profile Trends

Axial burnup profiles for selected PWR assemblies from Ringhals-3 are shown in Figure 4. The plotted values are in units of gigawatt days per metric ton uranium (GWd/MTU). The profiles are plotted as a function of and fractional assembly height, where a value of 1 corresponds to the top of the fuel assembly. As is typical of PWR assemblies, the profiles are relatively symmetric about the assembly center plane. The burnup profiles shown here are representative of the other discharged assemblies.

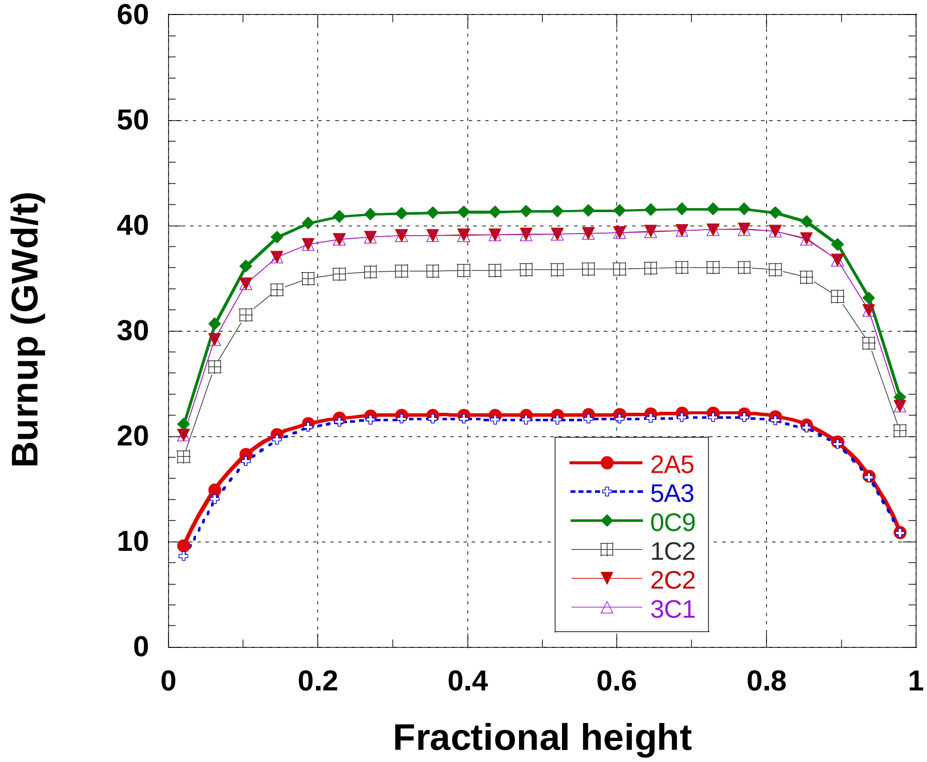

Figure 4 PWR burnup profiles for Ringhals 3 reactor assemblies

Burnup profiles were not available for all BWR assemblies. BWR burnup profiles (as compared to PWR ones) are generally not symmetric about the assembly centerline height because of the axial variation in void, and thus moderator density, and the insertion of control blades. The burnup profile for assembly 14076 from the Barsebäck 2 BWR reactor is illustrated in Figure 5 (again, the plotted values are GWd/MTU). This profile is not symmetric; it peaks in the lower half of the assembly where the moderator density is highest. A selection of BWR burnup profiles for assemblies from the Oskarshamn 2 reactor is shown in Figure 6. Because the profiles represent discharge values, they do not reflect possible cycle-to-cycle variations in axial power during irradiation.

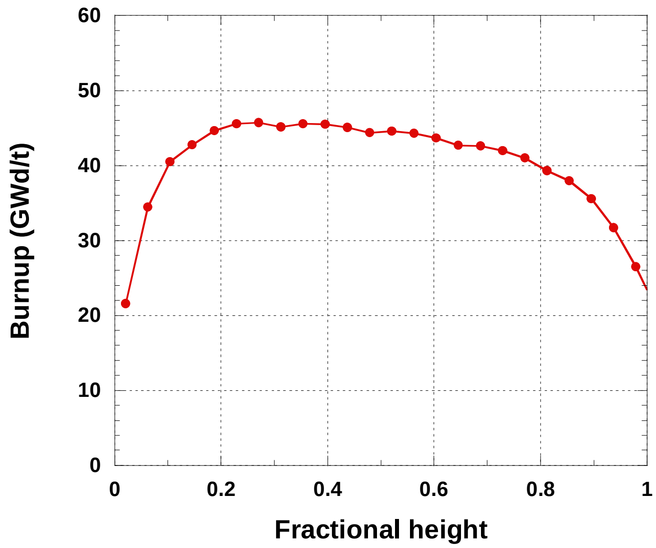

Figure 5 BWR burnup profile for Barsebäck 2 assembly 14076

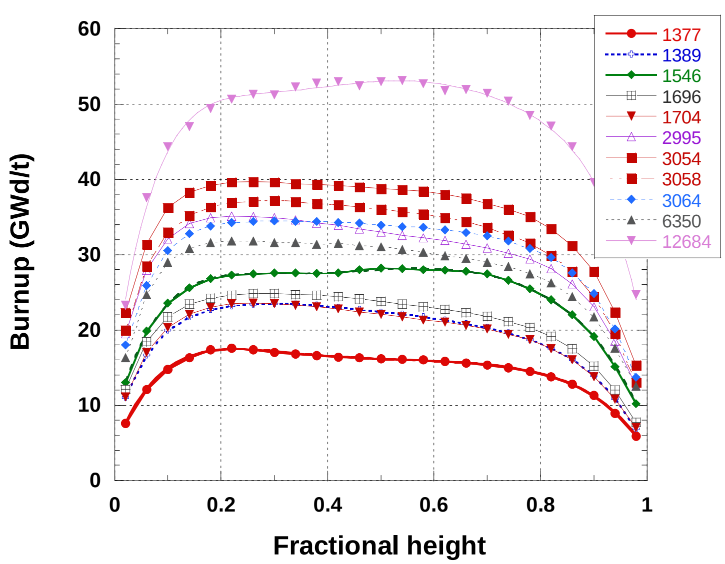

Figure 6 BWR burnup profiles for selected Oskarshamn 2 assemblies

(Note: Several assemblies are shown that were not considered in this report.)

7 MODERATOR DATA

This section documents the reactor moderator data. These data are important to the analysis of the assembly decay heat because the moderator density, soluble boron levels, and temperature affect the neutron spectrum in the fuel and therefore influence the average cross sections that determine the isotopic inventories in the fuel. The data provided in this section include the moderator soluble boron concentrations, density, temperature, and axial void profiles.

7.1 Boron Levels

In PWR plants, an important moderator parameter is the soluble boron level. During a reactor operating cycle the boron level in the moderator is gradually reduced from its initial value at the start of a reactor cycle for the purposes of reactivity control. The cycle-average soluble boron levels in the Ringhals 2 and 3 PWR plants were provided for most of the cycles. A more detailed time-dependent representation of the variation in boron levels can be reasonably approximated as a linearly decreasing function with a beginning-of-cycle value of 1.9 times the average value, and an end-of-cycle value of 0.1 times the average boron level. The cycle-average boron concentrations in Ringhals 2 and 3 plants are given by operating cycle in Table 41.

