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Measurements of decay heat in spent nuclear fuel at the Swedish interim storage facility, Clab

Svensk Kärnbränslehantering AB

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Svensk Kärnbränslehantering AB
Swedish Nuclear Fuel
and Waste Management Co
Box 5864
SE-102 40 Stockholm Sweden
Tel 08-459 84 00
+46 8 459 84 00
Fax 08-661 57 19
+46 8 661 57 19

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Measurements of decay heat in spent nuclear fuel at the Swedish interim storage facility, Clab

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Measurements of decay heat in spent nuclear fuel at the Swedish central interim storage facility, Clab

Calorimetric and gamma radiation measurements on spent nuclear fuel have been performed at the Swedish central interim storage facility, Clab, on 50 BWR fuel assemblies and 34 PWR fuel assemblies during 2004.

The purpose with the measurements is to develop a quick and simple method to determine the decay heat in spent nuclear fuel prior to encapsulation and final disposal.

The equipment and the measurements are described in this report, which consists of five parts:

Part 1. Clab – Measurements of decay heat in spent nuclear fuel assemblies

In this part the calorimetric measurements are summarized. Measurement results are presented and a comparison between measured and calculated values is accounted for.

Part 2. Clab – Gamma scanning of spent nuclear fuel assemblies: determination of residual thermal power using new data acquisition and analysis software

The gamma scanning is presented in this part. The equipment, measurements and results are presented.

Part 3. Clab – Calibration curve for calorimetric measurements of fuel assemblies

Development of the calibration curve for the calorimeter is presented in this part.

Part 4. Clab – Uncertainty analysis of the calorimeter (system 251) using the temperature increase method

An uncertainty analysis of the calorimeter and the measured decay heat values is performed in this part.

Part 5. Clab – Data for fuel assemblies used in calorimetric and nuclear measurements

In this part the fuel data for the spent nuclear fuel is presented as received from the power plants.

Part 1

Clab– Measurements of decay heat in spent nuclear fuel assemblies

Fredrik Sturek, Lennart Agrenius

Contents

1 Introduction

Svensk Kärnbränslehantering AB (SKB) is conducting measurements of decay heat and gamma radiation on spent fuel assemblies in the Swedish central interim storage facility for spent nuclear fuel (Clab).

The objectives of these measurements are:

Primary:

- Accurate and simple determination of decay power in final disposal canisters for spent nuclear fuel by use of correlation with gamma measurements on fuel assemblies.
- Verification of burnup and cooling time of spent nuclear fuel prior to encapsulation.
- More accurate prediction of total decay power in Clab.

Secondary:

- More accurate decay power prediction prior to fuel transport to Clab.
- Calibration of decay heat calculations by e.g. Origen and Decay (Swedish).
- Provide a basis for BU-credit (if needed) in final disposal canister.

This report describes the measurements and calculations on 50 BWR – and 34 PWR – assemblies performed so far (end of 2004).

Measurements will be repeated in certain intervals in the future on the same selected fuel assemblies. The population may later be increased by assemblies of different designs.

2 Calorimetric method

2.1 General

A calorimeter was designed with the purpose to measure the decay heat power in spent nuclear fuel assemblies of PWR- and BWR-types.

Decay heat power from 50 W to 1,000 W should be possible to measure.

The design goal was that the uncertainty of the decay heat power measurement should be less than ± 2%.

The equipment is designed to be located under water in one of the pools in the Clab reception area. Fuel assemblies are placed in and removed from the equipment with the normal fuel handling system in Clab.

2.2 Description of the calorimeter

The calorimeter is 5 m long and is composed of two concentric pipes. The inner pipe, which has an inner diameter of 0.33 m forms the test chamber. The test chamber is 4.5 m long. The space between the inner and outer cylinders is filled with polyuretan foam, which acts as thermal insulation between the test chamber and the pool water.

A lid is placed at the top of the calorimeter. The purpose of the lid is to form at leak tight barrier between the test chamber and the pool water. The lid is opened, closed, locked and unlocked with help of compressed air.

The calorimeter is normally placed in the service pool in the reception area at the Clab facility.

The fuel assembly is placed in the calorimeter with the normal fuel handling equipment in Clab. In the test chamber there is a fixed insert for PWR fuel and a removable insert for BWR-fuel. The inserts maintain the fuel assembly in centred vertical position.

A centrifugal pump circulates water in the calorimeter in order to maintain a homogenous temperature in the test chamber. The nominal capacity of the pump is 60 l/min. A flow through the test chamber can be established with help of a measurement flow pump with a controllable flow in the range of 0–20 l/min. The measurement flow is measured by a flow-measuring unit, which can be calibrated by means of a calibration tank in which the mass of water is measured by a scale.

In the calorimeter the temperatures are measured with 16 PT-100 sensors. Eight sensors are placed in the water inside the test chamber. Two sensors are placed on the inside and outside surfaces of the calorimeter, and two sensors are placed in the water outside the calorimeter to measure the pool water temperature. Temperatures of the measurement flow are measured at the incoming and outgoing flow of the calorimeter.

Outside the calorimeter five gamma radiation monitors are placed on a movable arm to measure the radial distribution of the gamma radiation that escapes from the calorimeter. The arm is movable axially in 10 fixed positions and can be turned 90 degrees around the calorimeter.

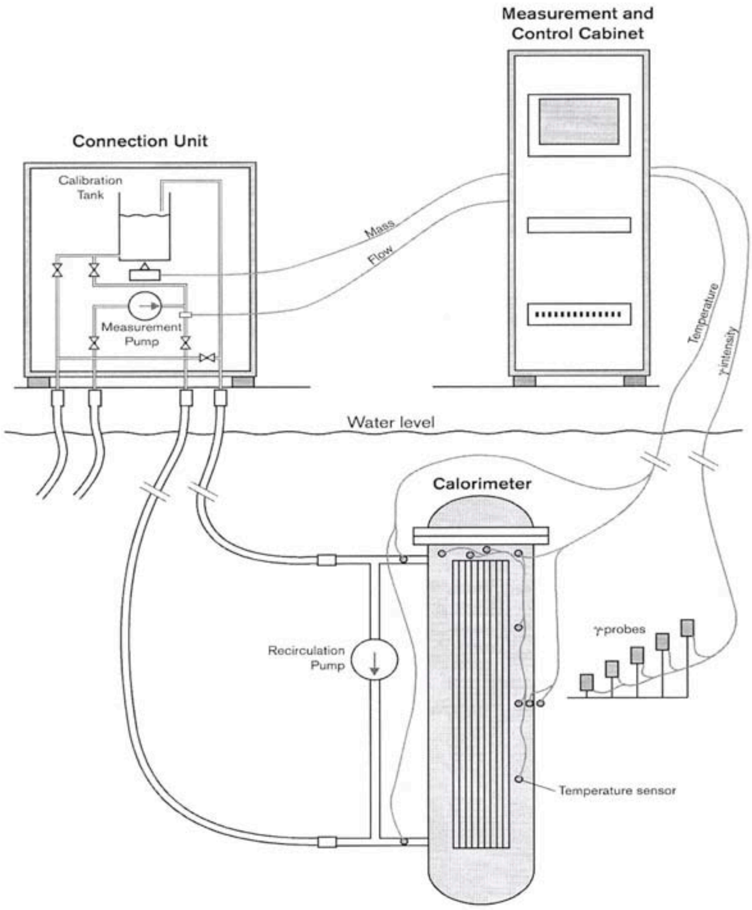

Figure 2-1. *Calorimeter.*

Calibration of the calorimeter is performed with an electric heater designed in the same shape as a BWR fuel assembly.

Valves and pumps are controlled by a PC-based system. All data are logged by the PC-system.

2.3 Measurement principles

The basic measurement principle is to measure the temperature increase of the water in the calorimeter caused by the decay heat power from a fuel assembly placed in the calorimeter.

The decay heat power is determined by comparing the temperature increase to a calibration curve. Before each measurement campaign a calibration curve is established using an electric heater. The temperature increase in the calorimeter is measured for several power levels. Based on these measurements a calibration curve is established. Calibration curves could be established for the three different measurement methods.

The three different methods to measure the temperature increase are:

1. Temperature increase method.
2. Recirculation method.
3. Equilibrium method.

Temperature increase method

A fuel assembly is placed in the calorimeter. The lid is closed. In order to assure that the calorimeter is completely full with water the measurement flow pump is operated until water is flowing out into the calibration tank. The pump is stopped and the water is freely communicating with the calorimeter thus creating an overpressure in the calorimeter. The circulation pump is started and the temperature increase is monitored. After an increase of around 4ºC the measurement is stopped. The measured increase rate of the temperature is compared to the corresponding calibration measurements and the decay power is determined. The gamma radiation field is measured and the power escaped with the gamma radiation is determined. The sum of the measured decay power and power from the escaped gamma gives the total decay heat power.

Recirculation method

A fuel assembly is placed in the calorimeter. The lid is closed. In order to assure that the calorimeter is completely full with water the measurement flow pump is operated until water is flowing out into the calibration tank. Then the recirculation flow is redirected back to the pool. In this case there is a flow through the calorimeter, which will be heated up. When equilibrium is reached the measurement is stopped. Based of the flow, the temperature difference between incoming and outgoing water and the gamma escape the decay heat power could be evaluated.

Equilibrium method

A fuel assembly is placed in the calorimeter. The lid is closed. In order to assure that the calorimeter is completely full with water the measurement flow pump is operated until water is flowing out into the calibration tank. The pump is stopped and the water is freely communicating with the calorimeter thus creating an overpressure in the calorimeter. Then circulation pump is started and the temperature increase is monitored. The temperature is increasing until equilibrium is reached.

The temperature difference between starting temperature and equilibrium temperature is compared to the calibration curve. This will give the decay power in the calorimeter. Correction for gamma escape will give the total decay heat power.

Comparison between the methods

Tests have shown that the equilibrium method is very time consuming. It takes at least one week to establish equilibrium in the calorimeter (one measurement point). More than 20 measurement points are required to get a good calibration curve and around 20 assemblies are planned to be measured each year. This method would give too long measurement times and will not be used.

With the temperarature increase and the circulation methods one measurement point takes around 4–5 hours for calibration. Fuel assemblies takes longer because time is needed for fuel handling. Realistically one fuel assembly could be measured in one day.

The circulation method shows also to be time consuming and requires more attention from the operator than the other methods.

The conclusion of these experiences is that the temperature increase method will be used.

2.4 Calibration

To be able to translate the temperature increase into decay power a calibration curve has been established, see also part 3. An immersion heater was used to heat the volume of water in the calorimeter. The heater was designed to be similar to a BWR-fuel assembly using structural parts from a fuel assembly. A heating cable was attached in the structure to simulate the fuel assembly geometry.

The heating cable was powered from a stabilised power supply and the power input was measured by a wattmeter. The measurement data is automatically recorded.

The heater is placed in the calorimeter and the heater power is adjusted to a preset value. Deionised water is circulated through the calorimeter in order to cool it to around 1.5°C below the pool water temperature.

The circulation of ionised water is stopped and the temperature in the calorimeter will start to increase. Logging of the temperatures, time and other parameters is started. The logging is stopped after a certain temperature increase

The temperature difference between the calorimeter and the pool water is calculated by subtracting the average value of the temperature sensors inside from average value of the temperature sensors outside the calorimeter. Presently two sensors inside and two sensors outside the calorimeter are used.

A second degree polynomical is correlated to the temperature difference and time. The slope of the curve at the zero temperature difference is given by the coefficient of the first degree term in the equation.

The procedure is repeated at several power levels of the electric heater. The result is a table with slope values and corresponding power values. From this table a calibration curve is generated by correlating a strait line to the slope and power values. The correlation gives the equation of this strait line.

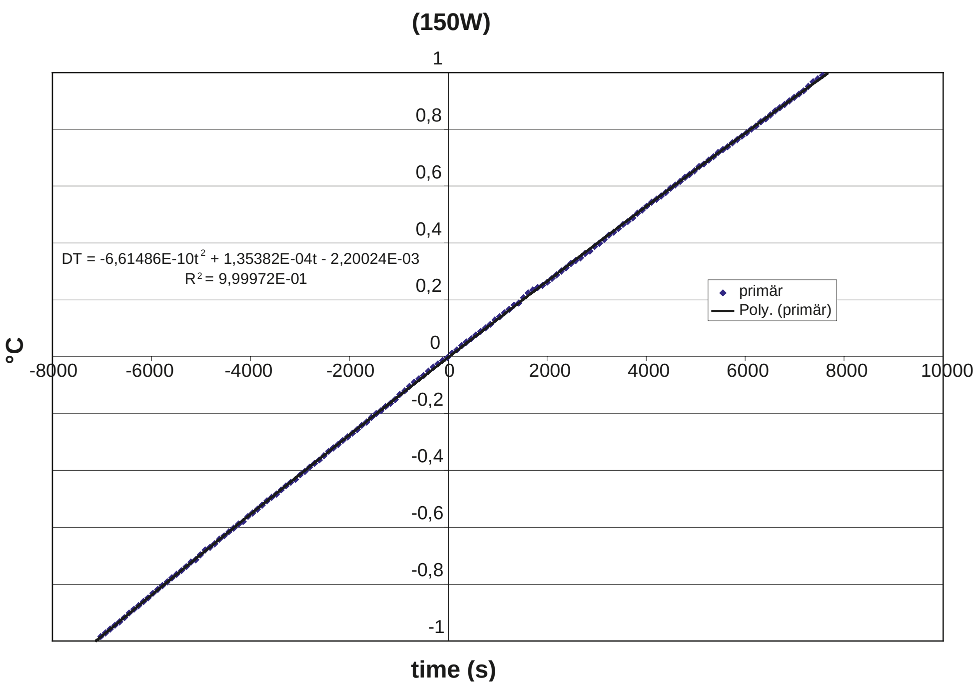

Figure 2-2. Diagram – sample temperature increase during calibration with 150 W.

In total 51 measurements have been carried out at a power input range of 49 to 735 watts. These measurements have been used to generate calibration curves for the BWR- and the PWR- cases.

By fitting a strait line using the least squares method to all the heat rate values and powers, an equation for the calibration curve is obtained. The general equation is

P_{cal} = a + b dt/dT where

P_{cal} = power in the heater at calibration

a and b = constants from the curve fitting

dt/dT = measured rate of temperature increase

For BWR the power is expected to be between 60 and 350 W and the fit between these values gives the following equation for BWR:

$P_{cal} = 1.73\times10^6 \times dt/dT - 90.0$

For PWR a calibration curve is generated for powers between 260 and 950 W. The resulting equation is:

$P_{cal} = 1.72\times10^6 \times dt/dT - 86.4$

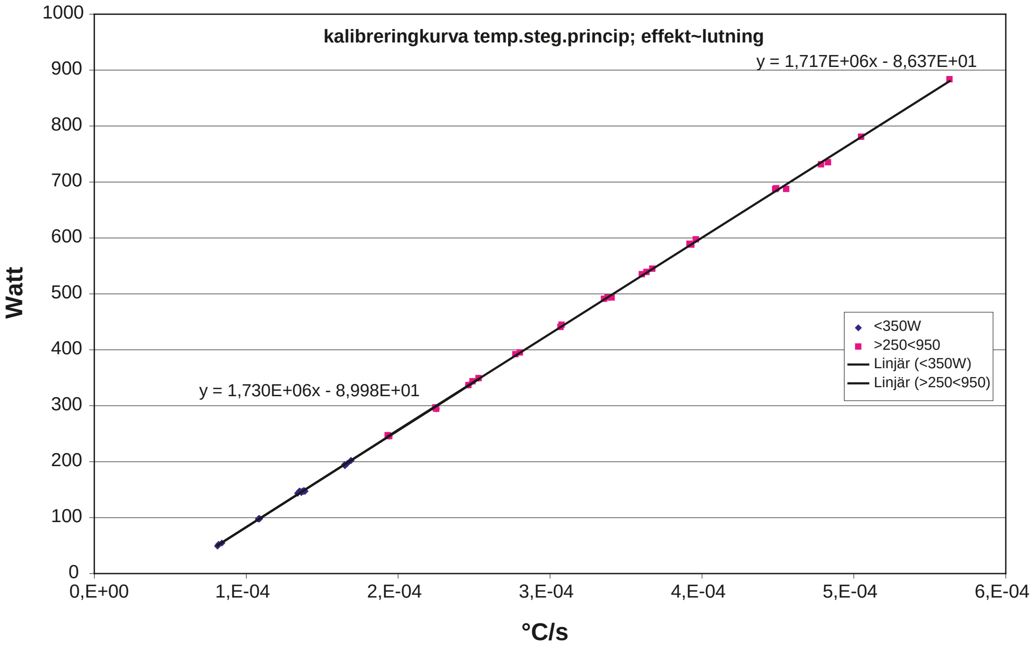

Figure 2-3. *Diagram – Calibration curve.*

2.5 Heat loss due to gamma radiation

A fraction of the decay heat from the fuel assembly is lost from the calorimetric measurement by the gamma radiation that escapes from the calorimeter.

The measured decay heat values have to be corrected accordingly. Gamma intensity measurements are used to assess this effect.

To accomplish that gamma radiation from the fuel are measured with five gamma probes at the outside of the calorimeter. The gamma probes are at the distance from the center of the vessel as presented in Table 2-1.

A relation between gamma escape power Pγ, measured gamma dose rate (Gy/h) d_i and the gamma probes placing r_i is shown in reference 1. The relation is as follows:

$$P_\gamma = a \frac{\sum_{i=1}^{5} d_i e^{-\lambda r_i}}{\sum_{i=1}^{5} (e^{-\lambda r_i})^2} \left\{ e^{-\lambda} \left(-\frac{1}{\lambda^2} - \frac{1}{\lambda} \right) + e^{-0.228\lambda} \left(\frac{1}{\lambda^2} + \frac{0.228}{\lambda} \right) \right\} F \qquad \text{Equation 2-1}$$

a = 8.14 W for BWR and 8.41 W for PWR.

λ = 8.4 m^{-1} attenuation coefficient.

r_i = The gamma probes distance from the center according.

F = Profile factor, unique for each fuel assembly. In Appendix 2 the F-factors for the fuel assemblies are found.

For each fuel measurement the gamma dose rate are measured with the probes d_1–d_5. The gamma dose rate is used in the relation above and the gamma escape power is possible to calculate

Table 2-1. Distance between the center of the vessel and the gamma probe.

Probe d_i	Radius (m)
1	0.26
2	0.38
3	0.50
4	0.63
5	0.77

3 Calorimetric measurements on spent nuclear fuel

3.1 General

When measuring a fuel assembly the following procedure is followed. An assembly is placed in the calorimeter (the heater is removed before). The calorimeter is cooled down with deionised water. After the circulation is stopped, logging of the temperatures, time, gamma radiation rate and other parameters is started. Logging is stopped after a certain temperature increase.

The temperature difference between the calorimeter of the pool is calculated by subtracting the average value of the temperature sensors inside with average value of the temperature sensors outside the calorimeter. Presently two sensors inside and two sensors outside the calorimeter are used.

A second degree curve is correlated to the temperature difference and time. The slope of the curve at zero temperature difference is given by the coefficient of the first degree term in the equation.

A correction of the slope is done to account for the fact that the fuel assembly has different volume and contains different materials than the electric heater.

The resulting slope is used in the calibration curve equation, which is solved for the power. With the measured gamma dose rates the power that escapes the calorimeter with the gamma radiation is calculated using the equation given above.

The sum of the power in the calorimeter and the power corresponding to the gamma field will give the decay heat power for the measured fuel assembly.

3.2 Measurement program

50 BWR and 34 PWR assemblies were selected for measurement from the Clab inventory. The selected assemblies met the following criteria:

- Fuel types PWR: 15×15, 17×17 and BWR: 8×8, Svea64, Svea100 were included.
- Assemblies were gamma scanned in this measurement campaign and fuel has long cooling times.
- The assemblies possessed a large spread in burnup.
- The assemblies possessed a large spread in initial enrichment.
- The assemblies possessed long cooling times.
- The assemblies did not contain inserts as boron glass rods, neutron sources or other parts.
- The assemblies were not mechanically damaged or had leaking rods

Main data for the selected fuel is presented in Table 3-1 for BWR fuel and Table 3-2 for PWR fuel.

Table 3-1. BWR fuel.

Assembly no	Box	Fuel type	Reactor	Enrichment (%U235)	Burnup (MWd/tU)	Initial weight (g U)	Shutdown date
10288	Yes	8×8	B1	2.95	35,180	179,159	1988-09-16
2014	Yes	8×8	B1	2.33	19,648	179,878	1979-04-13
2018	Yes	8×8	B1	2.33	20,605	179,852	1980-09-03
2048	Yes	8×8	B1	2.33	22,559	179,741	1979-04-13
2074	Yes	8×8	B1	2.33	22,923	179,657	1980-09-03
2118	Yes	8×8	B1	2.50	20,654	179,607	1978-05-09
9329	Yes	8×8	B1	2.92	41,094	178,771	1988-09-16
14076	Yes	8×8	B2	3.15	40,010	179,571	1992-07-09
3838	Yes	8×8	F1	2.09	25,669	177,903	1992-07-10
KU0100	Yes	8×8–2	F1	2.98	34,193	174,920	1990-09-01
KU0269	Yes	9×9–5	F1	2.94	35,113	177,020	1990-09-02
KU0278	Yes	9×9–5	F1	2.94	35,323	177,133	1991-06-08
KU0282	Yes	9×9–5	F1	2.94	37,896	177,097	1991-06-06
11494	Yes	Svea 64	F2	2.92	32,431	181,088	1988-07-25
11495	Yes	Svea 64	F2	2.91	32,431	181,070	1988-07-27
13775	Yes	Svea 64	F2	2.85	32,837	181,340	1991-07-18
5535	Yes	8×8	F2	2.10	19,944	177,689	1988-07-15
13847	Yes	Svea 100	F3	2.77	31275	180,669	1990-07-22
13848	Yes	Svea 100	F3	2.77	31275	180,667	1990-07-22
12684	Yes	Svea 64	O2	2.90	46,648	182,320	1991-08-05
1377	Yes	8×8	O2	2.20	14,546	183,575	1977-05-20
1389	Yes	8×8	O2	2.20	19,481	183,650	1981-07-23
1546	Yes	8×8	O2	2.20	24,470	183,968	1983-08-25
1696	Yes	8×8	O2	2.20	20,870	184,253	1983-08-25
1704	Yes	8×8	O2	2.20	19,437	184,022	1982-07-30
2995	Yes	8×8	O2	2.70	29,978	179,382	1981-07-25
3054	Yes	8×8	O2	2.89	34,893	160,262	1983-08-25
3058	Yes	8×8	O2	2.89	31,987	160,372	1983-08-25
3064	Yes	8×8	O2	2.89	30,391	160,318	1982-07-30
6350	Yes	8×8	O2	2.88	27,675	179,003	1985-06-14
12078	Yes	8×8	O3	2.58	25,160	177,404	1988-07-08
13628	Yes	Svea 100	O3	2.71	35619	180,774	1991-06-28
13630	Yes	Svea 100	O3	2.71	40363	180,775	1991-06-28
0582	No	8×8	R1	2.26	21,270	177,394	1980-09-15
0596	No	8×8	R1	2.26	22,256	177,199	1980-09-15
0710	No	8×8	R1	2.26	22,614	177,308	1982-09-27
0900	No	8×8	R1	2.26	23,152	177,362	1982-09-27
1136	No	8×8	R1	2.26	22,230	171,581	1983-08-23
1177	Yes	8×8	R1	2.65	36,242	180,587	1985-09-12
1186	Yes	8×8	R1	2.65	30,498	180,515	1985-09-12
5829	Yes	8×8	R1	2.71	44,861	156,410	1987-08-27
6423	No	8×8	R1	2.90	35,109	177,701	1988-09-05
6432	No	8×8	R1	2.89	36,861	177,520	1988-09-05
6454	No	8×8	R1	2.90	37,236	177,683	1986-07-18
6478	No	8×8	R1	2.90	35,183	126,675	1986-07-18
8327	No	8×8	R1	2.90	37,851	177,544	1991-08-15
8331	No	8×8	R1	2.91	35,903	177,690	1989-09-21
8332	No	8×8	R1	2.90	34,977	177,519	1988-08-13
8338	No	8×8	R1	2.91	34,830	177,596	1988-08-13
8341	No	8×8	R1	2.89	34,099	174,113	1988-08-13

Table 3-2. PWR fuel.

Assembly no	Fuel type	Reactor	Enrichment (%U235)	Burnup (MWd/tU)	Initial weight (g U)	Shutdown date
C01	15×15	R2	3.10	36,688	455,789	1981-05-17
C12	15×15	R2	3.10	36,385	453,736	1981-05-16
C20	15×15	R2	3.10	35,720	454,758	1985-04-04
C42	15×15	R2	3.10	35,639	453,923	1988-05-12
D27	15×15	R2	3.25	39,676	432,589	1983-06-13
D38	15×15	R2	3.25	39,403	434,214	1982-05-27
E38	15×15	R2	3.20	33,973	433,593	1982-05-29
E40	15×15	R2	3.20	34,339	434,244	1982-05-28
F14	15×15	R2	3.20	34,009	436,382	1983-06-12
F21	15×15	R2	3.20	36,273	435,939	1984-04-23
F25	15×15	R2	3.20	35,352	437,281	1983-06-12
F32	15×15	R2	3.20	50,962	436,993	1988-05-22
G11	15×15	R2	3.19	35,463	436,180	1985-05-02
G23	15×15	R2	3.21	35,633	436,125	1985-05-02
I09	15×15	R2	3.20	40,188	437,353	1988-05-12
I20	15×15	R2	3.20	34,313	423,896	1986-06-30
I24	15×15	R2	3.20	34,294	429,597	1986-06-30
I25	15×15	R2	3.20	36,859	433,062	1987-04-25
0C9	17×17	R3	3.10	38,442	457,639	1986-06-18
0E2	17×17	R3	3.10	41,628	463,598	1988-07-07
0E6	17×17	R3	3.10	35,993	461,769	1988-07-07
1C2	17×17	R3	3.10	33,318	459,050	1986-06-17
1C5	17×17	R3	3.10	38,484	457,992	1986-06-17
1E5	17×17	R3	3.10	34,638	463,898	1988-07-07
2A5	17×17	R3	2.10	20,107	462,026	1984-05-25
2C2	17×17	R3	3.10	36,577	459,490	1986-06-17
3C1	17×17	R3	3.10	36,572	458,433	1986-06-17
3C4	17×17	R3	3.10	38,447	456,170	1986-06-18
3C5	17×17	R3	3.10	38,373	458,873	1986-06-17
3C9	17×17	R3	3.10	36,560	459,138	1986-06-17
4C4	17×17	R3	3.10	33,333	459,050	1986-06-17
4C7	17×17	R3	3.10	38,370	458,256	1986-06-17
5A3	17×17	R3	2.10	19,699	461,477	1984-05-24
5F2	17×17	R3	3.40	47,308	451,743	1991-06-20

3.3 Measurements

Totally 109 measurements have been carried out. Eight assemblies were measured twice, two assemblies three times, one four times, one five times, and one seven times. The procedure for decay heat determination was as follow.

The fuel assembly to be measured was lowered into the vessel and the lid was mounted over the opening of the calorimeter.

Deionized water is connected to the vessel to cool it down to 1.5°C below the surrounding water in the basin.

Data was logged down until the temperature was 1.5°C above the surrounding water.

The difference in temperature between the inside of the vessel and the surrounding water was plotted against time, see Figure 3-1 which shows, as an example, the measuring of fuel assembly number 8341 date 040312. The time zero is the time when the temperature difference between the vessel and the surrounding basin is zero. An equation of second degree is fitted in the best way to the line. The slope in the time zero point is defined (1.488×10^{-4} in Figure 3-1).

The fuel assembly and the electric heater, used to produce the calibration curve, have not the same volume and material content. This means that the amounts of energy to increase the temperature one degree differ between the calibration and the fuel assembly measurement. To compensate for the difference in thermal capacity, a correction factor is used, which is presented in appendices 3 and 4. In the tables, the volume, amount of zirconium, steel/inconel, and uranium dioxide can also be seen. This information is used when the correction factors are calculated. The calculations of the correction factors for fuel assembly 6432, 9329 and 5A3 are presented in detail in part 3.

Appendix 3 gives the correction factor for fuel assembly 8341 to 0.972 implying a corrected slope value of 1.446×10^{-4}.

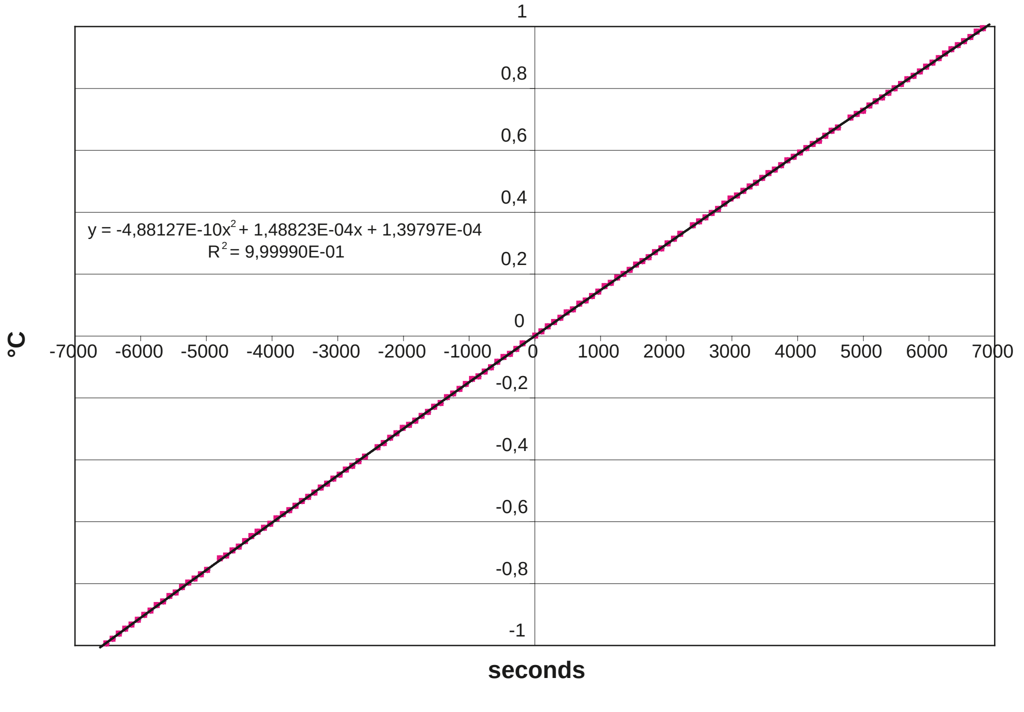

Figure 3-1. *Diagram – Temperature versus time of fuel assembly 8341.*

The corrected slope value was used to determine the decay power for the fuel assembly, by using the equations presented above. The equations are:

P = $1.73 \times 10^6 \times$(corrected slope) –90.0 for fuel assembly with a power below 350 W for BWR-fuel.

For fuel assembly with an power between 250 Watt and 950 Watt (PWR-fuel) the equation is: P = $1.72 \times 10^6 \times$(corrected slope)–86.4.

In appendices 5 and 6 the slope value, corrected slope value and the decay power for all measured fuel assembly are presented.

Measurements on BWR fuel

In total 66 measurements have been carried out. Six assemblies were measured twice, two assemblies three times and one seven times.

The results of the measurement and the evaluated decay powers including correction for the heat loss due to gamma radiation are presented in Table 3-3 for the BWR-assemblies:

Table 3-3. Results from measurements BWR-assemblies.

Assembly no	Fuel type	Measured decay heat (W)					Average	Gamma escape (W)	Total decay heat (W)
		1	2	3	4	5			
582	8×8	89.3					89.3	2.3	91.7
596	8×8	85.3	88.2				86.8	3.0	89.7
710	8×8	93.3	89.9	89.3			90.9	3.0	93.9
900	8×8	93.7					93.7	2.8	96.5
1136	8×8	92.6	93.2				92.9	2.6	95.5
1177	8×8	173.4					173.4	4.5	177.9
1186	8×8	137.5					137.5	3.3	140.8
1377	8×8	54.8					54.8	1.4	56.2
1389	8×8	81.7					81.7	2.2	83.9
1546	8×8	105.4					105.4	2.7	108.1
1696	8×8	90.0					90.0	2.3	92.4
1704	8×8	81.8					81.8	2.1	84.0
2014	8×8	80.8					80.8	1.9	82.7
2018	8×8	82.3					82.3	2.0	84.3
2048	8×8	92.4					92.4	2.2	94.6
2074	8×8	95.5					95.5	2.3	97.8
2118	8×8	95.9					95.9	2.4	98.3
2995	8×8	127.3					127.3	3.2	130.5
3054	8×8	137.4					137.4	3.7	141.0
3058	8×8	123.3					123.3	3.5	126.7
3064	8×8	118.6					118.6	3.2	121.7
3838	8×8	123.4	122.6				123.0	3.4	126.4
5535	8×8	82.4					82.4	2.2	84.6

Assembly no	Fuel type	Measured decay heat (W)					Average	Gamma escape (W)	Total decay heat (W)
		1	2	3	4	5			
5829	8×8	205.2					205.2	5.5	210.7
6350	8×8	123.7	126.2				124.9	3.2	128.2
6423	8×8	169.1					169.1	5.2	174.2
6432×	8×8	179.9	184.0				182.0	5.5	187.5
6432××	8×8	178.9	177.1	179.4	175.8	176.4	177.5	5.5	183.1
6454	8×8	181.3					181.3	5.0	186.3
6478	8×8	117.8					117.8	3.7	121.5
8327	8×8	191.0					191.0	6.0	196.9
8331	8×8	181.3					181.3	5.7	187.0
8332	8×8	163.0					163.0	5.1	168.1
8338	8×8	164.9					164.9	4.6	169.5
8341	8×8	160.1	158.1				159.1	4.8	163.9
9329*	8×8	217.4	218.9				218.2	5.4	223.6
9329**	8×8	213.2					213.2	5.4	218.7
10288	8×8	181.2					181.2	4.6	185.8
11494	Svea 64	161.7					161.7	4.4	166.0
11495	Svea 64	163.3					163.3	4.3	167.6
12078	8×8	116.9					116.9	3.3	120.2
12684	Svea 64	274.9					274.9	7.8	282.7
13628	Svea 100	188.2					188.2	5.8	194.0
13630	Svea 100	228.6					228.6	7.1	235.7
13775	Svea 64	173.1					173.1	5.3	178.4
13847	Svea 100	165.4	164.7				165.0	4.9	169.9
13848	Svea 100	165.6					165.6	5.1	170.7
14076	8×8	233.7					233.7	6.6	240.3
KU0100	8x8–2	180.2					180.2	5.1	185.3
KU0269	9x9–5	187.1					187.1	5.6	192.7
KU0278	9x9–5	189.9					189.9	5.5	195.4
KU0282	9x9–5	212.5					212.5	5.9	218.5

*) measured 2003, **) measured 2004

Five measurements were carried out for assembly 6432 between 13/2 – 23/2 2004. The average power is 177.5 W with the standard deviation of 1.6 W (1%).

Measurements on PWR fuel

34 PWR assemblies were measured. In total 43 measurements were carried out, two assemblies were measured twice, one four times and one five times.

The following results were obtained for the PWR-assemblies.

Table 3-4. Results from PWR-measurements.

Assembly no	Fuel type	Measured decay heat (W)					Average	Gamma escape (W)	Total decay heat (W)
		1	2	3	4	5			
0C9	17×17	478.6					478.6	12.6	491.2
0E2	17×17	572.4					572.4	15.5	587.9
0E6	17×17	475.1					475.1	12.6	487.8
1C2	17×17	407.3					407.3	10.4	417.7
1C5	17×17	486.5					486.5	12.7	499.2
1E5	17×17	456.9					456.9	11.9	468.8
2A5	17×17	227.9					227.9	5.8	233.8
2C2	17×17	454.8					454.8	11.7	466.5
3C1	17×17	458.3					458.3	11.9	470.2
3C4	17×17	484.9					484.9	12.4	497.3
3C5	17×17	488.9					488.9	12.5	501.4
3C9	17×17	456.5					456.5	11.9	468.4
4C4	17×17	411.4					411.4	10.6	422.0
4C7	17×17	485.9					485.9	12.8	498.7
5A3*	17×17	231.9	230.8	237.6			233.4	5.8	239.3
5A3**	17×17	225.1	224.4				224.8	5.8	230.6
5F2	17×17	695.5					695.5	18.5	714.1
C01	15×15	406.3					406.3	9.4	415.8
C12	15×15	401.6					401.6	8.7	410.3
C20	15×15	406.1	416.4	419.2	425.9		416.9	9.7	426.6
C42	15×15	431.7	437.8				434.7	10.6	445.3
D27	15×15	444.6					444.6	11.4	456.1
D38	15×15	431.6					431.6	10.8	442.3
E38	15×15	366.9	364.9				365.9	9.4	375.3
E40	15×15	372.2					372.2	9.0	381.3
F14	15×15	372.5					372.5	9.3	381.8
F21	15×15	410.2					410.2	10.7	420.9
F25	15×15	386.7					386.7	10.0	396.7
F32	15×15	675.4					675.4	16.6	692.0
G11	15×15	405.7					405.7	10.6	416.4
G23	15×15	409.6					409.6	11.1	420.6
I09	15×15	494.5					494.5	13.4	507.9
I20	15×15	393.8					393.8	9.7	403.5
I24	15×15	398.2					398.2	11.8	410.1
I25	15×15	434.0					434.0	11.8	445.8

*) measured 2003, **) measured 2004

Four measurement were carried out for assembly C20 during the period 14/4– 23/4 2004. The average power is 416.9 W with the standard deviation of 8.2 W (2%).

4 Calculations

4.1 Codes

The decay heats for the current assemblies have been calculated using the SAS2 sequence in the SCALE code system. SAS2 is sequence designed to calculate comprehensive nuclide concentrations, radiation source terms, and decay heat generation for spent nuclear fuel. The fuel burnup and decay analysis, and calculation of the neutron and gamma ray sources is performed by the ORIGEN-S code. A key feature of SAS2 is the ability to generate problem-dependent cross section for the burnup analysis based on user-specified assembly design characteristics, fuel type, reactor operating conditions, and irradiation and decay history. Cross sections for the reactor fuel assembly are developed using the one-dimensional (1-D) neutron transport analysis code XSDRNPM using a two-part procedure with two separate lattice-cell models. This procedure provides a pseudo 2-D analysis capability using 1-D transport methods that is suitable to many commercial LWR and research reactor fuel designs. The cross sections for the burnup analysis derived from the transport analysis are applied in an ORIGEN-S point-depletion computation to produce the burnup-dependent fuel compositions that are used in the next spectrum calculation. The cross sections are generated using the neutron flux spectrum for the assembly model for the specified burnup-dependent fuel compositions, reference 2.

4.2 Fuel data

Fuel type, enrichment, initial uranium weight, burnup and shutdown date for all fuel assemblies can be seen in Tables 3-1 and 3-2. Detailed fuel data and irradiation history of each assembly are presented in part 5.

Concerning the power history the number of cycles is correctly modelled, but the detailed power history within each cycle is not represented. Each assembly has been assigned a mean value for the entire cycle. Power changes during the cycles and during coast-down operation have consequently not been modelled, other than in the mean value.

4.3 Results

BWR

The following Table 4-1 compares the BWR-measurements and the calculations.

Table 4-1. Comparison between measured and calculated values for BWR.

Assembly no	Measured decay heat (W)	Calculated decay heat (W)
582	91.7	89.7
596	89.7	94.3
710	93.9	97.1
900	96.5	100.1
113	695.5	97.4
1177	177.9	177.4
1186	140.8	143.1
1377	56.2	59.5
1389	83.9	77.4
1546	108.1	112.1
1696	92.4	84.3
1704	84.0	85.0
2014	82.7	83.3
2018	84.3	86.8
2048	94.6	94.9
2074	97.8	98.5
2118	98.3	88.9
2995	130.5	132.1
3054	141.0	144.9
3058	126.7	130.6
3064	121.7	121.7
3838	126.4	129.8
5535	84.6	92.0
5829	210.7	204.3
6350	128.2	131.3
6423	174.2	176.9
6432*	187.5	187.8
6432**	183.1	185.1
6454	186.3	182.2
6478	121.5	119.9
8327	196.9	201.2
8331	187.0	184.6
8332	168.1	173.6
8338	169.5	172.9
8341	163.9	168.9
9329*	223.6	223.2
9329**	218.7	220.7
10288	185.8	184.6
11494	166.0	165.7
11495	167.6	166.0
12078	120.2	133.7
12684	282.7	276.1
13628	194.0	193.9
13630	235.7	228.5
13775	178.4	178.2
13847	169.9	166.6
13848	170.7	166.4
14076	240.3	249.6
KU0100	185.3	173.6
KU0269	192.7	179.8
KU0278	195.4	182.3
KU0282	218.5	197.9

*) measured 2003, **) measured 2004

Figure 4-1 shows a comparison between the measured value and the calculated value by Scale. The calculations show excellent agreement with the measurements on the average. The average ratio between calculated an measured data is 1.001.

PWR

The measured and calculated values are shown in Table 4-2.

Figure 4-2 shows a comparison between the measured value and the calculated value by Scale. The calculations show good agreement with the measurements on the average. The calculations seem overestimate the power with 2% on average.

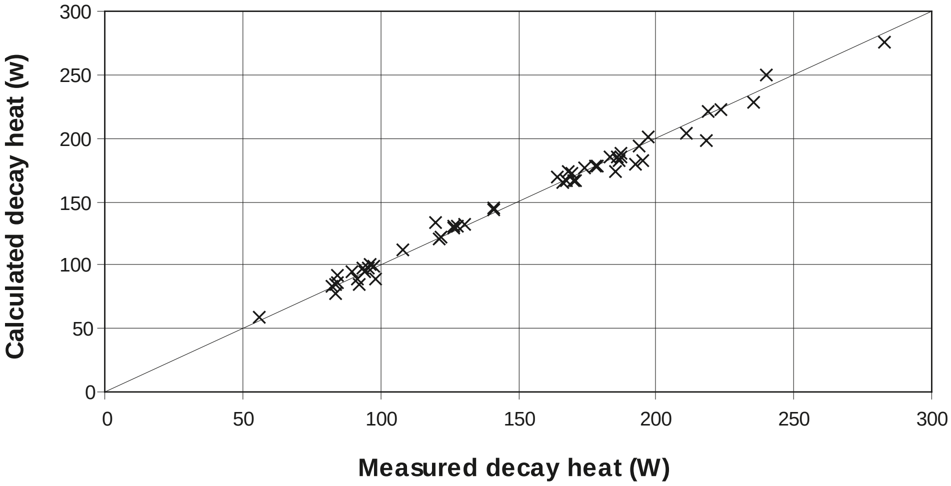

Figure 4-1. BWR-comparison between calculated and measured decay heat.

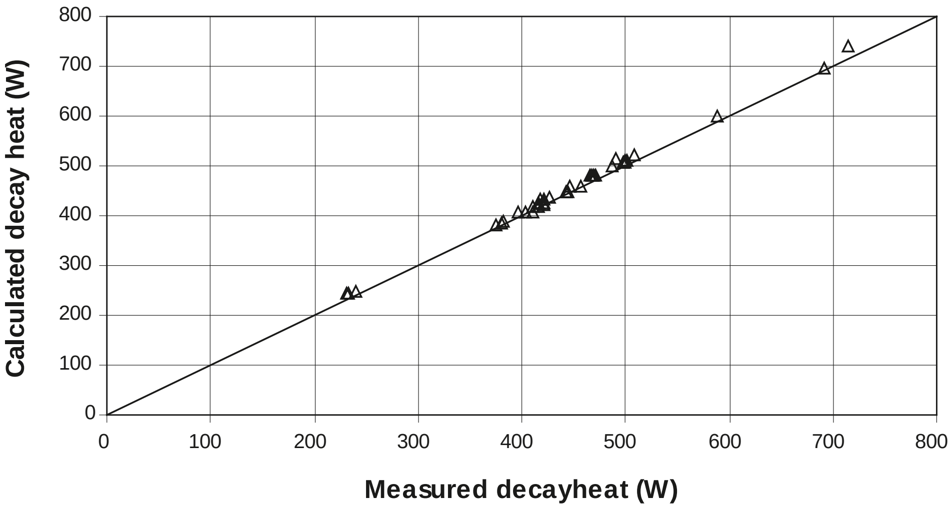

Figure 4-2. PWR-comparison between calculated and measured values.

Table 4-2. Comparison between measured and calculated values PWR.

Assembly no	Measured decayheat (W)	Calculated de-cayheat (W)
0C9	491.2	514.4
0E2	587.9	599.4
0E6	487.8	501.1
1C2	417.7	431.9
1C5	499.2	510.1
1E5	468.8	482.1
2A5	233.8	243.4
2C2	466.5	482.3
3C1	470.2	480.9
3C4	497.3	509.2
3C5	501.4	509.3
3C9	468.4	481.2
4C4	422.0	433.8
4C7	498.7	508.2
5A3*	239.3	248.2
5A3**	230.6	244.2
5F2	714.1	742.4
C01	415.8	425.0
C12	410.3	420.2
C20	426.6	435.9
C42	445.3	447.1
D27	456.1	459.4
D38	442.3	448.9
E38	375.3	380.4
E40	381.3	384.5
F14	381.8	389.2
F21	420.9	423.5
F25	396.7	407.9
F32	692.0	695.8
G11	416.4	418.3
G23	420.6	426.2
I09	507.9	520.7
I20	403.5	407.8
I24	410.1	408.8
I25	445.8	457.9

*) measured 2003, **) measured 2004

5 Conclusions

The calorimetric measurement method used is working as anticipated and has, up to now, shown good reproducibility. The estimated uncertainty of the measurement equipment is less than 1% for BWR and less than 2% for PWR (one standard deviation) based on repeated measurements on the same assembly.

The measured decay heat values have been compared to calculated values. The comparison shows good agreement for BWR. For PWR the calculations seem to over predict the decay heat with 2%.

References

/1/ Rapport angående avgiven gammaeffekt i BWR- och PWR-bränsle. Institutionen för strålningsvetenskap Uppsala reg.nr. 2004-05604.

/2/ NUREG/CR-0200, Revision 7, SAS2: A COUPLED ONE-DIMENSIONAL DEPLETION AND SHIELDING ANALYSIS MODULE, I. C. Gauld, O. W. Hermann, Date Published: May 2004.

Appendix 1

Power and temperature values in the calibration curve

Startdate	Power (W)	Pool temp (°C)	dt/dT at T=0°C	Box/no box
30508	49	19.2	8.11E–05	box
30408	52	18.5	8.18E–05	
30210	55	18.3	8.40E–05	
30314	97	18.0	1.08E–04	
30327	98	18.4	1.08E–04	
30512	98	19.6	1.09E–04	box
30528	98	19.8	1.08E–04	box
30428	99	19.0	1.09E–04	
40202	143	19.9	1.34E–04	box?
21216	145	18.8	1.36E–04	
40203	146	20.0	1.37E–04	box
30107	147	19.1	1.38E–04	
30321	147	18.2	1.37E–04	
30325	147	18.3	1.35E–04	
31103	147	19.1	1.38E–04	box
30430	147	19.1	1.39E–04	box
30526	147	19.8	1.35E–04	box
30407	149	18.5	1.38E–04	
30516	193	19.6	1.65E–04	box
30422	195	18.9	1.65E–04	
30220	197	17.9	1.67E–04	
40204	202	19.9	1.69E–04	box
40205	202	19.9	1.69E–04	box
30411	245	18.6	1.94E–04	
30319	246	18.2	1.94E–04	
30520	247	19.8	1.93E–04	box
30502	295	19.1	2.25E–04	box
30131	297	18.6	2.25E–04	
30324	337	18.2	2.46E–04	
31104	343	19.1	2.49E–04	box
30521	349	19.8	2.53E–04	box
30519	392	19.2	2.77E–04	box
30320	395	18.2	2.80E–04	
30114	441	19.1	3.07E–04	
30522	445	19.9	3.08E–04	box
30321	491	18.2	3.36E–04	
30601	493	19.7	3.38E–04	box
30505	493	19.1	3.41E–04	box
30523	535	19.8	3.61E–04	box
30524	539	19.8	3.64E–04	box

Startdate	Power (W)	Pool temp (°C)	dt/dT at T=0°C	Box/no box
30327	545	18.4	3.67E–04	
30423	588	18.9	3.93E–04	
30326	589	18.3	3.92E–04	
30124	597	18.8	3.96E–04	
30318	687	18.1	4.56E–04	
30325	687	18.3	4.48E–04	
30424	689	18.9	4.49E–04	
30328	731	18.4	4.78E–04	
30506	735	19.1	4.83E–04	box
30317	781	18.0	5.05E–04	
30324	884	18.2	5.63E–04	

Appendix 2

F-factors for gamma escape-calculations

Assembly no	F-factor	Assembly no	F-factor
2014	0.976	8327	0.951
2018	0.915	8331	0.987
2048	0.963	8332	1.004
2074	0.956	8338	0.939
2118	0.881	8341	0.980
9329	0.994	8327	0.978
10288	1.036	6423	0.968
14076	0.970	6478	0.752
3838	1.038	A05	0.993
KU0100	1.012	A11	0.973
KU0269	0.897	C01	1.100
KU0278	0.969	C12	1.011
KU0282	0.937	C20	1.031
5535	1.146	C42	1.047
11494	1.052	D27	0.960
11495	1.022	D38	1.002
13775	1.014	E38	0.961
13847	1.007	E40	1.006
13848	1.001	F14	0.999
12078	0.995	F21	0.972
13628	1.025	F25	1.020
13630	1.002	F32	1.029
1377	1.081	G11	0.995
1389	0.880	G23	0.994
1546	0.989	I09	1.059
1696	1.015	I20	0.956
1704	0.955	I24	1.055
2995	0.946	I25	0.975
3054	1.007	E38	0.985
3058	0.990	2A5	1.031
3064	0.969	5A3	1.019
6350	1.011	0C9	0.977
12684	0.986	1C2	1.033
582	0.991	1C5	0.999
596	1.014	2C2	1.004
710	0.982	3C1	1.050
900	0.995	3C4	1.098
1136	1.010	3C5	1.025
1177	1.015	3C9	0.942
1186	0.969	4C4	1.001
5829	0.987	4C7	1.023
6423	0.965	0E5	1.032
6432	0.965	0E6	1.028
6454	0.913	1E5	1.036
6478	0.920	5F2	0.976

Appendix 3

Correction factors to compensate for thermal capacity difference between electric heater and BWR fuel assemblies

No	Volume dm³	Zirconium kg	SS/Inc kg	UO2 kg	Correction factor
2014	36.2	84.5	9.2	204.2	0.963
2018	36.2	84.5	9.2	204.1	0.963
2048	36.2	84.5	9.2	204.0	0.963
2074	36.2	84.5	9.2	203.9	0.962
2118	36.2	84.5	9.2	203.9	0.962
9329	36.2	84.5	9.2	202.9	0.962
10288	36.2	82.9	9.2	203.4	0.962
14076	36.2	84.5	9.2	203.8	0.962
3838	35.8	82.2	9.3	201.9	0.963
KU0100	36.3	84.3	9.3	198.5	0.961
KU0269	36.2	81.9	9.3	200.9	0.962
KU0278	36.2	81.9	9.3	201.1	0.962
KU0282	36.2	81.9	9.3	201.0	0.962
5535	35.8	82.2	9.2	201.7	0.963
11494	36.4	77.1	9.2	205.5	0.961
11495	36.4	77.1	9.2	205.5	0.961
13775	36.4	77.1	9.2	205.8	0.961
13847	35.5	75.2	13.0	205.1	0.964
13848	35.5	75.2	13.0	205.1	0.964
1377	36.5	84.7	9.2	208.4	0.962
1389	36.5	84.7	9.2	208.5	0.962
1546	36.5	84.7	9.2	208.8	0.962
1696	36.5	84.7	9.2	209.1	0.962
1704	36.5	84.7	9.2	208.9	0.962
2995	36.5	84.7	9.2	203.6	0.962
3054	33.2	79.4	9.2	182.0	0.966
3058	33.2	79.4	9.2	182.0	0.966
3064	33.2	79.4	9.2	182.0	0.966
6350	36.1	82.3	9.2	203.2	0.962
12684	36.4	76.9	13.0	206.9	0.962
12078	36.3	82.3	9.3	201.3	0.961
13628	35.6	75.3	13.0	205.2	0.964
13630	35.6	75.3	13.0	205.2	0.964
582	29.5	47.0	4.2	201.4	0.971
596	29.5	47.0	4.2	201.1	0.970
710	29.5	47.0	4.2	201.3	0.970
900	29.5	47.0	4.2	201.3	0.970
1136	28.4	47.0	4.2	194.8	0.972
1177	35.0	79.1	9.2	205.0	0.964

No	Volume dm^3	Zirconium kg	SS/Inc kg	UO2 kg	Correction factor
1186	35.0	79.1	9.2	204.9	0.964
5829	33.1	82.5	9.2	177.5	0.966
6423	29.0	48.0	4.2	201.7	0.972
6432	29.0	48.0	4.2	201.5	0.972
6454	29.0	48.0	4.2	201.7	0.972
6478	22.2	48.0	4.2	143.8	0.981
8327	29.0	48.0	4.2	201.5	0.972
8331	29.0	48.0	4.2	201.7	0.972
8332	29.0	48.0	4.2	201.5	0.972
8338	29.0	48.0	4.2	201.6	0.972
8341	29.0	48.0	4.2	200.3	0.972

Appendix 4

Correction factors to compensate for thermal capacity difference between electric heater and PWR fuel assemblies

No	Volume dm³	Zirconium kg	SS/Inc kg	UO2 kg	Correction factor
A05	75.2	111.3	18.1	518.3	0.916
A11	75.2	111.3	18.1	519.1	0.917
C01	75.2	111.3	18.1	517.4	0.916
C12	75.2	111.3	18.1	515.0	0.916
C20	75.2	111.3	18.1	516.2	0.916
C42	75.2	111.5	18.1	515.2	0.916
D27	75.5	129.1	17.6	491.0	0.915
D38	75.5	129.1	17.6	492.9	0.915
E38	75.5	129.1	17.6	492.2	0.915
E40	75.5	129.1	17.6	492.9	0.915
F14	75.5	129.1	17.6	495.3	0.915
F21	75.5	129.1	17.6	494.8	0.915
F25	75.5	129.1	17.6	496.4	0.915
F32	75.5	129.1	17.6	496.0	0.915
G11	75.5	129.1	17.6	495.1	0.915
G23	75.5	129.1	17.6	495.0	0.915
I09	75.5	129.1	17.6	496.4	0.915
I20	74.8	128.0	17.6	481.2	0.915
I24	75.5	129.1	17.6	487.6	0.914
I25	75.5	129.1	17.6	491.6	0.915
2A5	76.7	117.0	20.9	524.4	0.915
5A3	76.7	117.0	20.9	523.8	0.915
0C9	76.7	117.0	20.9	519.5	0.915
1C2	76.7	117.0	20.9	521.1	0.915
1C5	76.7	117.0	20.9	519.9	0.915
2C2	76.7	117.0	20.9	521.6	0.915
3C1	76.7	117.0	20.9	520.4	0.915
3C4	76.4	116.6	20.9	517.8	0.915
3C5	76.7	117.0	20.9	520.9	0.915
3C9	76.7	117.0	20.9	521.2	0.915
4C4	76.7	117.0	20.9	521.1	0.915
4C7	76.7	117.0	20.9	520.2	0.915
0E2	76.7	117.2	20.9	526.2	0.916
0E6	76.7	117.2	20.9	524.1	0.915
1E5	76.7	117.2	20.9	526.6	0.916
5F2	74.4	126.5	14.9	512.8	0.919

Appendix 5

Raw data from the measurements BWR

Assembly no	Meassured date	Pool temp (°C)	Slope value	Corrected slope value	Decay power (W)
9329	30602	19.7	1.85E–04	1.78E–04	217
9329	30604	19.7	1.86E–04	1.79E–04	219
6432	30610	19.8	1.61E–04	1.56E–04	180
6432	30612	19.8	1.63E–04	1.58E–04	184
11495	31107	19.1	1.52E–04	1.46E–04	163
1186	31110	19.1	1.36E–04	1.32E–04	137
2018	31111	19.1	1.03E–04	9.96E–05	82
10288	31112	19.1	1.63E–04	1.57E–04	181
13847	31113	19.1	1.53E–04	1.48E–04	165
13847	31114	19.1	1.53E–04	1.47E–04	165
2074	31117	19.2	1.11E–04	1.07E–04	95
12078	31118	19.2	1.24E–04	1.20E–04	117
2048	31119	19.3	1.10E–04	1.05E–04	92
9329	31120	19.4	1.82E–04	1.75E–04	213
13848	31124	19.2	1.53E–04	1.48E–04	166
2014	31125	19.1	1.03E–04	9.87E–05	81
1177	31126	19.2	1.58E–04	1.52E–04	173
1389	31128	19.2	1.03E–04	9.93E–05	82
KU0282	31201	19.1	1.82E–04	1.75E–04	213
11494	31202	19.2	1.51E–04	1.45E–04	162
1696	31203	19.2	1.08E–04	1.04E–04	90
6350	31204	19.2	1.28E–04	1.24E–04	124
6350	31205	19.2	1.30E–04	1.25E–04	126
1704	31208	19.0	1.03E–04	9.93E–05	82
14076	31209	19.1	1.94E–04	1.87E–04	234
3838	31210	19.3	1.28E–04	1.23E–04	123
3838	31211	19.3	1.28E–04	1.23E–04	123
13630	31212	19.3	1.91E–04	1.84E–04	229
3058	31215	19.3	1.28E–04	1.23E–04	123
12684	31216	19.3	2.19E–04	2.11E–04	275
2118	31217	19.3	1.12E–04	1.07E–04	96
5535	31218	19.4	1.04E–04	9.97E–05	82
13775	31219	19.4	1.58E–04	1.52E–04	173
KU0278	31222	19.4	1.68E–04	1.62E–04	190
2995	40107	19.2	1.31E–04	1.26E–04	127
13628	40108	19.2	1.67E–04	1.61E–04	188
KU0100	40109	19.2	1.62E–04	1.56E–04	180
5829	40112	19.3	1.77E–04	1.71E–04	205
3064	40113	19.3	1.25E–04	1.21E–04	119
3054	40114	19.4	1.36E–04	1.31E–04	137
1546	40116	19.4	1.17E–04	1.13E–04	105

Assembly no	Meassured date	Pool temp (°C)	Slope value	Corrected slope value	Decay power (W)
KU0269	40119	19.4	1.67E–04	1.60E–04	187
1377	40122	19.6	8.70E–05	8.37E–05	55
710	40206	19.9	1.09E–04	1.06E–04	93
1136	40209	19.8	1.09E–04	1.06E–04	93
1136	40210	19.7	1.09E–04	1.06E–04	93
582	40211	19.7	1.07E–04	1.04E–04	89
6423	40212	19.6	1.54E–04	1.50E–04	169
6432	40213	19.6	1.60E–04	1.55E–04	179
6478	40216	19.6	1.22E–04	1.20E–04	118
6454	40217	19.7	1.61E–04	1.57E–04	181
900	40218	19.8	1.09E–04	1.06E–04	94
596	40219	19.9	1.04E–04	1.01E–04	85
596	40220	20.0	1.06E–04	1.03E–04	88
6432	40223	20.0	1.59E–04	1.54E–04	177
6432	40224	20.1	1.60E–04	1.56E–04	179
6432	40301	20.5	1.58E–04	1.54E–04	176
6432	40302	20.6	1.59E–04	1.54E–04	176
8332	40304	20.8	1.50E–04	1.46E–04	163
8338	40309	20.9	1.52E–04	1.47E–04	165
8327	40310	20.9	1.67E–04	1.62E–04	191
8331	40311	20.8	1.61E–04	1.57E–04	181
8341	40312	20.7	1.49E–04	1.45E–04	160
8341	40315	20.5	1.48E–04	1.43E–04	158
710	40322	20.5	1.07E–04	1.04E–04	90
710	40323	20.7	1.07E–04	1.04E–04	89

Appendix 6

Raw data from the measurements PWR

Assembly no	Meassured date	Pool temp (°C)	Slope value	Corrected slope value	Decay power (W)
5A3	30613	19.8	2.03E–04	1.85E–04	232
5A3	30616	19.7	2.02E–04	1.85E–04	231
5A3	30618	19.7	2.06E–04	1.89E–04	238
E38	40330	20.9	2.89E–04	2.64E–04	367
E38	40331	20.9	2.87E–04	2.63E–04	365
c42	40401	20.8	3.29E–04	3.02E–04	432
c42	40402	20.6	3.33E–04	3.05E–04	438
D38	40405	20.4	3.30E–04	3.02E–04	432
C12	40406	20.4	3.10E–04	2.84E–04	402
I25	40413	20.2	3.31E–04	3.03E–04	434
C20	40414	20.5	3.13E–04	2.87E–04	406
C20	40415	20.5	3.20E–04	2.93E–04	416
C20	40416	20.5	3.21E–04	2.94E–04	419
C20	40423	20.6	3.26E–04	2.98E–04	426
D27	40426	20.4	3.38E–04	3.09E–04	445
5A3	40427	20.4	1.98E–04	1.81E–04	225
3c5	40428	20.4	3.66E–04	3.35E–04	489
3C4	40429	20.4	3.64E–04	3.33E–04	485
3C1	40430	20.4	3.47E–04	3.17E–04	458
2A5	40503	20.3	2.00E–04	1.83E–04	228
4C7	40504	20.4	3.64E–04	3.33E–04	486
2C2	40505	20.6	3.45E–04	3.15E–04	455
0C9	40506	20.7	3.60E–04	3.29E–04	479
3C9	40507	20.8	3.46E–04	3.16E–04	456
5A3	40510	20.9	1.98E–04	1.81E–04	224
I20	40513	20.9	3.06E–04	2.80E–04	394
IC2	40514	20.9	3.14E–04	2.88E–04	407
I09	40517	21.0	3.70E–04	3.38E–04	495
G23	40518	21.0	3.16E–04	2.89E–04	410
5F2	40519	21.0	4.95E–04	4.55E–04	696
G11	40524	21.0	3.13E–04	2.87E–04	406
I24	40526	21.2	3.09E–04	2.82E–04	398
4C4	40527	21.1	3.17E–04	2.90E–04	411
F32	40528	21.2	4.85E–04	4.44E–04	675
C01	40610	21.3	3.13E–04	2.87E–04	406
1E5	40611	21.3	3.46E–04	3.16E–04	457
E40	40614	21.2	2.92E–04	2.67E–04	372
0E2	40616	21.4	4.19E–04	3.84E–04	572
1C5	40617	21.3	3.65E–04	3.34E–04	487
F14	40618	21.3	2.92E–04	2.67E–04	372
F25	40621	21.6	3.01E–04	2.76E–04	387
0E6	40622	21.7	3.57E–04	3.27E–04	475
F21	40623	21.8	3.16E–04	2.89E–04	410

Appendix 7

Raw data from gamma measurements

Fuel assembly	Measurement date	Probe 1 Gy/h	Probe 2 Gy/h	Probe 3 Gy/h	Probe 4 Gy/h	Probe 5	Gamma escape power Gy/h(W)
11495	31107	9.5	3.8	1.3	0.5	0.3	4.3
1186	31110	7.7	3.1	1.0	0.4	0.2	3.3
2018	31111	4.9	2.0	0.6	0.2	0.1	2.0
10288	31112	10.1	4.0	1.4	0.5	0.3	4.6
13847	31113	10.9	4.4	1.5	0.6	0.3	4.9
13847	31114	11.0	4.4	1.5	0.6	0.3	4.9
2074	31117	5.5	2.2	0.6	0.2	0.1	2.3
12078	31118	7.4	3.0	1.0	0.3	0.2	3.3
2048	31119	5.3	2.1	0.6	0.2	0.1	2.2
9329	31120	12.3	4.9	1.7	0.6	0.4	5.4
13848	31124	11.4	4.5	1.6	0.6	0.3	5.1
2014	31125	4.4	1.7	0.5	0.1	0.1	1.9
1177	31126	9.7	3.9	1.3	0.5	0.3	4.5
1389	31128	5.6	2.2	0.7	0.2	0.1	2.2
KU0282	31201	14.3	5.7	2.1	0.7	0.4	5.9
11494	31202	10.0	4.0	1.4	0.5	0.3	4.4
1696	31203	5.2	2.1	0.6	0.2	0.1	2.3
6350	31204	7.4	2.9	1.0	0.3	0.2	3.2
1704	31208	5.1	2.0	0.6	0.2	0.1	2.1
14076	31209	15.3	6.1	2.3	0.8	0.5	6.6
3838	31210	7.3	3.0	1.1	0.3	0.2	3.4
3838	31211	7.3	3.0	1.0	0.3	0.2	3.4
13630	31212	16.0	6.3	2.4	0.8	0.5	7.1
3058	31215	7.9	3.2	1.1	0.3	0.2	3.5
12684	31216	17.9	7.1	2.7	1.0	0.5	7.8
2118	31217	6.1	2.5	0.8	0.2	0.2	2.4
5535	31218	4.3	1.8	0.5	0.1	0.1	2.2
13775	31219	11.8	4.6	1.7	0.6	0.3	5.3
KU0278	31222	12.9	5.1	1.9	0.7	0.4	5.5
2995	40107	7.7	3.0	1.0	0.3	0.2	3.2
13628	40108	12.8	5.1	1.9	0.7	0.4	5.8
KU0100	40109	11.5	4.6	1.7	0.6	0.3	5.1
5829	40112	12.6	5.0	1.8	0.6	0.3	5.5
3064	40113	7.3	3.0	1.0	0.3	0.2	3.2
3054	40114	8.2	3.3	1.2	0.4	0.2	3.7
1546	40116	6.2	2.5	0.8	0.2	0.1	2.7
KU0269	40119	14.0	5.5	2.0	0.7	0.4	5.6
1377	40122	3.0	1.3	0.4	0.0	0.1	1.4
1136	40209	5.9	2.3	0.7	0.2	0.1	2.6
1136	40210	5.9	2.3	0.7	0.2	0.1	2.6
582	40211	5.2	2.1	0.7	0.2	0.1	2.3

Fuel assembly	Measurement date	Probe 1 Gy/h	Probe 2 Gy/h	Probe 3 Gy/h	Probe 4 Gy/h	Probe 5	Gamma escape power Gy/h(W)
6423	40212	12.1	4.7	1.7	0.6	0.3	5.2
6432	40213	13.0	5.0	1.8	0.6	0.3	5.5
6478	40216	11.3	4.3	1.5	0.5	0.3	3.7
6454	40217	12.5	4.9	1.7	0.6	0.3	5.0
900	40218	6.4	2.6	0.8	0.2	0.1	2.8
596	40219	6.6	2.6	0.8	0.2	0.1	3.0
596	40220	6.6	2.6	0.8	0.2	0.1	3.0
6432	40223	13.4	5.2	1.9	0.7	0.4	5.7
6432	40224	13.5	5.2	1.9	0.6	0.4	5.7
6432	40301	13.6	5.2	1.9	0.7	0.3	5.8
6432	40302	13.0	5.0	1.8	0.6	0.3	5.5
8332	40304	11.6	4.5	1.6	0.5	0.3	5.1
8338	40309	11.2	4.4	1.5	0.5	0.3	4.6
8327	40310	14.1	5.5	1.9	0.7	0.3	6.0
8331	40311	13.2	5.1	1.8	0.6	0.3	5.7
8341	40312	11.1	4.3	1.5	0.5	0.3	4.8
8341	40315	11.1	4.3	1.5	0.5	0.3	4.8
710	40322	6.9	2.8	0.8	0.2	0.1	3.0
710	40323	7.0	2.8	0.9	0.2	0.1	3.0
E38	40330	21.5	8.0	2.7	1.0	0.5	9.4
E38	40331	21.6	8.1	2.8	1.0	0.5	9.4
C42	40401	22.2	8.4	2.9	1.1	0.5	10.6
C42	40402	22.7	8.6	3.0	1.1	0.6	10.8
D38	40405	23.6	8.9	3.2	1.2	0.6	10.8
C12	40406	18.9	7.3	2.5	0.9	0.5	8.7
I25	40413	26.7	10.1	3.5	1.3	0.6	11.8
C20	40414	20.6	7.9	2.7	1.0	0.5	9.7
C20	40415	20.6	7.8	2.7	1.0	0.4	9.6
C20	40416	20.6	7.9	2.7	1.0	0.5	9.7
C20	40423	20.7	8.1	2.8	1.0	0.5	9.8
D27	40426	26.1	10.0	3.5	1.3	0.6	11.4
5A3	40427	12.5	4.9	1.5	0.5	0.2	5.8

Part 2

Gamma scanning of spent nuclear fuel assemblies: determination of residual thermal power using new data acquisition and analysis software

Otasowie Osifo, Uppsala universitet

Abstract

New data-acquisition software has been developed for the gamma scanning of spent nuclear fuel assemblies. The system has been tested in two measurement campaigns at the central interim storage for spent nuclear fuel (Clab) in Oskarshamn Sweden.

The results from the measurement campaigns were used to determine calibration constants that relate the intensity of the 662 keV gamma radiation to the residual thermal power of the fuel. Using the calibration constants, the residual thermal power for each assembly in the data set was predicted. The predicted values were found to agree with the calorimetric values with a standard deviation of 2.23%.

Contents

1 Introduction

The determination of the residual power in spent nuclear fuel assemblies is a necessary condition for the realization of the Swedish strategy for long-term storage of the spent nuclear fuel. The method of storage envisioned implies the encapsulation of fuel assemblies in copper canisters after a cooling time of about 30 years. Eventually these canisters will be embedded in bentonite clay in a deep geological storage. To maintain the buffer properties of the bentonite clay, an upper limit of 100ºC /1/ for the temperature on the surface of the copper canisters has been defined. Thus, knowledge of the thermal power developed in the spent fuel is essential for a safe storage.

The residual power may be calculated by using the various codes available, e.g. Origen. These codes generally calculate residual power with typical accuracies ranging between 2% and 5% /2/. However, the accuracy of the output is strongly correlated to the authenticity of the input data, e.g. irradiation history. From an operational point of view, such sensitivity is not desirable and should be relaxed by using complementary techniques such as measurements.

The measuring technique available until now is calorimetry /3/ and /4/. Although this technique may be performed with high accuracy, it suffers from measuring times of the order of days per assembly. Such a long measuring time is not feasible for industrial application and an alternative method has therefore been proposed /5, 6/. This method is based on gamma-spectroscopic measurements performed by using gamma-scanning equipment of the type installed in all nuclear power plants and at the interim storage Clab in Sweden. As shown in /5, 6, 7, 8/, the intensity from ^{137}Cs is closely related to the residual thermal power and this fact can be utilised for a fast and reasonably accurate determination of the residual power. In this work, it was shown that typical measuring and analysis times per assembly were about 15 minutes using the gamma scanning method, while the relative uncertainty in the determined residual power was about 2%.

In principle, the method is not dependent on that operator declared fuel parameters such as burnup and cooling time are available. In fact, these parameters may be experimentally determined by making use of the gamma-ray intensities from the decays of the isotopes: ^{137}Cs, ^{134}Cs and ^{154}Eu. This property makes the method interesting also from a safeguards point of view.

The gamma scanning technique thus provides a complement to pure theoretical approaches for two reasons; Firstly, complex calculations, in which mistakes can be made with regards to both the input parameters as well as the interpretation of the output, can be checked with a simple calculation based on experimentally obtained gamma intensities. Secondly, in cases where input data is questionable or lacking, a value of the residual power may still be obtained although with a somewhat larger uncertainty.

The present report accounts for a new data acquisition system equipped with special designed software. A dedicated calorimeter has been utilised for calibration of the gamma-scanning measurements using the acquisition system and the results of this work are also presented.

2 The method

The radiation from ^{137}Cs is suitable to use for several reasons:

i) Studies using Origen-2 (/7/) showed that the intensity of ^{137}Cs is linearly dependent on the fuel burnup and nearly independent of such parameters as initial enrichment and void (in the case of BWR).

ii) ^{137}Cs has a half-life of 30 years, which is adequate for measurements in connection to encapsulation, where cooling times of the fuel assemblies are expected to be in the range of 15–50 years.

iii) The gamma-ray energy interferes very little with other gamma-ray intensities from fission or activation products in the gamma-ray spectrum (see Figure 5-2).

The relationship between the residual thermal power (P_{tot} expressed in Watts) of the spent fuel and the intensity (I expressed in counts per second) of the 662 keV gamma line is given by /5, 6/:

$$P_{tot} = C\frac{I}{f} \qquad (2\text{-}1)$$

The factor f represents the fractional power due to the decay of ^{137}Cs and the constant C is a calibration constant that relates the power to the measured intensity. The factor f is defined as:

$$f = \frac{P_{137}}{P_{tot}} \qquad (2\text{-}2)$$

Where P_{137} is the power developed in the fuel due to the decay of ^{137}Cs.

Figure 2-1 shows the values of f as a function of the cooling time for a BWR 8×8 fuel assembly, as calculated by Origen-2. Figure 2-1 shows that in this case the fractional power (f) reaches a maximum when the cooling time is about 13 years. The time to reach this maximum value is a function of the discharge burnup of the fuel.

Figure 2-2 shows the dependency of f on the discharge burnup for cooling times of 16 years, 27 years and 32 years respectively. An interesting feature of Figures 2-1 and 2-2 is the relative constancy of the factor f for cooling times greater than 13 years. For a typical time of final reposition of 30 years and a burnup of 36 GWd/tU, the factor f varies ± 10 % for a variation in the cooling time of ± 10 years.

Similarly, for a cooling time of about 30 years, the change in f is about ± 5% for a change in burnup of ± 10 GWd/tU. These relatively small changes and the simple dependency of f are additional arguments for the feasibility to use the ^{137}Cs-intensity to determine the residual power, i.e. one do not expect drastic variations due to, for example, irregular irradiation histories.

As the factor f is included in Equation 2-1 one would argue that since f is calculated with e.g. Origen-2, the same computational uncertainties are introduced as when the residual power is determined entirely by using calculations. However, due to the simple dependencies of the factor f as discussed above, this factor can be parameterised in the variables burnup and cooling time, which are to be experimentally determined anyway.

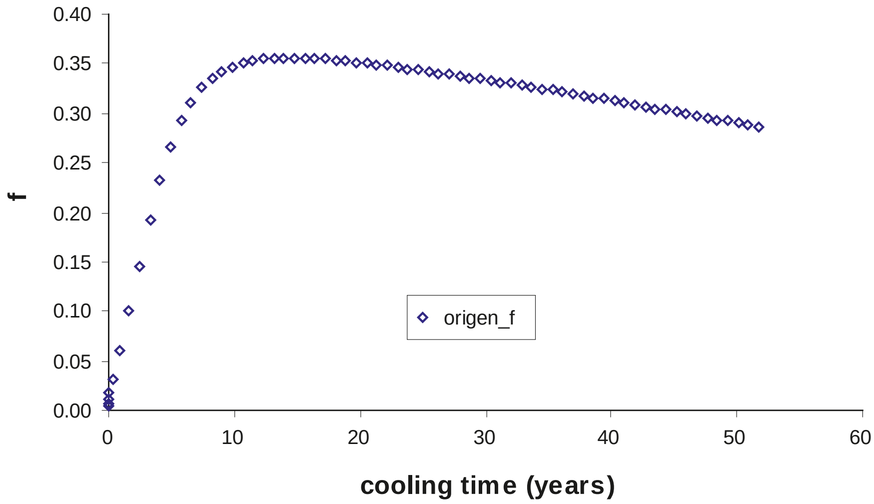

Figure 2-1. The value of the fractional power f as a function of the cooling time for a BWR 8×8 assembly irradiated for five power cycles. The discharge burnup of the fuel was 36.86 GWd/tU and the initial enrichment was 2.89%. The curve was plotted from Origen-2 data.

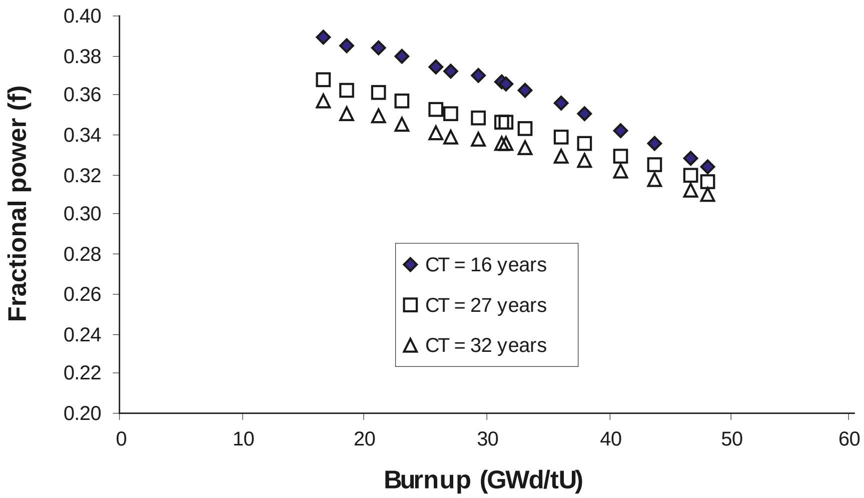

Figure 2-2. The dependency of the fractional power (f) on the discharge burnup for cooling times of 16, 27 and 32 years for a fuel assembly BWR 8×8 type, i.e. the same assembly type as in Figure 2-1.

Consequently these variables will be the only input to determine f and the experimentally determined residual power will thus not depend on detailed calculations where input parameters such as irradiation history may be erroneous. The basic requirement for this argument to hold is that f, as shown in figs. 2.1 and 2.2, represents reality with reasonable good accuracy. As will be shown in the later sections, this is indeed the case.

In this work we have adopted the following parameterization of f:

$$f = aBU + bT^2 + cT + d \qquad (2\text{-}3)$$

i.e. a linear dependency on the discharge burnup (BU) and a quadratic dependency on cooling time (T). The latter dependency is motivated by the exponential decay of the radioactive isotopes. By expanding the exponential function to second order, the quadratic dependency of f on cooling time is obtained.

As the method includes relative measurements, it requires that the residual power is determined calorimetrically for a number of fuel assemblies with well-known properties in order to determine the calibration constant C in Equation 2-1. The value of C depends on the measuring geometry and the type of fuel assembly being investigated, implying that calibration curves have to be established for each fuel type of interest. Also, a representative assembly from each fuel type should be selected for regular efficiency calibration (since the measuring geometry may change between the measurements). Every new measuring campaign should start with measurements of these "reference" assemblies and the measured ^{137}Cs-intensities, properly corrected for decay time, would thus constitute a norm to which all other measurements within the same set of assembly type would be related.

3 Experimental equipment and instrumentation

The equipment and instruments used during the measuring campaigns discussed in Section 5 can be divided into three parts; the mechanical equipment (elevator and its associated control system), the gamma-ray detector and a computer-based data-acquisition and analysis system.

3.1 The mechanical equipment

The gamma scanning equipment consists of a collimator, an elevator, fixtures for holding the fuel assembly in a vertical position in the elevator and control mechanism for regulating the motion of the elevator, see Figure 3-1. The fuel assembly of interest is placed in the fixture and may be rotated about its symmetry axis. This allows each of the four corners of the assembly to be placed in such a way as to face the detector. In this way, the positioning uncertainty is minimised /9/ leading to maximum consistency of the measured gamma-ray intensities.

The collimator is made of iron with a length of 1.2 m. The collimator slit is horizontal and its height can be varied between 1 m and 5 mm. The width varies from 24.3 cm at the end facing the fuel assembly to 8.2 cm at the end facing the detector. This arrangement allows for a solid angle covering the diagonal of all fuel types of interest.

3.2 The gamma-ray detector

In this application, high-intensity gamma radiation is expected in conjunction with low-intensity radiation. This leads to the following requirements of the detector system:

1. The detector system should be able to record events at considerable count rates in order to reach sufficient statistics while minimizing the measuring time.
2. The detector should preferably be large in order to obtain high peak-to-Compton ratio and thereby facilitating accurate analysis of the energy spectra.

Based on the above requirements, an 80% germanium detector from Ortec, equipped with a transistor-reset preamplifier was chosen. This detector system allows for input count rates exceeding 100,000 counts per second (cps). The stated energy resolution was 2.0 keV and the peak-to-Compton ratio was 75:1. Both these parameters were measured at 1,322 keV. As a backup, a 55% detector from Eurisys Measures was available. The latter detector was however equipped with a resistive-feedback preamplifier, which limited the maximum count rate to about 60,000 counts per second. The backup detector was used in the second of the two measuring campaigns reported here.

3.3 Data-acquisition system

The data-acquisition software used in /5, 6, 7, 8/ was a test system that was highly hardware dependent. As new hardware is introduced in a very high pace, new software that adapt to this situation had to be developed. This section describes a data-acquisition system developed especially to collect and analyse data for the purpose of determining residual power.

3.3.1 The hardware

The output signals from the detector were connected to a series 5000 pc board from APTEC-NRC, which includes signal processing electronics and a multi-channel analyser. This board has three types of linear amplifiers, an ADC and an ADC memory. The system also contains user software supplied by the manufacturer and application programmers' interface (API) in the form of a dynamic linked library (DLL) of low-level functions. The API allows user the to write custom software that can be used to control and access the board in order to meet stipulated needs.

The on-board amplifiers are of the following types: unipolar, bipolar and gated integrator. Although giving a somewhat degraded energy resolution, the gated integrator is well suited for high-count-rate applications. However, the moderate count rates encountered in this work motivated the use of the standard unipolar amplifier with an integration time of 2µs.

The analogue-to-digital conversion was made using a 12-bit ADC (4,096 channels) with a fixed conversion time of 800 ns. It converts the amplitude of the detector signal, i.e. the energy deposited in the detector, to a channel number or memory position. For each event recorded by the detector, the number stored in the corresponding memory position is incremented by one. In this way, an energy spectrum of the type shown in Figure 5-2 is obtained.

3.3.2 The software

Data-acquisition software was developed for use with the series 5000-board. This software acts as the interface between the user and the low-level i/o-functions that are used to access the series 5000-board. It allows the user to access the data stored in the ADC memory using the low-level i/o-functions while scanning an assembly. The number of times that the ADC memory is accessed, while scanning a corner of an assembly, is defined by the user. The spectrum collected and stored between each access to the ADC memory is called a sub-spectrum in this report.

Through the graphic user interface presented in Figure 4-3, the user can enter the necessary parameters for initialising the board and controlling the scanning procedure. The list below gives an example of the parameters that can be set by the user:

- The collection time for each sub-spectrum.
- The number of sub-spectra.
- Type of linear amplifier: The user can select one of the three linear amplifiers on board the MCA or make use of an external amplifier.
- Type of signal from the preamplifier.
- The amplifier gain.
- The amplifier time constant.
- Pole-zero adjustment.
- The type of preamplifier signal connected to the input of the board.
- The polarity of the input signal.
- The number of ADC channels to be used for collection (varies from 256 to 4,096 in powers of 2).
- Choice of pulse pile-up rejection/total live time correction: The user can choose to turn on or off the pulse pile up rejection circuit on the card.
- Pulse pile up discrimination level for the amplifier.

The software was designed in modules for easy adaptation to various hardware. The sub-spectrum files are stored in text format. Altogether this means that the analysis software is independent of any file format or hardware.

A flow chart of the spectrum collection and initialization module of the data-acquisition software is shown in the flow chart in Figure 3-2.

Dead-time losses due to accesses to the ADC memory are reduced to barest minimum using the timing and delay functions provided by the compiler system. The lost time (see flow chart) is usually in the range of 0.35 µs. This time is subtracted from the collection time in order to set the delay time.