Table 41 Average soluble boron concentrations for Ringhals 2 and 3

Ringhals 2	
Cycle	Boron (ppm)
1	
2	
3	342
4	530
5	350
6	395
7	308
8	323
9	299
10	340
11	277
12	302

Ringhals 3	
Cycle	Boron (ppm)
1A	
1B	270
2	389
3	452
4	402
5	401

7.2 Void Profiles

Moderator void fractions as a function of assembly elevation are available for many, but not all, of the BWR assemblies. The void-fraction data for the 8 × 8, 9 × 9, SVEA-64, and SVEA-100 assemblies are listed in Tables 41, 42, 43 and 44, respectively. The BWR void fractions are provided at 25 equally spaced axial zones, consistent with the axial burnup profile data. In general, the void fractions range from about 0 to 0.8. In some cases negative void fraction values were reported. These negative values are small, and it was assumed that they are the result of predictive modeling. In the tables that follow, the negative void fraction values have been set to zero.

The void profiles represent averages over the exposure history of the assembly. Power level variations over the course of burnup will be reflected in void-fraction variations. Following the void-fraction tables, there is a section discussing trends in the void profile data.

7.3 Pressure-Density-Temperature

Moderator temperature and pressure data for each reactor are listed in Table 1. It is evident from the table that the operating temperatures and pressures for the BWR plants are very similar. The operating data for the PWR plants are also similar. The typical operating temperature and pressures were used to derive representative water moderator density values for each reactor type. For the PWR plants operating at a pressure of about 15 MPa and average temperatures of 577 K, the average water moderator density in the core is estimated to be about 0.72 g/cm^3.

The BWR plants, operating at a nominal pressure of 7 MPa and a temperature of about 552 K, the density of the water moderator without void is about 0.75 g/cm^3. For the BWR assemblies, the effect of axial voiding in the reactor must also be taken into account because this reduces the effective moderator density. However, non-boiling regions of the assembly (e.g., water rods, water outside the box) can be represented using the derived value of 0.75 g/cm^3. For boiling water regions in the assembly, the effective density can be estimated from the void data as $\rho = \rho_0 (1 - V)$ where ρ_0 = 0.75 g/cm^3 and V is the void fraction. Effective axial water moderator density data were provided for 11 assemblies from the Forsmark plants and are listed in Table 46. The effective density data estimated using the expression for ρ was found to agree with the actual Forsmark plant data values to within about 5%.

Table 42 Void fractions for 8 × 8 assemblies

Reactor	Ringhals 1	Ringhals 1	Barsebäck 1	Barsebäck 1	Barsebäck 2	Oskarshamn 3	Forsmark 1	Forsmark 2
Assembly ID	**1177**	**1186**	**9329**	**10288**	**14076**	**12078**	**3838**	**5535**
Axial level	Void fraction							
1 (bottom)	0.000*	0.000*	0.000	0.000	0.000	0.000*	0.000*	0.000*
2	0.000*	0.001	0.000	0.000	0.000	0.000*	0.000*	0.000*
3	0.017	0.022	0.000	0.000	0.000	0.010	0.000*	0.000*
4	0.055	0.060	0.029	0.052	0.052	0.072	0.000*	0.003
5	0.104	0.105	0.084	0.118	0.125	0.144	0.028	0.053
6	0.159	0.155	0.148	0.190	0.200	0.215	0.062	0.101
7	0.217	0.204	0.213	0.256	0.271	0.280	0.097	0.139
8	0.272	0.253	0.275	0.314	0.333	0.338	0.132	0.167
9	0.324	0.297	0.332	0.368	0.390	0.389	0.174	0.191
10	0.371	0.337	0.384	0.419	0.441	0.436	0.221	0.211
11	0.415	0.373	0.430	0.464	0.486	0.478	0.267	0.229
12	0.453	0.406	0.472	0.504	0.525	0.514	0.309	0.247
13	0.487	0.434	0.509	0.539	0.561	0.548	0.348	0.265
14	0.516	0.461	0.543	0.571	0.592	0.579	0.386	0.287
15	0.544	0.487	0.574	0.599	0.619	0.608	0.421	0.311
16	0.569	0.511	0.601	0.634	0.642	0.633	0.452	0.332
17	0.591	0.533	0.625	0.646	0.664	0.655	0.479	0.352
18	0.611	0.554	0.647	0.666	0.683	0.675	0.504	0.370
19	0.630	0.573	0.667	0.683	0.700	0.692	0.526	0.386
20	0.646	0.589	0.683	0.699	0.715	0.707	0.544	0.399
21	0.661	0.604	0.698	0.712	0.728	0.720	0.560	0.411
22	0.674	0.617	0.712	0.734	0.739	0.732	0.574	0.421
23	0.684	0.627	0.722	0.734	0.749	0.742	0.586	0.431
24	0.693	0.635	0.730	0.741	0.756	0.749	0.594	0.439
25 (top)	0.698	0.638	0.736	0.746	0.760	0.753	0.605	0.459

* Reported negative void fractions set to zero.

Table 42 Void fractions for 8 × 8 assemblies (continued)

Reactor	Oskarshamn 2							Forsmark 1
Assembly ID	**1377**	**1389**	**1546**	**1696**	**1704**	**2995**	**6350**	**KU0100**
Axial level	Void fraction							
1 (bottom)	0.000	0.000	0.000	0.000	0.000	0.000	0.000*	0.000*
2	0.007	0.000	0.004	0.001	0.000	0.005	0.001	0.000*
3	0.040	0.002	0.027	0.011	0.006	0.028	0.038	0.000*
4	0.091	0.018	0.068	0.038	0.029	0.073	0.102	0.017
5	0.146	0.045	0.114	0.078	0.068	0.129	0.171	0.086
6	0.221	0.077	0.172	0.118	0.111	0.192	0.241	0.164
7	0.298	0.113	0.232	0.162	0.162	0.253	0.304	0.238
8	0.374	0.155	0.283	0.208	0.218	0.311	0.356	0.303
9	0.435	0.198	0.334	0.250	0.272	0.363	0.402	0.362
10	0.484	0.238	0.383	0.285	0.320	0.410	0.445	0.416
11	0.526	0.278	0.426	0.318	0.364	0.452	0.483	0.464
12	0.562	0.316	0.463	0.351	0.406	0.488	0.515	0.506
13	0.592	0.353	0.497	0.380	0.440	0.520	0.544	0.544
14	0.618	0.387	0.529	0.409	0.472	0.548	0.571	0.578
15	0.642	0.419	0.557	0.437	0.501	0.575	0.594	0.608
16	0.663	0.448	0.582	0.462	0.526	0.598	0.617	0.634
17	0.680	0.473	0.604	0.485	0.548	0.618	0.637	0.657
18	0.696	0.496	0.625	0.507	0.568	0.638	0.654	0.679
19	0.710	0.517	0.644	0.527	0.588	0.654	0.669	0.697
20	0.721	0.535	0.661	0.543	0.603	0.669	0.685	0.714
21	0.730	0.551	0.675	0.558	0.617	0.683	0.697	0.728
22	0.735	0.564	0.687	0.572	0.630	0.694	0.707	0.741
23	0.739	0.575	0.697	0.582	0.639	0.703	0.716	0.751
24	0.745	0.583	0.704	0.589	0.647	0.710	0.723	0.758
25 (top)	0.750	0.590	0.711	0.597	0.654	0.716	0.726	0.763

* Reported negative void fractions set to zero.

Table 43 Void fractions for 9 × 9 assemblies

Reactor	Forsmark 1		
Assembly ID	**KU0269**	**KU0278**	**KU0282**
Axial level	Void fraction		
1 (bottom)	0.000*	0.000*	0.000*
2	0.000*	0.000*	0.000*
3	0.000*	0.000*	0.000*
4	0.047	0.022	0.037
5	0.128	0.083	0.105
6	0.208	0.147	0.170
7	0.283	0.208	0.236
8	0.349	0.265	0.298
9	0.408	0.320	0.354
10	0.461	0.371	0.405
11	0.507	0.418	0.450
12	0.548	0.461	0.491
13	0.583	0.500	0.529
14	0.615	0.537	0.563
15	0.643	0.569	0.594
16	0.668	0.597	0.621
17	0.689	0.622	0.645
18	0.708	0.645	0.666
19	0.725	0.664	0.684
20	0.739	0.681	0.700
21	0.752	0.697	0.713
22	0.763	0.710	0.725
23	0.771	0.720	0.733
24	0.776	0.729	0.740
25 (top)	0.776	0.728	0.738

* Reported negative void fractions set to zero.