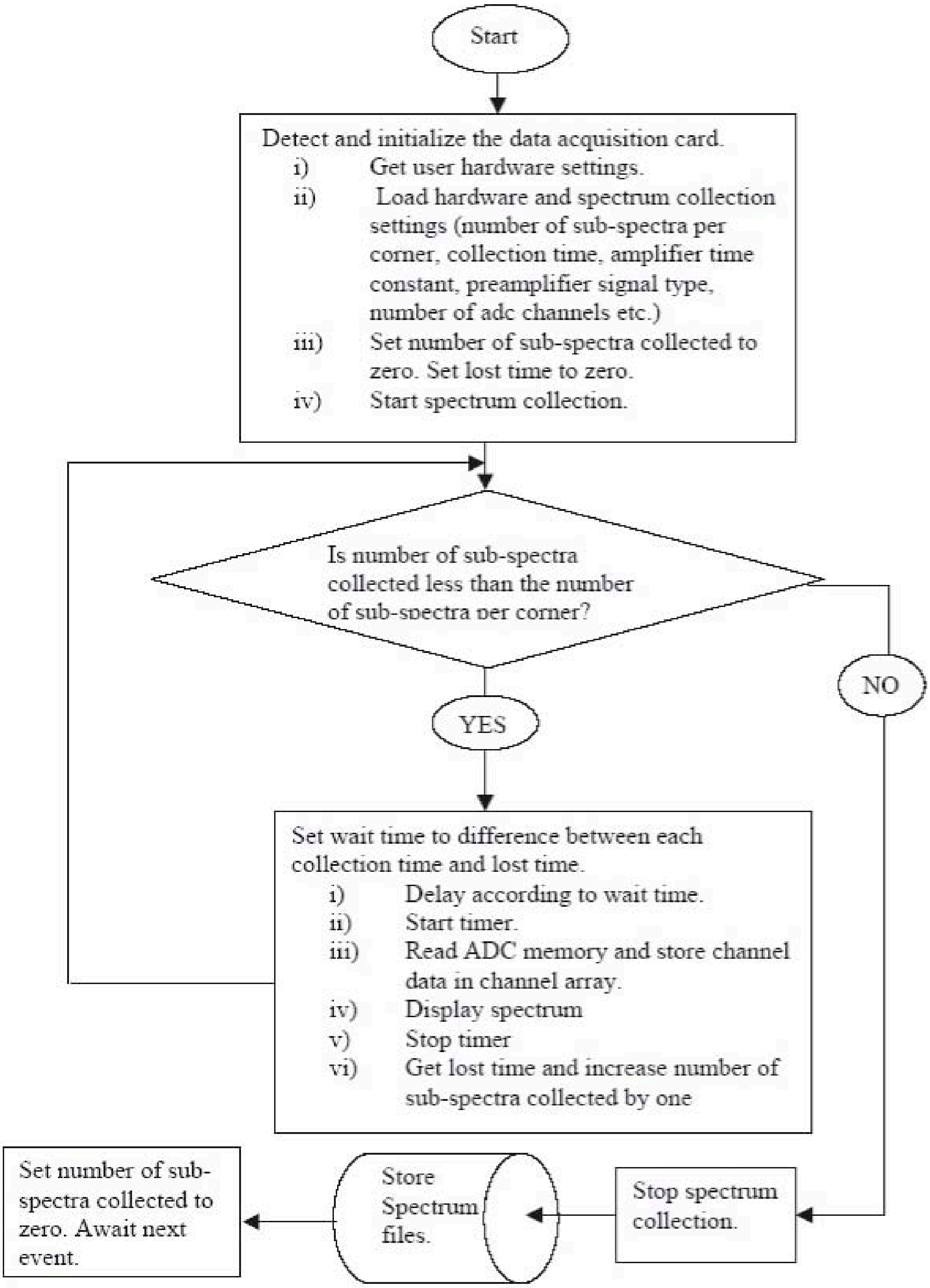

Figure 3-2. *A flow chart showing the principles behind the data-acquisition software.*

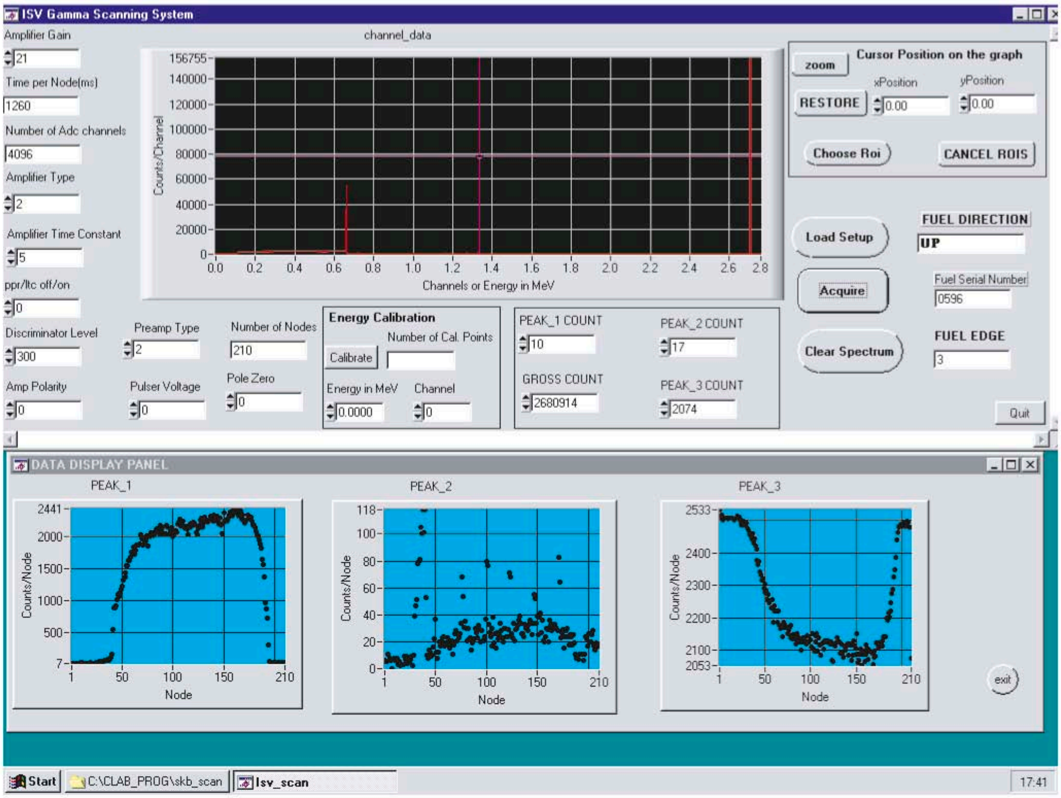

Figure 3-3. *The graphic interface of the data-acquisition module, showing the gamma-ray spectrum and the profiles of three selected gamma-ray peaks. Here, peak_1 is the peak area for* ^{137}*Cs, which reflects the axial burnup profile, peak_2 is the peak area for* ^{60}*Co, which allows for detecting the positions of the spacers and peak_3 is the peak area for an artificial pulse peak used for obtaining the dead time profile. In this figure, a sub spectrum is called a node.*

3.4 Analysis procedure

A software tool has been developed for analysing the data obtained in a measurement campaign. The tool is used to compute the relative intensities of ^{137}Cs for each fuel assembly by performing the following tasks:

- Dead-time correction of each sub spectrum.
- Computation of the relative intensities for each of three peaks in the spectrum.

It also performs the following tasks:

i) Provision of diagnostic information about the analysis.

ii) Verification of the discharge burnup and cooling time for each fuel assembly.

iii) Computation of the calibration constant C in Equation 2-1.

iv) Presentation of the residual thermal power using the constant C and the relative intensity of ^{137}Cs.

In order to use the analysis tool, the user is required to enter a file name where to find input information, such as the path to where the spectrum data files are stored, the date that each assembly was scanned, the fuel id, whether the assembly is reconstructed or not, fuel geometry, fuel type and enrichment. An example of the content of such an input file is shown in Figure 3-4.

Two other input files are required:

i) Irradiation history file, which contains information about the core lifetime of each assembly, as declared by the power plant operators.

ii) Residual thermal power file used for the calibration.

An example of the content of the irradiation history file is shown in Figure 3-5 and an example of the residual thermal power file is shown in Figure 3-6. The latter file also contains values of the fractional power (f) obtained from Origen-2.

Fuel id	Reactor type	Scan date	Path	Enrichment	Status	Fuel channel
1177	BWR	01-22-2003	C	2.65	OK	Yes
9329	BWR	01-22-2003	C	2.92	OK	Yes
1186	BWR	01-21-2003	C	2.65	OK	Yes
1389	BWR	01-23-2003	C	2.201	OK	Yes
1546	BWR	01-29-2003	C	2.201	OK	Yes
1696	BWR	01-23-2003	C	2.201	OK	Yes
1704	BWR	01-27-2003	C	2.201	OK	Yes
2014	BWR	01-22-2003	C	2.33	OK	Yes
2018	BWR	01-21-2003	C	2.33	OK	Yes
2048	BWR	01-21-2003	C	2.33	OK	Yes
2995	BWR	01-28-2003	C	2.699	OK	Yes
3058	BWR	01-28-2003	C	2.751	OK	Yes
3064	BWR	01-29-2003	C	2.751	OK	Yes
3838	BWR	01-28-2003	C	2.09	OK	Yes

Figure 3-4. *An example of the contents of the input data file. The column named ”Path” is used to determine the disk drive where the spectrum data are stored while the column named “Status” allows the analysis tool to determine if the fuel assembly has been rebuilt or not.*

ID:C01		
06-19-1974	04-13-1977	11247
07-07-1977	03-31-1978	9403
05-26-1978	04-03-1979	7569
06-25-1979	04-01-1980	0
06-18-1980	04-04-1981	8469
06-23-1981	05-06-1982	0
07-29-1982	04-28-1983	0
07-28-1983	04-13-1984	0
07-12-1984	04-04-1985	0
06-14-1985	04-30-1986	0
07-02-1986	04-25-1987	0
06-18-1987	05-12-1988	0

Figure 3-5. *An example showing the contents of the irradiation cycle file. The presented data accounts for the assembly with id number C01. The first column shows the date when a cycle was started, the second column shows the date the cycle ended while the third column shows the burnup (MWd/tU) of the fuel during the cycle. This file contains the data that is used for the verification of the operator's declared burn up and cooling time.*

0582	8X8	02-11-2004	89.35	2.30	91.65	0.36532
0596	8X8	02-19-2004	85.33	2.96	88.29	0.36432
0596	8X8	02-20-2004	88.25	2.97	91.21	0.36432
0710	8X8	02-06-2004	93.32	3.01	96.33	0.36149
0710	8X8	03-22-2004	89.94	3.01	92.95	0.36149
0710	8X8	03-23-2004	89.29	3.02	92.31	0.36149
0900	8X8	02-18-2004	93.67	2.80	96.48	0.35940
1136	8X8	02-09-2004	92.61	2.62	95.23	0.35472
1136	8X8	02-10-2004	93.15	2.63	95.78	0.35472

Figure 3-6. *An example showing the contents of the calibration information file. Each line gives the data for a given fuel assembly. The information in each column are: the fuel id, the fuel geometry type, the date of calorimetric measurement, the measured residual power, the estimated power due to the escape of gamma photons from the calorimeter, the total calorimetric power and the fractional power (f) at the time of the calorimetric measurements.*

4 Measurements

In order to obtain the calibration constant C in Equation 2-1, data from calorimetric measurements and gamma scanning were used. These measurements are described below.

4.1 Fuel assemblies included in the assay

The measurements using the gamma scanning technique were performed during two campaigns: one in January 2003 and the other in June 2003. A total number of 86 assemblies from 10 reactors were scanned. 77 assemblies were scanned in January, 12 assemblies were scanned in June while 3 were scanned both in January and in June. A summary of the fuel assembly types scanned is shown in Table 4-1.

The initial enrichments of the assemblies varied from 1.95% to 3.43%. A full list of the scanned fuel assemblies is available in Appendix A.

Of the total 86 assemblies measured, 22 were excluded from the results and analysis for the following reasons:

i) PWR fuel assemblies that contains control rods. The residual power of these assemblies was not measured with the calorimeter so they could not be used in the determination of the calibration constants.

ii) Fuel assemblies that were rebuilt. These assemblies will be subject for further analysis.

iii) Fuel assemblies of a type that were too few to be used in constructing a calibration curve.

The assemblies that were excluded are shown in Table A-3 Appendix A.

Table 4-1. The fuel types that were scanned in January and June 2003.

Reactor type	Total	Fuel type	Fuel channel	No of assemblies
		8×8	Yes	24
BWR	50	8×8	No	14
		SVEA64	Yes	4
		SVEA100	Yes	4
		KWU8×8	Yes	1
		KWU9×9–5	Yes	3
PWR	36	15×15	No	20
		17×17	No	16

4.2 Gamma spectroscopic measurements

To perform a scan, the assembly was placed in the fixture described in Section 3.1. The fixture was rotated so that the detector viewed a corner of the assembly. The scan was then performed by starting the data acquisition system and moving the assembly upwards in front of the collimator. When the scan was completed, the fixture was rotated 90° and the next scan was initiated by moving the assembly downwards.

The speed of the elevator was set to about 120 cm per minute while travelling upwards and about 150 cm per minute while travelling downwards. These speeds were considered a feasible compromise between short measuring times and small uncertainties due to counting statistics.

The different speeds were considered when setting the time windows used to collect and store data. When the elevator was travelling upwards, data was collected in each sub spectrum during a time of 1.26 seconds. When the elevator was travelling downwards, the measuring time was 1.01 seconds per sub spectrum. A total of 210 sub spectra per corner were collected.

The procedure was repeated for all four corners of the assembly. The measuring time per assembly was about 15 minutes. Including fuel handling, the measurements were performed at a typical rate of one fuel assembly every 30 minutes.

4.3 Calorimetric measurements

The calorimetric data were obtained from measurements performed by the staff of the Swedish Nuclear Fuel Company (SKB) and the OKG AB (parts 3 and 4). The same fuel assemblies that were used in the gamma scanning measurements were also used in the calorimetric measurements with the exception of two assemblies: A05 and A11. These two assemblies were excluded from the calorimetric measurements at this stage because they contain control rods. The results from the calorimetric measurements of the residual power are shown in Table C-1.

5 Analysis

5.1 Dead-time correction

In this work, gross input count rates reaching more than 130,000 cps were encountered. This together with the performance of the detector system implied dead-time losses that varied from a few percent up to about 70%. Such large varying dead-time losses necessitate a proper correction of the measured count rates. In this work, the stored sub spectra for each fuel assembly were corrected for dead-time using the pulser method. External pulses from a pulse generator with a well-defined event rate of (2,000 ± 1) Hz were injected into the detector system.

By forming the ratio between the number of events injected during the measuring time and the number of events in the pulser peak, a dead-time correction factor was obtained for each sub spectrum. The number of counts in each channel in a given sub spectrum was then multiplied with this factor to obtain a dead-time corrected spectrum.

Figure 5-1 shows the variation of the dead-time correction factor along the axis of the fuel assembly 5F2.

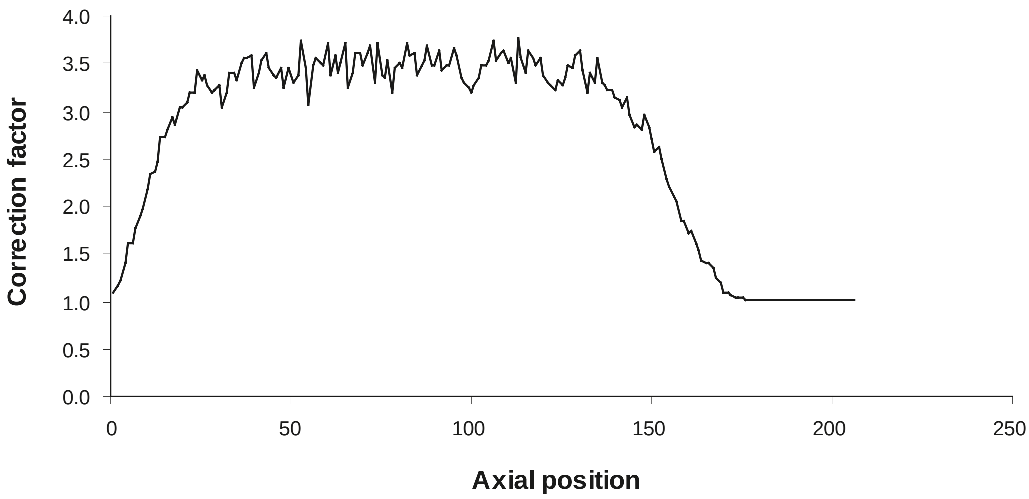

Figure 5-1. *Variation of the dead-time correction factor along the axis of the fuel assembly with the assembly id: 5F2. The maximum gross count rate for a sub-spectrum during this particular measurement was about 42,000 counts per second (obtained from non dead-time corrected spectra). The fuel assembly had a discharge burnup of 47GWd/tU and a cooling time of about 12 years.*

5.2 Computing the relative intensities in selected gamma-ray lines

For a given fuel assembly, the dead-time-corrected sub spectra for each of the four corners were summed up to give a total spectrum. In such a way, four energy spectra were obtained for further analysis to determine the net count rate in each selected gamma-ray peak. Figure 5-2 shows an example of such an energy spectrum.

The first step in this procedure was to locate the position of each selected gamma ray peak in the spectrum using a search algorithm. Here, the peaks indicated in Figure 5-2 were selected i.e. from ^{137}Cs, ^{134}Cs, and ^{154}Eu respectively. When a peak was found, its centroid and full width at half maximum (FWHM) were determined. The peak position and the FWHM were used to define windows that correspond to peak and background regions, which were used to calculate the net count rate in the peak, see Figure 5-3.

In this work, the windows selected for the gamma-ray peaks were 14 channels wide while the window selected for the pulser peak was 12 channels wide. The total number of counts in a peak was obtained by summing the counts in regions 4 and 5 in Figure 5-3. The regions 1 and 6 in the same figure defined the background regions so that the contents in regions 2 and 3 were subtracted from the total number of counts to obtain the net content in the peak. The details of the technique used to obtain the background contribution are described in /12, 13/.

The net content obtained for each selected peak was used to compute the corresponding relative intensity for that given peak from:

$$\text{Relative intensity } (I_r) = \frac{\text{Net count in the peak}}{\text{True time}} \qquad (5\text{-}1)$$

True time is defined as the actual measuring time because the analyzed spectra were dead time corrected.

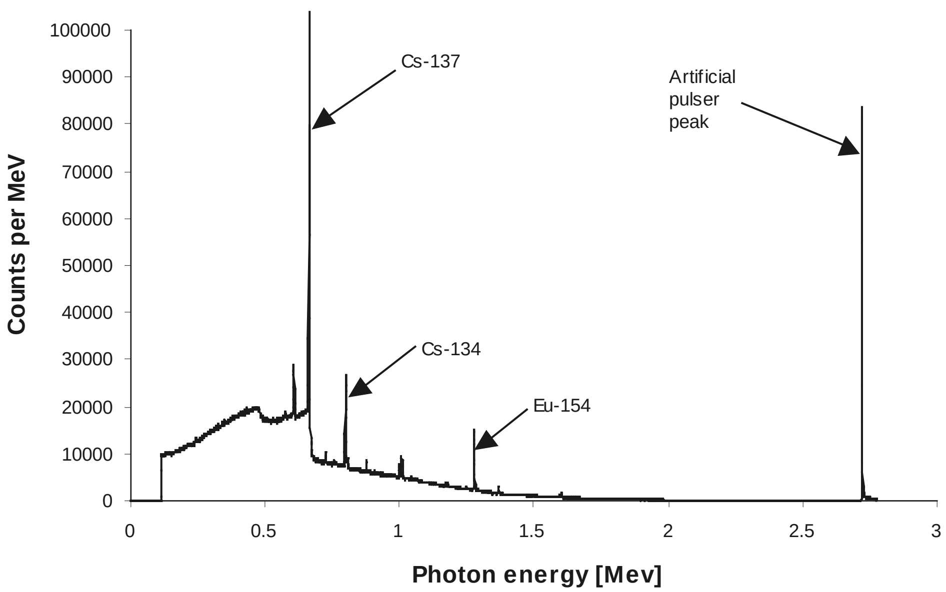

Figure 5-2. *The gamma-ray energy spectrum collected from the fuel assembly: 5F2. The assembly had a cooling time of 11.6 years. The following spectrum lines are indicated: ^{137}Cs at 662 keV, ^{134}Cs at 794 keV, ^{154}Eu at 1,274 keV and the artificial pulser peak at about 2,700 keV.*

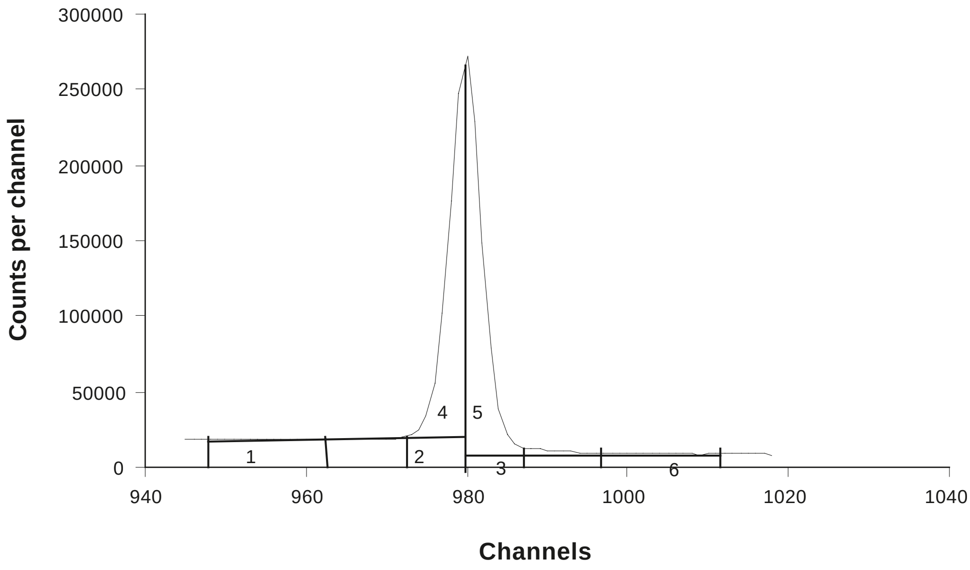

Figure 5-3. *The windows defining the peak and the background areas.*

6 Experimental results

To determine the residual heat using the gamma scanning technique, the measurements have to be calibrated. The calibration was done by using data obtained from calorimetric measurements.

6.1 Correlation between the spectroscopic and the calorimetric measurements

The value of the factor f for each assembly was obtained by using Equation 2-3 and 2-2. The values of the fitting constants a, b, c and d of Equation 2-3 are shown in Table 6-1. These fitting constants are independent of the fuel design.

From the gamma scanning measurements, the relative intensity I of the gamma radiation from the ^{137}Cs decay was obtained enabling the calculation of $\frac{I}{f}$ for each assembly. The results are shown in Table 6-2.

Table 6-1. Numerical values of the fitting coefficients in Equation 2-3. The values were determined using linear regression methods.

Fitting constant	Numerical value
a (tU/GWd)	-1.44×10^{-6}
b (/days^2)	-1.82×10^{-10}
c (/days)	-1.00×10^{-06}
d	4.17×10^{-1}

Table 6-2. The ratio $\frac{I}{f}$ for the fuel assemblies that were scanned and analysed in this study.

Fuel id	f	$\frac{I}{f}$ (cps)	Uncertainty of $\frac{I}{f}$ * (cps)	Fuel id	f	$\frac{I}{f}$ (cps)	Uncertainty of $\frac{I}{f}$ * (cps)
1177	0.350	5,445	386	3C1	0.350	14,872	1,052
9329	0.348	6,932	491	3C5	0.348	15,840	1,121
1186	0.359	4,328	307	3C9	0.350	14,791	1,046
1389	0.369	2,605	185	4C4	0.355	13,535	958
1546	0.365	3,416	242	4C7	0.348	15,928	1,127
1696	0.370	2,844	202	0E2	0.345	18,615	1,317
1704	0.370	2,578	183	0E6	0.354	15,202	1,075
2995	0.354	4,034	286	1E5	0.356	14,536	1,028
3838	0.373	3,700	262	I09	0.347	16,576	1,173
6350	0.362	4,166	295	D27	0.342	14,929	1,056
10288	0.356	5,812	411	F25	0.348	12,686	898
12078	0.370	3,914	277	D38	0.341	14,509	1,026
14076	0.352	7,239	512	E38	0.349	12,431	879
8338	0.356	6,108	432	E38	0.349	12,532	887
8327	0.354	7,074	501	E40	0.348	12,214	864
1136	0.363	3,464	245	F14	0.350	12,319	872
6423	0.355	6,464	458	F21	0.348	13,416	949
6432	0.353	6,637	470	F32	0.332	21,434	1,516
8341	0.357	3,005	216	G11	0.350	13,355	945
8331	0.355	3,383	242	G23	0.350	14,138	1,000
8332	0.355	3,196	229	I24	0.353	13,466	953
8327	0.354	3,665	263	I25	0.351	15,035	1,064
6423	0.355	3,369	241	11494	0.359	5,919	419
6454	0.350	3,395	243	11495	0.359	5,946	421
C01	0.343	12,904	913	12684	0.342	9,422	667
C12	0.344	12,876	911	13775	0.362	6,234	441
C20	0.350	12,634	894	13630	0.351	7,955	563
0C9	0.348	15,641	1,106	13628	0.358	6,788	480
2A5	0.371	7,075	501	13847	0.363	5,895	417
5A3	0.373	7,245	513	13848	0.363	5,881	416
1C2	0.355	13,152	930	KU0269	0.358	6,039	428
1C5	0.347	15,734	1,113	KU0278	0.358	6,079	430
2C2	0.350	14,757	1,044	KU0282	0.354	6,668	472

* These values give a conservative estimate of the uncertainty in because the relative uncertainty in each component of f was assumed to be 5% /2/.

Using the results from the calorimetric (P_{tot}) and the gamma scanning measurements, the correlation coefficient $C = P_{tot} / \frac{I}{f}$ in Equation 2-1 was determined by performing a least squares fit (Appendix B) of P_{tot} as a function of $\frac{I}{f}$. The values of C thus obtained are shown in Table 6-3. Because different detectors were used in January and June, two calibration curves had to be established for each of the following geometries: 8×8 (with fuel channel) and 8×8 (without fuel channel). All calibration curves can be found in Appendix B.

Table 6-3. The calibration constants for each assembly type determined from the calibration curves. Different detectors were used in the January and June measurement campaigns.

Assembly type	Fuel channel	Measurement campaign	Calibration constant (10^{-2} Ws)
8×8	Yes	January	3.23 ± 0.10
8×8	No	January	2.76 ± 0.04
		June	5.38 ± 0.05
KWU 15×15	No	January	3.10 ± 0.07
W15×15	No	January	3.25 ± 0.10
W 17×17	No	January	3.17 ± 0.05
SVEA 64	Yes	January	2.89 ± 0.09
SVEA100	Yes	January	2.90 ± 0.05
KWU9×9–5	Yes	January	3.23 ± 0.04

Using the calibration constant obtained for each fuel type, Equation 2-1 was used to predict the expected residual power for each assembly that was scanned. The residual power obtained from gamma scanning (P_{scan}) and the residual power obtained from the calorimetric measurements (P_{cal}) is shown in Tables 6-4 to 6-10 for each fuel type. In addition, Table D-1 in Appendix D gives a summary of the results for all the fuel types that were analyzed.

Table 6-4. Agreement between calorimetric measurements and gamma scanning for 8×8 assemblies with fuel channel.

Fuel type: 8×8 with fuel channel			
Fuel id	P_{cal} (W)	P_{scan} (W)	Difference (%)
1177	177.92	175.80	1.19
9329	222.82	223.80	–0.44
1186	140.78	139.72	0.75
1389	83.92	84.11	–0.22
1546	108.12	110.28	–1.99
1696	92.37	91.83	0.59
1704	83.98	83.22	0.90
2995	130.50	130.24	0.20
3838	126.80	119.45	5.79
6350	126.91	134.50	–5.98
10288	185.81	187.63	–0.98
12078	120.17	126.37	–5.16
14076	240.28	233.70	2.74
Relative Standard Deviation (%)	3.04		

Table 6-5. Agreement between calorimetric measurements and gamma scanning for 8×8 assemblies without fuel channels.

Fuel type: 8×8 without fuel channel			
Fuel id	P_{cal} (W)	P_{scan} (W)	Difference (%)
8338	169.50	168.45	0.62
8327	196.94	195.09	0.94
1136	95.23	95.52	–0.31
6423	174.21	178.27	–2.33
6432	184.44	183.04	0.76
8341	164.92	161.74	1.93
8331	187.03	182.05	2.66
8332	168.10	172.00	–2.32
8327	196.94	197.26	–0.16
6423	174.21	181.29	–4.07
6454	186.30	182.70	1.93
Relative Standard Deviation (%)	2.09		

Table 6-6. Agreement between calorimetric measurements and gamma scanning for W17×17 assemblies.

Fuel type: W17×17			
Fuel id	P_{cal} (W)	P_{scan} (W)	Difference (%)
0C9	491.17	496.14	–1.01
2A5	233.76	224.42	4.00
5A3	237.72	229.81	3.33
1C2	417.67	417.19	0.12
1C5	499.17	499.10	0.01
2C2	466.53	468.12	–0.34
3C1	470.23	471.75	–0.32
3C5	501.41	502.47	–0.21
3C9	468.42	469.18	–0.16
4C4	422.04	429.33	–1.73
4C7	498.75	505.26	–1.30
0E2	587.90	590.48	–0.44
0E6	487.75	482.23	1.13
1E5	468.77	461.09	1.64
Relative Standard Deviation (%)	1.66		

Table 6-7. Agreement between calorimetric measurements and gamma scanning for KWU15×15 assemblies.

Fuel type: KWU15×15			
Fuel id	P_{cal} (W)	P_{scan} (W)	Difference (%)
I09	507.94	509.56	–0.32
D27	456.05	458.94	–0.63
F25	396.75	389.96	1.71
D38	442.34	446.01	–0.83
E38	374.33	382.13	–2.08
E38	376.31	385.23	–2.37
E40	381.25	375.46	1.52
F14	381.81	378.68	0.82
F21	420.90	412.42	2.02
F32	691.99	658.88	4.78
G11	416.37	410.54	1.40
G23	420.63	434.62	–3.33
I24	410.07	413.94	–0.94
I25	445.79	462.19	–3.68
Relative Standard Deviation (%)	2.34		

Table 6-8. Agreement between calorimetric measurements and gamma scanning for SVEA 64 assemblies.

Fuel type: Svea 64 Fuel id	P_{cal} (W)	P_{scan} (W)	Difference (%)
11494	166.04	171.05	–3.02
11495	167.55	171.82	–2.55
12684	282.74	272.28	3.70
13775	178.35	180.16	–1.01
Relative Standard Deviation (%)	3.07		

Table 6-9. Agreement between calorimetric measurements and gamma scanning for SVEA 100 assemblies.

Fuel type: Svea 100 Fuel id	P_{cal} (W)	P_{scan} (W)	Difference (%)
13630	235.67	231.03	1.97
13628	194.04	197.12	–1.59
13847	169.58	171.20	–0.96
13848	170.70	170.79	–0.05
Relative Standard Deviation (%)	1.55		

Table 6-10. Agreement between calorimetric measurements and gamma scanning for KWU9×9–5 assemblies.

Fuel type: KWU9×9–5 Fuel id	P_{cal} (W)	P_{scan} (W)	Difference (%)
KU0269	192.69	195.02	–1.21
KU0278	195.44	196.29	–0.44
KU0282	218.46	215.31	1.44
Relative Standard Deviation (%)	1.36		

7 Summary

Gamma scanning of 86 spent nuclear fuel assemblies was performed during two measurement campaigns. Of these, 64 assemblies were used in the analysis for the determination of the residual thermal power, while 22 assemblies were set aside from the analysis due to the reasons as accounted for in Section 4.1. The excluded assemblies will be included in further studies.

Typical measuring times where about 15 minutes and the total time spent on each assembly was about 30 minutes including fuel handling.

In the first step of the analysis, the calibration constants were calculated for each fuel type. In the second step, the residual power was determined. The values of the residual power obtained agreed with the values obtained from calorimetric measurements with a standard deviation of 2.23% (Table 13-1, Appendix D).

It has also been shown that the new data acquisition and analysis software is applicable for collecting gamma-scanning data for determining the residual thermal power. Furthermore, both software tools hve been used to carry out the necessary computations including the regression fit for computing the calibration constants. With the developed software, it will be possible to obtain the value of the residual thermal power for a given assembly directly after scanning.

8 Outlook

The overall accuracy of 2.23% stated above refers to the whole set of fuel assemblies considered. Within the various types of assemblies the accuracy varies, however, from about 1.4% to about 3.1%. Here one should bear in mind that some subsets consist of very few assemblies which makes the determined accuracy somewhat questionable. It is therefore strongly suggested that future work includes more fuel assemblies in these subsets.

To improve the gamma scanning technique for determination of residual power, the following areas will be considered:

i) Integration of the current software tools (analysis and data acquisition) to provide an integrated gamma-scanning tool for the determination of residual thermal power.

ii) The use of gamma transport coefficients /14/ (as calculated with a technique used in tomographic computations) to relate the calibration constants (C) for different fuel designs to each other. This would make it possible to construct one calibration curve for all fuel types. By using the gamma transport coefficients, it may be possible to handle the following cases:

   a) Enable the determination of the residual power for fuel designs that are too few to be used in a calibration curve.

   b) Enable the modelling and determination of the residual thermal power for fuel assemblies that have been reconstructed through the replacement or removal of fuel rods as well as assemblies that still contains control rods

   c) Use of one single reference fuel assembly for calibration purposes. This would, in principle, facilitate the process of relating previous measurement geometries to current and future geometries.

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/11/ Deleted.

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Appendix A

Fuel assemblies included in the assay

Tables A-1 and A-2 show the fuel assemblies that were included in the assay. The data for the January campaign are shown in Table 10-1 while the data for the June campaign are shown in Table A-2. The fuel assemblies that were not part of the analysis are listed in Table A-3.

Table A-1. This table shows the fuel assemblies that were scanned in the January measurement campaign.

Fuel id	Geometry	Fuel channel	Enrichment (%)	Declared BU (GWd/tU)	Cooling time (days)
1177	8×8	Yes	2.65	36.242	6,382
9329	8×8	Yes	2.92	41.127	5,240
1186	8×8	Yes	2.65	30.498	6,381
1389	8×8	Yes	2.20	19.481	7,862
1546	8×8	Yes	2.20	24.47	7,103
1696	8×8	Yes	2.20	20.87	7,097
1704	8×8	Yes	2.20	19.437	7,493
2995	8×8	Yes	2.70	29.978	7,867
3838	8×8	Yes	2.09	25.669	3,854
6350	8×8	Yes	2.88	27.674	6,440
10288	8×8	Yes	2.95	35.218	5,239
12078	8×8	Yes	2.58	25.16	5,310
14076	8×8	Yes	3.15	40.01	3,862
8338	8×8	No	2.91	34.83	5,283
8327	8×8	No	2.90	37.851	4,185
6423	8×8	No	2.90	35.109	5,282
6432	8×8	No	2.89	36.861	5,282
1136	8×8	No	2.25	25.498	7,158
I09	KWU15×15	No	3.20	40.188	5,362
D27	KWU15×15	No	3.25	39.676	7,201
F25	KWU15×15	No	3.20	35.352	7,203
D38	KWU15×15	No	3.25	39.403	7,557
E38	KWU15×15	No	3.20	33.973	7,557
E38	KWU15×15	No	3.20	33.973	7,564
E40	KWU15×15	No	3.20	34.339	7,559
F14	KWU15×15	No	3.20	34.009	7,203
F21	KWU15×15	No	3.20	36.273	6,852
F32	KWU15×15	No	3.20	50.962	5,366
G11	KWU15×15	No	3.19	35.463	6,497
G23	KWU15×15	No	3.21	35.633	6,497
I24	KWU15×15	No	3.20	34.337	6,109
I25	KWU15×15	No	3.20	36.859	5,743
C01	W15×15	No	3.095	36.688	7,956
C12	W15×15	No	3.095	36.385	7,955

Fuel id	Geometry	Fuel channel	Enrichment (%)	Declared BU (GWd/tU)	Cooling time (days)
C20	W15×15	No	3.095	35.720	6,494
0C9	W17×17	No	3.10	38.442	6,074
2A5	W17×17	No	2.10	20.107	6,823
5A3	W17×17	No	2.10	19.699	6,822
1C2	W17×17	No	3.10	33.318	6,075
1C5	W17×17	No	3.10	38.484	6,074
2C2	W17×17	No	3.10	36.577	6,074
3C1	W17×17	No	3.10	36.572	6,074
3C5	W17×17	No	3.10	38.373	6,073
3C9	W17×17	No	3.10	36.56	6,074
4C4	W17×17	No	3.10	33.333	6,079
4C7	W17×17	No	3.10	38.37	6,074
0E2	W17×17	No	3.10	41.628	5,305
0E6	W17×17	No	3.10	35.993	5,306
1E5	W17×17	No	3.10	34.638	5,305
11494	SVEA 64	Yes	2.92	32,431	5,305
11495	SVEA 64	Yes	2.91	32,431	5,303
12684	SVEA 64	Yes	2.902	46,648	4,197
13775	SVEA 64	Yes	2.85	32,837	4,218
13630	SVEA 100	Yes	2.711	40,363	4,236
13628	SVEA 100	Yes	2.711	35,619	4,236
13847	SVEA 100	Yes	2.77	31,275	4,575
13848	SVEA 100	Yes	2.77	31,275	4,575
KU0269	KWU9×9–5	Yes	2.938	35,113	4,548
KU0278	KWU9×9–5	Yes	2.938	35,323	4,267
KU0282	KWU9×9–5	Yes	2.938	37,896	4,262

Table A-2. The fuel assemblies that were scanned in the June measurement campaign.

Fuel id	Geometry	Fuel channel	Enrichment (%)	Declared BU (GWd/tU)	Cooling time (days)
8341	8×8	No	2.89	34.099	5,415
8331	8×8	No	2.89	35.903	5,010
8332	8×8	No	2.90	34.977	5,415
8327	8×8	No	2.90	37.851	4,317
6423	8×8	No	2.90	35.109	5,415
6454	8×8	No	2.90	37.236	6,137

Table A-3. Assemblies that were not part of the analysis.

Fuel id	Status	Geometry
5829	Rebuilt	8×8
3058	Rebuilt	8×8
3064	Rebuilt	8×8
6478	Rebuilt	8×8
5F2	Rebuilt	AA17×17
2014	Rebuilt	8×8
2018	Rebuilt	8×8
2048	Rebuilt	8×8
2074	Rebuilt	8×8
2118	Rebuilt	8×8
3054	Rebuilt	8×8
0582	Rebuilt	8×8
0596	Rebuilt	8×8
0900	Rebuilt	8×8
3C4	Rebuilt	W17×17
I20	Rebuilt	KWU15×15
C42	Rebuilt	W15×15
A05	Contains control rods	W15×15
A11	Contains control rods	W15×15
5535	Too few	8×8
1377	Too few	8×8
KU0100	Too few	8×8–2

Appendix B

Calibration curves

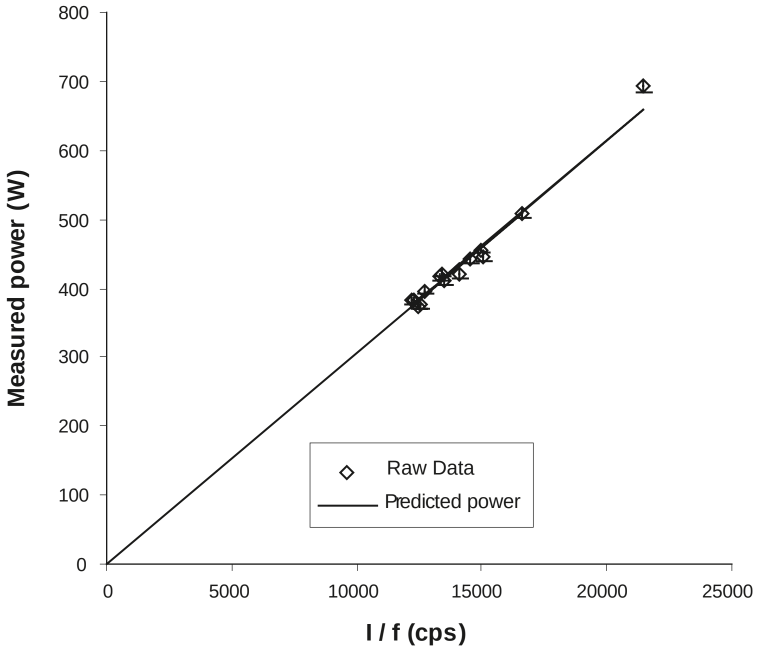


Figure B-1. *The calibration curve for the residual power in KWU15×15 fuel assemblies. The estimated deviation of the least square fit is: 2.34%.*

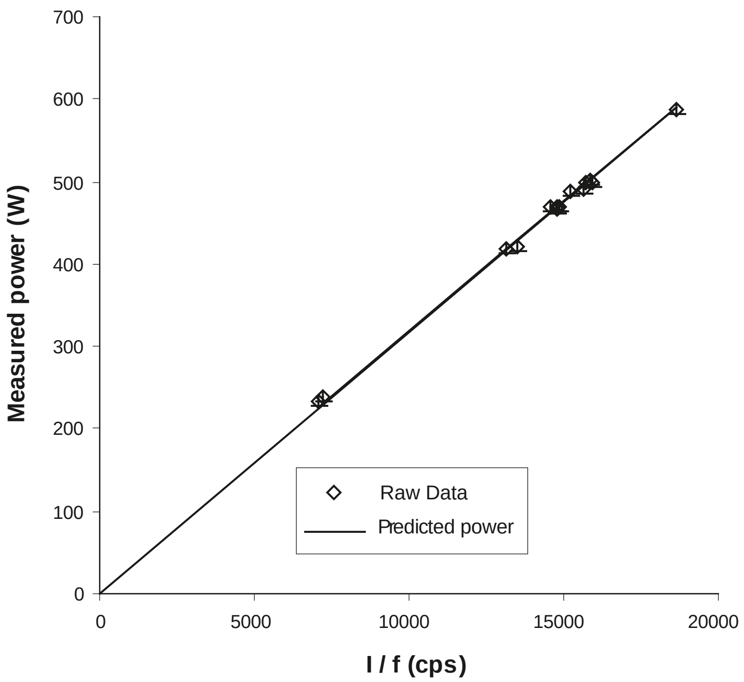


Figure B-2. *The calibration curve for the residual power in W17×17 fuel assemblies. The estimated deviation of the least square fit is: 1.66%.*

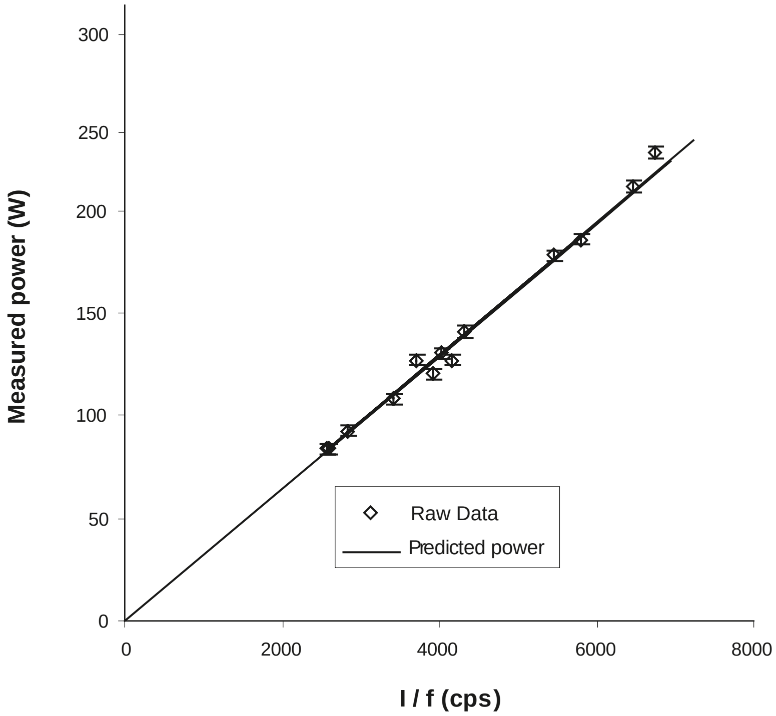


Figure B-3. *The calibration curve for the residual power of 8×8 assemblies with fuel channel. These assemblies were scanned in the January campaign. The estimated deviation of the least square fit is: 3.15%.*

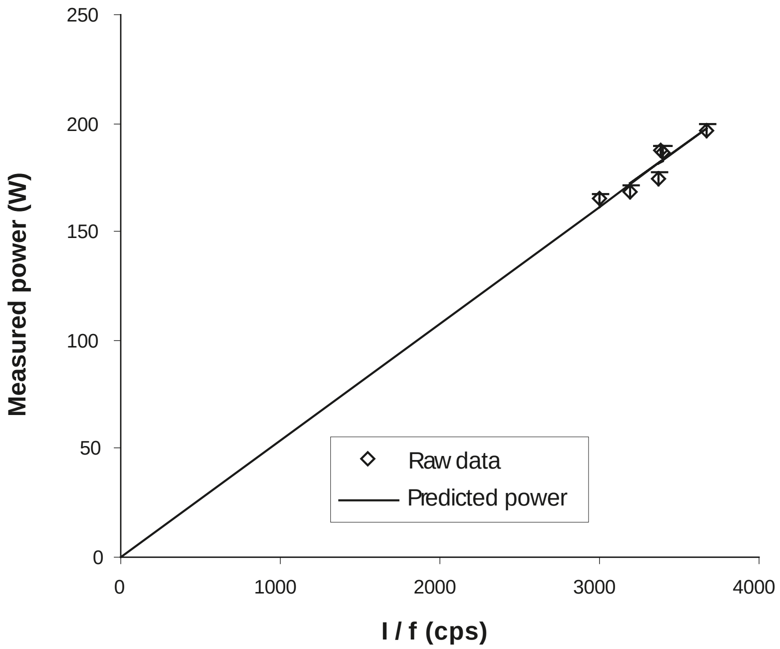


Figure B-4. *The calibration curve for the residual power in 8×8 assemblies without fuel channels. These assemblies were scanned in the June campaign. The estimated deviation of the least square fit is: 2.70%.*

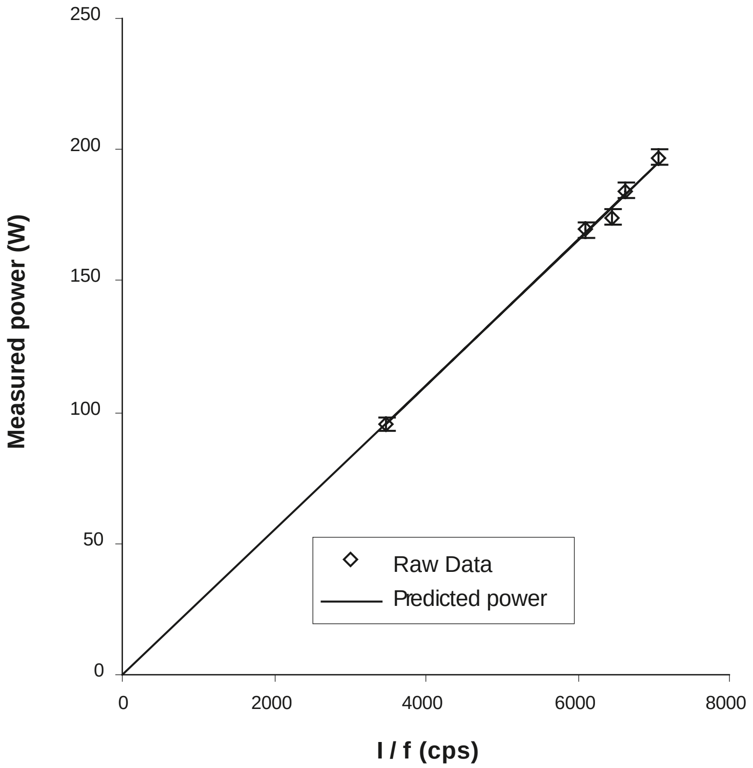


Figure B-5. *The calibration curves for the residual power of 8×8 assemblies without fuel channel. These assemblies were scanned in the January campaign. The estimated deviation of the least square fit is: 1.35%.*

Appendix C

Results from the calorimetric measurements

Table C-1. Results from the calorimetric measurements of the thermal residual power.