Table 44 Void fractions for SVEA-64 assemblies

Reactor	Oskarshamn 2	Forsmark 2	Forsmark 2	Forsmark 2
Assembly ID	**12684**	**11494**	**11495**	**13775**
Axial level	Void fraction			
1 (bottom)	0.000*	0.000*	0.000*	0.000*
2	0.000*	0.000*	0.000*	0.000*
3	0.014	0.000*	0.000*	0.000*
4	0.085	0.043	0.043	0.050
5	0.167	0.114	0.114	0.122
6	0.245	0.187	0.187	0.197
7	0.313	0.257	0.257	0.267
8	0.371	0.318	0.318	0.330
9	0.423	0.374	0.374	0.385
10	0.471	0.425	0.425	0.436
11	0.514	0.472	0.472	0.482
12	0.551	0.512	0.512	0.520
13	0.584	0.548	0.548	0.555
14	0.614	0.580	0.580	0.585
15	0.640	0.609	0.609	0.612
16	0.662	0.634	0.634	0.635
17	0.683	0.657	0.657	0.656
18	0.701	0.677	0.677	0.675
19	0.718	0.695	0.695	0.692
20	0.732	0.711	0.711	0.706
21	0.744	0.725	0.725	0.719
22	0.754	0.737	0.737	0.730
23	0.763	0.747	0.747	0.738
24	0.768	0.753	0.753	0.744
25 (top)	0.773	0.759	0.759	0.747

* Reported negative void fractions set to zero.

Table 45 Void fractions for SVEA-100 assemblies

Reactor	Oskarshamn 3	Oskarshamn 3	Forsmark 3	Forsmark 3
Assembly ID	**13628**	**13630**	**13847**	**13848**
Axial level	Void fraction			
1 (bottom)	0.000*	0.000*	0.000*	0.000*
2	0.000*	0.000*	0.000*	0.000*
3	0.000*	0.001	0.000*	0.000*
4	0.064	0.065	0.062	0.062
5	0.145	0.146	0.143	0.143
6	0.223	0.225	0.222	0.222
7	0.291	0.296	0.296	0.296
8	0.350	0.358	0.361	0.361
9	0.401	0.414	0.418	0.418
10	0.447	0.463	0.468	0.468
11	0.487	0.506	0.512	0.512
12	0.522	0.544	0.550	0.550
13	0.554	0.578	0.583	0.583
14	0.583	0.607	0.612	0.612
15	0.609	0.634	0.638	0.638
16	0.632	0.656	0.661	0.661
17	0.653	0.677	0.682	0.682
18	0.672	0.696	0.700	0.700
19	0.689	0.712	0.717	0.717
20	0.704	0.727	0.731	0.731
21	0.717	0.739	0.744	0.744
22	0.728	0.750	0.755	0.755
23	0.736	0.758	0.764	0.764
24	0.742	0.764	0.771	0.771
25 (top)	0.742	0.763	0.771	0.771

* Reported negative void fractions set to zero.

Table 46 Water moderator densities for Forsmark assemblies

Reactor	Forsmark 1	Forsmark 1	Forsmark 1	Forsmark 1	Forsmark 1	Forsmark 2	Forsmark 2	Forsmark 2	Forsmark 2	Forsmark 3	Forsmark 3
Assembly ID	**3838**	**KU0100**	**KU0269**	**KU0278**	**KU0282**	**11494**	**11495**	**13775**	**5535**	**13847**	**13848**
Axial level	Water density (g/cm^3)										
1 (bottom)	0.764	0.763	0.764	0.763	0.763	0.762	0.762	0.762	0.765	0.757	0.757
2	0.762	0.760	0.760	0.760	0.760	0.756	0.756	0.757	0.762	0.753	0.753
3	0.754	0.750	0.740	0.748	0.742	0.738	0.738	0.739	0.749	0.730	0.730
4	0.738	0.722	0.700	0.720	0.706	0.703	0.703	0.707	0.724	0.686	0.686
5	0.717	0.678	0.647	0.681	0.661	0.658	0.658	0.665	0.691	0.633	0.633
6	0.693	0.625	0.594	0.639	0.617	0.611	0.611	0.621	0.659	0.580	0.580
7	0.669	0.573	0.544	0.598	0.574	0.565	0.565	0.579	0.632	0.530	0.530
8	0.643	0.525	0.498	0.560	0.535	0.523	0.523	0.540	0.613	0.486	0.486
9	0.613	0.482	0.457	0.523	0.497	0.484	0.484	0.503	0.598	0.448	0.448
10	0.579	0.444	0.420	0.488	0.462	0.448	0.448	0.469	0.584	0.414	0.414
11	0.547	0.410	0.388	0.456	0.431	0.416	0.416	0.438	0.571	0.384	0.384
12	0.516	0.381	0.360	0.426	0.403	0.388	0.388	0.410	0.559	0.359	0.359
13	0.488	0.356	0.336	0.398	0.377	0.364	0.364	0.385	0.545	0.337	0.337
14	0.461	0.333	0.315	0.373	0.353	0.342	0.342	0.363	0.529	0.317	0.317
15	0.436	0.313	0.296	0.351	0.332	0.323	0.323	0.343	0.512	0.300	0.300
16	0.415	0.296	0.279	0.331	0.313	0.306	0.306	0.326	0.499	0.285	0.285
17	0.395	0.280	0.265	0.314	0.297	0.290	0.290	0.310	0.486	0.271	0.271
18	0.378	0.266	0.252	0.298	0.282	0.277	0.277	0.296	0.474	0.259	0.259
19	0.363	0.253	0.241	0.285	0.270	0.264	0.264	0.284	0.464	0.248	0.248
20	0.350	0.242	0.231	0.273	0.259	0.253	0.253	0.273	0.456	0.238	0.238
21	0.338	0.232	0.222	0.262	0.250	0.244	0.244	0.263	0.449	0.229	0.229
22	0.329	0.224	0.214	0.253	0.243	0.235	0.235	0.255	0.443	0.221	0.221
23	0.321	0.217	0.208	0.246	0.237	0.228	0.228	0.249	0.438	0.215	0.215
24	0.315	0.211	0.203	0.239	0.232	0.223	0.223	0.243	0.432	0.210	0.210
25 (top)	0.308	0.208	0.204	0.239	0.233	0.219	0.219	0.239	0.418	0.206	0.206

7.4 Trends in Void-Profile Data

In the absence of void profiles for some BWR assemblies, it is possible to estimate the void profile from the data that are available. Figures 7 and 8 show reported void profiles for selected assemblies from the Barsebäck 1 and Oskarshamn 2 plants, respectively.