Fuel id	Calorimetric power (W)	Escape power (W)	Total power (W)	Uncertainty (W)	Fuel id	Calorimetric power (W)	Escape power (W)	Total power (W)	Uncertainty (W)
1177	173.38	4.54	177.92	2.82	6454	181.27	5.03	186.30	2.86
9329	217.40	5.42	222.82	3.05	C01	406.3	9.45	415.75	5.14
1186	137.48	3.3	140.78	2.65	C12	401.64	8.7	410.34	5.11
1389	81.74	2.18	83.92	2.41	C20	416.39	9.64	426.03	5.19
1546	105.39	2.73	108.12	2.50	C42	431.7	10.58	442.28	5.27
1696	90.04	2.33	92.37	2.44	0C9	478.62	12.55	491.17	5.53
1704	81.84	2.14	83.98	2.41	2A5	227.92	5.84	233.76	4.34
2014	80.80	1.9	82.70	2.40	5A3	231.89	5.83	237.72	4.36
2018	82.32	1.99	84.31	2.41	1C2	407.29	10.38	417.67	5.15
2048	92.36	2.23	94.59	2.45	1C5	486.51	12.66	499.17	5.57
2995	127.29	3.21	130.50	2.60	2C2	454.81	11.72	466.53	5.40
3838	122.56	3.38	125.94	2.58	3C1	458.29	11.94	470.23	5.42
6350	123.69	3.22	126.91	2.58	3C4	484.91	12.43	497.34	5.56
10288	181.18	4.63	185.81	2.86	3C5	488.88	12.53	501.41	5.58
12078	116.91	3.26	120.17	2.56	3C9	456.47	11.95	468.42	5.41
14076	233.70	6.58	240.28	3.15	4C4	411.41	10.63	422.04	5.17
2074	95.47	2.3	97.77	2.46	4C7	485.91	12.84	498.75	5.57
2118	95.92	2.38	98.30	2.46	0E2	572.38	15.52	587.90	6.06
3054	137.37	3.67	141.04	2.65	0E6	475.12	12.63	487.75	5.51
5535	82.40	2.2	84.60	2.41	1E5	456.86	11.91	468.77	5.41
1377	54.80	1.43	56.23	2.31	I09	494.53	13.41	507.94	5.62
8338	164.86	4.64	169.50	2.78	D27	444.65	11.4	456.05	5.34
8327	190.97	5.97	196.94	2.92	F25	386.71	10.04	396.75	5.05
582	89.35	2.3	91.65	2.44	D38	431.59	10.75	442.34	5.27
596	85.33	2.96	88.29	2.43	E38	366.95	9.36	376.31	4.95
710	89.94	3.01	92.95	2.44	E38	366.95	9.36	376.31	4.95
900	93.68	2.8	96.48	2.46	E40	372.24	9.01	381.25	4.97
1136	93.15	2.63	95.78	2.45	F14	372.47	9.34	381.81	4.98
6423	169.05	5.16	174.21	2.80	F21	410.2	10.7	420.90	5.17
6432	178.90	5.54	184.44	2.86	F32	675.4	16.59	691.99	6.66
8341	158.06	4.79	162.85	2.75	G11	405.75	10.62	416.37	5.14
8331	181.30	5.73	187.03	2.87	G23	409.56	11.07	420.63	5.17
8332	162.95	5.15	168.10	2.77	I20	393.78	9.68	403.46	5.08
8327	190.97	5.97	196.94	2.92	I24	398.24	11.83	410.07	5.11
6423	169.05	5.16	174.21	2.80	I25	433.99	11.8	445.79	5.29
11494	161.66	4.38	166.04	2.77	13847	164.66	4.92	169.58	2.78
11495	163.26	4.29	167.55	2.77	13848	165.64	5.06	170.70	2.79
12684	274.91	7.83	282.74	3.39	KU0269	187.13	5.56	192.69	2.90
13775	173.07	5.28	178.35	2.83	KU0278	189.90	5.54	195.44	2.91
13630	228.58	7.09	235.67	3.12	KU0282	212.54	5.92	218.46	3.03
13628	188.24	5.8	194.04	2.90					

Appendix D

Summary of the measurement results

Table D-1. Results of the measurements for all fuel types that were used in the analysis.

Fuel id	Pcal (W)	Pscan (W)	Difference (%)	Fuel id	Pcal (W)	Pscan (W)	Difference (%)
1177	177.92	175.80	1.19	3C5	501.41	502.47	–0.21
9329	222.82	223.80	–0.44	3C9	468.42	469.18	–0.16
1186	140.78	139.72	0.75	4C4	422.04	429.33	–1.73
1389	83.92	84.11	–0.22	4C7	498.75	505.26	–1.30
1546	108.12	110.28	–1.99	0E2	587.9	590.48	–0.44
1696	92.37	91.83	0.59	0E5	487.75	482.23	1.13
1704	83.98	83.22	0.90	1E5	468.77	461.09	1.64
2995	130.50	130.24	0.20	I09	507.94	509.56	–0.32
3838	126.80	119.45	5.79	D27	456.05	458.94	–0.63
6350	126.91	134.50	–5.98	F25	396.75	389.96	1.71
10288	185.81	187.63	–0.98	D38	442.34	446.01	–0.83
12078	120.17	126.37	–5.16	E38	374.33	382.13	–2.08
14076	240.28	233.70	2.74	E38	376.31	385.23	–2.37
8338	169.50	168.45	0.62	E40	381.25	375.46	1.52
8327	196.94	195.09	0.94	F14	381.81	378.68	0.82
1136	95.23	95.52	–0.31	F21	420.9	412.42	2.02
6423	174.21	178.27	–2.33	F32	691.99	658.88	4.78
6432	184.44	183.04	0.76	G11	416.37	410.54	1.40
8341	164.92	161.74	1.93	G23	420.63	434.62	–3.33
8331	187.03	182.05	2.66	I24	410.07	413.94	–0.94
8332	168.10	172.00	–2.32	I25	445.79	462.19	–3.68
8327	196.94	197.26	–0.16	11494	166.04	171.05	–3.02
6423	174.21	181.29	–4.07	11495	167.55	171.82	–2.55
6454	186.30	182.70	1.93	12684	282.74	272.28	3.70
C01	415.75	420.40	–1.12	13775	178.35	180.16	–1.01
C12	410.34	419.48	–2.23	13630	235.67	231.03	1.97
C20	426.03	411.58	3.39	13628	194.04	197.12	–1.59
0C9	491.17	496.14	–1.01	13847	169.58	171.20	–0.96
2A5	233.76	224.42	4.00	13848	170.7	170.79	–0.05
5A3	237.72	229.81	3.33	KU0269	192.69	195.02	–1.21
1C2	417.67	417.19	0.12	KU0278	195.44	196.29	–0.44
1C5	499.17	499.10	0.01	KU0282	218.46	215.31	1.44
2C2	466.53	468.12	–0.34				
3C1	470.23	471.75	–0.32				
Relative Standard Deviation (%)	2.23						

Part 3

Clab – Calibration curve for calorimetric measurement of fuel assemblies

Fredrik Sturek, OKG Aktiebolag

Contents

1 Background

In order to optimize the final repository for spent fuel, it is desirable to be able to measure the decay heat power in the fuel. Decay heat power measurement is also needed to verify programs that calculate the decay heat power. This report describes how decay heat power measurement has been carried out in Clab with a specially designed calorimeter (system 251) according to the temperature increase method and the circulation method.

An illustration of the calorimeter is shown in Appendix 1 and a detailed description is found in reference 1.

2 Measurement method

2.1 Temperature increase method

The principle of calorimetric measurement of decay heat power according to the temperature increase method is that the fuel assembly is placed in a limited and insulated water volume, in this case a calorimeter. Depending on how much decay heat power the fuel emits, the temperature of the water in the calorimeter will increase at different rates. The rate of temperature increase will be a direct measure of the decay heat power of the fuel. In order to permit the rate of temperature increase to be related to a decay heat power value, a calibration curve has been plotted.

2.2 Circulation method

Just as in the case of the temperature increase method, the fuel assembly is placed in the calorimeter. In contrast to the temperature increase method, a known flow is started to and from the otherwise insulated calorimeter. After a while a steady state will be reached where the temperature in the calorimeter is stable. In this state the decay heat power and the rate of heat emission to the surrounding water are equal. Most of the heat is carried away with the flow pumped through the calorimeter. Furthermore, the temperature difference between the calorimeter water and the surrounding water results in a convective heat loss that passes through the insulated wall of the calorimeter. The heat lost to the water circulating through the calorimeter can be determined with good precision by measuring the mass flow and the temperature of the water both as it enters and as it leaves the calorimeter. But in order to take into account the heat loss through the calorimeter wall, calibration measurements have been performed.

3 Equipment

Clab system 251 (calorimeter system for decay heat power measurement) was used for the measurements.

The calorimeter system consists of:

- A console (8.PAM.406) containing a control computer and measurement instruments.
- A connection module with valves, calibration tank and pump.
- A calorimeter where the fuel assembly and the electric heater (BWR dummy) are placed.

The fuel assembly whose decay heat power is to be measured is placed in the calorimeter, whose lid keeps the calorimeter watertight. An electric heater with the same geometry as a real BWR assembly is used for calibration. The heater has 64 “fuel rods” with 261 m of heating cable with a resistance of 0.1 ohm/m. From the console there is a 20 m one-way transport cable with a resistance of 0.012 ohm/m. Some of the heat will be lost in the transport cable. In order to produce the heat power that is delivered by the electric heater, the power value must be multiplied by $261\times0.1/(261\times0.1+2\times20\times0.012) = 0.982$. For practical reasons the electric heater has its own lid to ensure watertightness. There are temperature sensors in the calorimeter whose values are recorded in the control computer. All activations of valves and pumps take place from the control computer program’s process display.

4 Measurement uncertainty

The system description for system 251 (ref /1/) gives the error limits for the equipment:

Temperature	± 0.01°C
Mass flow	± 0.5% within 0.36 kg/min–7.2 kg/min
Power output	± 0.25% within 50 W–1,000 W
Gamma dose rate	± 5% within 0–100 Gy/h
Mass	± 0.02%

These errors contribute to the random errors in the measurements. A detailed analysis of measurement uncertainty is found in Section 3, part 4 in this report.

5 Calibration measurements

Calibration measurements were performed in the range 50 to 1,000 Watts. A total of 49 calibration measurements were performed according to the temperature increase method 26 according to the circulation method. Following is a description of how the calibrations were carried out and their results.

5.1 Temperature increase method

5.1.1 Calibration according to the temperature increase method

- The fuel-like heating element is placed in the calorimeter.
- The electric heater is set to the power output to be run.
- Deionized water: 733 water is connected to the calorimeter to cool it to 1.5°C below the temperature of the surrounding pool water.
- All measurement data are logged until the temperature in the calorimeter is 1.5°C warmer than the surrounding water.
- The temperature difference between the calorimeter and the surrounding pool water (KA502–KA531, see Table 5-1 below) is plotted as a function of time in a graph (see Figure 5-1). Time zero is when the temperature difference between the calorimeter and the pool (DT) is zero. A second degree curve is fitted as closely as possible to the plotted points.
- The slope of the second degree curve in the point DT = 0°C is determined (1.35382×10^{-4} in Figure 5-1).
- The calibration curve is drawn by plotting the power values (KA901, see Table 5-1 below) for the different measurements as a function of the slope in the point DT = 0°C. The power value is multiplied by 0.982 as described in Chapter 3. This run thus contributes the point (1.35382×10^{-4}; 149.9×0.982W) to the calibration curve (Figure 5-2).

Table 5-1 shows an extract from the primary data saved in connection with a calibration measurement according to the temperature increase method. More complete primary data are found in Appendix 2.

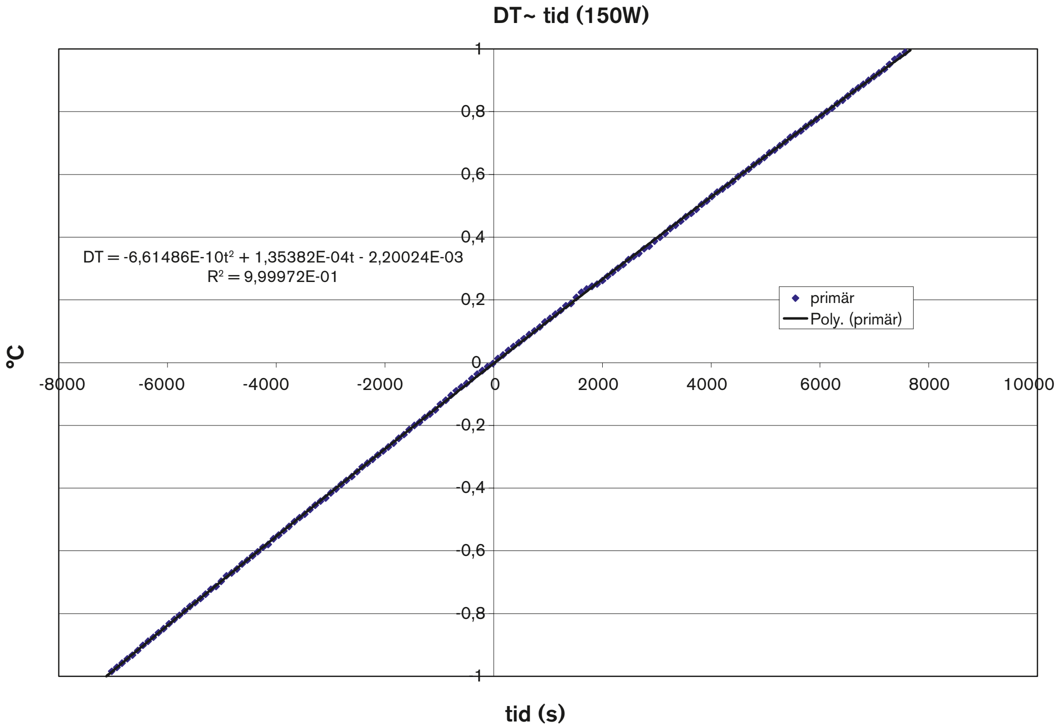


Figure 5-1. *Temperature difference between calorimeter and surrounding pool as a function of time. Measurement with starting date 26 May 2003 and with a box on the electric heater.*

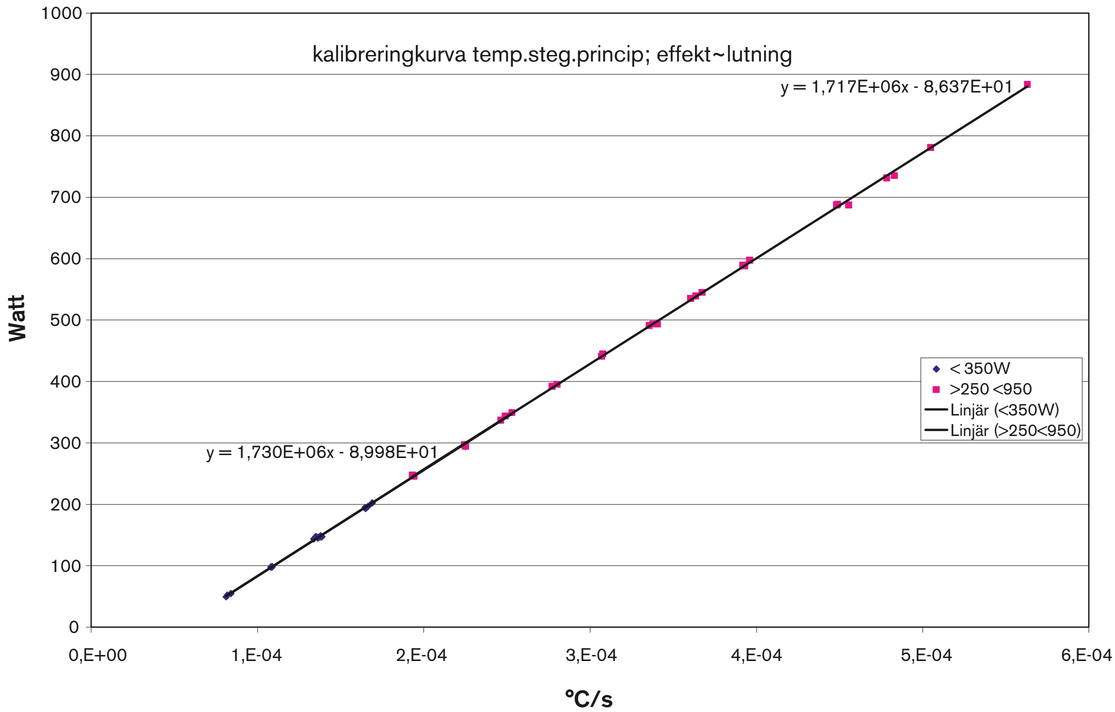


Figure 5-2. *Calibration curve for temperature increase method. Power as a function of slope.*

Table 5-1. Primary data in calibration according to the temperature increase method.

Tinfo1			Tinfo2					
Fredrik Sturek								
Kalib. Temperaturstegringsprincipen			150Wtempstegbox030526					
KA701	KA702							
360	16							
0.00424	0.00421							
KA703	KA704							
76	–514							
0.00449	0.00425							
KA705	KALIB.TEMP							
–132	21.5							
0.00451	Förstärkning							
	023							
Mon May 26 2003 08:30:22								
Logg_tid	T1	T5	T6	T16	T17	T18	T20	T21
tid	_251KA901_ A_kW	_251KA502_ B1	_251KA502_ B2	_251KA751_ Vikt	_251KA101	_251KA521_ B1	_251KA531_ B1	_251KA531_ B2
sekunder	W	°C	°C	kg	bar	°C	°C	°C
60	149.52							
96		18.276	18.279				19.743	19.749
120	149.81							
180	149.73							
192		18.268	18.273			18.218	19.752	19.751
240	150.10							
288		18.271	18.274				19.749	19.746
300	150.16			11.17				
360	150.16							
384		18.269	18.275			18.248	19.745	19.751
420	149.73							
480	149.90	18.291	18.297				19.748	19.747
540	149.69							
576		18.307	18.313			18.280	19.746	19.748
600	149.78			11.17	1.39			
660	149.24							
672		18.321	18.325				19.746	19.748
720	149.49							
768		18.337	18.338			18.310	19.746	19.748
780	149.95							
840	150.41							
864		18.351	18.355				19.739	19.749
900	150.13			11.17				
960	150.32	18.364	18.368			18.342	19.744	19.747
1020	149.89							
1056		18.379	18.383				19.746	19.742
1080	150.41							
1140	150.36							
1152		18.391	18.397			18.368	19.746	19.747
1200	150.30			11.17	1.37			
1248		18.404	18.411				19.746	19.749
1260	150.36							
1320	150.93							
1344		18.422	18.425			18.397	19.746	19.748
1380	150.51							
1440	149.54	18.436	18.439				19.746	19.746
1500	149.49			11.17				
1536		18.449	18.453			18.425	19.745	19.749
1560	149.42							
1620	149.84							
1632		18.465	18.466				19.747	19.750
1680	149.87							
1728		18.478	18.483			18.455	19.747	19.749
1740	149.74							
1800	149.57			11.18	1.38			

Table 5-2 below shows the values on which the calibration curve in Figure 5-2 is based.

Table 5-2. Power and slope values included in the calibration curve (Figure 5-2).

Starting date	Power (W)	Pool temp (°C)	Slope at $\Delta T = 0°C$
030508box	49	19.24	8.11E–05
30408	52	18.53	8.18E–05
30210	55	18.33	8.40E–05
30314	97	18.02	1.08E–04
030512box	98	19.64	1.09E–04
30327	98	18.40	1.08E–04
030528box	98	19.76	1.08E–04
30428	99	19.00	1.09E–04
040202box?	143	19.89	1.34E–04
21216	145	18.80	1.36E–04
40203box	146	19.95	1.37E–04
031103box	147	19.07	1.38E–04
30321	147	18.24	1.37E–04
30526box	147	19.75	1.35E–04
30325	147	18.27	1.35E–04
30107	147	19.12	1.38E–04
30430box	147	19.12	1.39E–04
30407	149	18.51	1.38E–04
030516box	193	19.60	1.65E–04
30422	195	18.91	1.65E–04
30220	197	17.93	1.67E–04
040205box	202	19.91	1.69E–04
040204box	202	19.94	1.69E–04
30411	245	18.59	1.94E–04
30319	246	18.15	1.94E–04
030520box	247	19.83	1.93E–04
30502box	295	19.11	2.25E–04
30131	297	18.63	2.25E–04
30324	337	18.23	2.46E–04
31104box	343	19.10	2.49E–04
030521box	349	19.84	2.53E–04
030519box	392	19.22	2.77E–04
30320	395	18.23	2.80E–04
30114	441	19.05	3.07E–04
030522box	445	19.85	3.08E–04
30321	491	18.22	3.36E–04
30505box	493	19.10	3.41E–04
030601box	493	19.69	3.38E–04
030523box	535	19.84	3.61E–04
030524box	539	19.81	3.64E–04
30327	545	18.39	3.67E–04

Starting date	Power (W)	Pool temp (°C)	Slope at ΔT = 0°C
30423	588	18.91	3.93E–04
30326	589	18.34	3.92E–04
30124	597	18.80	3.96E–04
30325	687	18.27	4.48E–04
30318	687	18.07	4.56E–04
30424	689	18.91	4.49E–04
30328	731	18.41	4.78E–04
30506box	735	19.10	4.83E–04
30317	781	18.01	5.05E–04
30324	884	18.22	5.63E–04

The decay heat power of the BWR assemblies to be measured is expected to lie between 60 and 350 Watts, so a linear relationship was sought for the points between 50 and 350 Watts. The relationship is: Power = 1.73×10^{6} ×slope –90.0. The standard deviation for the expression is ± 1.9 Watts. The decay heat power of the PWR assemblies to be measured is expected to lie between 260 and 920 Watts, so a linear relationship was sought for the points between 250 and 950 Watts. The relationship is: Power = 1.72×10^{6} ×slope –86.4. The standard deviation for the expression is ± 3.4 Watts.

5.1.2 Determination of the decay heat power of a fuel assembly with the calibration curve

- The fuel assembly is placed in the calorimeter.
- Deionized water: 733 water is connected to the calorimeter to cool it to 1.5°C below the temperature of the surrounding pool water.
- All measurement data are logged until the temperature in the cylinder is 1.5°C warmer than the surrounding water.
- The temperature difference between the cylinder and the surrounding pool water (KA502–KA531) is plotted as a function of time in a graph in the same way as in calibration. Time zero is the time when the temperature difference between the calorimeter and the pool (DT) is zero. A second degree curve is fitted as closely as possible to the plotted points.
- The slope of the second degree curve in the point DT = 0°C is determined.

The fuel assembly and the electric heater do not have the same volume, which means that the amount of energy needed to heat everything one degree differs slightly. The amount of energy per degree (kJ/°C) is calculated in Table 5-3. Multiplying the slope by the ratio (at the bottom of Table 5-3) between the fuel assembly in question and the heater compensates for the difference between heater and fuel assembly. The corrected slope value is then used to determine the decay heat power of the fuel assembly by using the functions obtained in the calibration curve in Figure 5-2.

Table 5-3. Compensation for volume difference between electric heater and fuel assembly.

		Electric heater (fuel dummy)		Fuels		
		without box	with box	6432	9329	5A3
Volumes	Vol (dm^3)					
Calorimeter with truss and BWR guide	389.80	389.80	389.80	389.80	389.80	
Calorimeter with truss						390.20
Truss	5.25					
BWR guide	0.40					
Spacer	1.41			1.41		
Electric heater	13.30	13.30	13.30			
Plates for electric heater	2.27		2.27			
Guide	0.51	0.51	0.51			
Boxed BWR	36.2				36.2	
Unboxed BWR	29.0			29.0		
Element	76.7					76.72
Free water (dm^3)		**375.99**	**373.72**	**359.38**	**353.62**	**313.48**
Quantity of steel in calorimeter						
Shell (kg)		112.33	112.33	112.33	112.33	112.33
Bottom (kg)		2.15	2.15	2.15	2.15	2.15
Nozzle (kg)		48.36	48.36	48.36	48.36	48.36
Lid (kg)				3.42	3.42	3.42
Circulation line (kg)		5.84	5.84	5.84	5.84	5.84
Truss (kg)		42.03	42.03	42.03	42.03	42.03
BWR guide (kg)		3.23	3.23	3.23	3.23	
Spacer (kg)				10.90		
Quantity of steel in heater (kg)						
Electric heater (kg)		71.70	71.70			
Heater lid (kg)		5.38	5.38			
Guide (kg)		4.11	4.11			
Plates (kg)			18.16			
Total quantity of steel (kg)		**295.13**	**313.29**	**228.26**	**217.36**	**214.13**
Quantity of steel in calorimeter (kg)		295.13	313.29	228.26	217.36	214.13
Quantity of water in calorimeter (kg)		375.99	373.72	359.38	353.62	313.48
Quantity of Cu in heater (kg)		3.48	3.48			
Quantity of plastic in heater (kg)		8.61	8.61			
Quantity of Zr in fuel (kg)				48.0	84.5	117.0
Quantity of steel/inc in fuel (kg)				4.2	9.2	20.90
Quantity of UO2 in fuel (kg)				201.5	202.9	523.80
	Cp					
MCp for steel in calorimeter (kJ/°C)	0.46	135.76	144.11	105.00	99.99	98.50
MCp for water in calorimeter (kJ/°C))	4.18	1,572.18	1,562.69	1,502.74	1,478.65	1,310.82
MCp for Cu in heater (kJ/°C)	0.39	1.34	1.34			
MCp for plastic in heater (kJ/°C)	1.00	8.61	8.61			
MCp for Zr in fuel (kJ/°C)	0.28			13.43	23.67	32.76
MCp for steel/inc in fuel (kJ/°C)	0.46			1.93	4.24	9.61
MCp for UO2 in fuel (kJ/°C)	0.23			46.34	46.67	120.47
Total MCp (kJ/°C)		1,717.9	1,716.7	1,669.4	1,653.2	1,572.17
K			0.999	0.972	0.962	0.915

Table 5-4 shows the results of the decay heat power determination of 3 fuel assemblies in the summer of 2003.

Table 5-4. Fuel measurements performed in the summer of 2003.

Fuel	Date	Pool temp °C	Power PA2 Watt	Slope °C/S	Volume-corr slope	Fuel output Watts
9329	30602	19.68	127.7	1.85E–04	1.78E–04	217 ± 4
9329	30604	19.68	128.1	1.86E–04	1.79E–04	219 ± 4
6432	30610	19.77	127.8	1.61E–04	1.56E–04	180 ± 4
6432	30612	19.79	128.1	1.63E–04	1.58E–04	184 ± 4
5A3	30613	19.76	128.5	2.03E–04	1.85E–04	232 ± 7
5A3	30616	19.66	128.1	2.02E–04	1.85E–04	231 ± 7
5A3	30618	19.74	127.8	2.06E–04	1.89E–04	238 ± 7

5.1.3 Error analysis of temperature increase method

In connection with the calibration, a calibration curve was plotted (Figure 5-2) from the calibration values presented in Table 5-2. A regression analysis gave a standard deviation of ± 1.9 Watts for the curve that is planned to be used for BWR assemblies and ± 3.4 Watts for the curve that is planned to be used for PWR assemblies.

5.1.4 Sensitivity analysis for errors in data for fuel assemblies

For certain fuel assemblies there will be some uncertainty in the volume data. Table 5-5 below shows what it means if the (unboxed) volume of BWR assembly 6432 is changed from 29 litres to 26 litres, and if the volume of the PWR assembly is changed from 76.7 litres to 69 litres. The volume compensation parameter is changed from 0.972 to 0.979 and for the BWR assembly and from 0.915 to 0.934 for the PWR assembly. A 10% change in the volume of the BWR assembly entails a 0.7% change in the volume compensation parameter. In the case of the PWR assembly, a 10% change in volume entails a 2.1% change in the volume compensation parameter. The change in the calculated output is as great as the change in the volume compensation parameter.

Table 5-5. Compensation for volume difference between electric heater and fuel assembly. Changed fuel volumes in comparison with Table 5-3.

		Electric heater (fuel dummy)		Fuels		
		without box	**with box**	**6432**	**9329**	**5A3**
Volumes	**Vol (dm^3)**					
Calorimeter with truss and BWR guide	389.80	389.80	389.80	389.80	389.80	
Calorimeter with truss						390.2
Truss	5.25					
BWR guide	0.40					
Spacer	1.41			1.41		
Electric heater	13.30	13.30	13.30			
Plates for electric heater	2.27		2.27			
Guide	0.51	0.51	0.51			
Boxed BWR	36.2				36.2	
Unboxed BWR	26.0			26.0		
Element	69.0					69.0
Free water (dm^3)		**375.99**	**373.72**	**362.39**	**353.62**	**321.2**
Quantity of steel in calorimeter						
Shell (kg)		112.33	112.33	112.33	112.33	112.33
Bottom (kg)		2.15	2.15	2.15	2.15	2.15
Nozzle (kg)		48.36	48.36	48.36	48.36	48.36
Lid (kg)				3.42	3.42	3.42
Circulation line (kg)		5.84	5.84	5.84	5.84	5.84
Truss (kg)		42.03	42.03	42.03	42.03	42.03
BWR guide (kg)		3.23	3.23	3.23	3.23	
Spacer (kg)				10.90		
Quantity of steel in heater (kg)						
Electric heater (kg)		71.70	71.70			
Heater lid (kg)		5.38	5.38			
Guide (kg)		4.11	4.11			
Plates (kg)			18.16			
Total quantity of steel (kg)		295.13	313.29	228.26	217.36	214.13
Quantity of steel in calorimeter (kg)		295.13	313.29	228.26	217.36	214.13
Quantity of water in calorimeter (kg)		375.99	373.72	362.39	353.62	321.20
Quantity of Cu in heater (kg)		3.48	3.48			
Quantity of plastic in heater (kg)		8.61	8.61			
Quantity of Zr in fuel (kg)				48.0	84.5	117.0
Quantity of steel/inc in fuel (kg)				4.2	9.2	20.90
Quantity of UO2 in fuel (kg)				201.5	202.9	523.80
	Cp					
MCp for steel in calorimeter (kJ/°C)	0.46	135.76	144.11	105.00	99.99	98.50
MCp for water in calorimeter (kJ/°C))	4.18	1,572.18	1,562.69	1,515.32	1,478.65	1,343.08
MCp for Cu in heater (kJ/°C)	0.39	1.34	1.34			
MCp for plastic in heater (kJ/°C)	1.00	8.61	8.61			
MCp for Zr in fuel (kJ/°C)	0.28			13.43	23.67	32.76
MCp for steel/inc in fuel (kJ/°C)	0.46			1.93	4.24	9.61
MCp for UO2 in fuel (kJ/°C)	0.23			46.34	46.67	120.47
Total MCp (kJ/°C)		1,717.9	1,716.7	1,682.02	1,653.2	1,604.43
K			0.999	0.979	0.962	0.934

5.2 Circulation method

5.2.1 Calibration according to the circulation method

- The fuel-like heating element is placed in the calorimeter.
- The electric heater is set to the power output to be run. The power value is multiplied by 0.982 as described in Chapter 3.
- A flow through the calorimeter is created where surrounding pool water is pumped into the calorimeter.
- The electric heater brings the hot water in the calorimeter to a state of equilibrium with respect to the temperature of the pumped-in water and the pumped-out water.
- All measurement data are logged at this state of equilibrium. An example of logged primary data is found in Appendix 3.
- If the temperature increases or decreases during measurement, the amount of energy absorbed/emitted by the water, the fuel and the steel in the calorimeter is calculated. The above parameter is not included explicitly in Table 5-6, but is included in Appendix 4.
- The heat power that is carried away with the flow (Flow power in Table 5-6 below) through the calorimeter is calculated by $E = F \times cp \times \Delta T$, where E is the power (Watts), F is the flow (kg/s), cp is the heat capacity of water J/(kg×s) and ΔT is the difference between the temperature of the incoming water (KA501) and the temperature of the outgoing water (KA502).
  - • The water in the calorimeter is stirred with a circulation pump (PA2). This pump will add energy to the water in the calorimeter. The total power input to the pump is measured (PA2 power in Table 5-6), but it is not possible to determine how much of the pump power heats up the water in the calorimeter. Since the pump has the same operating case whether it is being used for calibration or measurement of fuel assemblies, the pump's contribution is cancelled out down to a few Watts of power variation. An attempt is made to take these small variations into account by adding the entire measured pump power to both the calibration and the fuel measurement.
- The electric heater's power output and the pump power are power supplied to the calorimeter. The flow power and the heat that is lost through the walls of the calorimeter are power removed from the calorimeter. Supplied and removed power must be equal, which makes it possible to calculate the power lost through the calorimeter wall E_k. Now the calculated E_k will always be greater than the actual value, since all pump power does not go into heating the water, but the difference can be assumed to be constant, which means that E_k will always be a set number of Watts greater than the actual value.
- The mean temperature difference ΔT_k is calculated by taking the difference between the temperature in the calorimeter (KA511) and the temperature of the surrounding water (KA531).
- A heat transfer coefficient is calculated by dividing E_k by ΔT_k: $KA = E_k/\Delta T_k$.

The calculations of KA that have been done can be seen in Table 5-6. Notice that the heater power is compensated as described in Chapter 3.

Table 5-6. Calculation of KA in calibration of the circulation method.

Name	Power heater Watts	DT °C	Tpool (KA531) °C	Tmc (KA511) °C	F kg/min	Flow power Watts	PA2 power Watts	Leakage Watts	KA W/°C	Difference^2
150Wcirk030329	145	2.02	18.5	20.6	1.46	205	128	68	32	8.86
380Wcirk030331	373	1.96	18.4	20.5	3.18	434	127	66	32	7.20
380Wcirk030401	373	1.95	18.4	20.5	3.18	432	126	68	33	2.27
840Wcirk030402	825	1.99	18.5	20.6	6.35	880	126	71	32	5.01
50W1cirk030403	57	1.78	18.5	20.4	0.97	121	127	64	32	4.15
150Wcirk030407	149	1.83	18.5	20.4	1.66	212	127	64	34	0.21
50Wcirk030409	52	1.79	18.6	20.4	0.95	118	127	61	33	1.37
300Wcirk030414	293	1.86	18.7	20.6	2.71	351	126	73	39	20.99
450Wcirk030417	442	2.17	18.8	21.1	3.28	496	126	72	32	6.34
200Wcirk030422	195	1.84	18.9	20.9	1.98	254	127	68	34	0.46
600Wcirk030423	588	1.87	18.9	21.1	4.89	639	126	75	34	0.13
700Wcirk030424	689	1.89	18.9	21.2	5.60	736	125	78	34	0.51
1000Wcirk030425	973	1.92	18.9	21.4	7.64	1,020	124	77	32	8.24
100Wcirk030428	99	1.71	19.1	21.2	1.27	152	127	73	35	0.48
300Wcirkbox030502	295	1.79	19.1	21.6	2.73	341	126	80	32	7.75
1000cirkbox030507	982	1.90	19.2	21.9	7.75	1,025	124	81	29	26.17
50cirkbox030508	49	1.68	19.7	21.4	0.92	108	128	69	40	31.96
100cirkbox030513	110	1.82	19.6	22.0	1.26	160	127	78	33	2.76
200cirkbox030516	193	1.72	19.8	21.6	2.07	248	127	72	40	27.54
400cirkbox030519	392	1.90	19.8	21.8	3.33	442	126	76	38	10.68
250cirkbox030520	247	1.83	19.8	21.8	2.37	301	127	73	38	14.22
355cirkbox030521	349	1.88	19.9	21.8	3.05	400	126	75	38	11.11
453cirkbox030522	445	1.86	19.8	21.9	3.81	493	126	76	38	12.24
550cirkbox030524	539	1.84	19.8	21.8	4.61	591	126	74	36	3.10
500cirkbox030601	494	1.90	19.7	21.8	4.17	553	125	65	31	9.80
150W1cirkbox030527	147	1.79	19.8	21.7	1.64	204	127	69	36	1.20
									mean	Total Difference^2
									34.48	224.76
										Standard deviation
										3.00

The heat transfer coefficient is assumed to be constant in the prevailing temperature range. The mean value is calculated to be 34.5 W/°C with a standard deviation of ± 3 W/°C.

5.2.2 Calculation of a fuel assembly's decay heat power by means of circulation calibration

- The fuel assembly is placed in the calorimeter.
- A flow through the calorimeter is created where surrounding pool water is pumped into the calorimeter.
- The fuel assembly brings the hot water in the calorimeter to a state of equilibrium with respect to the temperature of the pumped-in water and the pumped-out water.

- All measurement data are logged at this state of equilibrium.
- The heat output that is carried away with the flow (Flow power) through the calorimeter is calculated by $E = F \times cp \times \Delta T$, where E is the power (Watts), F is the flow (kg/s), cp is the heat capacity of water J/(kg×s) and ΔT is the difference between the temperature of the incoming water (KA501) and the temperature of the outgoing water (KA502).
- The heat that is transported through the calorimeter wall E_k is calculated by $E_k = KA \times \Delta T_k$.
- The fuel assembly's decay heat power is calculated by adding the flow power and the leakage power E_k and then subtracting the pump power (PA2).
- If the temperature increases or decreases during measurement, the amount of energy absorbed/emitted by the water, the fuel and the steel in the calorimeter is calculated. The effect of the temperature increase/decrease is rarely greater than 1 Watt.
- No compensation is made for the volume difference between the electric heater and the fuel assembly, since compensation is made on the deviation from the state of equilibrium, which is rarely greater than 1 Watt.

Table 5-7 shows calculations of the heat output for the three fuel assemblies that were measured in the summer of 2003.

The accuracy ± 6 Watts is based on the standard deviation for KA, which is ± 3 Watts/°C.

It should be pointed out that it is important in connection with calibration and particularly fuel measurement that the selected temperature difference be set as exactly as possible. In the event of deviation from the selected temperature difference, a measurement error will be introduced due to the fact that it is not known how large a percentage of the pump power is converted to heat in the calorimeter. With the calculation method that has been used, the entire pump power is added to the power that heats the water and enters into the heat transfer coefficient, KA, as the term $P/\Delta T_k$, where P is the pump power and ΔT_k is the temperature difference during calibration. Then during fuel measurement the heat transfer coefficient KA is multiplied by ΔT_m (the temperature difference during calibration), and thereby also by $P/\Delta T_k$. If ΔT_k and ΔT_m are not equal during calibration and measurement, an error will be introduced which is $\Delta T_m/\Delta T_k \times (P - P_{right})$ where P_{right} is the fraction of the pump power that heats the water in the calorimeter. It can be seen in Tables 5-6 and 5-7 that it is possible to reduce the difference in the temperature differences prior to the next calibration and fuel measurement and thereby improve accuracy.

Table 5-7. Heat output for 3 fuels.

Fuel	Date	Bulk temp °C	PA2 W	Flow kg/min	DT °C	Tmc °C	Flow power W	Leakage power W	Assembly's decay heat power W
9329	30602	19.68	126.7	2.23	1.79	21.70	279	70	220 ± 6
9329	30605	19.67	127.5	2.21	1.80	21.85	277	75	227 ± 6
6432	30607	19.79	127.5	1.83	1.93	21.88	246	72	190 ± 6
6432	30611	19.81	128.0	1.86	1.90	21.87	246	71	190 ± 6
5A3	30614	19.71	127.6	2.34	1.82	21.68	297	68	237 ± 6
5A3	30617	19.75	127.7	2.34	1.83	21.72	298	68	239 ± 6
5A3	30619	19.32	127.6	2.34	1.83	21.27	299	67	238 ± 6

5.3 Heat losses due to gamma radiation

Some of the decay energy from the fuel assembly is lost with gamma radiation that is not stopped in the calorimeter, called gamma escape. The above-calculated decay heat power must be corrected for the energy quantity that is lost with the gamma radiation. To do this, the gamma radiation from the fuel is measured on the outside of the calorimeter with 5 gamma probes at a distance from the centre as given in Table 5-8 below.

The gamma arm on which the gamma probes are mounted is positioned approximately 1.7 m from the bottom of the fuel.

In ref. /2/ a relationship has been determined between the gamma escape power P_γ and the measured gamma dose rate (Gy/h) d_i based on the geometric configuration of the gamma probes. The expression is as follows.

$$P_\gamma = a \frac{\sum_{i=1}^{5} d_i e^{-\lambda r_i}}{\sum_{i=1}^{5} (e^{-\lambda r_i})^2} \left\{ e^{-\lambda} \left(-\frac{1}{\lambda^2} - \frac{1}{\lambda} \right) + e^{-0.228\lambda} \left(\frac{1}{\lambda^2} + \frac{0.228}{\lambda} \right) \right\} F \qquad \text{Equation 5-1}$$

a = 8.14 W for BWR fuel and 8.41 W for PWR fuel.

$\lambda = 8.4\ m^{-1}$ the attenuation coefficient.

r_i = the distance of the gamma probes from the centre as shown in Table 5-8.

F = the profile factor, which is unique for each fuel. Appendix 5 gives F factors for a number of fuel assemblies.

For each fuel measurement, the gamma dose rates are logged with the probes d_1–d_5. The dose rates are inserted in the above expression and the gamma escape power P_y can be calculated. The dose rates for the five probes d_1–d_5 for the three assemblies 9329, 6432 and 5A3 are given in Table 5-9.

Table 5-8. Distance between centre and gamma probe.

Probe d_i	Radius (m)
1	0.26
2	0.38
3	0.50
4	0.63
5	0.77

With the data in Table 5-9, Equation 5-1 gives the gamma escape power P_y, which is shown in Table 5-10.

Table 5-9. The dose rates for the five probes d_1–d_5 for the three assemblies 9329, 6432 and 5A3.

Fuel	Probe d_i (Gy/h) 1	2	3	4	5
9329 (030602)	5.86	3.71	1.81	0.75	0.39
9329 (030604)	5.92	3.76	1.83	0.75	0.39
6432 (030610)	6.84	3.86	1.77	0.74	–0.04
6432 (030612)	7.10	3.94	1.76	0.74	0.38
5A3 (040427)	12.50	4.88	1.49	0.50	0.20

Table 5-10.

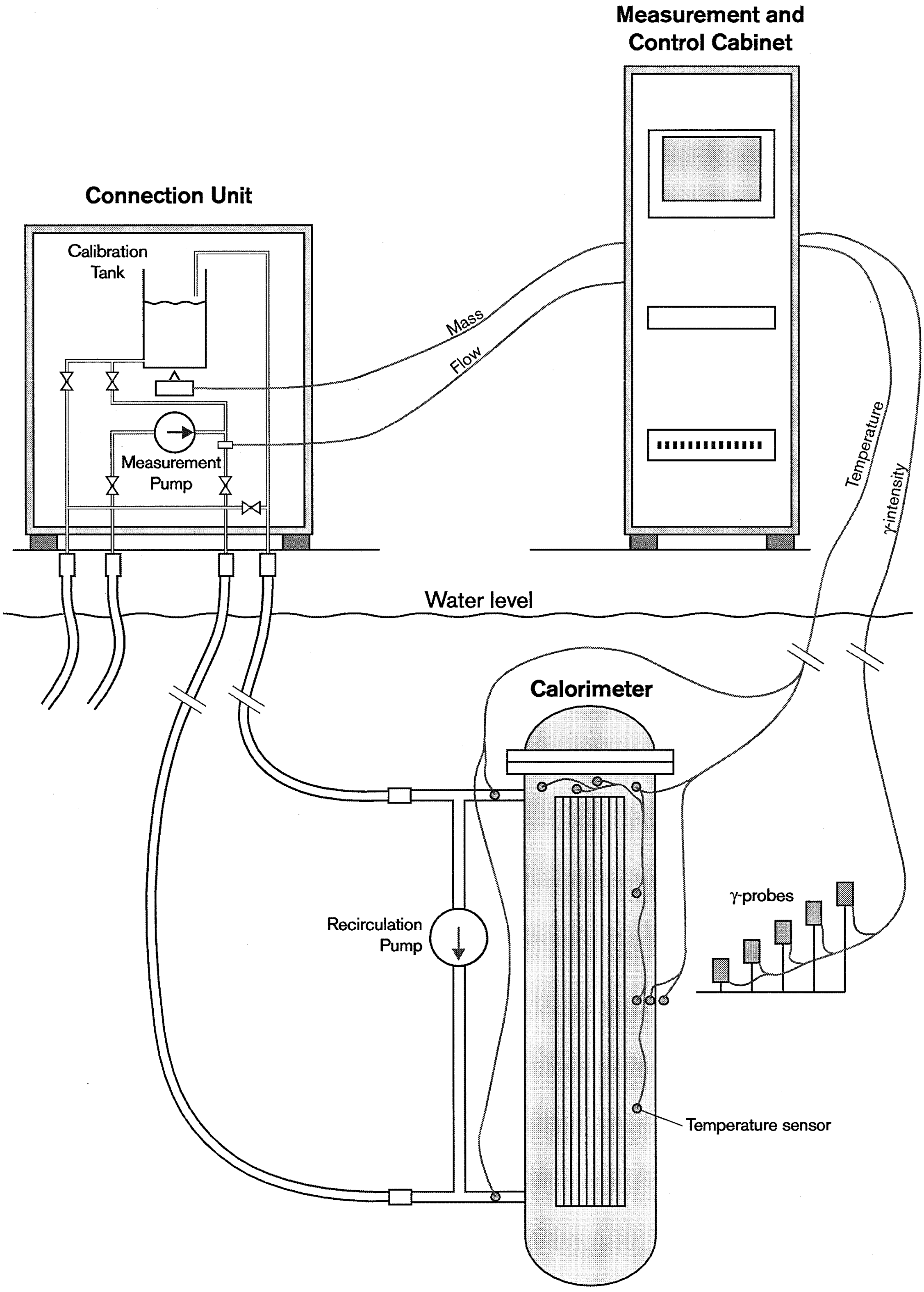
Fuel	Gamma escape power P_y (Watts)
9329 (030602)	2.8
9329 (030604)	2.8
6432 (030610)	3.1
6432 (030612)	3.2
5A3 (040427)	5.8

6 References

/1/ Systembeskrivning Clab System 251.

/2/ Rapport angående avgiven gammaeffekt i BWR- och PWR-bränsle. Department of Radiation Sciences Uppsala reg nr 2004-05604.

Illustration of calorimeter system 251



Primary data temperature increase method

Tinfo1	Tinfo2	Logg_tid	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13
Fredrik Sturek															
Calib. Temperature increase method	150Wtempstegbox03052														
KA701	KA702														
360	16														
0,00424	0,00421														
KA703	KA704														
76	-514														
0,00449	0,00425														
KA705	CALIB. TEMP														
-132	21,5														
0,00451	AMPLIFICATION														
	023		_251KA901_A_k	_251KA509	_251KA501_B1	_251KA501_B2	_251KA502_B1	_251KA502_B2	_251KA511_B1	_251KA511_B2	_251KA511_B3	_251KA511_B4	_251KA511_B5	_251KA511_B6	_251KA511_B7
			W	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C
Mon May 26 2003 08:30:22		60	149.52												
		96		0,180	18.067	18.127	18.276	18.279							
		120	149.81												
		180	149.73												
		192		-0,191	18.452	18.470	18.268	18.273	18.252	18.244	18.234	18.235	18.182	18.184	18.256
		240	150.10												
		288		-0,307	18.567	18.593	18.271	18.274							
		300	150.16												
		360	150.16												
		384		-0,475	18.733	18.760	18.269	18.275	18.207	18.232	18.241	18.251	18.225	18.252	18.283
		420	149.73												
		480	149.90	-0,613	18.896	18.918	18.291	18.297							
		540	149.69												
		576		-0,728	19.029	19.048	18.307	18.313	18.271	18.290	18.282	18.288	18.276	18.291	18.306
		600	149.78												
		660	149.24												
		672		-0,821	19.134	19.155	18.321	18.325							
		720	149.49												
		768		-0,884	19.215	19.229	18.337	18.338	18.297	18.322	18.310	18.317	18.305	18.318	18.332
		780	149.95												
		840	150.41												
		864		-0,934	19.280	19.294	18.351	18.355							
		900	150.13												
		960	150.32	-0,971	19.332	19.342	18.364	18.368	18.331	18.348	18.341	18.348	18.330	18.347	18.362
		1020	149.89												
		1056		-1,001	19.378	19.388	18.379	18.383							
		1080	150.41												
		1140	150.36												
		1152		-1,022	19.410	19.423	18.391	18.397	18.355	18.379	18.370	18.376	18.357	18.374	18.391
		1200	150.30												
		1248		-1,044	19.444	19.459	18.404	18.411							
		1260	150.36												
		1320	150.93												
		1344		-1,053	19.470	19.482	18.422	18.425	18.383	18.404	18.398	18.403	18.390	18.404	18.418
		1380	150.51												
		1440	149.54	-1,063	19.495	19.506	18.436	18.439							
		1500	149.49												
		1536		-1,070	19.515	19.528	18.449	18.453	18.413	18.431	18.425	18.435	18.416	18.432	18.448
		1560	149.42												
		1620	149.84												
		1632		-1,076	19.535	19.547	18.465	18.466							
		1680	149.87												
		1728		-1,078	19.553	19.564	18.478	18.483	18.444	18.462	18.453	18.464	18.443	18.458	18.475
		1740	149.74												
		1800	149.57												
		1824		-1,080	19.568	19.579	18.492	18.495							
		1860	149.72												
		1920	150.43	-1,080	19.582	19.594	18.506	18.510	18.469	18.487	18.483	18.490	18.471	18.487	18.503
		1980	149.78												
		2016		-1,078	19.595	19.607	18.520	18.528							
		2040	149.97												
		2100	149.57												
		2112		-1,076	19.607	19.618	18.534	18.540	18.499	18.514	18.514	18.520	18.502	18.518	18.534
		2160	149.13												
		2208		-1,070	19.616	19.627	18.550	18.554							
		2220	149.13												
		2280	149.54												
		2304		-1,064	19.624	19.635	18.564	18.568	18.528	18.540	18.538	18.548	18.530	18.545	18.563
		2340	149.51												
		2400	149.89	-1,055	19.632	19.643	18.579	18.585							

T14	T15	T16	T17	T18	T19	T20	T21	T22	T23	T24	T25	T26	T27
_251KA511_B8 °C	_251KA511 °C	_251KA751_Vikt kg	_251KA101 bar	_251KA521_B1 °C	_251KA522_B1 °C	_251KA531_B1 °C	_251KA531_B2 °C	_251KA701 Gy/h	_251KA702 Gy/h	_251KA703 Gy/h	_251KA704 Gy/h	_251KA705 Gy/h	_251KA901_B_P. W
						19.743	19.749						
18.196	18,223			18.218	19.741	19.752	19.751						
						19.749	19.746						
		11,17											
18.254	18,243			18.248	19.746	19.745	19.751						
						19.748	19.747						
18.287	18,286			18.280	19.747	19.746	19.746						
		11,17	1.39					-0.22	-0.10	-0.08	-0.10	-0.04	127.97
						19.746	19.748						
18.318	18,315			18.310	19.745	19.746	19.748						
						19.739	19.749						
		11,17											
18.343	18,344			18.342	19.741	19.744	19.747						
						19.746	19.742						
18.368	18,371			18.368	19.742	19.746	19.747						
		11,17	1.37					-0.22	-0.10	-0.08	-0.10	-0.04	127.65
						19.746	19.749						
18.402	18,400			18.397	19.741	19.746	19.748						
						19.746	19.746						
		11,17											
18.427	18,428			18.425	19.739	19.745	19.749						
						19.747	19.750						
18.455	18,457			18.455	19.740	19.747	19.749						
		11,18	1.38					-0.28	-0.17	-0.18	-0.18	-0.15	127.57
						19.746	19.747						
18.487	18,485			18.485	19.739	19.747	19.749						
						19.747	19.751						
		11,18											
18.524	18,516			18.512	19.737	19.747	19.747						
						19.746	19.749						
18.544	18,542			18.527	19.738	19.746	19.748						
		11,19	1.37			19.747	19.751	-0.25	-0.14	-0.13	-0.14	-0.10	127.52

Primary data circulation method

info1	Tinfo2
redrik Sturek	
alibration Recirculation method	150W1cirkbox030507
A701	KA702
60	16
,00424	0,00421
A703	KA704
6	-514
,00449	0,00425
A705	CALIB. TEMP
132	21,5
,00451	AMPLIFICATION
	023
ue May 27 2003 11:30:16	

Logg_tid	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13
	_251KA901_A_k\ W	_251KA301_M_F kg/min	_251KA509 °C	_251KA501_B1 °C	_251KA501_B2 °C	_251KA502_B1 °C	_251KA502_B2 °C	_251KA511_B1 °C	_251KA511_B2 °C	_251KA511_B3 °C	_251KA511_B4 °C	_251KA511_B5 °C	_251KA511_B6 °C
60	149.21	1.660											
96			1,107	20.115	20.121	21.222	21.228						
120	149.45	1.658											
180	149.48	1.660											
192			1,177	20.046	20.054	21.226	21.227	21.198	21.210	21.202	21.209	21.190	21.191
240	150.09	1.663											
288			1,230	19.998	19.997	21.227	21.228						
300	149.57	1.659											
360	149.70	1.661											
384			1,265	19.961	19.973	21.230	21.234	21.206	21.213	21.214	21.218	21.205	21.201
420	149.96	1.659											
480	150.01	1.657	1,285	19.943	19.954	21.232	21.235						
540	149.45	1.658											
576			1,295	19.936	19.948	21.232	21.241	21.215	21.223	21.223	21.227	21.213	21.209
600	150.26	1.661											
660	149.49	1.657											
672			1,304	19.934	19.944	21.241	21.244						
720	149.10	1.657											
768			1,309	19.931	19.942	21.243	21.248	21.224	21.229	21.230	21.231	21.220	21.218
780	149.00	1.658											
840	149.50	1.658											
864			1,315	19.930	19.941	21.248	21.254						
900	149.36	1.658											
960	148.56	1.659	1,315	19.932	19.943	21.251	21.255	21.230	21.236	21.234	21.240	21.229	21.223
1020	148.97	1.656											
1056			1,317	19.933	19.944	21.253	21.259						
1080	149.78	1.663											
1140	150.02	1.659											
1152			1,319	19.935	19.946	21.258	21.262	21.234	21.241	21.241	21.246	21.234	21.229
1200	150.00	1.656											
1248			1,321	19.937	19.946	21.260	21.265						
1260	150.10	1.658											
1320	149.68	1.659											
1344			1,328	19.932	19.944	21.264	21.268	21.243	21.247	21.246	21.252	21.239	21.235
1380	149.73	1.658											
1440	150.10	1.658	1,329	19.934	19.946	21.266	21.271						
1500	150.11	1.660											
1536			1,330	19.932	19.946	21.269	21.269	21.247	21.253	21.255	21.258	21.246	21.241
1560	149.97	1.657											
1620	149.55	1.656											
1632			1,335	19.936	19.949	21.275	21.281						
1680	149.19	1.656											
1728			1,336	19.935	19.949	21.276	21.281	21.254	21.261	21.260	21.266	21.252	21.249
1740	149.18	1.657											
1800	149.37	1.661											

T14	T15	T16	T17	T18	T19	T20	T21	T22	T23	T24	T25	T26	T27	T28	T29	T30
_251KA511_B7 °C	_251KA511_B8 °C	_251KA511 °C	_251KA751_Vikt kg	_251KA101 bar	_251KA521_B1 °C	_251KA522_B1 °C	_251KA531_B1 °C	_251KA531_B2 °C	_251KA701 Gy/h	_251KA702 Gy/h	_251KA703 Gy/h	_251KA704 Gy/h	_251KA705 Gy/h	_251KA901_B_P W	_251KA111 bar	_251KA112 bar
21.194	21.197	21,199														
			0,00													
21.201	21.211	21,209														
21.212	21.217	21,217	0,01	1.53					-0.20	-0.07	-0.02	-0.08	-0.00	127.36	0.55	0.37
					21.207	19.762	19.745	19.745								
21.215	21.222	21,224														
			0,00													
21.222	21.228	21,230														
21.229	21.233	21,236	0,00	1.53					-0.25	-0.14	-0.13	-0,14	-0.09	127.09	0.54	0.38
21.235	21.241	21,242			21.229	19.762	19.749	19.750								
			-0,01													
21.242	21.248	21,249														
21.248	21.256	21,256	0,00	1.54					-0.13	0.02	0.11	0.01	0.10	126.56	0.55	0.38

Appendix 4

Example of calculation of KA in connection with calibration according to circulation method

Circulation medthod calibration.

Mean flow; F (kg/min)	1.459 kg/min
Mean DT; °C	2.016°C
Tpool mean	18.455°C
Tmc mean	20.616°C
Mean poer from heater (Watts)	147.247 W
Volume of calorimeter (litres)	389.8
Volume of electric heater without guide (litres)	13.3 litres
H_2O quantity in calorimeter (litres)	376.5 litres
Density H_2O in calorimeter kg/m^3	998.27843 kg/m^3
Enthalpy for H_2O in calorimeter at Dtstart	86.095739 KJ/kg
Enthalpy for H_2O in calorimeter at Dtstop	85.983561 KJ/kg
Pressure at lower part of calorimeter	2.5 bar
Pressure at upper part of calorimeter	2 bar
Cp in calorimeter	4.1810906 kJ/kg°C
Cp for steel	0.46 kJ/kg°C
Cp for copper	0.385 kJ/kg°C
Cp for PTFE	1 kJ/kg°C

Flow power (Watts): q1 q1=F×DT×cp /Watt = W/	**204.993 Watt**
Pump power	**127.53 Watt**
Total supplied power: qtot	**274.773 Watt**
Energy change H_2O	
equ for DT –5,61156E–07×2,09661E+00	
start DT (°C)	2.029
stop DT (°C)	2.002
energy	–42.162 KJ
during period /sek = s/	4,7811.0 sek
Power	–0.882 Watt
Energy change steel liner	
cp×(DTstart-DTstop)×m	–3.642 KJ
during period	4,7811 sek
Power	–0.076 Watt
Energy change copper wire	
cp×(DTstart-DTstop)×m	–0.036 KJ
during period	4,7811 sek
Power	–0.0008 Watt

Energy change PTFE	
cp×(DTstart-DTstop)×m	–0.231 KJ
during period	4,7811 sek
Power	–0.0048 Watt
Energy change total:q2	**–0.9636 Watt**
Heat leakage :q3	70.7444 Watt
KA coefficient	**32.732035 W/°C**

Appendix 5

F factors for calculation of gamma escape power

Table of F factors for calculation of gamma escape power.

2014	0.975622
2018	0.914954
2048	0.962891
2074	0.955906
2118	0.881336
9329	0.994241
10288	1.035675
14076	0.970250
3838	1.038405
KU0100	1.012166
KU0269	0.897371
KU0278	0.969331
KU0282	0.937214
5535	1.146337
11494	1.052320
11495	1.022379
13775	1.014151
13847	1.007282
13848	1.000800
12078	0.995409
13628	1.024523
13630	1.001697
1377	1.081402
1389	0.880393
1546	0.988952
1696	1.015446
1704	0.955050
2995	0.945833
3054	1.006630
3058	0.990371
3064	0.968811
6350	1.011223
12684	0.985654
582	0.991357
596	1.013750
710	0.982377
900	0.995106
1136	1.009810
1177	1.015357
1186	0.969020
5829	0.987186
6423	0.964806
6432	0.964992
6454	0.913335
6478	0.919575

8327	0.951297
8331	0.986884
8332	1.003705
8338	0.938861
8341	0.979672
8327	0.977504
6423	0.967928
6478	0.752138
A05	0.993411
A11	0.973324
C01	1.100458
C12	1.011120
C20	1.030648
C42	1.047301
D27	0.959770
D38	1.001761
E38	0.961359
E40	1.005867
F14	0.998639
F21	0.972326
F25	1.020216
F32	1.028738
G11	0.995221
G23	0.993674
I09	1.059126
I20	0.956234
I24	1.054825
I25	0.974561
E38	0.984836
2A5	1.030900
5A3	1.018698
0C9	0.977004
1C2	1.032726
1C5	0.999136
2C2	1.003833
3C1	1.050024
3C4	1.097825
3C5	1.025466
3C9	0.941833
4C4	1.000587
4C7	1.022885
0E5	1.032234
0E6	1.028331
1E5	1.035667
5F2	0.975622

Part 4

Clab – Uncertainty analysis of the calorimeter (system 251) using the temperature increase method

Lennart Agrenius
Agrenius Ingenjörsbyrå AB

Contents

1 Introduction

The design target for the calorimeter is that decay heat power should be determined with the uncertainty of ± 2%.

The interpretation of this is that the real decay heat power should be within –2% till +2% of the measured value with 95% confidence. If for example the measurement shows that the decay power an assembly is 200 W the probability should be 95% that the real power is between 196 W and 204 W.

The design target is high and even if it shows the target not is met within the whole measurement range 50–1,000 W this high ambition has contributed to the fact that the equipment has been designed so the uncertainties will be as small as possible with reasonable means.

As comparison it could be mentioned that the GE-Morris equipment, which has served as basis for the Clab-calorimeter gave an uncertainty of ± 15 W (two standard deviations). This corresponds to ± 7.5% with 95% confidence at 200 W.

The purpose with this report is to determine the uncertainty in the measured decay heat power.

2 General about uncertainties

Uncertainties in the measured value could come from variations (errors) in the measurement chains and equipment. These errors could be separated into three categories which are systematic, variable and random /1, 2/.

- Systematic errors are constant errors which will not change at repeated measurements of the same measurement point.
- Variable errors will change systematically at repeated measurements of the same measurement point.
- Random errors will show up at random at repeated measurements of the same measurement point.

In this investigation the errors that occur at random and variable errors are analysed. Variable errors are interpreted as errors that occur as result of different measurement conditions at repeated measurements.

Systematic errors are not analysed in this work.

3 Procedure for measurement and evaluation

In part 3 the procedure for developing a calibration curve for the equipment is described.

In summary the procedure is:

1. The electric heater is installed in the calorimeter and adjusted to a predetermined power.
2. The calorimeter is cooled down by circulating water from the deionised water system, which has lower temperature than the pool water.
3. After the circulation is stopped logging of the temperatures, time and other parameters is started.
4. Logging is stopped after a certain temperature increase

The temperature difference between the calorimeter and the pool water is calculated by subtracting the average value of the temperature sensors inside with average value of the temperature sensors outside the calorimeter. Presently two sensors inside and two sensors outside the calorimeter are used.

A second degree curve is correlated to the temperature difference and time. The slope of the curve at the zero temperature difference is given by the coefficient of the first degree term in the equation.

The procedure is repeated at several different powers in the electric heater. The result will be a table with slope values and corresponding power values. From this table a calibration curve is generated by correlating a strait line to the slope and power values. The correlation gives the equation of this strait line.

When measuring a fuel assembly the following procedure is followed:

1. An assembly is placed in the calorimeter (the heater is removed before).
2. The calorimeter is cooled down with deionised water.
3. After the circulation is stopped logging of the temperatures, time, gamma radiation rate and other parameters is started.
4. Logging is stopped after a certain temperature increase.

The temperature difference between the calorimeter of the pool is calculated by subtracting the average value of the temperature sensors inside with average value of the temperature sensors outside the calorimeter. Presently two sensors inside and two sensors outside the calorimeter are used.

A second degree curve is correlated to the temperature difference and time. The slope of the curve at the zero temperature difference is given by the coefficient of the first degree term in the equation.

A correction of the slope is done to account for the fact that the fuel assembly has different volume and contains different materials than the electric heater.

The resulting slope is used in the calibration curve equation, which is solved for the power.

With the measured gamma dose rates the power that escapes the calorimeter with the gamma radiation is calculated using the equation given in part 3.

The sum of the power in the calorimeter and the power corresponding to the gamma field will give the decay heat power for the measured fuel assembly.

4 Uncertainties

In the system description of system no 251 /3/ the following error limits are reported for the measurement equipment:

Temperature	± 0.01°C
Massflow	± 0.5% in the rang 0.36 kg/min–7.2 kg/min
Power	± 0.25% in the range 50 W–1,000 W
Gamma dose rate	± 5% in the range 0–100 Gy/h
Mass	± 0.02%

These errors contribute to the random errors in the measurements.

To identify the parameters which can give uncertainties a basic, simplified heat balance could be used. The following notations are used:

Total power in the calorimeter: P
Power in the circulation pump: P_{pump}
Efficiency of pump: η
Heat loss from calorimeter with gamma radiation: P_{gamma}
Heat loss through the calorimeter: P_{loss}
Heat loss due to heating up the calorimeter with inserts: P_{cp}
Measured temperatures in calorimeter: $t_{KA502B1}$, $t_{KA502B2}$
Measured temperature in the pool: $t_{KA531B1}$,$t_{KA531B2}$
Measured gamma dose rates: $d_{KA701,}$ $d_{KA702,}$ $d_{KA703,}$ $d_{KA704,}$ d_{KA705}
Measured time points: T_1, T_2

A heat balance for the calorimeter will look as follows:

$P + \eta P_{pump} = P_{loss} + P_{cp} + P_{gamma}$ where

P_{pump} = measured value of the pump power
η = pump efficiency is not known

$P_{loss} = kA(t_{cal}–t_{pool})$, where k is the aggregate heat transfer coefficient of the calorimeter, A is the calorimeter surface area, the temperature in the calorimeter is $t_{cal} = 0.5(t_{KA501B1}+t_{KA502B2})$ and $t_{pool} = 0.5(t_{KA531B1}+t_{KA531B2})$ is temperature in the pool. Here the aggregate heat transfer coefficient k is unknown.

$P_{cp} = \Sigma(mc_p)_i\, dt/dT$ that is the sum of mass times latent heat for all different materials in the calorimeter times the rate of temperature increase. This term can be calculated.

$P_{gamma} = 0.378d_{KA701}+0.138d_{KA702}+0.050d_{KA703} +0.017d_{KA704} +0.005d_{KA705}$ is the power generated in the fuel but escapes from the calorimeter with the gamma radiation. This is a development of the formula given in part 3 to calculate $P_{gamma,}$ see enclosure 2. The coefficients in front of each measured dose rate is calculated from parameter which correlates the measured dose rate values to an exponential function.

The heat balance will be:

$$P = kA(t_{cal}–t_{pool}) + \Sigma(mc_p)_i dt/dT + P_{gamma} – \eta P_{pump}$$

And the rate of temperature increase:

$dt/dT = (P + \eta P_{pump} – kA(t_{cal}–tpool) – P_{gamma})/\Sigma mc_p$

It can be seen that during calibration the uncertainty is controlled by uncertainties in power in the electric heater, heat from the pump, heat losses from the calorimeter and the material in the calorimeter.

When measuring a fuel element the uncertainties are governed by uncertainties in heat from the pump, heat losses from the calorimeter, the material in the calorimeter and determination of the gamma power.

The temperature increase is calculated with help of four temperature sensors each with an uncertainty of ± 0.01°C which gives a total uncertainty ± 0.02°C $\sqrt{(4\times0.01^2)}$.

The power in the electric heater is known and regulated with a specified accuracy of ± 0.25%, which corresponds to ± 0.5 W at 200 W. The reading of the power is corrected to account for the heat loss in the electric heater feed cable.

The gamma field outside the calorimeter is measured by five gamma probes. The gamma dose rate is measured with an accuracy of ± 5%. Five probes give a total uncertainty around ± 10%.

The heat losses from the calorimeter depends on the calorimeter surface area, which is constant and the heat transfer coefficient which in turn depends on temperature conditions, geometries, flow conditions and temperature in the surrounding pool water. Uncertainties here are generated by variations in flow conditions because the heater and the fuel assembly placing in the calorimeter are different at different measurements and also by variations in circulation flow and variations in the pool temperature.

The power from the circulation pump is constant and monitored continuously. Added heat to the calorimeter is controlled by the efficiency, which is unknown. This contributes to the uncertainty.

The material in the calorimeter consists of the calorimeter itself, inner frame work, inserts, water, the heater or a fuel assembly. These are known.

Of this discussion follows that following parameters that can be quantified gives contributions to the uncertainties.

- Measurement uncertainties of the power in the electric heater, of the power in the circulation pump, of temperatures and gamma dose rate.
- Uncertainties in materials and volumes of the heater and the fuel elements, including length increase due to irradiation.

Other parameters for which uncertainties not can be quantified separately today:

- Variations in flow and temperature conditions in the calorimeter, which influence the heat transfer from the fuel rods to the water in the calorimeter and the heat transport from the calorimeter the outside. Differences in the designs of heater and fuel assemblies and different designs of fuel assemblies can give different flow conditions in the calorimeter. This uncertainty is minimized two ways, the temperature in the calorimeter is equalized by the circulation flow and the measurement is performed at zero temperature difference between the calorimeter and the pool water. The heat transfer from the fuel rods to the water in the calorimeter is, however, influenced by different fuel assembly designs (box/no box, BWR/PWR, water channel/no water channel and others).

- Variations in the pool water temperature are monitored but the influence on the measured result has not been quantified and this effect has to be treated as an uncertainty.
- Variations in pool water temperature are monitored but the influence on the measured result has not been quantified and this effect has to be treated as an uncertainty
- Axial (vertical) variations in temperature along the calorimeter has been measured /4/ and found small. Thos effect is judged not to contribute to the uncertainty.

5 Determination of uncertainties

When important parameters in the calorimeter are unknown an analytical determination of the uncertainties can not be done. It remains to assess these by experiment, for example by measure the reproducibility by measuring the same power several times and study the spread of the measurements or study the spread of a series of measurements.

Uncertainty in one single measurement

When developing calibration curves measurements have been done for a large number of cases at different powers. In each case the temperature is monitored during a long time period. For one case at 150 W the temperature was logged 150 times during 4 hours. Then the temperature had increased 2°C. The measurement series is adjusted so that the time is zero when the temperature difference is zero. This means that the measurement series starts at – 7,200 sec and –1°C and stops at 7,200 sec and 1°C. A correlation of the series to a second degree curve is done. In this equation the coefficient before the first degree term is the wanted slope value. The standard deviation in the temperature valued can be computed to 0.005°C which is a very low value. Based on this the standard deviation of the slope value is judged to be very small. The uncertainty in the in fitting of the second degree curve the measured points is judged to give a negligible contribution to the uncertainty.

Uncertainty in repeated measurements

The uncertainty can be determined experimentally by measuring the slope value several times at the same power. In the measurement series there are three measurement points at 147.3 W which gave 1.3494E–04, 1.3837E–04 respective 1.3874E–04°C/s. The difference between the highest and lowest value is 3% which give an indication of the reproducibility and the uncertainty.

Uncertainty in a calibration curve

A large number of measurements are done at different powers to get information to produce a calibration curve. This curve is produced by fitting a strait line by the last square method to the all the slope values and powers. The general equation is then

P_{cal} = a + b dt/dT where

P_{cal} = power in the heater at calibration
a and b = constants from the curve fitting
dt/dT = measured rate of temperature increase

In part 3 fittings of a strait line is done for the measured points in power between 50–350 W. The fit gives the following:

$P_{cal} = 1.73\times10^{6} \times dt/dT - 90.0$, this equation is used for evaluation of BWR –fuel.

The standard deviations (s) in the constants in the equations has been calculated to s_b = 6,938 Ws/°C respective s_a = 1.9 W according to /1/, see enclosure 1.

For the PWR-assemblies in the measurement program the powers are expected to be in the range of 250 and 900 W. This gives the equation:

$P_{cal} = 1.72 \times 10^6 \times dt/dT - 86.4$. The standard deviations (s) in the constants in the equations has been calculated to s_b = 6,442 Ws/°C respective s_a = 3.5 W according to /1/, see enclosure 1.

Uncertainty in measuring one fuel assembly

When measuring the decay heat power of one fuel assembly the temperature increase rate is determined (dt/dT). This value has to be corrected with a constant (k) reflecting the difference between the materials and volumes between the heater and the fuel assembly.

This constant is calculated according a procedure in part 3 and summarized in Table 5-1 below:

Table 5-1. Volumes and materials in the calorimeter, heater and typical fuel.

		Volumes with heater		**Volumes BWR**		**Volumes PWR**	
		no box	**box**	**no box**	**box**	**15x15**	**17x17**
Volumes	Vol (dm^3)						
Mätcylinder med fackverk och BWR instyrning	389.80	389.80	389.80	389.80	389.80		
Mätcylinder med fackverk						390.20	390.20
Fackverk	5.25						
BWR-instyrning	0.40						
Distans	1.41			1.41			
Elvärmare	13.30	13.30	13.30				
Plåtar till elvärmare	2.27		2.27				
Instyrning	0.51	0.51	0.51				
Boxat BWR	35.60				35.78		
Oboxat BWR	30.10			28.61			
PWR-element	85.8					75.41	76.56
Free water (dm^3)		**375.99**	**373.72**	**359.78**	**354.02**	**314.79**	**313.64**
Mass steel in calorimeter							
Mantel (kg)		112.33	112.33	112.33	112.33	112.33	112.33
Botten (kg)		2.15	2.15	2.15	2.15	2.15	2.15
Dysa (kg)		48.30	48.30	48.30	48.30	48.30	48.30
Lock (kg)				3.42	3.42	3.42	3.42
Cirkledning (kg)		5.84	5.84	5.84	5.84	5.84	5.84
Fackverk (kg)		42.03	42.03	42.03	42.03	42.03	42.03
BWR-instyrning (kg)		3.23	3.23	3.23	3.23		
Distans (kg)				10.90			
Mass steel in heater (kg)							
Värmarlock (kg)		5.38	5.38				
Instyrning (kg)		4.11	4.11				
Plåtar (kg)			18.60				
Total mass steel (kg)		**295.07**	**313.67**	**228.20**	**217.30**	**214.07**	**214.07**

Mass material in calorimeter		Volumes with heater		Volumes BWR		Volumes PWR	
		no box	box	no box	box	15x15	17x17
Mängd stål i kalorimetern (kg)		295.07	313.67	228.20	217.30	214.07	214.07
Mängd vatten i kalorimetern (kg)		375.99	373.72	359.78	354.02	314.79	313.64
Mängd Cu i värmaren (kg)		3.48	3.48				
Mängd plast i värmaren(kg)		8.60	8.60				
Mängd Zr i bränslet (kg)				47.62	81.39	123.75	117.59
Mängs stål/inc i bränslet (kg)				4.20	9.75	17.83	20.55
Mängd UO2 i bränslet (kg)				196.7931733	201.8064	499.98	521.33
	Cp						
MCp för stål i kalorimetern (kJ)	0.46	135.73	144.29	104.97	99.96	98.47	98.47
MCp för vatten i kalorimetern (kJ)	4.18	1,571.64	1,562.15	1,503.89	1,479.81	1,315.83	1,311.03
MCp för Cu i värmaren (kJ)	0.40	1.39	1.39				
MCp för plast i värmaren(kJ)	1.00	8.60	8.60				
MCp för Zr i bränslet (kJ)	0.28			13.33	22.79	34.65	32.93
MCp för stål/inc i bränslet (kJ)	0.46			1.93	4.48	8.20	9.45
MCp för UO2 i bränslet (kJ)	0.23			45.26	46.42	114.99	119.90
Summa MCp		1,717.36	1,716.43	1,669.39	1,653.46	1,572.15	1,571.79
k			0.9995	0.9721	0.9628	0.9154	0.9152

The volume of water and steel and the volume of the heater are determined by experiment, see /5/. Uncertainties in these values are small and could be neglected.

An uncertainty will be introduced when the heater is replaced by a fuel assembly. The volume value of a fuel assembly is received from the power plant or the fuel manufacturer and contains a certain uncertainty.

This uncertainty will be analyzed for all the fuel assemblies in the measurement program. The volume of a BWR assembly is around 36 dm^3. Assume that this value has an error of 3 dm^3. If the volume is overestimated water will be replaced by fuel material, the total volume being constant. If Zr, SS and UO_2 are increased with 3 dm^3 the k will increase with a factor of 0.003 or 0.3%. An error in the fuel volume gives a relatively small error in the measured power. For PWR a 10% error in the volume estimation will give an error of 0.7% in the measured power.

An error in the fuel volume gives a relatively small error in the measured power.

Uncertainty in P_{gamma}

P_{gamma} is calculated with the equation $0.378d_{KA701}+0.138d_{KA702}+0.050d_{KA703}+0.017d_{KA704}+0.005d_{KA705}$. The uncertainty in P_{gamma} depends on the uncertainty in the parameters that are included in the constants before each measured dose rate value

There are presently not enough data to calculate these uncertainties based on experimental data. Therefore the uncertainty in P_{gamma} is estimated based on part 3. There P_{gamma} for assembly 9329 is calculated to 5.2 W with an error of ± 0.48 W or 9%. The calorimetric measured power was 217.4 W and the total decay heat power is then 232 W. P_{gamma} is 2.3% of P and the error in P_{gamma} corresponds to 0.2% of the total power. For now it is assumed that P_{gamma} is proportional to the calorimetric power.

Uncertainty in the power of a fuel assembly

The complete equation which will give the power from the temperature increase rate is:

$P = P_{cal} + P_{gamma} = (a + b\ k\ dt/dT + 0.378d_{KA701} + 0.138d_{KA702} + 0.050d_{KA703} + 0.017d_{KA704} + 0.005d_{KA705})$.

If P_{gamma} is assumed to be proportional to P_{cal} the equation will be

$P = P_{cal} + P_{gamma} = P_{cal}(1+\alpha)$

where α is the fraction power that will disappear from the calorimeter with the gamma radiation. This gives:

$P = (a+b\ k\ dt/dT)(1+\alpha)$

The constants are summarized below

Constants	BWR (with box)	PWR
a	–89.98	–86.36
b	1,729,644	1,716,819
k	0.963	0.915
α	0.024	0.024

The errors in the constants (standard deviations) are summarized:

Parameter	BWR	PWR
s_a	1.9	3.5
s_b	6,938.0	6,442.0
s_k	0.0030	0.0070
s_α	0.002	0.002

In order to get the standard deviation in P the standard deviations of the parameters are combined as follows according to the method in /2/:

$s_p = \sqrt{[\ (s_a(1+\alpha))^2 + (s_b\ k(1+\alpha)\ dt/dT)^2 + (s_k\ b(1+\alpha)\ dt/dT)^2 + (s_\alpha\ b\ k\ dt/dT)^2]}$

The standard deviation has to be calculated for each measurement. As example a calculation is of the standard deviation is done for two measurements, for one BWR-assembly and for one PWR-assembly.

In the BWR-case dt/dT = 1.8464E–4°C/s was measured for assembly 9329. According to the equation above the total power is calculated to P = 222.6W, P = (–89.98 +1.8464E–4×1.73E6×0.963)(1+0.024).

The standard deviation is calculated to ± 2.6 W [$s_p = \sqrt{(1.9\times1.024)^2+(6{,}938\times1.8464E{-}4\times0.963\times1.024)^2+(0.003\times1.8464E{-}4\times1.73E6\times1.024)^2+(0.002\times1.736E6\times0.963\times1.84635E{-}4)^2}$].

In the PWR-case dt/dT = 2.0255E–04°C/s is measured for 5A3. According to the equation above the total power is calculated to P = 237.1 W, P = (–86.36 +2.0255E–4× 1.749E6×0.915)(1+0.024).

The standard deviation is calculated to ± 4.6 W [$s_p = \sqrt{}(3.5\times1.024)^2+(6{,}442\times2.0255E{-}04\times 0.915\times1.024)^2+(0.007\times2.0255E{-}4\times1.72E6\times1.024)^2+(0.002\times0.915\times1.72E6\times2.0255E{-}4)^2$].

An assessment of the uncertainty of the calorimeter over the whole measurement range could be done the same way.

BWR-assemblies are measured in the range 50– 350W. The standard deviation is calculated to ± 2.1 at 50 W and ± 3.1 W at 350 W.

PWR-assemblies are measured in the 250– 900W. The standard deviation is calculated to ± 4.6W at 250 W and ± 9.4 W at 900 W.

6 Conclusion

A procedure to calculate the standard deviation (s_P) in measured decay heat values has been developed. The resulting values for the calorimeter are:

BWR assembly 50 W: $s_p = 2.1$ W
BWR assembly 350 W: $s_P = 3.1$ W

PWR assembly 250 W: $s_p = 4.6$ W
PWR assembly 900 W: $s_p = 9.4$ W

The design target was that the uncertainty in the measured decay heat power should be less than ± 2% with 95% confidence. 95% corresponds to ± $1.96s_P$

For BWR assemblies the uncertainty will be:

Power (W)	Uncertainty (W)	Uncertainty (%)
50	4.2	8.4
350	6.2	1.8

For PWR assemblies the uncertainty will be:

Power (W)	Uncertainty (W)	Uncertainty (%)
250	9.2	3.7
900	18.8	2.1

References

/1/ Introductory Statistics, T. H: Wannacott et al.

/2/ Uncertainty analysis, a tutorial, J Engel et al.

/3/ Systembeskrivning Clab System 251.

/4/ Variationer av temperaturen i höjdled, OKG, F Sturek.