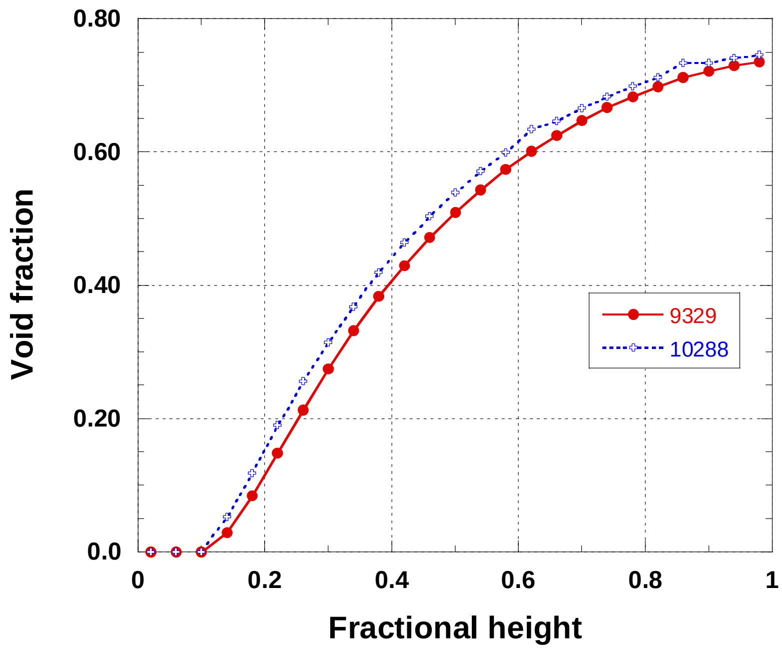

Figure 7 Void fraction profile for Barsebäck 1 assemblies

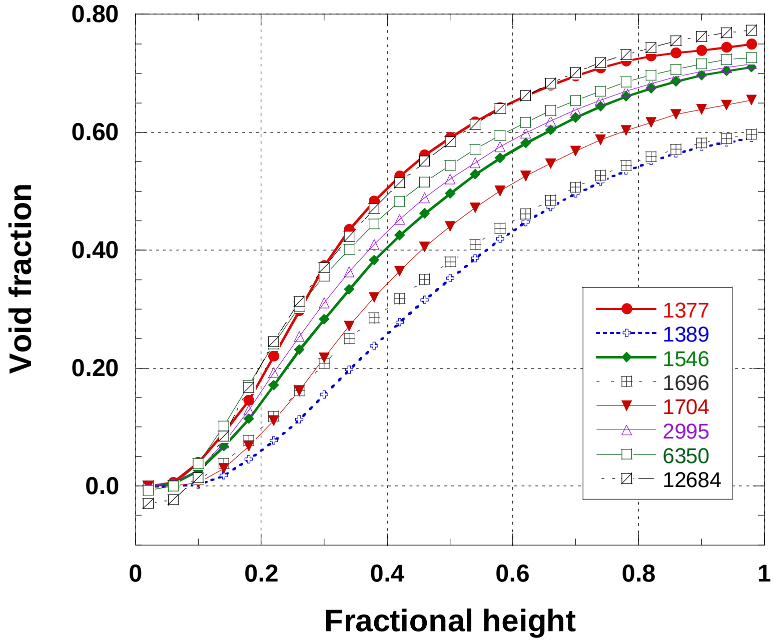

Figure 8 Void fraction profile for Oskarshamn 2 assemblies

The shape of all the profiles is similar. In the case of the Oskarshamn 2 data, the void fractions shown below zero can be assumed as effectively zero and are attributed to the core simulation codes. The profiles for other BWR assemblies are similar. A distinguishing characteristic of the profiles is the maximum void fraction (or alternatively, the average void profile value).

Void conditions are dependent on the power density in the fuel. The correlation between maximum void fraction and power density for the assemblies for which void data were reported is illustrated in Figure 9. The relationship between void and assembly power is clear. The points show some scatter as one might expect given that the power and void fractions used to construct the plot are averages over a number of burnup cycles. The best-fit trend line shown in Figure 9 is as follows:

$$V = 0.522 + (0.00992)\cdot P,$$

where V is the maximum void fraction, and P is the average assembly power in MW/MTU.

Therefore, knowing the average assembly power, one can estimate with some confidence the maximum void fraction experienced by the assembly. The void profiles can be obtained from assemblies from the same reactor having a similar power density.

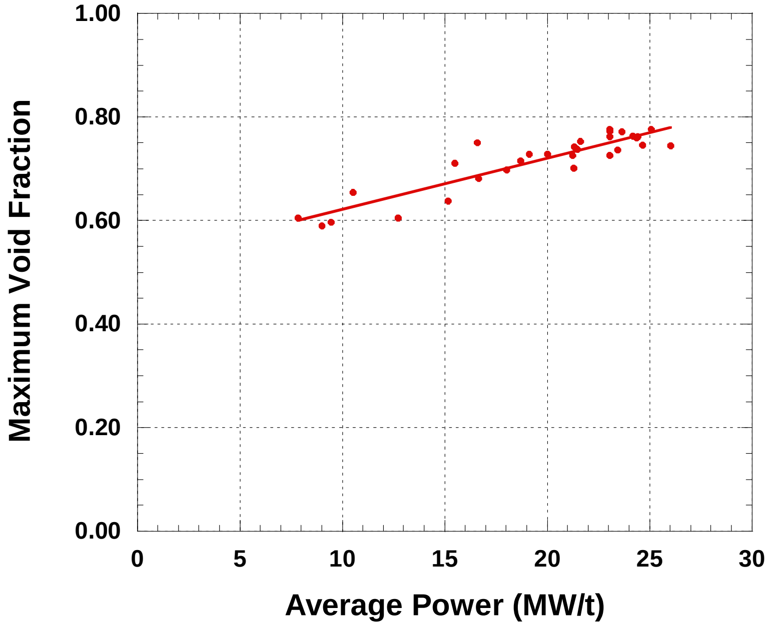

Figure 9 Maximum void fraction vs. assembly average power

8 SUMMARY

This report is a compilation of assembly design data, fuel data, and reactor operating history data necessary for the computational analysis of decay heat measurements performed on spent fuel assemblies at the Swedish Central Interim Storage Facility for Spent Nuclear Fuel, CLAB. The design data and measurement results are provided to enable validation of computation methods and data for the prediction of the heat generation in nuclear fuel. This report contains design and measurement data for 34 BWR assemblies and 30 PWR assemblies and includes many modern fuel designs with moderate enrichment levels and burnups that extend to about 51,000 MWd/MTU. The experimental data presented in this report expands significantly the range of validation for decay heat predictions well beyond the range covered by previous measurements.[5,8]

For some assemblies, incomplete data have been reported. Most notably, enrichment zoning and burnable poison rod configurations were not available for the BWR assemblies. For these data, representative values can generally be obtained from alternate sources.

The measurements documented in this report include all those completed to date at the CLAB facility for spent fuel assemblies that were not rebuilt (removal or reconfiguration of fuel rods). The data for rebuilt assemblies may be added in the future as more data on the details of the reconstruction become available. This validation database may be expanded in the future as additional measurements are performed and reported for assemblies with higher enrichment and burnup values.

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APPENDIX A: ASSEMBLY DIAGRAMS

Diagrams (cross-section views) are shown for the various configurations of assemblies measured in the CLAB decay heat project in Figures A.1 through A.6. Each diagram shows the typical configuration for each assembly. Details of the dimensions vary from assembly to assembly within a configuration. When studying the diagrams, the reader can substitute the appropriate dimensions that are listed in the tables presented in this report. Dimensions are not always exactly to scale. This is particularly true, for instance, in the case of fuel cladding where the thicknesses are exaggerated for purposes of visual clarity. For the BWR assemblies the fuel rods are zoned according to enrichment levels, in general. This enrichment zoning is indicated for some of the assemblies. The lower enrichment zones (typically at the outer edge of the assembly), are indicated by lighter colors. The assembly enrichments listed in this report are assembly average values. The actual enrichment zoning information was not available at the time this report was published.

For the BWR assemblies shown here, the orientation is such that the control blade will be to the top left of the diagram.

A.1 PWR Assembly Configurations

Two diagrams are shown for the PWR assemblies: a 17 × 17 (Figure A.1) assembly and a 15 × 15 assembly (Figure A.2). The 17 × 17 assembly has 25 water holes. These correspond with 24 guide tubes and one central instrument tube. The 15 × 15 assembly shows a typical arrangement with 21 water holes corresponding to 20 guide tubes and 1 central instrument tube.

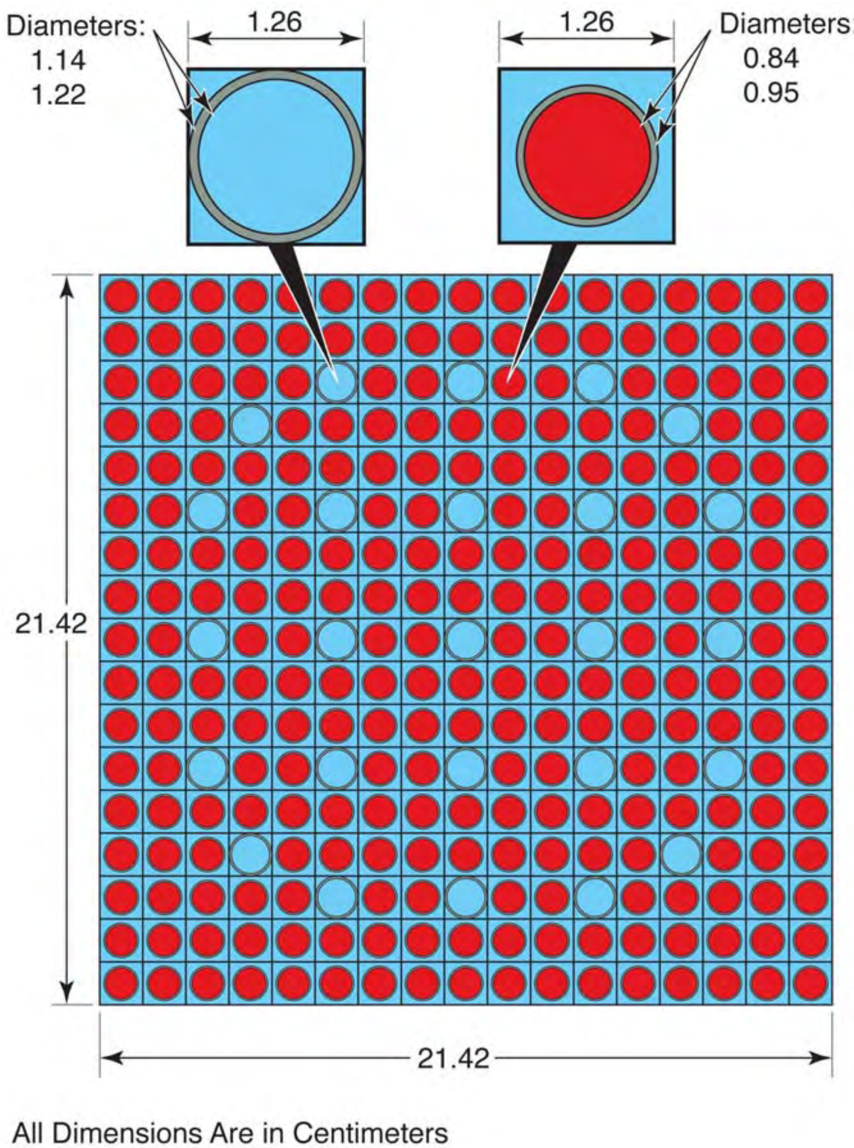

Figure A.1 17 × 17 PWR assembly layout

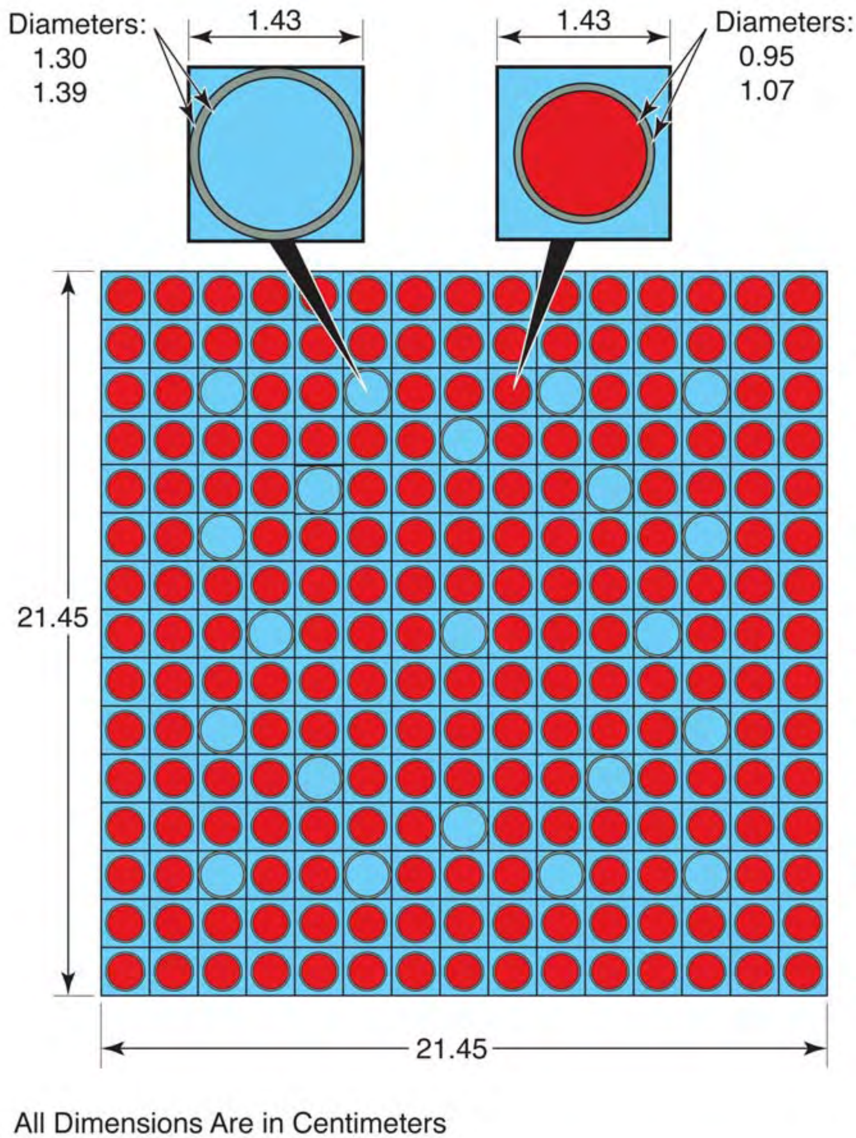

Figure A.2 15 × 15 PWR assembly layout

A.2 BWR Assembly Configurations

The 8 × 8 assembly is shown in Figure A.3 together with the associated surrounding channel water. The outermost dimension is equal to the assembly pitch. Four gadolinium-bearing burnable poison rods are identified in yellow. The location of the poison rods was not provided, and the configuration shown was assumed. There is a single water rod located near the center of the assembly. The individual lattice cells (square) are shown. There is an additional layer of water inside of the Zircaloy box when one accounts for the area of the 8 × 8 lattice inside of the flow tube area. As noted, many 8 × 8 assemblies have slightly smaller corner rods; however, for the assembly shown here, all rods are of equal size.