/5/ Clab system 251 Volymbestämning av mätcylindern, 2002-09-06, OKG, F Sturek.

Enclosure 1

Anpassning till 50–350 W

						a=	176.14
						b=	1,729,649.32
	X=dt/dT	**Y=P**	**x=X–Xmedel**	**xY**	**x^2**	**y=a+bx**	**(Y–y)^2**
	8.11E–05	49.1	–7.27E–05	–3.57E–03	5.29E–09	50.34	1.58
	8.18E–05	52.2	–7.21E–05	–3.76E–03	5.19E–09	51.49	0.45
	8.40E–05	54.6	–6.99E–05	–3.82E–03	4.88E–09	55.30	0.47
	1.08E–04	97.4	–4.58E–05	–4.46E–03	2.10E–09	96.91	0.29
	1.09E–04	97.7	–4.51E–05	–4.41E–03	2.03E–09	98.15	0.18
	1.08E–04	98.2	–4.54E–05	–4.46E–03	2.07E–09	97.53	0.40
	1.08E–04	98.2	–4.57E–05	–4.49E–03	2.09E–09	97.04	1.26
	1.09E–04	98.6	–4.51E–05	–4.45E–03	2.04E–09	98.06	0.27
	1.34E–04	143.4	–2.01E–05	–2.88E–03	4.02E–10	141.45	3.92
	1.36E–04	144.9	–1.76E–05	–2.54E–03	3.08E–10	145.78	0.69
	1.37E–04	146.3	–1.71E–05	–2.51E–03	2.94E–10	146.48	0.03
	1.38E–04	146.6	–1.63E–05	–2.39E–03	2.65E–10	147.97	1.76
	1.37E–04	147.1	–1.69E–05	–2.48E–03	2.85E–10	146.94	0.02
	1.35E–04	147.2	–1.85E–05	–2.72E–03	3.41E–10	144.19	9.33
	1.35E–04	147.3	–1.89E–05	–2.79E–03	3.58E–10	143.42	14.77
	1.38E–04	147.3	–1.55E–05	–2.28E–03	2.40E–10	149.35	4.34
	1.39E–04	147.3	–1.51E–05	–2.23E–03	2.29E–10	149.99	7.26
	1.38E–04	148.7	–1.59E–05	–2.36E–03	2.52E–10	148.69	0.00
	1.65E–04	192.9	1.12E–05	2.15E–03	1.25E–10	195.45	6.59
	1.65E–04	194.9	1.10E–05	2.14E–03	1.21E–10	195.15	0.05
	1.67E–04	196.9	1.27E–05	2.50E–03	1.62E–10	198.14	1.64
	1.69E–04	202.1	1.51E–05	3.05E–03	2.28E–10	202.28	0.03
	1.69E–04	202.2	1.51E–05	3.05E–03	2.28E–10	202.27	0.01
	1.94E–04	245.5	4.02E–05	9.87E–03	1.62E–09	245.70	0.05
	1.94E–04	245.9	4.03E–05	9.91E–03	1.62E–09	245.83	0.00
	1.93E–04	247.1	3.93E–05	9.72E–03	1.55E–09	244.16	8.66
	2.25E–04	294.6	7.13E–05	2.10E–02	5.08E–09	299.44	23.86
	2.25E–04	296.8	7.06E–05	2.10E–02	4.99E–09	298.33	2.28
	2.46E–04	336.8	9.25E–05	3.11E–02	8.55E–09	336.05	0.54
	2.49E–04	343.5	9.52E–05	3.27E–02	9.06E–09	340.81	7.23
	2.53E–04	349.1	9.91E–05	3.46E–02	9.83E–09	347.62	2.32
Summa			7.32E–19	1.24E–01	7.18E–08		100.27
Medel	1.54E–04	176.14				s^2 i a	3.46
						s i a	1.86
						s^2 i b	4,8136,343.10
						s i b	6,938.04

Anpassning till 50–350 W

						a=		503.49
						b=		1,716,827.82
	X=dt/dT	**Y=P**	**x=X–Xmedel**	**xY**	**x^2**		**y=a+bx**	**(Y–y)^2**
	1.94E–04	2.45E+02	–1.50E–04	–3.67E–02	2.24E–08		246.82	1.83
	1.94E–04	2.46E+02	–1.49E–04	–3.67E–02	2.23E–08		246.95	1.18
	1.93E–04	2.47E+02	–1.50E–04	–3.72E–02	2.26E–08		245.29	3.27
	2.25E–04	2.95E+02	–1.18E–04	–3.49E–02	1.40E–08		300.17	31.48
	2.25E–04	2.97E+02	–1.19E–04	–3.53E–02	1.42E–08		299.07	5.03
	2.46E–04	3.37E+02	–9.73E–05	–3.28E–02	9.46E–09		336.50	0.08
	2.49E–04	3.43E+02	–9.45E–05	–3.25E–02	8.93E–09		341.23	5.16
	2.53E–04	3.49E+02	–9.06E–05	–3.16E–02	8.20E–09		347.99	1.33
	2.77E–04	3.92E+02	–6.64E–05	–2.60E–02	4.40E–09		389.58	5.72
	2.80E–04	3.95E+02	–6.33E–05	–2.50E–02	4.01E–09		394.74	0.18
	3.07E–04	4.41E+02	–3.66E–05	–1.61E–02	1.34E–09		440.67	0.02
	3.08E–04	4.45E+02	–3.59E–05	–1.60E–02	1.29E–09		441.87	8.16
	3.36E–04	4.91E+02	–7.97E–06	–3.91E–03	6.35E–11		489.81	1.31
	3.41E–04	4.93E+02	–2.92E–06	–1.44E–03	8.54E–12		498.48	26.68
	3.38E–04	4.93E+02	–5.66E–06	–2.79E–03	3.21E–11		493.77	0.09
	3.61E–04	5.35E+02	1.70E–05	9.07E–03	2.87E–10		532.60	6.09
	3.64E–04	5.39E+02	2.00E–05	1.08E–02	3.98E–10		537.76	1.36
	3.67E–04	5.45E+02	2.38E–05	1.30E–02	5.67E–10		544.37	0.37
	3.93E–04	5.88E+02	4.95E–05	2.91E–02	2.45E–09		588.50	0.25
	3.92E–04	5.89E+02	4.83E–05	2.85E–02	2.33E–09		586.37	9.42
	3.96E–04	5.97E+02	5.24E–05	3.13E–02	2.75E–09		593.52	15.64
	4.48E–04	6.87E+02	1.05E–04	7.20E–02	1.10E–08		683.32	15.86
	4.56E–04	6.87E+02	1.12E–04	7.69E–02	1.25E–08		695.69	69.47
	4.49E–04	6.89E+02	1.05E–04	7.26E–02	1.11E–08		684.40	18.49
	4.78E–04	7.31E+02	1.35E–04	9.86E–02	1.82E–08		734.99	12.82
	4.83E–04	7.35E+02	1.39E–04	1.03E–01	1.94E–08		742.90	58.61
	5.05E–04	7.81E+02	1.61E–04	1.26E–01	2.60E–08		780.32	0.25
	5.63E–04	8.84E+02	2.19E–04	1.94E–01	4.81E–08		880.19	11.05
Summa			–3.87E–20	4.95E–01	2.88E–07			311.22
Medel	3.44E–04	503.49				s^2 i a		12.45
						s i a		3.53
						s^2 i b		43,163,868.01
						s i b		6569.92

Enclosure 2

Simplification of the formula for P_γ

According to part 3 is the formula for P_γ:

$$P_\gamma = 8.14 \frac{\sum_{i=1}^{5} d_i e^{-\lambda r_i}}{\sum_{i=1}^{5} (e^{-\lambda r_i})^2} \left\{ e^{-\lambda} \left(-\frac{1}{\lambda^2} - \frac{1}{\lambda} \right) + e^{-0.228\lambda} \left(\frac{1}{\lambda^2} + \frac{0.228}{\lambda} \right) \right\} F$$

Where

P_γ is the power escaping from the calorimeter with the gamma radiation (W)

$\lambda = 8.4\ m^{-1}$ is a curve fitting parameter to measured values of dose rates

F is a weigh factor compensating variations in the burnup profiles in the four corners of the fuel assembly

d_i is measured dose rate (Gy/h)

r_i is the distance between the probe and the fuel centre:

Prob nr (i)	Radie (m) (r_i)
1	0.26
2	0.38
3	0.50
4	0.63
5	0.77

By input of numerical values the formula could be simplified:

$P_\gamma = 0.378d_{KA701} + 0.138d_{KA702} + 0.050d_{KA703} + 0.017d_{KA704} + 0.005d_{KA705}$

Part 5

Clab – Data for fuel assemblies used in calorimetric and nuclear measurements

Lennart Agrenius
Agrenius Ingenjörsbyrå AB

Contents

1 Introduction

SKB is conducting measurements of decay heat and gamma radiation on spent fuel assemblies in Clab.

This report describes the fuel data on the 50 BWR – and 34 PWR – assemblies in the present measurement program. The fuel assemblies are from different nuclear power plants:

Forsmark 1

Forsmark 2

Forsmark 3

Oskarshamn 2

Oskarshamn 3

Ringhals 1

Ringhals 2

Ringhals 3

Barsebäck 1

Basebäck 2

In Section 2 data is presented for each reactor and the fuel assemblies from the reactors. Fuel rod diagrams and enrichment diagrams are presented for the fuel assemblies. These diagrams are copies of the plant original data. The diagrams are not translated and we regret that the quality of some diagrams is not good, but all are included for completeness. In Table 2-1 below all fuel assemblies are listed by id number, fuel type and reactor.

The data has been collected from the power plants.

2 Fuel data

Table 2-1. Assemblies listed by number.

BWR-assemblies			PWR-assemblies		
Assembly no	**Fuel type**	**Reactor**	**Assembly no**	**Fuel type**	**Reactor**
0582	8×8	R1	0E2	17×17	R3
0596	8×8	R1	0E6	17×17	R3
0710	8×8	R1	1E5	17×17	R3
0900	8×8	R1	0C9	17×17	R3
1136	8×8	R1	1C2	17×17	R3
1177	8×8	R1	1C5	17×17	R3
1186	8×8	R1	2A5	17×17	R3
1377	8×8	O2	2C2	17×17	R3
1389	8×8	O2	3C1	17×17	R3
1546	8×8	O2	3C4	17×17	R3
1696	8×8	O2	3C5	17×17	R3
1704	8×8	O2	3C9	17×17	R3
2014	8×8	B1	4C4	17×17	R3
2018	8×8	B1	4C7	17×17	R3
2048	8×8	B1	5A3	17×17	R3
2074	8×8	B1	5F2	17×17	R3
2118	8×8	B1	C01	15×15	R2
2995	8×8	O2	C12	15×15	R2
3054	8×8	O2	C20	15×15	R2
3058	8×8	O2	C42	15×15	R2
3064	8×8	O2	D27	15×15	R2
3838	8×8	F1	D38	15×15	R2
5535	8×8	F2	E38	15×15	R2
5829	8×8	R1	E40	15×15	R2
6350	8×8	O2	F14	15×15	R2
6423	8×8	R1	F21	15×15	R2
6432	8×8	R1	F25	15×15	R2
6454	8×8	R1	F32	15×15	R2
6478	8×8	R1	G11	15×15	R2
8327	8×8	R1	G23	15×15	R2
8331	8×8	R1	I09	15×15	R2
8332	8×8	R1	I20	15×15	R2
8338	8×8	R1	I24	15×15	R2
8341	8×8	R1	I25	15×15	R2
9329	8×8	B1			
288	8×8	B1			

BWR-assemblies			PWR-assemblies		
Assembly no	**Fuel type**	**Reactor**	**Assembly no**	**Fuel type**	**Reactor**
11494	Svea 64	F2			
11495	Svea 64	F2			
12078	8×8	O3			
12684	Svea 64	O2			
13628	Svea 100	O3			
13630	Svea 100	O3			
13775	Svea 64	F2			
13847	Svea 100	F3			
13848	Svea 100	F3			
14076	8×8	B2			
KU0100	8×8–2	F1			
KU0269	9×9–5	F1			
KU0278	9×9–5	F1			
KU0282	9×9–5	F1			

2.1 Forsmark 1

REACTOR FORSMARK 1

Reactor data	Value
Reactor pressure (MPa) at full power	7
Inlet temperature into core (C) at full power	274
Outlet temperature into core (C) at full power	286
Avg. temperature in the uranium pellets at full power (C)	508
Avg. temperature in the cladding at full power (C)	290
Temperature in the boxwall at full power (C)	286

Cycle data

Cycle no	Start	Stop	Reactor power MW	Burnup avg/cycle MWd/tU	No of assemblies in core
1a	1980-04-23	1981-06-25	2,711	5,894	676
1b	1981-08-16	1982-06-19	2,711	6,156	676
2	1982-08-25	1983-07-15	2,711	6,156	676
3	1983-08-05	1984-07-13	2,711	6,375	676
4	1984-08-06	1985-05-31	2,711	5,848	676
5	1985-07-08	1986-07-04	2,928	6,959	676
6	1986-07-22	1987-07-31	2,928	7,770	676
7	1987-08-19	1988-06-10	2,928	6,404	676
8	1988-07-10	1989-07-14	2,928	7,253	676
9	1989-08-18	1990-08-17	2,928	7,129	676
10	1990-09-16	1991-05-24	2,928	5,686	676
11	1991-06-20	1992-07-10	2,928	8,347	676
12	1992-08-03	1993-07-02	2,928	7,092	676

Fuel data	Fuel id				
	3838	**KU0100**	**KU0269**	**KU0278**	**KU0282**
Fuel type	AA8×8–1	KWU8×8–2	KWU9×9–5	KWU9×9–5	KWU9×9–5
No of fuel rods	63	62	76	76	76
Rod pitch normal rods (mm)	16.3	16.25	14.45	14.45	14.45
Rod pitch normal – corner rods (mm)	16.05				
Rod pitch corner – corner rods (mm)	15.8				
Rod diameter normal rod (mm)	12.25	12.3	11	11	11
Clad thickness normal rod (mm)	0.8	0.82	0.665	0.665	0.665
Pellet diameter normal rod (mm)	10.44	10.44	9.5	9.5	9.5
No of normal rods	51	62	76	76	76
Rod diameter corner rod (mm)	11.75				
Clad thickness corner rod (mm)	0.8				
Pellet diameter corner rod (mm)	9.94				
No of corner rods	12				
Active length (mm)	3,680	3,680	3,680	3,680	3,680
Density UO2 (g/cc)	10.5	10.3	10.3	10.3	10.3
Porsity,dishing etc (%)	1.29	1.255	1.545	1.483	1.504
No of spacer rods	1	1	1	1	1
Material in spacer rods	Zr2	Zr	Zr	Zr	Zr
Outer diameter spacer rods (mm)	12.25	15	15	15	15
Cladding thickness spacer rod	0.8	0.8	0.8	0.8	0.8
No of water rods		1	4	4	4
Material in water rods		Zr2	Zr2	Zr2	Zr2
Outer diameter water rods (mm)		15	15	15	15
Inner diameter water rods (mm)		0.8	0.8	0.8	0.8
No of BA rods	3	4	6	6	6
% Gd2O3	3.95	2.5	2.5	2.5	2.5
Rel poison	1	1	1	1	1
No of spacers	6	6	6	6	6
Spacer material	Inconel	Zr4	Zr4	Zr4	Zr4
Mass of spacer (g)	135	323	323	323	323
Box material	Zr4	Zr4	Zr4	Zr4	Zr4
Box outer measure square (mm)	139	139	139	139	139
Box wall thickness (mm)	2.3	2.3	2.3	2.3	2.3

Initial data	3838	KU0100	KU0269	KU0278	KU0282
Initial mass Utot (g)	177,903	174,920	177,020	177,133	177,097
Initial mass U235 (g)	3,711	5,190	5,201	5,206	5,204
Avg.enrichment% U235	2.086	2.976	2.938	2.939	2.939
Data after rebuild 1					
Date of rebuild					
No of fuel rods					
No spacer rods					
No water rods					
No of water holes					
Mass Utot after rebuild (g)					
Mass U235 after rebuild (g)					
Data after rebuild 2					
Date of rebuild					
No of fuel rods					
No spacer rods					
No water rods					
No of water holes					
Mass Utot after rebuild (g)					
Mass U235 after rebuild (g)					
Cycle history burnup/cycle, MWd/tU					
1a	6,160				
1b	6,932				
2	2,898				
3	3,063				
4					
5					
6		10,643	10,158	10,414	10,122
7		8,063	8,629	7,271	8,678
8		7,924	8,366	7,079	7,044
9		7,563	7,960	4,649	6,268
10	2,786			5,910	5,784
11	3,830				
Axial BU distribution, EOL MWd/tU **Node no (top=25)**					
1	10,899	14,315	7,452	6,964	8,156
2	19,258	24,831	27,664	25,831	29,042
3	23,070	30,845	34,966	32,613	36,483
4	24,864	33,763	38,158	35,857	39,916
5	26,611	35,914	40,116	38,143	42,260
6	27,703	36,991	40,833	39,258	43,308
7	28,282	37,557	40,928	39,764	43,593
5	26,611	35,914	40,116	38,143	42,260
6	27,703	36,991	40,833	39,258	43,308
7	28,282	37,557	40,928	39,764	43,593
8	28,538	37,745	40,613	39,739	43,278
9	29,705	38,515	41,035	40,345	43,629
10	30,180	38,848	41,198	40,592	43,659
11	30,167	39,001	41,264	40,697	43,665
12	29,904	38,735	40,984	40,415	43,257
13	30,323	39,103	41,326	40,772	43,514
14	30,356	39,150	41,205	40,759	43,405
15	30,116	38,986	40,782	40,520	43,055
16	29,719	38,482	39,990	40,005	42,397
17	29,633	38,550	39,746	40,153	42,397
18	29,031	38,243	39,094	40,085	42,114
19	27,866	37,617	38,068	39,785	41,579
20	26,758	36,474	36,449	38,917	40,466
21	25,237	35,470	34,847	38,102	39,470
22	22,794	33,379	32,126	35,972	37,256
23	19,043	29,888	27,929	31,934	33,273
24	14,381	24,090	22,053	25,653	26,987
25	10,623	18,330	9,013	10,199	11,231

Void history Node no (top=25)	3838	KU0100	KU0269	KU0278	KU0282
1	–0.04	–0.03	–0.04	–0.03	–0.03
2	–0.03	–0.03	–0.03	–0.03	–0.03
3	–0.03	–0.02	–0.01	–0.02	–0.02
4	0.00	0.02	0.05	0.02	0.04
5	0.03	0.09	0.13	0.08	0.11
6	0.06	0.16	0.21	0.15	0.17
7	0.10	0.24	0.28	0.21	0.24
8	0.13	0.30	0.35	0.27	0.30
9	0.17	0.36	0.41	0.32	0.35
10	0.22	0.42	0.46	0.37	0.41
11	0.27	0.46	0.51	0.42	0.45
12	0.31	0.51	0.55	0.46	0.49
13	0.35	0.54	0.58	0.50	0.53
14	0.39	0.58	0.62	0.54	0.56
15	0.42	0.61	0.64	0.57	0.59
16	0.45	0.63	0.67	0.60	0.62
17	0.48	0.66	0.69	0.62	0.65
18	0.50	0.68	0.71	0.65	0.67
19	0.53	0.70	0.73	0.66	0.68
20	0.54	0.71	0.74	0.68	0.70
21	0.56	0.73	0.75	0.70	0.71
22	0.57	0.74	0.76	0.71	0.73
23	0.59	0.75	0.77	0.72	0.73
24	0.59	0.76	0.78	0.73	0.74
25	0.61	0.76	0.78	0.73	0.74
Density history Node no (top=25)					
2	0.76	0.76	0.76	0.76	0.76
3	0.75	0.75	0.74	0.75	0.74
4	0.74	0.72	0.70	0.72	0.71
5	0.72	0.68	0.65	0.68	0.66
6	0.69	0.63	0.59	0.64	0.62
7	0.67	0.57	0.54	0.60	0.57
8	0.64	0.53	0.50	0.56	0.54
9	0.61	0.48	0.46	0.52	0.50
10	0.58	0.44	0.42	0.49	0.46
11	0.55	0.41	0.39	0.46	0.43
12	0.52	0.38	0.36	0.43	0.40
13	0.49	0.36	0.34	0.40	0.38
14	0.46	0.33	0.32	0.37	0.35
15	0.44	0.31	0.30	0.35	0.33
16	0.42	0.30	0.28	0.33	0.31
17	0.40	0.28	0.27	0.31	0.30
18	0.38	0.27	0.25	0.30	0.28
19	0.36	0.25	0.24	0.29	0.27
20	0.35	0.24	0.23	0.27	0.26
21	0.34	0.23	0.22	0.26	0.25
22	0.33	0.22	0.21	0.25	0.24
23	0.32	0.22	0.21	0.25	0.24
24	0.32	0.21	0.20	0.24	0.23
25	0.31	0.21	0.20	0.24	0.23

Control rod history **Node no (top=25)**					
1	0.08	0.00	0.12	0.22	0.28
2	0.06	0.00	0.10	0.17	0.24
3	0.05	0.00	0.10	0.15	0.23
4	0.04	0.00	0.10	0.15	0.23
5	0.04	0.00	0.10	0.15	0.22
6	0.04	0.00	0.09	0.14	0.22
7	0.04	0.00	0.08	0.14	0.23
8	0.03	0.00	0.08	0.14	0.23
9	0.01	0.00	0.06	0.14	0.23
10	0.01	0.00	0.05	0.13	0.23
11	0.01	0.00	0.04	0.12	0.22
12	0.01	0.00	0.03	0.11	0.21
13	0.00	0.00	0.01	0.10	0.20
14	0.00	0.00	0.00	0.09	0.20
15	0.00	0.00	0.00	0.09	0.19
16	0.00	0.00	0.00	0.08	0.19
17	0.00	0.00	0.00	0.08	0.18
18	0.00	0.00	0.00	0.08	0.18
19	0.00	0.00	0.00	0.07	0.16
20	0.00	0.00	0.00	0.05	0.15
21	0.00	0.00	0.00	0.03	0.12
22	0.00	0.00	0.00	0.01	0.10
23	0.00	0.00	0.00	0.00	0.06
24	0.00	0.00	0.00	0.00	0.02
25	0.00	0.00	0.00	0.00	0.00

Forsmark 1 Fuel rod diagram assembly 3838

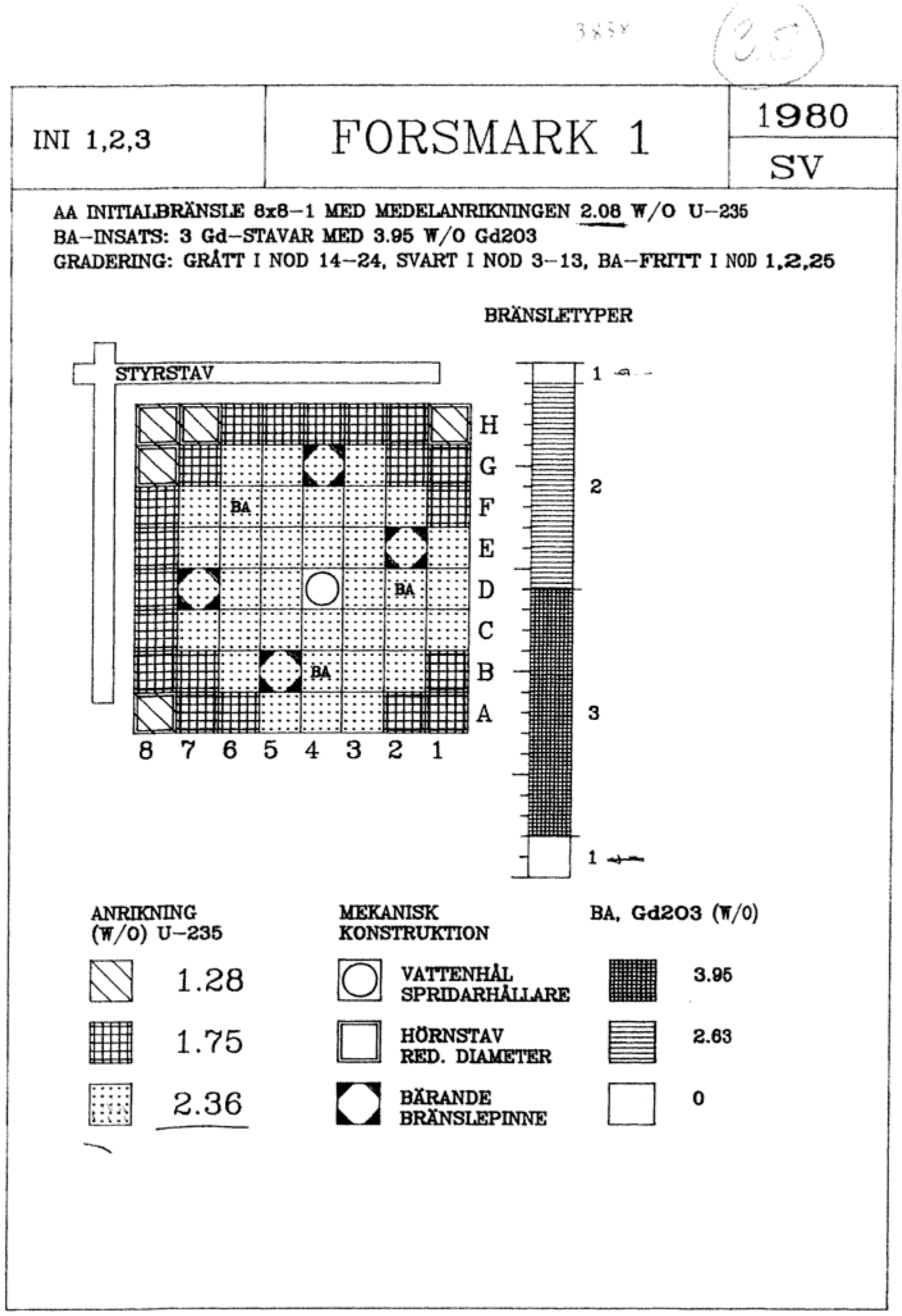
FORSMARKS KRAFTGRUPP

PATRON NR 3838
BOX NR 3916

ANRIKN % VERKL	ANTAL STAVAR	KG UO2	KG UTOT	KG U235
2.086	63	202.220	177.903	3.711

8	000- 9509 1.271 2596	000- 11359 1.729 2603	000- 36416 1.749 2858	000- 36403 1.748 2861	000- 36408 1.747 2862	000- 36380 1.751 2856	000- 9536 1.307 2601	000- 9616 1.310 2595
7	000- 11307 1.734 2595	000- 36308 1.747 2862	000- 30293 2.349 2895	000- 2697 2.359 2883	000- 30335 2.351 2893	000- 30308 2.348 2896	000- 36404 1.746 2864	000- 9547 1.310 2596
6	000- 36423 1.742 2871	000- 30282 2.346 2898	000- 30180 2.355 2888	000- 30304 2.346 2898	000- 30311 2.352 2891	000- 16511 2.346 2771	000- 30344 2.353 2890	000- 36314 1.750 2857
5	000- 30289 2.351 2893	000- 2635 2.366 2874	000- 30341 2.352 2891	000- 30322 2.355 2888	000- 30147 2.351 2893	000- 30260 2.351 2893	000- 30300 2.353 2890	000- 36355 1.748 2861
4	000- 30251 2.347 2897	000- 16506 2.341 2777	000- 30285 2.352 2891		000- 30135 2.356 2886	000- 30301 2.352 2891	000- 2680 2.358 2884	000- 36267 1.746 2863
3	000- 30271 2.352 2891	000- 30324 2.358 2884	000- 30170 2.358 2884	000- 30316 2.349 2895	000- 30336 2.350 2894	000- 30345 2.353 2890	000- 30270 2.350 2894	000- 36349 1.739 2876
2	000- 11314 1.732 2598	000- 30318 2.352 2891	000- 30334 2.352 2891	000- 16527 2.347 2769	000- 2591 2.369 2870	000- 30346 2.344 2901	000- 36410 1.743 2869	000- 11368 1.729 2602
1	000- 11474 1.760 2613	000- 11306 1.732 2598	000- 30283 2.346 2898	000- 30288 2.349 2895	000- 30339 2.350 2894	000- 36338 1.755 2849	000- 11524 1.762 2610	000- 9692 1.310 2595
	A	B	C	D	E	F	G	H

Forsmark 1 Enrichment diagram assembly 3838



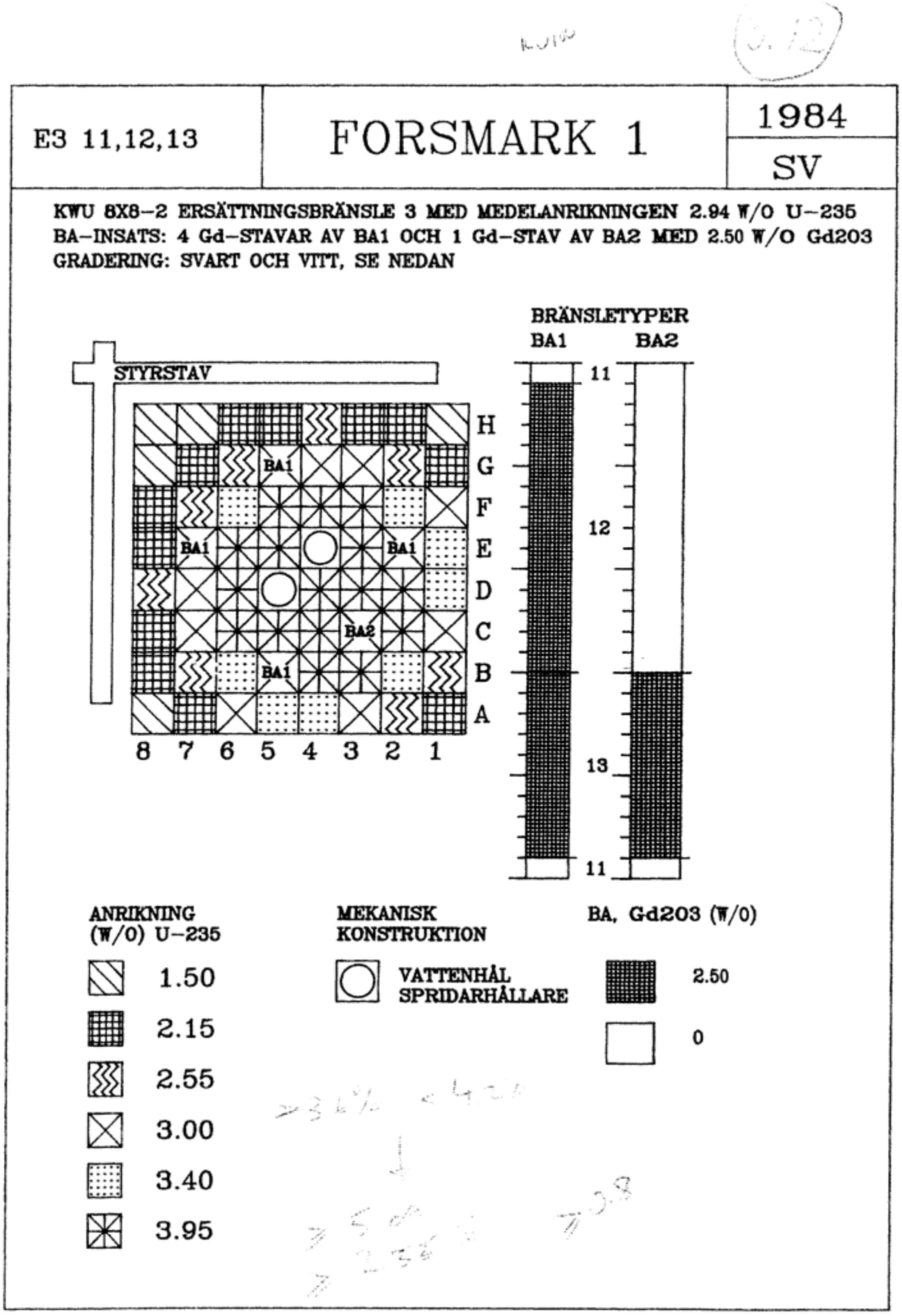
FORSMARKS KRAFTGRUPP

PATRON NR KU0100
BOX NR 3592

ANRIKN % VERKL	ANTAL STAVAR	KG UO2	KG UTOT	KG U235
2.967	62	198.760	174.920	5.190

	A	B	C	D	E	F	G	H
8	K02- AM0290 1.00 3212	K02- AN0288 2.00 3204	K02- AN0302 2.00 3204	K02- AP0202 2.00 3207	K02- AO0035 2.00 3207	K02- AN0295 2.00 3209	K02- AM0377 1.00 3219	K02- AL0118 1.00 3217
7	K02- AN0550 2.00 3195	K02- AQ0075 2.00 3203	K02- AD0229 3.00 3205	K02- AD0248 3.00 3199	K02- AR0102 3.00 3180	K02- AQ0067 2.00 3202	K02- AN0310 2.00 3194	K02- AM0262 1.00 3224
6	K02- AD0241 3.00 3197	K02- AS0290 3.00 3217	K02- AT1058 3.00 3204	K02- AT1141 3.00 3208	K02- AT1033 3.00 3205	K02- AS0412 3.00 3221	K02- AQ0103 2.00 3205	K02- AN1042 2.00 3215
5	K02- AU0087 3.00 3179	K02- AR0114 3.00 3167	K02- AT1412 3.00 3210		K02- AT1075 3.00 3211	K02- AT1377 3.00 3211	K02- AR0058 3.00 3178	K02- AO0187 2.00 3215
4	K02- AU0013 3.00 3184	K02- AT1022 3.00 3213	K02- AT1430 3.00 3211	K02- AT1011 3.00 3216		K02- AT1410 3.00 3215	K02- AD0475 3.00 3191	K02- AP0233 2.00 3218
3	K02- AD0236 3.00 3206	K02- AT1096 3.00 3216	K02- AV0051 3.00 3186	K02- AT1052 3.00 3216	K02- AT1104 3.00 3207	K02- AT1073 3.00 3207	K02- AD0463 3.00 3188	K02- AN1046 2.00 3217
2	K02- AQ0495 2.00 3208	K02- AS0381 3.00 3218	K02- AT1013 3.00 3215	K02- AT1134 3.00 3215	K02- AR0403 3.00 3184	K02- AS0376 3.00 3224	K02- AQ0079 2.00 3210	K02- AN1041 2.00 3210
1	K02- AN0290 2.00 3205	K02- AQ0065 2.00 3199	K02- AD0243 3.00 3201	K02- AU0056 3.00 3221	K02- AU0027 3.00 3212	K02- AD0454 3.00 3205	K02- AN0303 2.00 3201	K02- AM0298 1.00 3217

Forsmark 1 Enrichment diagram assembly KU0100



Forsmark 1 Fuel rod diagram assembly KU0269

FORSMARKS KRAFTGRUPP

PATRON NR KU0269
BOX NR 3896

ANRIKN % VERKL	ANTAL STAVAR	KG UO2	KG UTOT	KG U235
2.938	76	201.203	177.020	5.201

	A	B	C	D	E	F	G	H	I
9	K05- BR0007 2.00 2665	K05- BR0330 2.00 2665	K05- BS0729 2.60 2674	K05- BQ0263 2.60 2670	K05- BS0736 2.60 2667	K05- BQ0250 2.60 2676	K05- BR0601 2.00 2659	K05- BR0297 2.00 2667	K05- BP0044 1.50 2668
8	K05- BS0630 2.60 2675	K05- BL0056 3.00 2639	K05- BN0138 3.00 2665	K05- BT0496 3.70 2665	K05- BU1568 3.95 2678	K05- BL0053 3.00 2642	K05- BN0140 3.00 2671	K05- BS0295 2.60 2671	K05- BR0276 2.00 2666
7	K05- BN0983 3.00 2670	K05- BT0380 3.70 2679	K05- BU1580 3.95 2669	K05- BU1599 3.95 2667	K05- BU1570 3.95 2675	K05- BU1518 3.95 2673	K05- BN0985 3.00 2670	K05- BN0261 3.00 2659	K05- BR0408 2.00 2667
6	K05- BH0183 3.00 2664	K05- BU1566 3.95 2674	K05- BU1476 3.95 2669	K05- BU1609 3.95 2673	K05- BU1436 3.95 2668	K05- BU1469 3.95 2667	K05- BU1553 3.95 2672	K05- BL0037 3.00 2632	K05- BQ0192 2.60 2680
5	K05- BN0966 3.00 2670	K05- BL0492 3.00 2639	K05- BT0151 3.70 2674		K05- BT0470 3.70 2671	K05- BU1542 3.95 2672	K05- BU1539 3.95 2668	K05- BU1504 3.95 2676	K05- BS0601 2.60 2678
4	K05- BH0028 3.00 2662	K05- BT0419 3.70 2671				K05- BU1559 3.95 2666	K05- BU1560 3.95 2668	K05- BT0410 3.70 2672	K05- BQ0248 2.60 2681
3	K05- BN0253 3.00 2667	K05- BT0479 3.70 2676	K05- BK0070 3.00 1163		K05- BT0474 3.70 2666	K05- BU1448 3.95 2662	K05- BU1417 3.95 2672	K05- BN0198 3.00 2663	K05- BS0510 2.60 2673
2	K05- BS0743 2.60 2673	K05- BN0284 3.00 2667	K05- BT0506 3.70 2664	K05- BT0421 3.70 2674	K05- BL0276 3.00 2624	K05- BU1337 3.95 2673	K05- BT0485 3.70 2674	K05- BL0051 3.00 2648	K05- BR0230 2.00 2670
1	K05- BR0724 2.00 2677	K05- BS0640 2.60 2674	K05- BN0004 3.00 2669	K05- BH0084 3.00 2664	K05- BN0988 3.00 2662	K05- BH0198 3.00 2663	K05- BN0977 3.00 2669	K05- BS0605 2.60 2669	K05- BR0708 2.00 2668

FORSMARKS KRAFTGRUPP

PATRON NR KU0278
BOX NR 11B367

ANRIKN % VERKL	ANTAL STAVAR	KG UO2	KG UTOT	KG U235
2.939	76	201.335	177.133	5.206

9	K05- BR0671 2.00 2667	K05- BR0331 2.00 2663	K05- BS0746 2.60 2669	K05- BQ0343 2.60 2669	K05- BS0610 2.60 2672	K05- BQ0312 2.60 2666	K05- BR0410 2.00 2674	K05- BR0475 2.00 2675	K05- BP0087 1.50 2669
8	K05- BS0612 2.60 2677	K05- BL0361 3.00 2648	K05- BN0904 3.00 2668	K05- BT0478 3.70 2673	K05- BU1180 3.95 2674	K05- BL0219 3.00 2647	K05- BN0110 3.00 2671	K05- BS0672 2.60 2680	K05- BR0578 2.00 2658
7	K05- BN0090 3.00 2660	K05- BT0624 3.70 2692	K05- BU0946 3.95 2672	K05- BU1146 3.95 2675	K05- BU1112 3.95 2672	K05- BU1158 3.95 2673	K05- BN0960 3.00 2669	K05- BN0935 3.00 2662	K05- BR0220 2.00 2671
6	K05- BH0076 3.00 2669	K05- BU1167 3.95 2666	K05- BU1182 3.95 2667	K05- BU1132 3.95 2666	K05- BU0903 3.95 2671	K05- BU1220 3.95 2672	K05- BU0898 3.95 2670	K05- BL0113 3.00 2652	K05- BQ0146 2.60 2669
5	K05- BN0013 3.00 2665	K05- BL0194 3.00 2649	K05- BT0490 3.70 2671		K05- BT0614 3.70 2684	K05- BU1116 3.95 2671	K05- BU1589 3.95 2666	K05- BU1168 3.95 2671	K05- BS0589 2.60 2677
4	K05- BH0221 3.00 2663	K05- BT0688 3.70 2691				K05- BU1236 3.95 2669	K05- BU1129 3.95 2667	K05- BT0685 3.70 2683	K05- BQ0114 2.60 2665
3	K05- BN0196 3.00 2665	K05- BT0248 3.70 2670	K05- BK0017 3.00 1171		K05- BT0430 3.70 2673	K05- BU0968 3.95 2670	K05- BU1593 3.95 2668	K05- BN0170 3.00 2666	K05- BS0681 2.60 2678
2	K05- BS0721 2.60 2672	K05- BN0081 3.00 2662	K05- BT0047 3.70 2679	K05- BT0345 3.70 2673	K05- BL0362 3.00 2650	K05- BU1164 3.95 2672	K05- BT0298 3.70 2680	K05- BL0203 3.00 2645	K05- BR0676 2.00 2673
1	K05- BR0604 2.00 2673	K05- BS0631 2.60 2676	K05- BN0343 3.00 2668	K05- BH0204 3.00 2663	K05- BN0271 3.00 2669	K05- BH0131 3.00 2664	K05- BN0956 3.00 2662	K05- BS0571 2.60 2671	K05- BR0125 2.00 2662
	A	B	C	D	E	F	G	H	I

Forsmark 1 Fuel rod diagram assembly KU0282

FORSMARKS KRAFTGRUPP

PATRON NR KU0282
BOX NR 11B628

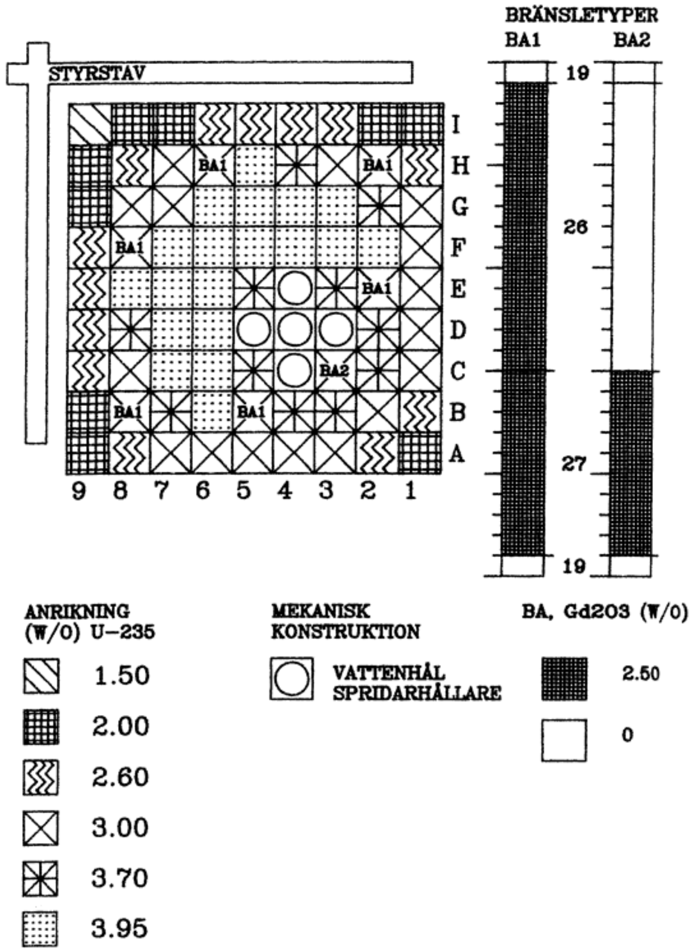
ANRIKN % VERKL	ANTAL STAVAR	KG UO2	KG UTOT	KG U235
2.939	76	201.296	177.097	5.204