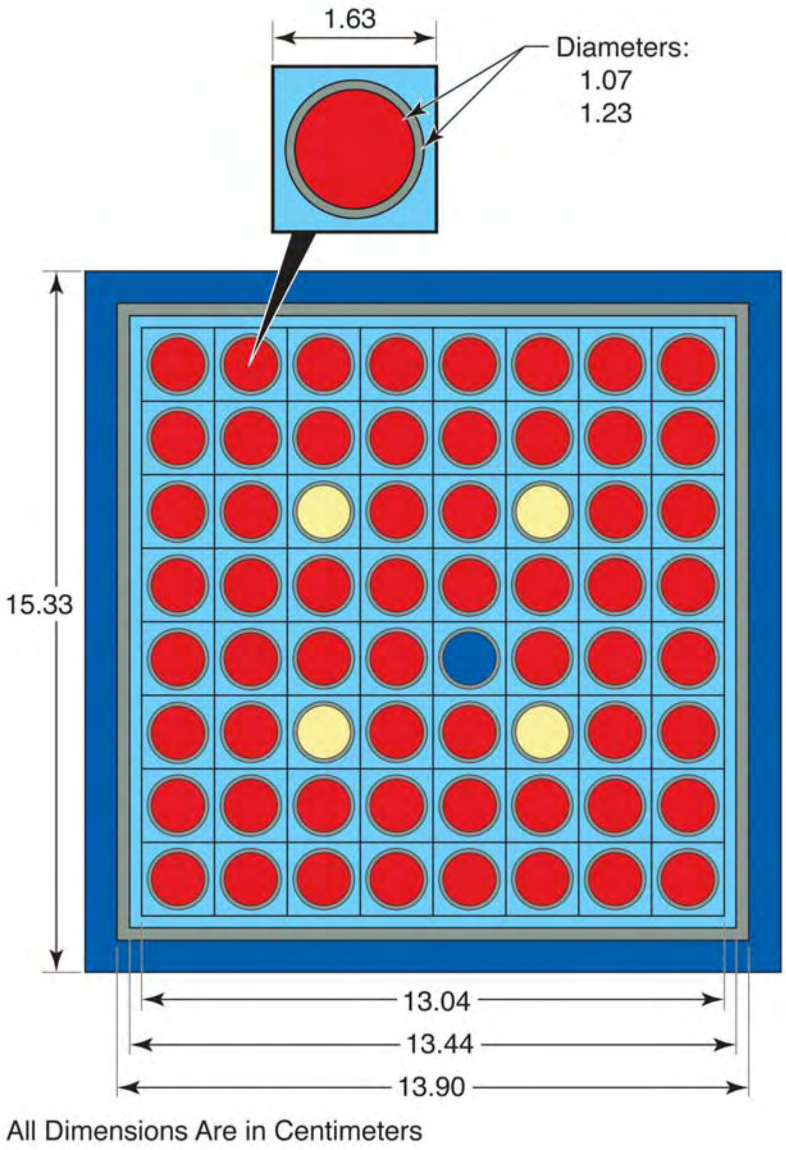

Figure A.3 8 × 8 BWR assembly layout

A 9 × 9 assembly, shown here with five water rods offset from the center of the assembly, is illustrated in Figure A.4. The fuel rod enrichment zoning is shown, with decreasing levels indicated by lighter colors. Enrichment zoning was not available for most of the assemblies; however the zoning pattern shown in Figure A.4 is typical of many BWR assemblies.

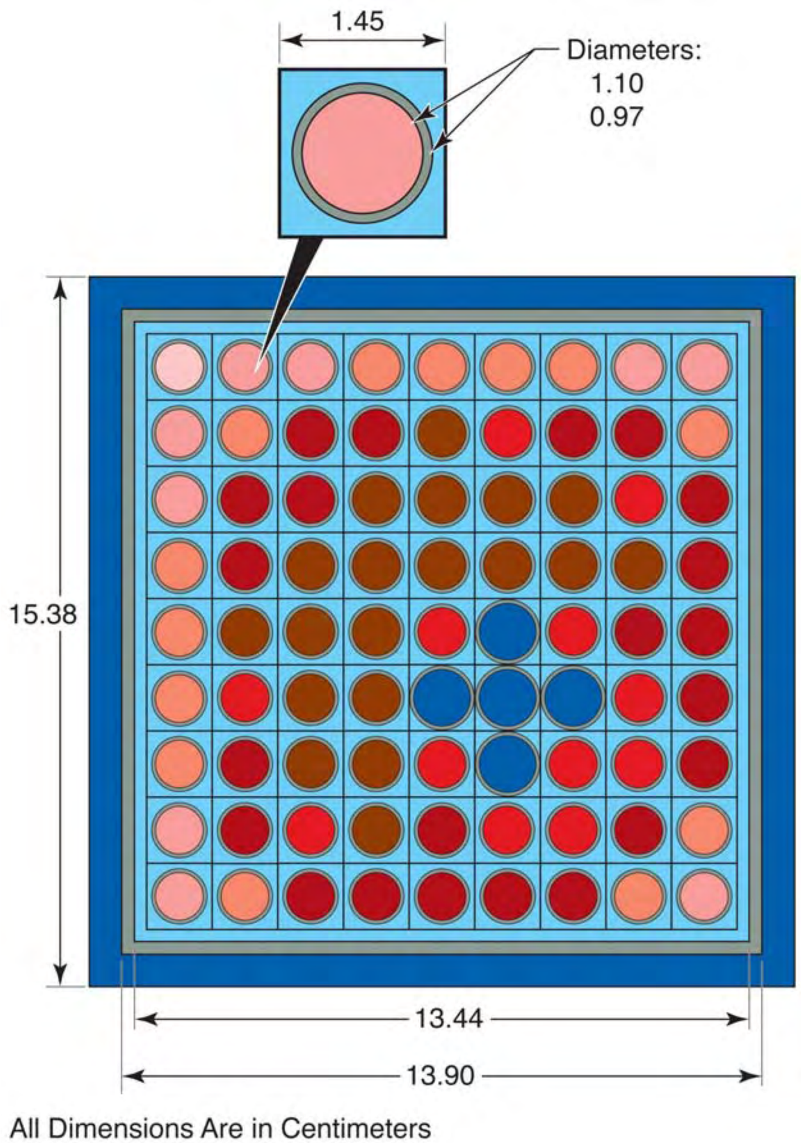

Figure A.4 9 × 9 BWR assembly layout

The following two diagrams (Figures A.5 and A.6) show a SVEA-64 and a SVEA-100 assembly. The SVEA-64 assemblies contained one water rod; the SVEA-100 assemblies had no water rods. For both assemblies, typical enrichment-zoning patterns are shown with lower enrichments indicated by lighter colored rods toward the assembly edges. Again, detailed enrichment zoning was not available for all assemblies. Five gadolinium-bearing poison rods are shown in the SVEA-64 assembly, and eight are shown in the SVEA-100 assembly.

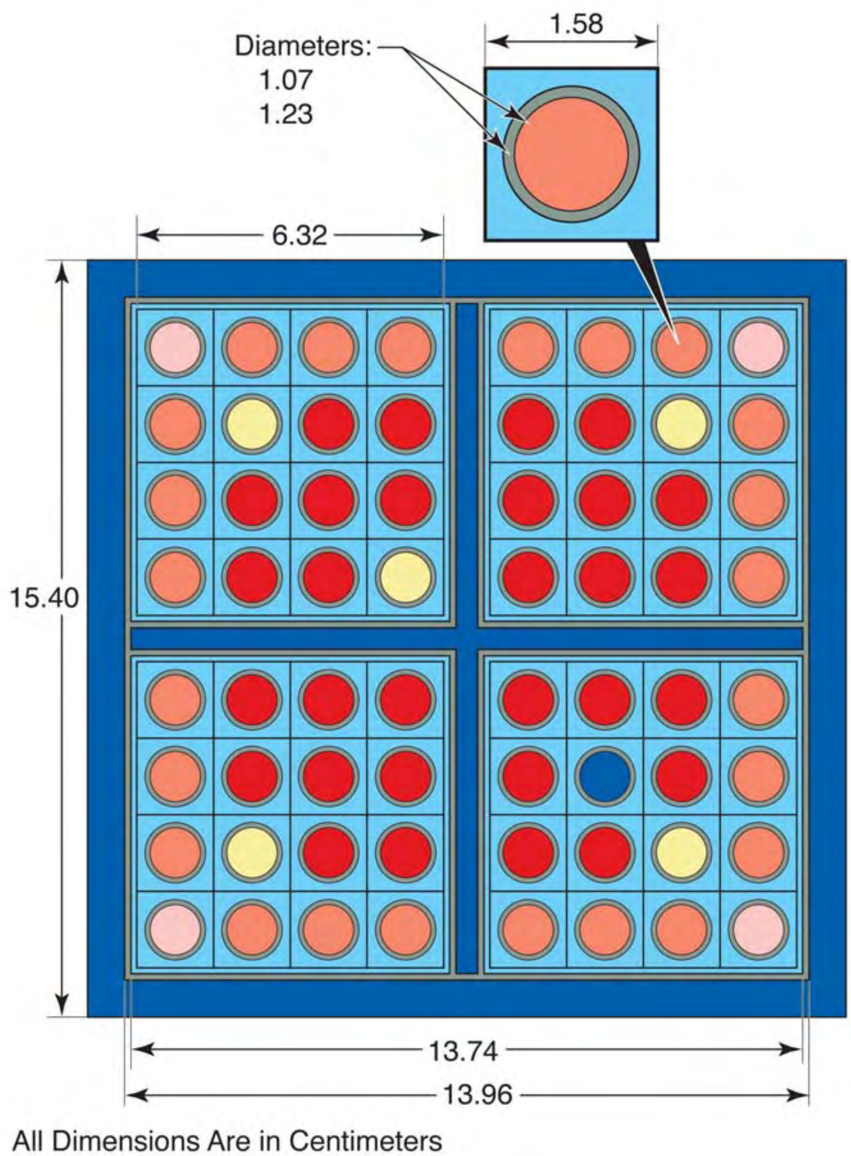

Figure A.5 SVEA-64 assembly layout

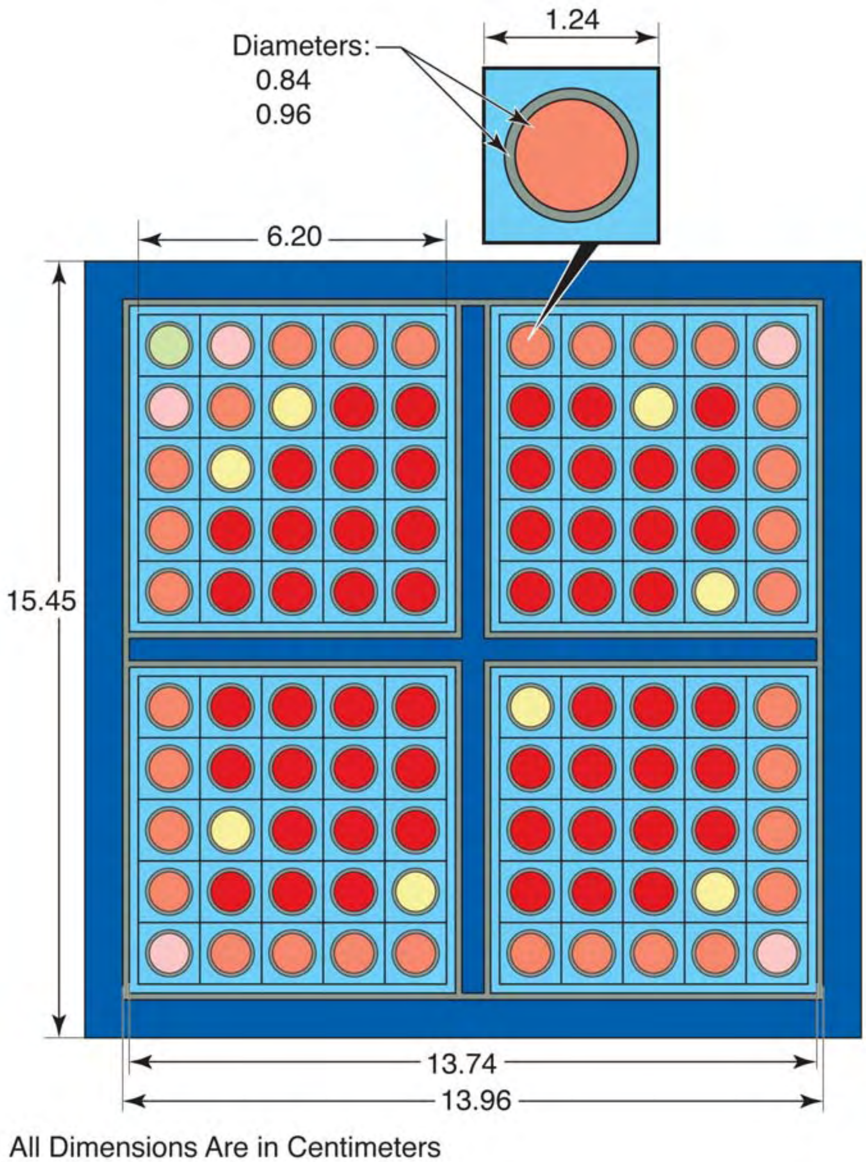

Figure A.6 SVEA-100 assembly layout

APPENDIX B: MEASURED DECAY HEAT VALUES

The decay-heat measurement data are listed in Tables B.1 and B.2 for PWR and BWR assemblies, respectively. Heat generation values measured by calorimetry are listed, as well as gamma-ray escape heat values. Also listed are assembly discharge dates, decay heat measurement dates, cooling times and assembly burnup values. Note that multiple measurements were performed on some of the assemblies.

Table B.1 Decay heat measurement results for PWR assemblies

Assembly	Design	Discharge date[a]	Measurement date	Decay time (days)	Burnup (MWd/MTU)	Calorimeter decay heat (W)	Gamma escape heat (W)	Total decay heat (W)
0C9	17 × 17	5/30/1986	5/6/2004	6551	38,442	478.6	12.6	491.2
0E2	17 × 17	7/7/1988	6/16/2004	5823	41,628	572.4	15.5	587.9
0E6	17 × 17	7/7/1988	6/22/2004	5829	35,993	475.1	12.6	487.8
1C2	17 × 17	5/30/1986	5/14/2004	6559	33,318	407.3	10.4	417.7
1C5	17 × 17	5/30/1986	6/17/2004	6593	38,484	486.5	12.7	499.2
1E5	17 × 17	7/7/1988	6/11/2004	5818	34,638	456.9	11.9	468.8
2A5	17 × 17	5/11/1984	5/3/2004	7297	20,107	227.9	5.8	233.8
2C2	17 × 17	5/30/1986	5/5/2004	6550	36,577	454.8	11.7	466.5
3C1	17 × 17	5/30/1986	4/30/2004	6545	36,572	458.3	11.9	470.2
3C5	17 × 17	5/30/1986	4/28/2004	6543	38,373	488.9	12.5	501.4
3C9	17 × 17	5/30/1986	5/7/2004	6552	36,560	456.5	11.9	468.4
4C4	17 × 17	5/30/1986	5/27/2004	6572	33,333	411.4	10.6	422.0
4C7	17 × 17	5/30/1986	5/4/2004	6549	38,370	485.9	12.8	498.7
5A3	17 × 17	5/11/1984	6/13/2003	6972	19,699	231.9	5.8	237.7
5A3	17 × 17	5/11/1984	6/16/2003	6975	19,699	230.8	5.8	236.7
5A3	17 × 17	5/11/1984	6/18/2003	6977	19,699	237.6	5.8	243.4
5A3	17 × 17	5/11/1984	4/27/2004	7291	19,699	225.1	5.8	230.9
5A3	17 × 17	5/11/1984	5/10/2004	7304	19,699	224.4	5.8	230.3

[a] Dates listed as month/day/year.