	A	B	C	D	E	F	G	H	I
9	K05- BR0055 2.00 2676	K05- BR0034 2.00 2670	K05- BS0748 2.60 2675	K05- BQ0306 2.60 2669	K05- BS0719 2.60 2671	K05- BQ0266 2.60 2661	K05- BR0462 2.00 2673	K05- BR0391 2.00 2664	K05- BP0003 1.50 2669
8	K05- BS0544 2.60 2671	K05- BL0114 3.00 2647	K05- BN0009 3.00 2663	K05- BT0130 3.70 2674	K05- BU0890 3.95 2670	K05- BL0101 3.00 2649	K05- BN0039 3.00 2662	K05- BS0713 2.60 2671	K05- BR0461 2.00 2669
7	K05- BN0192 3.00 2664	K05- BT0205 3.70 2668	K05- BU0938 3.95 2672	K05- BU1202 3.95 2670	K05- BU1145 3.95 2671	K05- BU1243 3.95 2670	K05- BN0335 3.00 2667	K05- BN0056 3.00 2665	K05- BR0392 2.00 2668
6	K05- BH0319 3.00 2668	K05- BU0930 3.95 2674	K05- BU0897 3.95 2669	K05- BU1207 3.95 2671	K05- BU1200 3.95 2671	K05- BU0948 3.95 2671	K05- BU1140 3.95 2670	K05- BL0163 3.00 2658	K05- BQ0162 2.60 2668
5	K05- BN0064 3.00 2666	K05- BL0169 3.00 2656	K05- BT0246 3.70 2672		K05- BT0236 3.70 2674	K05- BU1187 3.95 2673	K05- BU1245 3.95 2671	K05- BU1099 3.95 2667	K05- BS0584 2.60 2673
4	K05- BH0123 3.00 2663	K05- BT0398 3.70 2677				K05- BU1089 3.95 2671	K05- BU1128 3.95 2675	K05- BT0256 3.70 2679	K05- BQ0239 2.60 2663
3	K05- BN0358 3.00 2663	K05- BT0441 3.70 2672	K05- BK0050 3.00 1174		K05- BT0311 3.70 2672	K05- BU1600 3.95 2671	K05- BU1135 3.95 2671	K05- BN0341 3.00 2664	K05- BS0415 2.60 2677
2	K05- BS0508 2.60 2674	K05- BN0238 3.00 2666	K05- BT0291 3.70 2670	K05- BT0188 3.70 2674	K05- BL0110 3.00 2658	K05- BU1218 3.95 2668	K05- BT0271 3.70 2673	K05- BL0108 3.00 2651	K05- BR0221 2.00 2669
1	K05- BR0134 2.00 2670	K05- BS0506 2.60 2676	K05- BN0118 3.00 2665	K05- BH0305 3.00 2664	K05- BN0052 3.00 2669	K05- BH0247 3.00 2668	K05- BN0376 3.00 2662	K05- BS0423 2.60 2673	K05- BR0592 2.00 2663

Forsmark 1 Enrichment diagram assembly KU0269, KU0278 and KU0282

E5 19,26,27	FORSMARK 1	1986 SV

KWU 9x9-5 ERSÄTTNINGSBRÄNSLE 5 MED MEDELANRIKNINGEN 2.88 W/O U-235
ZONANRIKNING: 3.13 W/O I NOD. 2-24 OCH 0.71 W/O I NOD. 1 OCH 25
BA-INSATS: 6 Gd-STAVAR AV BA1 OCH 1 Gd-STAV AV BA2 MED 2.50 W/O Gd2O3



2.2 Forsmark 2

REACTOR FORSMARK 2

Reactor data	Value
Reactor pressure (MPa) at full power	7
Inlet temperature into core (C) at full power	273.7
Outlet temperature into core (C) at full power	286
Avg. temperature in the uranium pellets at full power (C)	486
Avg. temperature in the cladding at full power (C)	290
Temperature in the boxwall at full power (C)	286

Cycle data

Cycle no	Start	Stop	Reactor power MW	Burnup avg/cycle MWd/tU	No of assemblies in core
1a	1980-12-01	1982-05-01	2,711	7,214	676
1b	1982-08-18	1983-05-20	2,711	5,492	676
2	1983-06-11	1984-05-25	2,711	5,492	676
3	1984-07-13	1985-07-05	2,711	6,886	676
4	1985-07-26	1986-07-25	2,711	6,672	676
5	1986-08-09	1987-05-31	2,928	6,395	676
6	1987-06-20	1988-07-15	2,928	7,882	676
7	1988-08-04	1989-08-18	2,928	6,775	676
8	1989-09-04	1990-05-18	2,928	5,079	676
9	1990-06-12	1991-07-12	2,928	8,185	676
10	1991-07-31	1992-08-14	2,928	7,789	676
11	1992-08-31	1993-07-30	2,928	6,818	676
12	1993-09-07	1994-05-28	2,928	5,918	676

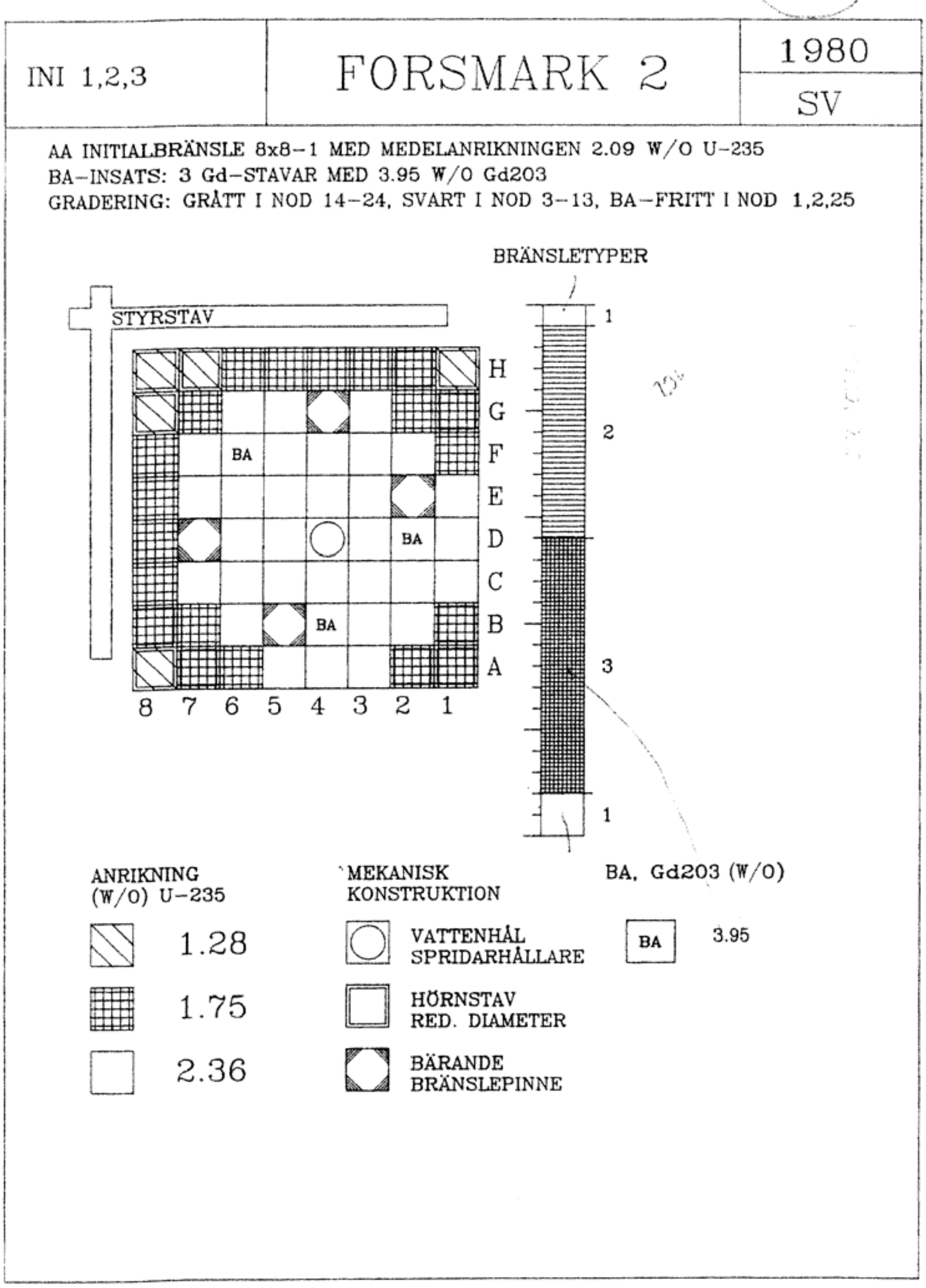
Fuel data	Fuel id 5535	11494	11495	13775
Fuel type	8×8–1	Svea 64	Svea 64	Svea 64
No of fuel rods	63	63	63	63
Rod pitch normal rods (mm)	16.3	15.8	15.8	15.8
Rod pitch normal – corner rods (mm)	16.05			
Rod pitch corner – corner rods (mm)	15.8			
Rod diameter normal rod (mm)	12.25	12.25	12.25	12.25
Clad thickness normal rod (mm)	0.8	0.8	0.8	0.8
Pellet diameter normal rod (mm)	10.44	10.44	10.44	10.44
No of normal rods	51	63	63	63
Rod diameter corner rod (mm)	11.75			
Clad thickness corner rod (mm)	0.8			
Pellet diameter corner rod (mm)	9.94			
No of corner rods	12			
Active length (mm)	3,680	3,680	3,680	3,680
Density UO2 (g/cc)	10.5	10.5	10.5	10.5
Porsity,dishing etc (%)	1.41	1.31	1.32	1.175
	10.35195	10.36245	10.3614	10.376625
No of spacer rods	1	1	1	1
Material in spacer rods	Zr2	Zr2	Zr2	Zr2
Outer diameter spacer rods (mm)	12.25	12.25	12.25	12.25
Cladding thickness spacer rod	0.8	0.8	0.8	0.8
No of water rods		1	4	4
Material in water rods		Zr2	Zr2	Zr2
Outer diameter water rods (mm)		15	15	15
Inner diameter water rods (mm)		0.8	0.8	0.8
No of BA rods		4	4	5
% Gd2O3		2.55	2.55	2.55
Rel poison		0.82	0.82	1
No of spacers	6	4×6	4×6	4×6
Spacer material	Inconel	Inconel	Inconel	Inconel
Mass of spacer (g)	135	35	35	35
Box material	Zr4	Zr4	Zr4	Zr4
Box outer measure square (mm)	139	140	140	140
Box wall thickness (mm)	2.3	1.1	1.1	1.1

Initial data	5535	11494	11495	13775
Initial mass Utot (g)	177,689	181,088	181,070	181,340
Initial mass U235 (g)	3,723	5,287	5,287	5,175
Avg.enrichment% U235	2.095	2.920	2.910	2.850
Data after rebuild 1				
Date of rebuild				
No of fuel rods				
No spacer rods				
No water rods				
No of water holes				
Mass Utot after rebuild (g)				
Mass U235 after rebuild (g)				
Data after rebuild 2				
Date of rebuild				
No of fuel rods				
No spacer rods				
No water rods				
No of water holes				
Mass Utot after rebuild (g)				
Mass U235 after rebuild (g)				
Cycle history burnup/cycle, MWd/tU				
1a	8,850			
1b	1,908			
2	2,104			
3	2,120	9,098	9,098	
4	1,683	7,578	7,578	
5	1,450	7,460	7,460	8,801
6	1,829	8,295	8,295	9,499
7				5,675
8				3,523
9				5,339
10				
Axial BU distribution, EOL MWd/tUNode no (top=25)				
2	18,572	24,831	27,664	25,831
3	22,317	30,845	34,966	32,613
4	24,211	33,763	38,158	35,857
5	26,162	35,914	40,116	38,143
6	27,304	36,991	40,833	39,258
7	27,967	37,557	40,928	39,764
8	28,225	37,745	40,613	39,739
9	29,300	38,515	41,035	40,345
10	29,976	38,848	41,198	40,592
11	30,173	39,001	41,264	40,697
12	29,875	38,735	40,984	40,415
13	30,437	39,103	41,326	40,772
14	30,582	39,150	41,205	40,759
15	30,509	38,986	40,782	40,520
16	29,857	38,482	39,990	40,005
17	29,951	38,550	39,746	40,153
18	29,519	38,243	39,094	40,085
19	28,674	37,617	38,068	39,785
20	27,211	36,474	36,449	38,917
21	26,148	35,470	34,847	38,102
22	24,196	33,379	32,126	35,972
23	21,218	29,888	27,929	31,934
24	16,789	24,090	22,053	25,653
25	12,124	18,330	9,013	10,199

Void history Node no (top=25)	5535	11494	11495	13775
1	–0.04	–0.03	–0.03	–0.03
2	–0.04	–0.03	–0.03	–0.03
3	–0.03	–0.01	–0.01	–0.01
4	0.00	0.04	0.04	0.05
5	0.05	0.11	0.11	0.12
6	0.10	0.19	0.19	0.20
7	0.14	0.26	0.26	0.27
8	0.17	0.32	0.32	0.33
9	0.19	0.37	0.37	0.39
10	0.21	0.43	0.43	0.44
11	0.23	0.47	0.47	0.48
12	0.25	0.51	0.51	0.52
13	0.27	0.55	0.55	0.56
14	0.29	0.58	0.58	0.59
15	0.31	0.61	0.61	0.61
16	0.33	0.63	0.63	0.64
17	0.35	0.66	0.66	0.66
18	0.37	0.68	0.68	0.68
19	0.39	0.70	0.70	0.69
20	0.40	0.71	0.71	0.71
21	0.41	0.73	0.73	0.72
22	0.42	0.74	0.74	0.73
23	0.43	0.75	0.75	0.74
24	0.44	0.75	0.75	0.74
25	0.46	0.76	0.76	0.75
Density history Node no (top=25)				
1	0.77	0.76	0.76	0.76
2	0.76	0.76	0.76	0.76
3	0.75	0.74	0.74	0.74
4	0.72	0.70	0.70	0.71
5	0.69	0.66	0.66	0.67
6	0.66	0.61	0.61	0.62
7	0.63	0.57	0.57	0.58
8	0.61	0.52	0.52	0.54
9	0.60	0.48	0.48	0.50
10	0.58	0.45	0.45	0.47
11	0.57	0.42	0.42	0.44
12	0.56	0.39	0.39	0.41
13	0.55	0.36	0.36	0.39
14	0.53	0.34	0.34	0.36
15	0.51	0.32	0.32	0.34
16	0.50	0.31	0.31	0.33
17	0.49	0.29	0.29	0.31
18	0.47	0.28	0.28	0.30
19	0.46	0.26	0.26	0.28
20	0.46	0.25	0.25	0.27
21	0.45	0.24	0.24	0.26
22	0.44	0.24	0.24	0.26
23	0.44	0.23	0.23	0.25
24	0.43	0.22	0.22	0.24
25	0.42	0.22	0.22	0.24

Control rod history **Node no (top=25)**				
1	0.00	0.03	0.03	0.00
2	0.00	0.02	0.02	0.00
3	0.00	0.02	0.02	0.00
4	0.00	0.01	0.01	0.00
5	0.00	0.01	0.01	0.00
6	0.00	0.01	0.01	0.00
7	0.00	0.01	0.01	0.00
8	0.00	0.01	0.01	0.00
9	0.00	0.01	0.01	0.00
10	0.00	0.01	0.01	0.00
11	0.00	0.01	0.01	0.00
12	0.00	0.01	0.01	0.00
13	0.00	0.01	0.01	0.00
14	0.00	0.01	0.01	0.00
15	0.00	0.00	0.00	0.00
16	0.00	0.00	0.00	0.00
17	0.00	0.00	0.00	0.00
18	0.00	0.00	0.00	0.00
19	0.00	0.00	0.00	0.00
20	0.00	0.00	0.00	0.00
21	0.00	0.00	0.00	0.00
22	0.00	0.00	0.00	0.00
23	0.00	0.00	0.00	0.00
24	0.00	0.00	0.00	0.00
25	0.00	0.00	0.00	0.00

Forsmark 2 Enricchment diagram assembly 5535 (without BA)



Forsmark 2 Fuel rod diagram assembly 11494

FORSMARKS KRAFTGRUPP

PATRON NR 11494
BOX NR 34S024

ANRIKN % VERKL	ANTAL STAVAR	KG UO2	KG UTOT	KG U235
2.920	63	205.704	181.088	5.287

	A	B	C	D	E	F	G	H
8	076- 20224 1.98 3263	076- 24651 2.48 3263	076- 24509 2.48 3260	076- 24549 2.48 3261	076- 24556 2.48 3261	076- 24538 2.48 3255	076- 24558 2.48 3262	076- 20221 1.98 3265
7	076- 24553 2.48 3259	076- 15458 3.17 3239	076- 00604 3.32 3278	076- 21902 3.32 3271	076- 21951 3.32 3275	076- 00639 3.32 3270	076- 15485 3.17 3235	076- 24528 2.48 3260
6	076- 24550 2.48 3261	076- 00610 3.32 3274	076- 00718 3.32 3268	076- 21907 3.32 3274	076- 21993 3.32 3275	076- 00708 3.32 3267	076- 00635 3.32 3272	076- 24709 2.48 3256
5	076- 24546 2.48 3260	076- 21971 3.32 3266	076- 21920 3.32 3271	076- 21852 3.32 3277	076- 21840 3.32 3272	076- 21955 3.32 3267	076- 21979 3.32 3275	076- 24589 2.48 3266
4	076- 24639 2.48 3268	076- 21906 3.32 3272	076- 21944 3.32 3280	076- 21918 3.32 3273	076- 21879 3.32 3267	076- 21903 3.32 3271	076- 21926 3.32 3270	076- 24529 2.48 3259
3	076- 24615 2.48 3261	076- 00665 3.32 3271		076- 21970 3.32 3273	076- 21972 3.32 3273	076- 00728 3.32 3265	076- 00663 3.32 3270	076- 24631 2.48 3264
2	076- 24552 2.48 3265	076- 15453 3.17 3230	076- 00603 3.32 3277	076- 21989 3.32 3274	076- 21991 3.32 3277	076- 00657 3.32 3267	076- 15474 3.17 3238	076- 24540 2.48 3253
1	076- 20211 1.98 3269	076- 24554 2.48 3266	076- 24590 2.48 3263	076- 24614 2.48 3261	076- 24609 2.48 3266	076- 24617 2.48 3258	076- 24580 2.48 3263	076- 20180 1.98 3262

Forsmark 2 Fuel rod diagram assembly 11495

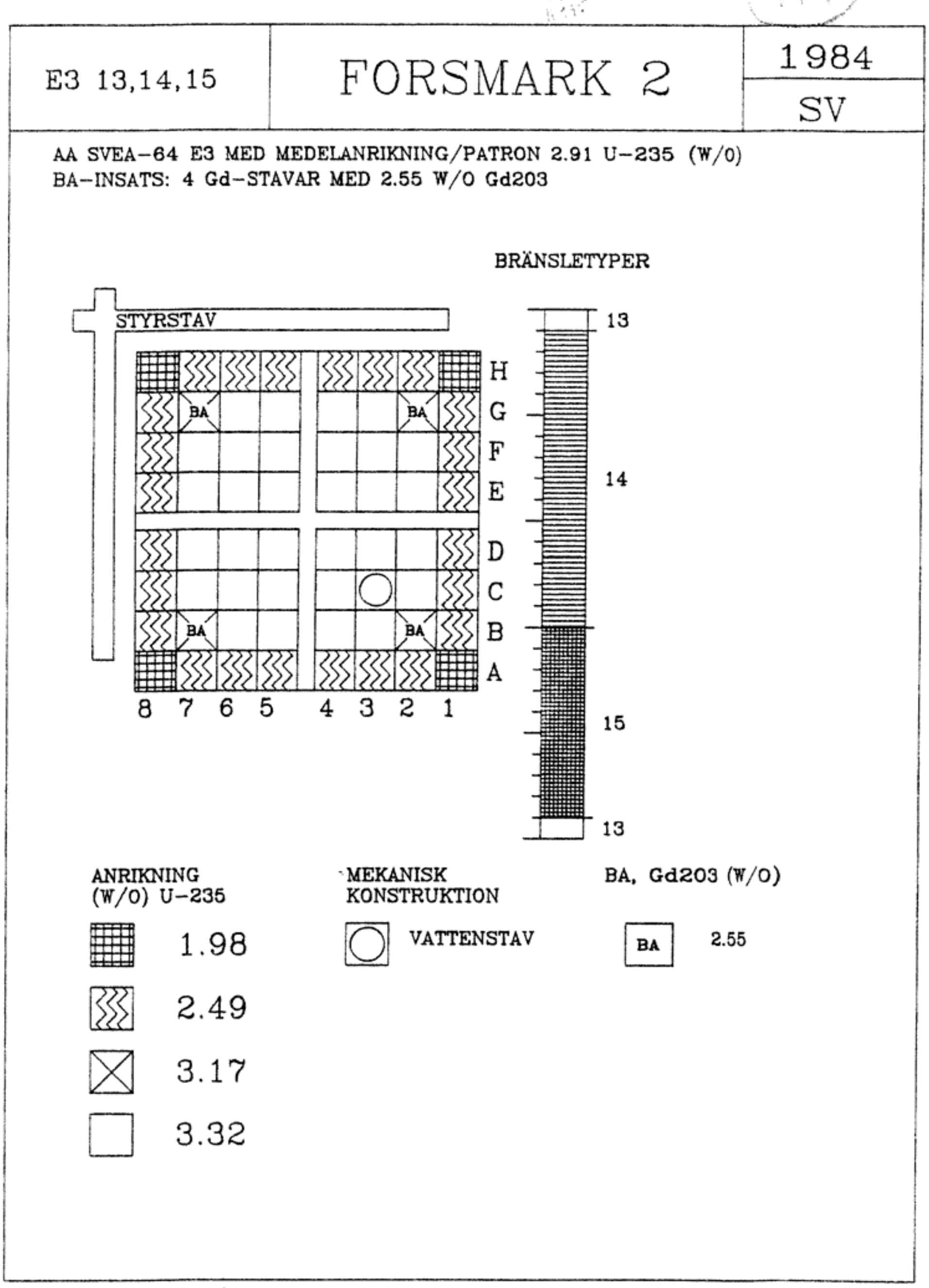
FORSMARKS KRAFTGRUPP

PATRON NR 11495
BOX NR 34S042

ANRIKN % VERKL	ANTAL STAVAR	KG UO2	KG UTOT	KG U235
2.920	63	205.684	181.070	5.287

	A	B	C	D	E	F	G	H
8	076-20204 1.98 3264	076-24572 2.48 3258	076-24519 2.48 3256	076-24534 2.48 3264	076-24624 2.48 3264	076-24555 2.48 3265	076-24655 2.48 3267	076-20184 1.98 3266
7	076-24563 2.48 3259	076-15479 3.17 3234	076-00623 3.32 3275	076-21839 3.32 3275	076-21823 3.32 3277	076-00654 3.32 3267	076-15491 3.17 3241	076-24566 2.48 3261
6	076-24571 2.48 3256	076-00636 3.32 3267	076-00729 3.32 3265	076-21847 3.32 3267	076-21820 3.32 3278	076-00717 3.32 3266	076-00664 3.32 3271	076-24542 2.48 3259
5	076-24524 2.48 3257	076-21807 3.32 3277	076-21868 3.32 3271	076-21832 3.32 3273	076-21867 3.32 3272	076-21801 3.32 3278	076-21934 3.32 3276	076-24578 2.48 3254
4	076-24515 2.48 3257	076-21822 3.32 3278	076-21893 3.32 3272	076-21887 3.32 3272	076-21806 3.32 3277	076-21889 3.32 3271	076-21896 3.32 3271	076-24511 2.48 3262
3	076-24569 2.48 3265	076-00605 3.32 3277		076-21953 3.32 3277	076-21884 3.32 3274	076-00701 3.32 3266	076-00651 3.32 3268	076-24573 2.48 3259
2	076-24712 2.48 3256	076-15473 3.17 3236	076-00655 3.32 3266	076-21805 3.32 3267	076-21875 3.32 3274	076-00621 3.32 3272	076-15452 3.17 3237	076-24536 2.48 3256
1	076-20214 1.98 3262	076-24595 2.48 3260	076-24643 2.48 3265	076-24567 2.48 3260	076-24564 2.48 3260	076-24557 2.48 3261	076-24582 2.48 3262	076-20213 1.98 3264

Forsmark 2 Enrichment diagram assemblies 11494 and 11495



Forsmark 2 Fuel rod diagram assembly 13775

FORSMARKS KRAFTGRUPP

PATRON NR 13775
BOX NR 44S196

ANRIKN % VERKL	ANTAL STAVAR	KG UO2	KG UTOT	KG U235
2.854	63	206.067	181.340	5.175

	A	B	C	D	E	F	G	H
8	099-20698 1.98 3266	099-20967 2.48 3268	099-21040 2.48 3266	099-21009 2.48 3267	099-21029 2.48 3273	099-20972 2.48 3275	099-20931 2.48 3271	099-20834 1.98 3270
7	099-21044 2.48 3265	099-15422 3.14 3253	099-114 3.29 3277	099-20631 3.29 3274	099-20658 3.29 3274	099-185 3.29 3263	099-15424 3.14 3252	099-20962 2.48 3271
6	099-21056 2.48 3274	099-202 3.29 3273	099-1017 3.29 3278	099-20602 3.29 3273	099-20567 3.29 3279	099-1041 3.29 3278	099-173 3.29 3271	099-20927 2.48 3271
5	099-20947 2.48 3274	099-20635 3.29 3281	099-20592 3.29 3278	099-20594 3.29 3274	099-15406 3.14 3248	099-20572 3.29 3274	099-20670 3.29 3274	099-20971 2.48 3275
4	099-20998 2.48 3279	099-20587 3.29 3278	099-20553 3.29 3274	099-20534 3.29 3271	099-20623 3.29 3274	099-20624 3.29 3271	099-20484 3.29 3273	099-21050 2.48 3278
3	099-20938 2.48 3273	099-067 3.29 3277		099-20483 3.29 3276	099-20625 3.29 3273	099-1038 3.29 3275	099-084 3.29 3287	099-20990 2.48 3254
2	099-21047 2.48 3276	099-15270 3.14 3251	099-001 3.29 3264	099-20532 3.29 3271	099-20550 3.29 3270	099-044 3.29 3279	099-15266 3.14 3247	099-21021 2.48 3266
1	099-20729 1.98 3273	099-21032 2.48 3279	099-20923 2.48 3267	099-20991 2.48 3270	099-20997 2.48 3266	099-21094 2.48 3273	099-20941 2.48 3274	099-20711 1.98 3268

Forsmark 2 Fuel rod diagram assembly 13775

FORSMARKS KRAFTGRUPP

PATRON NR 13775
BOX NR 44S196

ANRIKN % VERKL	ANTAL STAVAR	KG UO2	KG UTOT	KG U235
2.854	63	206.067	181.340	5.175

	A	B	C	D	E	F	G	H
8	099- 20698 1.98 3266	099- 20967 2.48 3268	099- 21040 2.48 3266	099- 21009 2.48 3267	099- 21029 2.48 3273	099- 20972 2.48 3275	099- 20931 2.48 3271	099- 20834 1.98 3270
7	099- 21044 2.48 3265	099- 15422 3.14 3253	099- 114 3.29 3277	099- 20631 3.29 3274	099- 20658 3.29 3274	099- 185 3.29 3263	099- 15424 3.14 3252	099- 20962 2.48 3271
6	099- 21056 2.48 3274	099- 202 3.29 3273	099- 1017 3.29 3278	099- 20602 3.29 3273	099- 20567 3.29 3279	099- 1041 3.29 3278	099- 173 3.29 3271	099- 20927 2.48 3271
5	099- 20947 2.48 3274	099- 20635 3.29 3281	099- 20592 3.29 3278	099- 20594 3.29 3274	099- 15406 3.14 3248	099- 20572 3.29 3274	099- 20670 3.29 3274	099- 20971 2.48 3275
4	099- 20998 2.48 3279	099- 20587 3.29 3278	099- 20553 3.29 3274	099- 20534 3.29 3271	099- 20623 3.29 3274	099- 20624 3.29 3271	099- 20484 3.29 3273	099- 21050 2.48 3278
3	099- 20938 2.48 3273	099- 067 3.29 3277		099- 20483 3.29 3276	099- 20625 3.29 3273	099- 1038 3.29 3275	099- 084 3.29 3287	099- 20990 2.48 3254
2	099- 21047 2.48 3276	099- 15270 3.14 3251	099- 001 3.29 3264	099- 20532 3.29 3271	099- 20550 3.29 3270	099- 044 3.29 3279	099- 15266 3.14 3247	099- 21021 2.48 3266
1	099- 20729 1.98 3273	099- 21032 2.48 3279	099- 20923 2.48 3267	099- 20991 2.48 3270	099- 20997 2.48 3266	099- 21094 2.48 3273	099- 20941 2.48 3274	099- 20711 1.98 3268

2.3 Forsmark 3

REACTOR FORSMARK 3

Reactor data	Value
Reactor pressure (MPa) at full power	7
Inlet temperature into core (C) at full power	260
Outlet temperature into core (C) at full power	286
Pitch between assemblis in the core (c–c, mm)	
Avg. temperature in the uranium pellets at full power (C)	507
Avg. temperature in the cladding at full power (C)	290
Temperature in the boxwall at full power (C)	286

Cycle data

Cycle no	Start	Stop	Reactor power MW	Burnup avg/cycle MWd/tU	No of assemblies in core
1a	1984-12-01	1985-06-21	3,020	804	700
1b	1985-07-16	1986-08-08	3,020	8,544	700
2	1986-09-02	1987-07-10	3,020	6,536	700
3	1987-08-09	1988-08-12	3,300	7,906	700
4	1988-09-05	1989-06-09	3,300	5,686	700
5	1989-07-13	1990-07-13	3,300	7,643	700
6	1990-07-29	1991-08-17	3,300	8,984	700
7	1991-09-02	1992-05-15	3,300	6,343	700
8	1992-06-16	1993-06-05	3,300	8,002	700
9	1993-06-21	1994-07-09	3,300	9,148	700
10	1994-07-27	1995-07-29	3,300	9,094	700
11	1995-08-16	1996-05-16	3,300	6,940	700
12	1996-06-17	1997-07-05	3,300	9,816	700

Fuel data	Fuel id 13847	13848
Fuel type	Svea 100	Svea100
No of fuel rods	100	100
Rod pitch normal rods (mm)	12.4	12.4
Rod pitch normal – corner rods (mm)		
Rod pitch corner – corner rods (mm)		
Rod diameter normal rod (mm)	12.4	12.4
Clad thickness normal rod (mm)	9.62	9.62
Pellet diameter normal rod (mm)	0.63	0.63
No of normal rods	8.19	8.19
	100	100
Rod diameter corner rod (mm)		
Clad thickness corner rod (mm)		
Pellet diameter corner rod (mm)		
No of corner rods		
Active length (mm)	3,680	3,680
Density UO2 (g/cc)	10.7	10.7
Porsity,dishing etc (%)	1.09	1.09
No of spacer rods		
Material in spacer rods		
Outer diameter spacer rods (mm)		
Cladding thickness spacer rod		
No of water rods		
Material in water rods		
Outer diameter water rods (mm)		
Inner diameter water rods (mm)		
No of BA rods	8	8
% Gd2O3	4.4	4.4
Rel poison	1	1
No of spacers	4×6	4×6
Spacer material	Inconel	Inconel
Mass of spacer (g)	35	35
Box material	Zr4	Zr4
Box outer measure square (mm)	139.6	139.6

Initial data	13847	13848
Initial mass Utot (g)	180,669	180,667
Initial mass U235 (g)	5,002	5,002
Avg.enrichment% U235	2.769	2.769
Data after rebuild 1		
Date of rebuild		
No of fuel rods		
No spacer rods		
No water rods		
No of water holes		
Mass Utot after rebuild (g)		
Mass U235 after rebuild (g)		
Data after rebuild 2		
Date of rebuild		
No of fuel rods		
No spacer rods		
No water rods		
No of water holes		
Mass Utot after rebuild (g)		
Mass U235 after rebuild (g)		
Cycle history burnup/cycle, MWd/tU		
1a		
1b		
2	7,857	7,857
3	9,360	9,360
4	6,562	6,562
5	7,496	7,496
6		
Axial BU distribution, EOL MWd/tUNode no (top=25)		
1	7,519	7,519
2	24,984	24,984
3	30,453	30,453
4	32,711	32,711
5	34,413	34,413
6	35,093	35,093
7	35,289	35,289
8	35,041	35,041
9	35,606	35,606
10	35,824	35,824
11	35,873	35,873
12	35,478	35,478
13	35,803	35,803
14	35,762	35,762
15	35,526	35,526
16	35,014	35,014
17	35,262	35,262
18	35,157	35,157
19	34,738	34,738
20	33,746	33,746
21	32,941	32,941
22	30,977	30,977
23	27,464	27,464
24	22,109	22,109
25	9,084	9,084

Void history Node no (top=25)	13847	13848
1	–0.02	–0.02
2	–0.02	–0.02
3	0.00	0.00
4	0.06	0.06
5	0.14	0.14
6	0.22	0.22
7	0.30	0.30
8	0.36	0.36
9	0.42	0.42
10	0.47	0.47
11	0.51	0.51
12	0.55	0.55
13	0.58	0.58
14	0.61	0.61
15	0.64	0.64
16	0.66	0.66
17	0.68	0.68
18	0.70	0.70
19	0.72	0.72
20	0.73	0.73
21	0.74	0.74
22	0.76	0.76
23	0.76	0.76
24	0.77	0.77
25	0.77	0.77
Density history **Node no (top=25)**		
1	757	757
2	753	753
3	730	730
4	686	686
5	633	633
6	580	580
7	530	530
8	486	486
9	448	448
10	414	414
11	384	384
12	359	359
13	337	337
14	317	317
15	300	300
16	285	285
17	271	271
18	259	259
19	248	248
20	238	238
21	229	229
22	221	221
23	215	215
24	210	210
25	206	206

Control rod history Node no (top=25)		
1	0.02	0.02
2	0.02	0.02
3	0.01	0.01
4	0	0
5	0	0
6	0	0
7	0	0
8	0	0
9	0	0
10	0	0
11	0	0
12	0	0
13	0	0
14	0	0
15	0	0
16	0	0
17	0	0
18	0	0
19	0	0
20	0	0
21	0	0
22	0	0
23	0	0
24	0	0
25	0	0

Forsmark 3 Fuel rod diagram assembly 13847

FORSMARKS KRAFTGRUPP

PATRON NR 13847
BOX NR 44S399

ANRIKN % VERKL	ANTAL STAVAR	KG UO2	KG UTOT	KG U235
2.769	100	205.738	180.669	5.002

	A	B	C	D	E	F	G	H	I	J
10	111- 20059 1.91 2060	111- 20181 2.41 2060	111- 20207 2.41 2063	111- 20103 2.41 2065	111- 20419 2.41 2060	111- 20358 2.41 2058	111- 20159 2.41 2065	111- 20191 2.41 2063	111- 20099 1.91 2060	111- 20098 1.64 2056
9	111- 20003 2.41 2067	111- 20414 3.08 2055	111- 15024 3.12 2038	111- 27 3.08 2055	111- 20289 3.08 2056	111- 20286 3.08 2057	111- 16 3.08 2059	111- 15023 3.12 2040	111- 20065 2.41 2065	111- 20039 1.91 2060
8	111- 20137 2.41 2058	111- 20444 3.08 2057	111- 1034 3.08 2063	111- 20445 3.08 2058	111- 20353 3.08 2059	111- 20236 3.08 2058	111- 20227 3.08 2054	111- 1026 3.08 2057	111- 15012 3.12 2040	111- 20263 2.41 2059
7	111- 20048 2.41 2060	111- 51 3.08 2056	111- 20310 3.08 2059	111- 20415 3.08 2059	111- 20380 3.08 2057	111- 20325 3.08 2059	111- 20341 3.08 2058	111- 20356 3.08 2055	111- 45 3.08 2059	111- 20222 2.41 2062
6	111- 20192 2.41 2061	111- 15025 3.12 2039	111- 20335 3.08 2058	111- 20401 3.08 2058	111- 20397 3.08 2057	111- 20328 3.08 2058	111- 20373 3.08 2055	111- 20261 3.08 2056	111- 20302 3.08 2057	111- 20186 2.41 2063
5	111- 20043 2.41 2065	111- 20426 3.08 2059	111- 20294 3.08 2059	111- 20347 3.08 2057	111- 15051 3.12 2042	111- 20233 3.08 2055	111- 20265 3.08 2058	111- 20322 3.08 2057	111- 20248 3.08 2054	111- 20202 2.41 2062
4	111- 20420 2.41 2058	111- 29 3.08 2058	111- 20421 3.08 2057	111- 20436 3.08 2057	111- 20342 3.08 2057	111- 20403 3.08 2058	111- 20410 3.08 2058	111- 20367 3.08 2058	111- 56 3.08 2059	111- 20150 2.41 2062
3	111- 20031 2.41 2063	111- 20434 3.08 2059	111- 1014 3.08 2059	111- 20361 3.08 2061	111- 20383 3.08 2055	111- 20385 3.08 2055	111- 20370 3.08 2057	111- 1032 3.08 2062	111- 15027 3.12 2043	111- 20363 2.41 2059
2	111- 20443 2.41 2059	111- 15007 3.12 2041	111- 20247 3.08 2059	111- 36 3.08 2060	111- 20362 3.08 2057	111- 15041 3.12 2043	111- 57 3.08 2058	111- 20351 3.08 2055	111- 20448 3.08 2058	111- 20114 2.41 2062
1	111- 20213 1.91 2055	111- 20252 2.41 2060	111- 20131 2.41 2062	111- 20433 2.41 2059	111- 20055 2.41 2063	111- 20154 2.41 2058	111- 20140 2.41 2061	111- 20311 2.41 2058	111- 20163 2.41 2059	111- 20195 1.91 2057

Forsmark 3 Fuel rod diagram assembly 13848

FORSMARKS KRAFTGRUPP

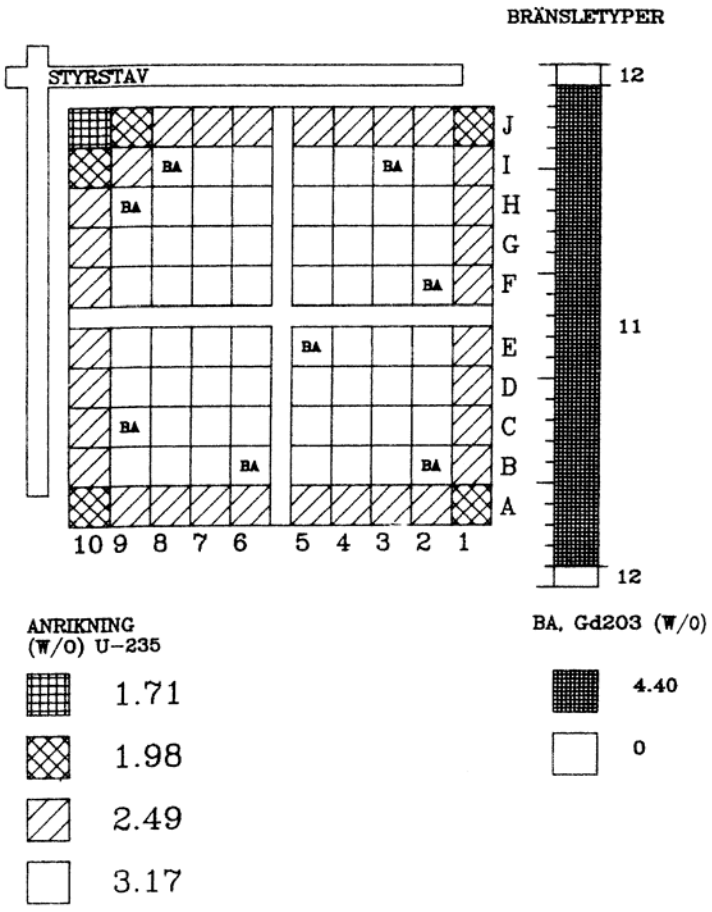
PATRON NR 13848
BOX NR 44S408

ANRIKN % VERKL	ANTAL STAVAR	KG UO2	KG UTOT	KG U235
2.769	100	205.734	180.667	5.002

	A	B	C	D	E	F	G	H	I	J
10	111- 20071 1.91 2057	111- 20117 2.41 2061	111- 20122 2.41 2065	111- 20442 2.41 2060	111- 20112 2.41 2064	111- 20146 2.41 2064	111- 20387 2.41 2060	111- 20021 2.41 2062	111- 20060 1.91 2057	111- 20002 1.64 2055
9	111- 20125 2.41 2060	111- 20339 3.08 2057	111- 15031 3.12 2042	111- 48 3.08 2059	111- 20424 3.08 2058	111- 20231 3.08 2058	111- 54 3.08 2058	111- 15015 3.12 2043	111- 20051 2.41 2061	111- 20092 1.91 2062
8	111- 20221 2.41 2056	111- 20296 3.08 2056	111- 1021 3.08 2065	111- 20388 3.08 2058	111- 20273 3.08 2058	111- 20226 3.08 2056	111- 20281 3.08 2058	111- 1020 3.08 2061	111- 15005 3.12 2041	111- 20249 2.41 2061
7	111- 20023 2.41 2059	111- 49 3.08 2058	111- 20441 3.08 2058	111- 20438 3.08 2057	111- 20450 3.08 2056	111- 20259 3.08 2056	111- 20285 3.08 2055	111- 20425 3.08 2057	111- 9 3.08 2059	111- 20132 2.41 2062
6	111- 20429 2.41 2059	111- 15017 3.12 2032	111- 20327 3.08 2058	111- 20354 3.08 2058	111- 20276 3.08 2055	111- 20301 3.08 2058	111- 20406 3.08 2058	111- 20306 3.08 2056	111- 20416 3.08 2055	111- 20111 2.41 2065
5	111- 20115 2.41 2061	111- 20355 3.08 2059	111- 20369 3.08 2056	111- 20277 3.08 2056	111- 15008 3.12 2044	111- 20288 3.08 2059	111- 20239 3.08 2057	111- 20366 3.08 2055	111- 20232 3.08 2059	111- 20217 2.41 2064
4	111- 20393 2.41 2059	111- 50 3.08 2060	111- 20293 3.08 2059	111- 20382 3.08 2058	111- 20314 3.08 2058	111- 20260 3.08 2056	111- 20374 3.08 2056	111- 20430 3.08 2054	111- 10 3.08 2058	111- 20158 2.41 2063
3	111- 20020 2.41 2062	111- 20235 3.08 2058	111- 1008 3.08 2063	111- 20412 3.08 2058	111- 20228 3.08 2058	111- 20272 3.08 2058	111- 20299 3.08 2056	111- 1003 3.08 2063	111- 15053 3.12 2042	111- 20061 2.41 2065
2	111- 20026 2.41 2059	111- 15037 3.12 2040	111- 20313 3.08 2058	111- 37 3.08 2055	111- 20439 3.08 2054	111- 15004 3.12 2037	111- 43 3.08 2060	111- 20329 3.08 2058	111- 20291 3.08 2054	111- 20012 2.41 2060
1	111- 20200 1.91 2054	111- 20022 2.41 2063	111- 20219 2.41 2064	111- 20127 2.41 2062	111- 20331 2.41 2058	111- 20147 2.41 2060	111- 20001 2.41 2057	111- 20025 2.41 2064	111- 20129 2.41 2061	111- 20053 1.91 2058
	A	B	C	D	E	F	G	H	I	J