Table B.1 Decay heat measurement results for PWR assemblies (continued)

Assembly	Design	Discharge date[a]	Measurement date	Decay time (days)	Burnup (MWd/MTU)	Calorimeter decay heat (W)	Gamma escape heat (W)	Total decay heat (W)
C01	15 × 15	4/4/1981	6/10/2004	8468	36,688	406.3	9.4	415.8
C12	15 × 15	4/4/1981	4/6/2004	8403	36,385	401.6	8.7	410.3
C20	15 × 15	4/4/1985	4/14/2004	6950	35,720	406.1	9.7	415.8
C20	15 × 15	4/4/1985	4/15/2004	6951	35,720	416.4	9.6	426.0
C20	15 × 15	4/4/1985	4/16/2004	6952	35,720	419.2	9.7	428.9
C20	15 × 15	4/4/1985	4/23/2004	6959	35,720	425.9	9.8	435.7
D27	15 × 15	4/28/1983	4/26/2004	7669	39,676	444.6	11.4	456.1
D38	15 × 15	5/6/1982	4/5/2004	8005	39,403	431.6	10.8	442.3
E38	15 × 15	5/6/1982	3/30/2004	7999	33,973	366.9	9.4	376.3
E38	15 × 15	5/6/1982	3/31/2004	8000	33,973	364.9	9.4	374.3
E40	15 × 15	5/6/1982	6/14/2004	8075	34,339	372.2	9.0	381.3
F14	15 × 15	4/28/1983	6/18/2004	7722	34,009	372.5	9.3	381.8
F21	15 × 15	4/13/1984	6/23/2004	7376	36,273	410.2	10.7	420.9
F25	15 × 15	4/28/1983	6/21/2004	7725	35,352	386.7	10.0	396.7
F32	15 × 15	5/12/1988	5/28/2004	5860	50,962	675.4	16.6	692.0
G11	15 × 15	4/4/1985	5/24/2004	6990	35,463	405.7	10.6	416.4
G23	15 × 15	4/4/1985	5/18/2004	6984	35,633	409.6	11.1	420.6
I09	15 × 15	5/12/1988	5/17/2004	5849	40,188	494.5	13.4	507.9
I24	15 × 15	4/30/1986	5/26/2004	6601	34,294	398.2	11.8	410.1
I25	15 × 15	4/25/1987	4/13/2004	6198	36,859	434.0	11.8	445.8

[a] Dates listed as month/day/year.

Table B.2 Decay heat measurement results for BWR assemblies

Assembly	Design	Discharge date	Measurement date	Decay time (days)	Burnup (MWd/MTU)	Calorimeter decay heat (W)	Gamma escape heat (W)	Total decay heat (W)
1177	8 × 8	8/2/1985	11/26/2003	6690	36,242	173.4	4.5	177.9
1186	8 × 8	8/2/1985	11/10/2003	6674	30,498	137.5	3.3	140.8
1377	8 × 8	5/13/1977	1/22/2004	9750	14,546	54.8	1.4	56.2
1389	8 × 8	7/15/1981	11/28/2003	8171	19,481	81.7	2.2	83.9
1546	8 × 8	8/19/1983	1/16/2004	7455	24,470	105.4	2.7	108.1
1696	8 × 8	8/19/1983	12/3/2003	7411	20,870	90.0	2.3	92.4
1704	8 × 8	7/23/1982	12/8/2003	7808	19,437	81.8	2.1	84.0
2995	8 × 8	7/15/1981	1/7/2004	8211	29,978	127.3	3.2	130.5
3838	8 × 8	7/10/1992	12/10/2003	4170	25,669	123.4	3.4	126.8
3838	8 × 8	7/10/1992	12/11/2003	4171	25,669	122.6	3.4	125.9
5535	8 × 8	7/15/1988	12/18/2003	5634	19,944	82.4	2.2	84.6
6350	8 × 8	6/7/1985	12/4/2003	6754	27,675	123.7	3.2	126.9
6350	8 × 8	6/7/1985	12/5/2003	6755	27,675	126.2	3.2	129.4
6423	8 × 8	8/5/1988	2/12/2004	5669	35,109	169.1	5.2	174.2
6432	8 × 8	8/5/1988	6/10/2003	5422	36,861	179.9	5.5	185.5
6432	8 × 8	8/5/1988	6/12/2003	5424	36,861	184.0	5.5	189.5
6432	8 × 8	8/5/1988	2/13/2004	5670	36,861	178.9	5.5	184.4
6432	8 × 8	8/5/1988	2/23/2004	5680	36,861	177.1	5.7	182.8
6432	8 × 8	8/5/1988	2/24/2004	5681	36,861	179.4	5.7	185.2
6432	8 × 8	8/5/1988	3/1/2004	5687	36,861	175.8	5.8	181.6
6432	8 × 8	8/5/1988	3/2/2004	5688	36,861	176.4	5.5	182.0
6454	8 × 8	8/15/1986	2/17/2004	6395	37,236	181.3	5.0	186.3
8327	8 × 8	8/6/1991	3/10/2004	4600	37,851	191.0	6.0	196.9
8331	8 × 8	9/15/1989	3/11/2004	5291	35,903	181.3	5.7	187.0
8332	8 × 8	8/5/1988	3/4/2004	5690	34,977	163.0	5.1	168.1
8338	8 × 8	8/5/1988	3/9/2004	5695	34,830	164.9	4.6	169.5

Table B.2 Decay heat measurement results for BWR assemblies (continued)

Assembly	Design	Discharge date	Measurement date	Decay time (days)	Burnup (MWd/MTU)	Calorimeter decay heat (W)	Gamma escape heat (W)	Total decay heat (W)
9329	8 × 8	9/17/1988	6/2/2003	5371	41,127	217.4	5.4	222.8
9329	8 × 8	9/17/1988	6/4/2003	5373	41,127	218.9	5.4	224.4
9329	8 × 8	9/17/1988	11/20/2003	5542	41,127	213.2	5.4	218.7
10288	8 × 8	9/17/1988	11/12/2003	5534	35,218	181.2	4.6	185.8
11494	SVEA-64	7/15/1988	12/2/2003	5618	32,431	161.7	4.4	166.0
11495	SVEA-64	7/15/1988	11/7/2003	5593	32,431	163.3	4.3	167.6
12078	8 × 8	7/8/1988	11/18/2003	5611	25,160	116.9	3.3	120.2
12684	SVEA 64	8/2/1991	12/16/2003	4519	46,648	274.9	7.8	282.7
13628	SVEA-100	6/24/1991	1/8/2004	4581	35,619	188.2	5.8	194.0
13630	SVEA-100	6/24/1991	12/12/2003	4554	40,363	228.6	7.1	235.7
13775	SVEA-64	7/12/1991	12/19/2003	4543	32,837	173.1	5.3	178.4
13847	SVEA-100	7/13/1990	11/13/2003	4871	31,275	165.4	4.9	170.3
13847	SVEA-100	7/14/1990	11/14/2003	4871	31,275	164.7	4.9	169.6
13848	SVEA-100	7/13/1990	11/24/2003	4882	31,275	165.6	5.1	170.7
14076	8 × 8	7/2/1992	12/9/2003	4177	40,010	233.7	6.6	240.3
KU0100	8 × 8	8/17/1990	1/9/2004	4893	34,193	180.2	5.1	185.3
KU0269	9 × 9	8/17/1990	1/19/2004	4903	35,113	187.1	5.6	192.7
KU0278	9 × 9	5/24/1991	12/22/2003	4595	35,323	189.9	5.5	195.4
KU0282	9 × 9	5/24/1991	12/1/2003	4574	37,896	212.5	5.9	218.5

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