D1 11	FORSMARK 3	1986 SV

AA SVEA 5*5, ej ändzoner U-235 hela knippet 2.71 W/O
Zonanrikningar (w/o): nod 2-24 2.88, nod 1,25 0.71
BA-insats: 8*4.40 w/o Gd203



2.4 Oskarshamn 2

REACTOR OSKARSHAMN 2

Reactor data	Value
Reactor pressure (MPa) at full power	7
Inlet temperature into core (C) at full power	274
Outlet temperature into core (C) at full power	286
Avg. temperature in the uranium pellets at full power (C)	500
Avg. temperature in the cladding at full power (C)	290
Temperature in the boxwall at full power (C)	286

Cycle data

Cycle no	Start	Stop	Reactor power MW	Burnup avg/ cycle MWd/tU	No of assem- blies in core
1	1974-10-02	1976-04-16	3,978	1,800	444
2	1976-07-02	1977-05-13	5,164	1,800	444
3	1977-08-07	1978-06-24	6,210	1,800	444
4	1978-09-03	1979-07-20	6,099	1,800	444
5	1979-08-30	1980-07-12	6,245	1,800	444
6	1980-08-20	1981-07-15	6,474	1,800	444
7	1981-08-30	1982-07-23	6,677	1,800	444
8	1982-08-23	1983-08-19	7,627	1,800	444
9	1983-09-19	1984-07-01	4,784	1,800	444
10	1984-08-24	1985-06-07	7,912	1,800	444
11	1985-07-13	1986-08-16	7,752	1,800	444
12	1986-09-27	1987-07-31	6,429	1,800	444
13	1987-09-04	1988-08-20	6,942	1,800	444
14	1988-09-10	1989-08-05	5,788	1,800	444
15	1989-09-01	1990-08-10	6,578	1,800	444
16	1990-10-11	1991-08-02	6,526	1,800	444

Fuel data	Fule id 1377	1389	1546	1696	1704	2995	3054	3058	3064	6350	12684
Fuel type	8×8	8×8	8×8	8×8	8×8	8×8	8×8	8×8	8×8	8×8	SVEA 64
No of fuel rods	63	63	63	63	63	63	63	63	63	63	63
Rod pitch normal rods (mm)	16.3	16.3	16.3	16.3	16.3	16.3	16.3	16.3	16.3	16.3	15.8
Rod pitch normal – corner rods (mm)	16.05	16.05	16.05	16.05	16.05	16.05	16.05	16.05	16.05	16.05	
Rod pitch corner – corner rods (mm)	15.8	15.8	15.8	15.8	15.8	15.8	15.8	15.8	15.8	15.8	
Rod diameter normal rod (mm)	12.25	12.25	12.25	12.25	12.25	12.25	12.25	12.25	12.25	12.25	12.25
Clad thickness normal rod (mm)	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Pellet diameter normal rod (mm)	10.44	10.44	10.44	10.44	10.44	10.44	10.44	10.44	10.44	10.44	10.44
No of normal rods	51	51	51	51	51	51	51	51	51	51	63
Rod diameter corner rod (mm)	11.75	11.75	11.75	11.75	11.75	11.75	11.75	11.75	11.75	11.75	
Clad thickness corner rod (mm)	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	
Pellet diameter corner rod (mm)	9.94	9.94	9.94	9.94	9.94	9.94	9.94	9.94	9.94	9.94	
No of corner rods	12	12	12	12	12	12	12	12	12	12	
Active length (mm)	3,712	3,712	3,712	3,712	3,712	3,712	3,712	3,712	3,712	3,712	3,712
Density UO2 (g/cc)	10.71	10.715	10.733	10.75	10.735	10.465	10.455	10.462	10.46	10.443	10.447
Porsity,dishing etc (%)	1	1	1	1	1	1	1	1	1	1	1
No of spacer rods	1	1	1	1	1	1	1	1	1	(1 tot)	3 (4 tot)
Material in spacer rods	Zr	Zr	Zr	Zr	Zr	Zr	Zr	Zr	Zr		Zr
Outer diameter spacer rods (mm)	12.25	12.25	12.25	12.25	12.25	12.25	12.25	12.25	12.25		12.25
Cladding thickness spacer rod											0.8
No of water rods										1 sprh	1 sprh
Material in water rods										Zr	Zr
Outer diameter water rods (mm)										12.25	12.25
Inner diameter water rods (mm)										10.65	10.65
No of BA rods	0	0	0	0	0	4	5	5	5	6	6
% Gd2O3	0	0	0	0	0	2	2.55	2.55	2.55	3.2	3.15
Rel poison	0	0	0	0	0	1	1	1	1	1	1
No of spacers	6	6	6	6	6	6	6	6	6	6	4×6
Spacer material	Inconel	Inconel	Inconel	Inconel	Inconel	Inconel	Inconel	Inconel	Inconel	Inconel	Inconel
Mass of spacer (g)	135	135	135	135	135	135	135	135	135	150	31
Box material	Zry–4	Zry–4	Zry–4	Zry–4	Zry–4	Zry–4	Zry–4	Zry–4	Zry–4	Zry–4	Zry–4
Box outer measure square (mm)	138.6	138.6	138.6	138.6	138.6	138.6	138.6	138.6	138.6	138.6	139.6
Box wall thickness (mm)	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	1,1/0,8

Initial data	1377	1389	1546	1696	1704	2995	3054	3058	3064	6350	12684
Initial mass Utot (g)	183,575	183,650	183,968	184,253	184,022	179,382	179,193	179,340	179,257	179,003	182,320
Initial mass U235 (g)	4,040	4,042	4,049	4,055	4,050	4,842	4,952	4,956	4,955	5,146	5,291
Avg.enrichment% U235	2.201	2.201	2.201	2.201	2.201	2.699	2.764	2.763	2.764	2.875	2.902
Data after rebuild 1											
Date of rebuild								1980-12-05	1980-12-15	1980-12-17	
No of fuel rods									56	56	56
No spacer rods											
No water rods											
No of water holes											
Mass Utot after rebuild (g)								160,262	160,372	160,318	
Mass U235 after rebuild (g)								4,633	4,637	4,635	
Data after rebuild 2											
Date of rebuild											
No of fuel rods											
No spacer rods											
No water rods											
No of water holes											
Mass Utot after rebuild (g)											
Mass U235 after rebuild (g)											
Cycle history burnup/cycle, MWd/tU											
1	8,982	4,315	6,961	4,492	4,587						
2	5,564	2,984		3,412	3,445	6,143					
3		4,529		5,354	5,353	7,217	5,703	6,120	8,133		
4		2,710		3,061	3,254	6,346	5,483	5,883	7,733		
5		2,394				3,872	7,921	7,837	6,038		
6		2,548	6,879			6,401				7,113	
7			7,192	2,183	2,799		6,487	7,935	8,487	7,796	
8			3,438	2,368			9,299	4,212		9,110	
9											
10										3,656	
11											11,134
12											8,898
13											8,152
14											7,311
15											7,589
16											3,564
Axial BU distribution, EOL MWd/tUNode no (top=25)											
1	7,600	11,000	13,000	12,100	11,100	19,500	22,300	20,000	18,000	16,300	23,300
2	12,100	16,700	19,800	18,400	17,000	27,900	31,400	28,500	25,900	24,700	37,600
3	14,800	20,000	23,600	21,700	20,300	32,100	36,200	33,000	30,500	29,000	44,300
4	16,300	21,700	25,600	23,400	22,100	34,100	38,300	35,200	32,800	30,800	47,000
5	17,400	22,700	26,800	24,200	23,000	34,900	39,200	36,300	33,800	31,600	49,400
6	17,600	23,200	27,300	24,600	23,500	35,100	39,600	36,900	34,300	31,800	50,700
7	17,400	23,400	27,400	24,800	23,600	35,000	39,700	37,100	34,400	31,800	51,300
8	17,000	23,500	27,600	24,800	23,500	34,900	39,600	37,200	34,500	31,600	51,200
9	16,800	23,400	27,600	24,700	23,300	34,600	39,400	37,000	34,400	31,600	52300
10	16,600	23,300	27,500	24,600	23,100	34,200	39,300	36,800	34,400	31,400	52,800
11	16,400	23,000	27,600	24,400	22,800	33,900	39,200	36,600	34,300	31,500	53,000
12	16,300	22,700	28,000	24,100	22,400	33,400	39,000	36,300	34,200	31,200	52,400
13	16,200	22,400	28,200	23,800	22,100	33,000	38,800	36,000	33,900	31,000	53,000
14	16,100	22,100	28,100	23,400	21,700	32,600	38,600	35,700	33,700	30,700	53,100
15	16,000	21,700	28,000	23,100	21,300	32,200	38,400	35,400	33,600	30,300	52,700
16	15,800	21,300	27,900	22,700	21,000	31,900	38,000	34,900	33,300	29,800	51,800
17	15,600	20,800	27,800	22,300	20,600	31,400	37,500	34,400	32,900	29,500	51,900
18	15,300	20,300	27,400	21,800	20,100	30,900	36,800	33,600	32,500	29,000	51,400
19	15,000	19,600	26,600	21,100	19,400	30,200	36,000	32,600	31,800	28,400	50,400
20	14,500	18,700	25,500	20,300	18,700	29,400	35,000	31,500	30,800	27,400	48,500
21	13,800	17,600	24,000	19,100	17,500	28,100	33,400	29,900	29,600	26,200	47,100
22	12,800	16,100	22,000	17,500	16,000	26,100	31,200	27,800	27,600	24,400	44,300
23	11,300	13,900	19,100	15,200	13,800	23,100	27,800	24,400	24,800	21,700	39,600
24	8,900	10,900	15,100	12,000	10,800	18,500	22,400	19,500	20,100	17,600	32,300
25	5,900	6,900	10,200	7,700	7,000	12,600	15,300	13,000	13,700	12,500	24,700

Void history Node no (top=25)											
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	–0.01	–0.03
2	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.02	0.00	–0.02
3	0.04	0.00	0.03	0.01	0.01	0.03	0.02	0.02	0.05	0.04	0.01
4	0.09	0.02	0.07	0.04	0.03	0.07	0.07	0.06	0.10	0.10	0.08
5	0.15	0.05	0.11	0.08	0.07	0.13	0.12	0.12	0.16	0.17	0.17
6	0.22	0.08	0.17	0.12	0.11	0.19	0.19	0.18	0.23	0.24	0.25
7	0.30	0.11	0.23	0.16	0.16	0.25	0.25	0.24	0.29	0.30	0.31
8	0.37	0.16	0.28	0.21	0.22	0.31	0.31	0.30	0.35	0.36	0.37
9	0.44	0.20	0.33	0.25	0.27	0.36	0.37	0.35	0.40	0.40	0.42
10	0.48	0.24	0.38	0.29	0.32	0.41	0.41	0.40	0.45	0.44	0.47
11	0.53	0.28	0.43	0.32	0.36	0.45	0.46	0.44	0.49	0.48	0.51
12	0.56	0.32	0.46	0.35	0.41	0.49	0.50	0.47	0.53	0.52	0.55
13	0.59	0.35	0.50	0.38	0.44	0.52	0.53	0.50	0.56	0.54	0.58
14	0.62	0.39	0.53	0.41	0.47	0.55	0.56	0.53	0.59	0.57	0.61
15	0.64	0.42	0.56	0.44	0.50	0.58	0.58	0.56	0.61	0.59	0.64
16	0.66	0.45	0.58	0.46	0.53	0.60	0.61	0.58	0.64	0.62	0.66
17	0.68	0.47	0.60	0.49	0.55	0.62	0.63	0.60	0.66	0.64	0.68
18	0.70	0.50	0.63	0.51	0.57	0.64	0.65	0.62	0.67	0.65	0.70
19	0.71	0.52	0.64	0.53	0.59	0.65	0.66	0.64	0.69	0.67	0.72
20	0.72	0.54	0.66	0.54	0.60	0.67	0.68	0.65	0.70	0.69	0.73
21	0.73	0.55	0.68	0.56	0.62	0.68	0.69	0.67	0.72	0.70	0.74
22	0.74	0.56	0.69	0.57	0.63	0.69	0.70	0.68	0.73	0.71	0.75
23	0.74	0.58	0.70	0.58	0.64	0.70	0.71	0.69	0.73	0.72	0.76
24	0.75	0.58	0.70	0.59	0.65	0.71	0.72	0.69	0.74	0.72	0.77
25	0.75	0.59	0.71	0.60	0.65	0.72	0.73	0.70	0.74	0.73	0.77
Control rod history Node no (top=25)											
1	0.12	0.00	0.18	0.00	0.00	0.00	0.00	0.00	0.19	0.00	0.00
2	0.11	0.00	0.17	0.00	0.00	0.00	0.00	0.00	0.18	0.00	0.00
3	0.12	0.00	0.16	0.00	0.00	0.00	0.00	0.00	0.16	0.00	0.00
4	0.13	0.00	0.16	0.00	0.00	0.00	0.00	0.00	0.13	0.00	0.00
5	0.08	0.00	0.16	0.00	0.00	0.00	0.00	0.00	0.12	0.00	0.00
6	0.08	0.00	0.15	0.00	0.00	0.00	0.00	0.00	0.12	0.00	0.00
7	0.07	0.00	0.15	0.00	0.00	0.00	0.00	0.00	0.12	0.00	0.00
8	0.07	0.00	0.15	0.00	0.00	0.00	0.00	0.00	0.12	0.00	0.00
9	0.07	0.00	0.14	0.00	0.00	0.00	0.00	0.00	0.12	0.00	0.00
10	0.07	0.00	0.13	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00
11	0.07	0.00	0.12	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00
12	0.07	0.00	0.11	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00
13	0.06	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00
14	0.06	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00
15	0.06	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00
16	0.06	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.09	0.00	0.00
17	0.06	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.09	0.00	0.00
18	0.06	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.08	0.00	0.00
19	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.00	0.00
20	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.00	0.00
21	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.00
22	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.00
23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00
24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00
25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Oskarshamn 2 Enrichment diagram for assemblies 1377, 1389, 1546, 1686 and 1704

ASEA-ATOM 28 JAN. 1972 KCA 175

Initialpatron

OII-Intern anrikningsfördelning.

C

1377
1389
1546
1686
1704

Bred spalt

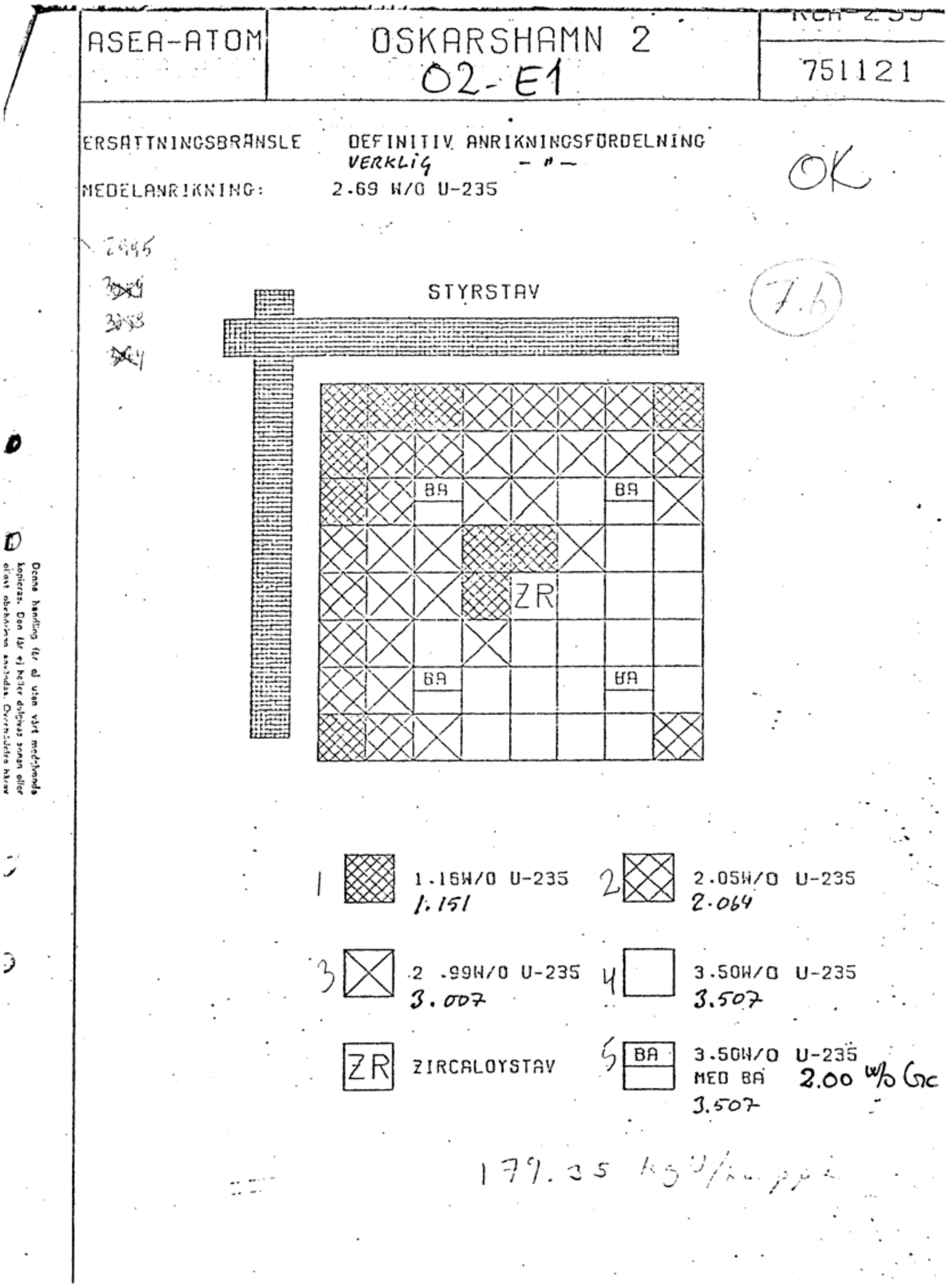
Bred spalt (left side)

3	3	3	3	2	2	2	2
3	2	2	2	2	1	1	1
3	2	2	1	1	1	1	1
3	2	1	~~1~~ 2	1	1	1	1
2	2	1	1	1	1	1	1
2	1	1	1	1	1	1	1
2	1	1	1	1	1	1	1
2	1	1	1	1	1	1	2

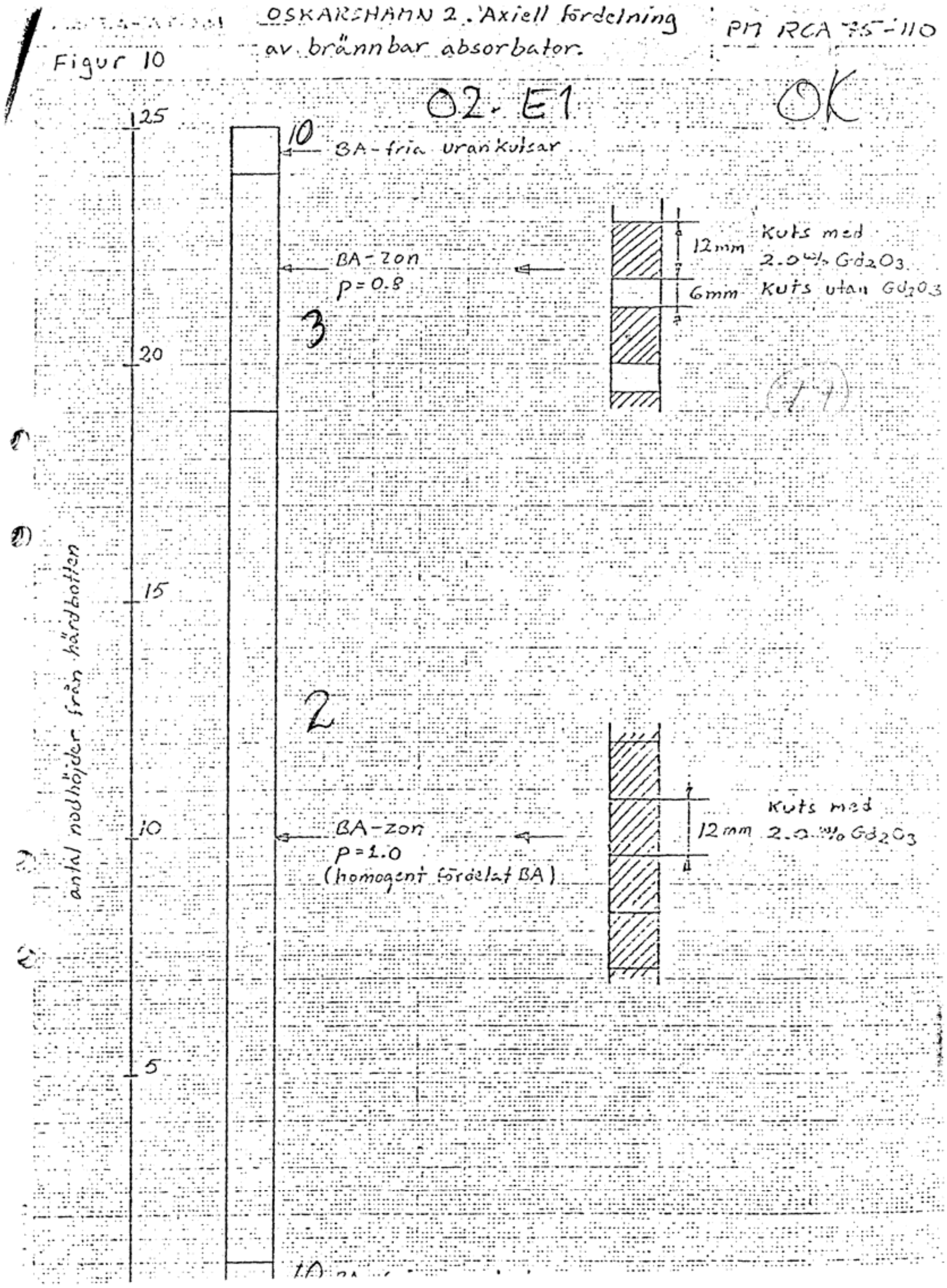
1 ~ 2,5 % U^{235}
2 ~ 1,65 % U^{235}
3 ~ 1,4 % U^{235}

(75)

Oskarshamn 2 2   Enrichment diagram for assembly 2995



Oskarshamn 2 Enrichment diagram for assembly 2995



Oskarshamn 2 Fuel rod diagram for assembly 3054

MONTERINGSPROTOKOLL

OSKARSHAMN II EBS2

PATRON NR 3054 DATUM: 07-04-77 REF. H

	A	B	C	D	E	F	G	H
8	2.02 2.979 5845	2.02 2.972 5838	2.02 3.303 20500	2.02 3.309 20463	2.02 3.294 20560	2.02 3.309 20643	1.18 2.973 5447	1.18 2.973 5418
7	2.80 3.000 6307	2.80 3.298 22215	2.80 3.295 22091	2.80 3.311 274	3.50BA 3.251 15330	2.80 3.295 22035	2.02 3.300 20487	1.18 2.980 5450
6	2.80 3.293 22084	3.50BA 3.255 15337	3.50 3.297 23823	2.80 3.292 22124	2.80 3.304 22093	3.50 3.293 23684	2.80 3.291 22075	2.02 3.300 20502
5	3.50 3.290 23639	3.50 3.298 144	2.80 3.294 22088	1.18 3.305 20167	1.18 3.303 20209	2.80 3.294 22074	3.50BA 3.253 15228	2.02 3.304 20575
4	3.50 3.295 23702	3.50 3.291 23742	3.50 3.295 23743	20101	1.18 3.295 20169	2.80 3.297 22095	2.80 3.311 277	2.02 3.304 20656
3	3.50 3.291 23649	3.50 3.298 23691	3.50 3.300 23756	3.50 3.294 23745	2.80 3.291 22051	3.50 3.298 23736	2.80 3.294 22061	2.02 3.305 20663
2	2.80 2.973 6283	3.50BA 3.249 15346	3.50 3.297 23729	3.50 3.290 23787	3.50 3.302 2	3.50BA 3.255 15344	2.80 3.296 22073	2.02 2.967 5804
1	2.80 2.994 6297	2.80 3.001 6296	3.50 3.297 23781	3.50 3.296 23779	3.50 3.296 23815	2.80 3.292 22081	2.80 2.999 6268	2.02 2.965 5805

ANRIKN.% NOM	VERKL.	ANTAL STAVAR	KG UO2	KG U	KG U-235
1.18	1.204	6	18.839	16.597	0.200
2.02	2.031	13	41.616	36.664	0.745
2.80	2.809	21	67.720	59.661	1.676
3.50	3.527	18	59.318	52.259	1.843
3.50BA	3.492	5	16.263	14.012	0.489
S:A	2.765	63	203.756	179.193	4.953

TOPPL.NR. :Z1872
BOTTPL.NR. :Z1033

SPRIDARE NR.: 9147 7955 7992 7958 7957 8286

BOX NR.:3783

URSPR.LAND FÖR URAN: USA INBLANDAD MÄNGD GD2 O3=4.0%

Oskarshamn 2 Fuel rod diagram for assembly 3054

M O N T E R I N G S P R O T O K O L L

OSKARSHAMN II ERS2

PATRON NR 3054 DATUM: 77-04-77 REF. H

Rev 80-12-05

	A	B	C	D	E	F	G	H
8	2.80 3.000 6307	2.02 2.972 5838	2.02 3.303 20500	2.02 3.309 20463	2.02 3.294 20560	2.80 3.292 22124	2.80 2.973 6283	1.18 3.303 20209
7	2.80 3.294 22088	2.80 3.298 22215	2.80 3.295 22091	2.80 3.311 274	3.508A 3.251 15330	2.80 3.295 22035	2.02 3.300 20487	2.80 3.001 6296
6	2.80 3.293 22084	3.508A 3.255 15337	3.50 3.297 23823		2.80 3.304 22093	3.50 3.293 23684	2.80 3.291 22075	2.80 3.297 22095
5	3.50 3.290 23639	3.50 3.298 144		1.18 3.305 20167		2.80 3.294 22074	3.508A 3.253 15223	2.02 3.304 20575
4	3.50 3.295 23702	3.50 3.291 23742	3.50 3.295 23743	20101	1.18 3.295 20169		2.80 3.311 277	2.02 3.304 20656
3	3.50 3.291 23649		3.50 3.300 23756	3.50 3.294 23745		3.50 3.298 23736	2.80 3.294 22061	2.02 3.305 20663
2	3.50 3.298 23691	3.508A 3.249 15346		3.50 3.290 23787	3.50 3.302 2	3.508A 3.255 15344	2.80 3.296 22073	2.02 2.967 5804
1	2.80 2.994 6297	3.50 3.297 23729	3.50 3.297 23781	3.50 3.296 23779	3.50 3.296 23815	2.80 3.292 22031	2.80 3.291 22051	2.80 2.999 6268

ANRIKN.% NOM	VERKL	ANTAL STAVAR	KG UO2	KG U	KG U-235
1.18	1.204	3	9.903	8.725	0.105
2.02	2.031	9	29.063	25.605	0.520
2.80	2.809	21	67.720	59.661	1.676
3.50	3.527	18	59.318	52.259	1.843
3.508A	3.492	5	16.263	14.012	0.489
S:A	2.765	56	182.267	160.262	4.653

TOPPL.NR. :Z1872
BOTTPL.NR.:Z1033

SPRIDARE NR.: 9147 7955 7992 7953 7957 8286
BOX NR.:3783
URSPR.LAND FÖR URAN: USA INBLANDAD MÄNGD GD2 O3=4.0%

Oskarshamn 2 Fuel rod diagram for assembly 3058

[illegible]INGSPROTOKOLL
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OSKARSHAMN II EP32

PATRON Nº 3058 DATUM:12-04-77 REF.

	A	B	C	D	E	F	G	H
8	2.02 2.972 5809	2.02 2.968 5815	2.02 3.304 20493	2.02 3.303 20557	2.02 3.305 20535	2.02 3.309 20666	1.18 2.987 5420	1.1[illegible] 2.98[illegible] 537[illegible]
7	2.80 2.997 6301	2.80 3.306 21816	2.80 3.300 21820	2.80 3.310 327	3.50BA 3.256 15328	2.80 3.302 22012	2.02 3.304 20642	1.18 2.990 5353
6	2.80 3.302 22000	3.50BA 3.254 15261	3.50 3.292 23695	2.80 3.300 22014	2.80 3.310 21801	3.50 3.291 23818	2.80 3.301 21824	2.02 3.307 20644
5	3.50 3.292 23750	3.50 3.305 47	2.80 3.303 21996	1.18 3.306 20200	1.18 3.303 20223	2.80 3.309 21807	3.50BA 3.252 15376	2.02 3.307 20641
4	3.50 3.289 23692	3.50 3.290 23817	3.50 3.298 23784	21223	1.18 3.303 20172	2.80 3.297 21967	2.80 3.303 417	2.02 3.303 20674
3	3.50 3.292 23791	3.50 3.299 23772	3.50 3.285 23819	3.50 3.292 23321	2.80 3.303 21864	3.50 3.295 23738	2.80 3.299 21973	2.02 3.307 20673
2	2.80 3.003 6194	3.50BA 3.251 15373	3.50 3.290 23805	3.50 3.298 23786	3.50 3.283 179	3.50BA 3.252 15372	2.80 3.305 21854	2.02 2.976 5852
1	2.80 3.005 6244	2.80 3.004 6311	3.50 3.288 23806	3.50 3.299 23762	3.50 3.293 23761	2.80 3.302 21813	2.80 3.001 6248	2.02 2.984 5773

ANRIKN.% NOM	VEPKL	ANTAL STAVAR	KG UO2	KG U	KG U-235
1.18	1.204	6	18.871	16.625	0.200
2.02	2.031	13	41.654	36.697	0.745
2.80	2.810	21	67.862	59.786	1.680
3.50	3.527	18	59.271	52.218	1.842
3.50BA	3.492	5	16.265	14.014	0.489
S:A	2.765	63	203.923	179.340	4.956

TOPPL.NR. :Z2244
BOTTPL.NR.:Z792

SPRIDARE NR.: 7963 7966 7996 8106 7988 8361
BOX NR.:3852
URSPR.LAND FÖR URAN: USA INBLANDAD MÄNGD GD2 O3=4.0%

Oskarshamn 2 Fuel rod diagram for assembly 3058

MONTERINGSPROTOKOLL

OSKARSHAMN II ERS2

PATRON NR 3058 DATUM:12-04-77 REF.

REV. 80-12-15

	A	B	C	D	E	F	G	H
8	2.80 2.997 6301	2.02 2.968 5815	2.02 3.304 20493	2.02 3.303 20557	2.02 3.305 20535	2.80 3.300 22014	2.80 3.003 6194	1.18 3.303 20223
7	2.80 3.303 21996	2.80 3.306 21816	2.80 3.300 21820	2.80 3.310 327	3.50BA 3.256 15328	2.80 3.302 22012	2.02 3.304 20642	2.80 3.004 6311
6	2.80 3.302 22000	3.50BA 3.254 15261	3.50 3.292 23695		2.80 3.310 21801	3.50 3.291 23818	2.80 3.301 21824	2.80 3.297 21967
5	3.50 3.292 23750	3.50 3.305 47		1.18 3.306 20200		2.80 3.309 21807	3.50BA 3.252 15376	2.02 3.307 20641
4	3.50 3.289 23692	3.50 3.290 23817	3.50 3.298 23784	21223	1.18 3.303 20172		2.80 3.303 417	2.02 3.303 20674
3	3.50 3.292 23791		3.50 3.285 23819	3.50 3.292 23321		3.50 3.295 23738	2.80 3.299 21973	2.02 3.307 20673
2	3.50 3.299 23772	3.50BA 3.251 15373		3.50 3.298 23786	3.50 3.283 179	3.50BA 3.252 15372	2.80 3.305 21854	2.02 2.976 5852
1	2.80 3.005 6244	3.50 3.290 23805	3.50 3.288 23806	3.50 3.299 23762	3.50 3.293 23761	2.80 3.302 21813	2.80 3.303 21864	2.80 3.001 6248

ANRIKN.% NOM	VERKL	ANTAL STAVAR	KG UO2	KG U	KG U-235
1.18	1.204	3	9.912	8,732	0.105
2.02	2.031	9	29.082	25,621	0.520
2.80	2.810	21	67.862	59.736	1.680
3.50	3.527	18	59.271	52.218	1.842
3.50BA	3.492	5	16.265	14.014	0.489
S:A	2.765	56	182.592	160.372	4.637

TOPPL.NR. :Z2244
BOTTPL.NR.:Z792

SPRIDARE NR.: 7963 7966 7996 8106 7938 8361

BOX NR.:3852

URSPR.LAND FÖR URAN: USA INBLANDAD MÄNGD GD2 O3=4.0%

Oskarshamn 2 Fuel rod diagram for assembly 3064

M O N T E R I N G S P R O T O K O L L

OSKARSHAMN II ERS2

PATRON NR 3064 DATUM: 12-04-77 REF. NR

	A	B	C	D	E	F	G	H
8	2.02 2.968 5754	2.02 2.966 5768	2.02 3.305 20478	2.02 3.312 20662	2.02 3.303 20612	2.02 3.307 20507	1.18 2.993 5369	1.18 2.971 5360
7	2.80 2.998 6247	2.80 3.303 21337	2.80 3.307 21994	2.80 3.307 269	3.50BA 3.242 15433	2.80 3.296 21846	2.02 3.298 20565	1.18 2.986 5363
6	2.80 3.306 21835	3.50BA 3.246 15435	3.50 3.290 23727	2.80 3.300 21992	2.80 3.302 22018	3.50 3.295 23623	2.80 3.298 21968	2.02 3.306 20564
5	3.50 3.287 23726	3.50 3.299 69	2.80 3.303 21861	1.18 3.298 20187	1.18 3.301 20205	2.80 3.294 21833	3.50BA 3.248 15449	2.02 3.306 20616
4	3.50 3.293 23675	3.50 3.295 23659	3.50 3.296 23678	20085	1.18 3.302 20159	2.80 3.305 21860	2.80 3.306 270	2.02 3.300 20665
3	3.50 3.293 23654	3.50 3.294 23686	3.50 3.290 23640	3.50 3.292 23612	2.80 3.304 22011	3.50 3.290 23724	2.80 3.297 21951	2.02 3.308 20517
2	2.80 2.999 6148	3.50BA 3.258 15311	3.50 3.298 23666	3.50 3.292 23744	3.50 3.298 92	3.50BA 3.247 15439	2.80 3.304 22001	2.02 2.979 5825
1	2.80 3.002 6337	2.80 2.996 6213	3.50 3.288 23751	3.50 3.295 23646	3.50 3.293 23749	2.80 3.294 22010	2.80 3.007 6178	2.02 2.967 5802

ANRIKN.% NOM	VERKL	ANTAL STAVAR	KG UO2	KG U	KG U-235
1.18	1.204	6	18.851	16.608	0.200
2.02	2.031	13	41.630	36.676	0.745
2.80	2.809	21	67.828	59.756	1.679
3.50	3.527	18	59.278	52.224	1.842
3.50BA	3.492	5	16.241	13.993	0.489
S:A	2.765	63	203.828	179.257	4.955

TOPPL.NR. :Z1991
BOTTPL.NR.:Z729

SPRIDARE NR.: 8383 8398 8393 8376 8259 9324

BOX NR.:4313

URSPR.LAND FÖR URAN: USA INBLANDAD MÄNGD GD2 O3=4.0%

Oskarshamn 2 Fuel rod diagram for assembly 3064

M O N T E R I N G S P R O T O K O L L

OSKARSHAMN II ERS2

PATRON NR 3064 DATUM:12-04-77 REF. HRP

Rev 80-12-17

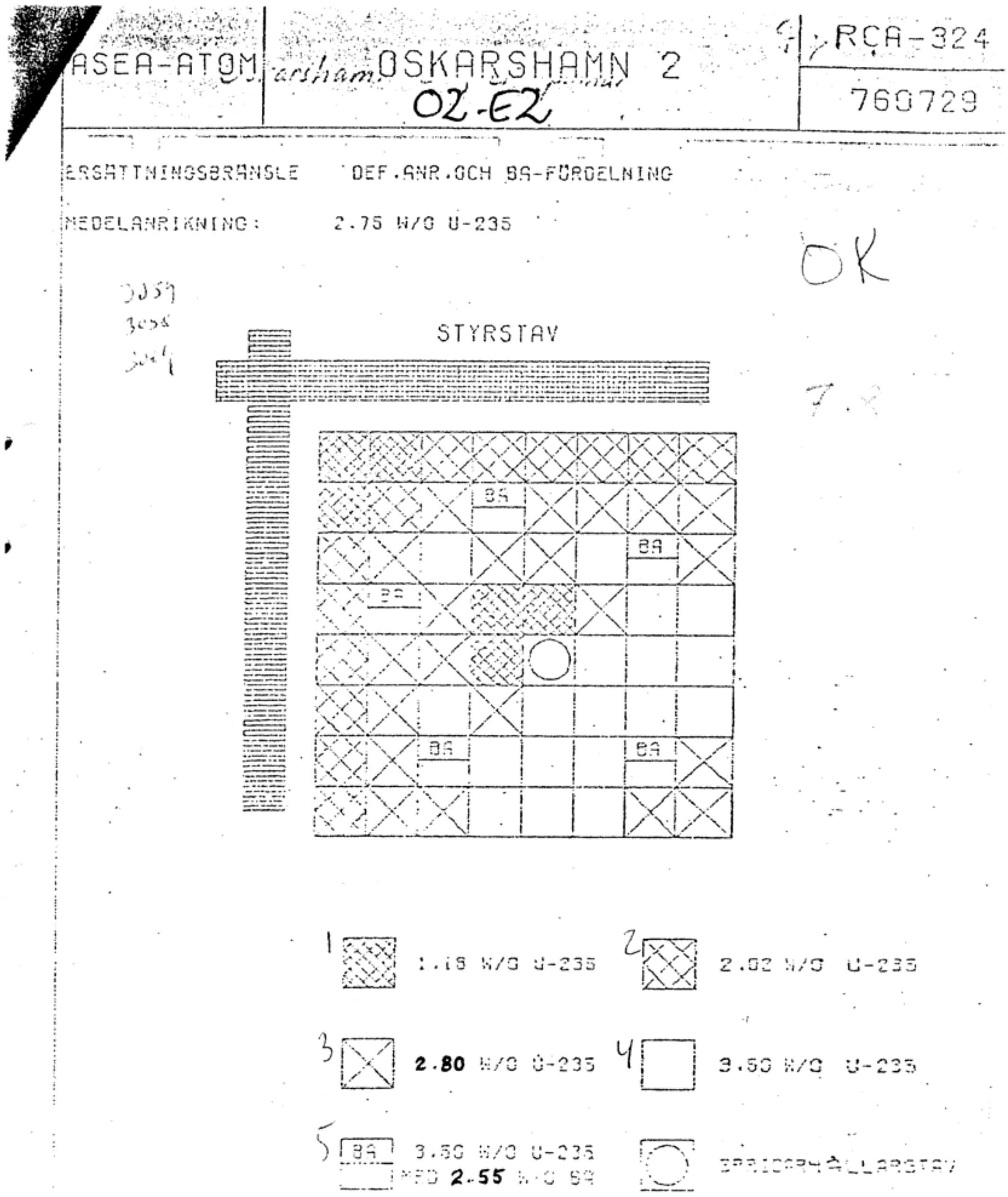
	A	B	C	D	E	F	G	H
8	2.80 2.998 6247	2.02 2.966 5768	2.02 3.305 20478	2.02 3.312 20662	2.02 3.303 20612	2.80 3.300 21992	2.80 2.999 6148	1.18 3.301 20205
7	2.80 3.303 21861	2.80 3.303 21837	2.80 3.307 21994	2.80 3.307 269	3.50BA 3.242 15433	2.80 3.296 21846	2.02 3.298 20565	2.80 2.996 6213
6	2.80 3.306 21835	3.50BA 3.246 15435	3.50 3.290 23727		2.80 3.302 22018	3.50 3.295 23623	2.80 3.298 21968	2.80 3.305 21860
5	3.50 3.287 23726	3.50 3.299 69		1.18 3.298 20187		2.80 3.294 21833	3.50BA 3.248 15449	2.02 3.306 20616
4	3.50 3.293 23675	3.50 3.295 23659	3.50 3.296 23678	20085	1.18 3.302 20159		2.80 3.306 270	2.02 3.300 20665
3	3.50 3.293 23654		3.50 3.290 23640	3.50 3.292 23612		3.50 3.290 23724	2.80 3.297 21951	2.02 3.308 20517
2	3.50 3.294 23686	3.50BA 3.258 15311		3.50 3.292 23744	3.50 3.298 92	3.50BA 3.247 15439	2.80 3.304 22001	2.02 2.979 5825
1	2.80 3.002 6337	3.50 3.298 23666	3.50 3.288 23751	3.50 3.295 23646	3.50 3.293 23749	2.80 3.294 22010	2.80 3.304 22011	2.80 3.007 6178

ANRIKN.% NOM	VERKL	ANTAL STAVAR	KG UO2	KG U	KG U-235
1.18	1.204	3	9.901	8.723	0.105
2.02	2.031	9	29.082	25.621	0.520
2.80	2.809	21	67.828	59.756	1.679
3.50	3.527	18	59.278	52.224	1.842
3.50BA	3.492	5	16.241	13.993	0.489
S:A	2.765	56	182.330	160.318	4.635

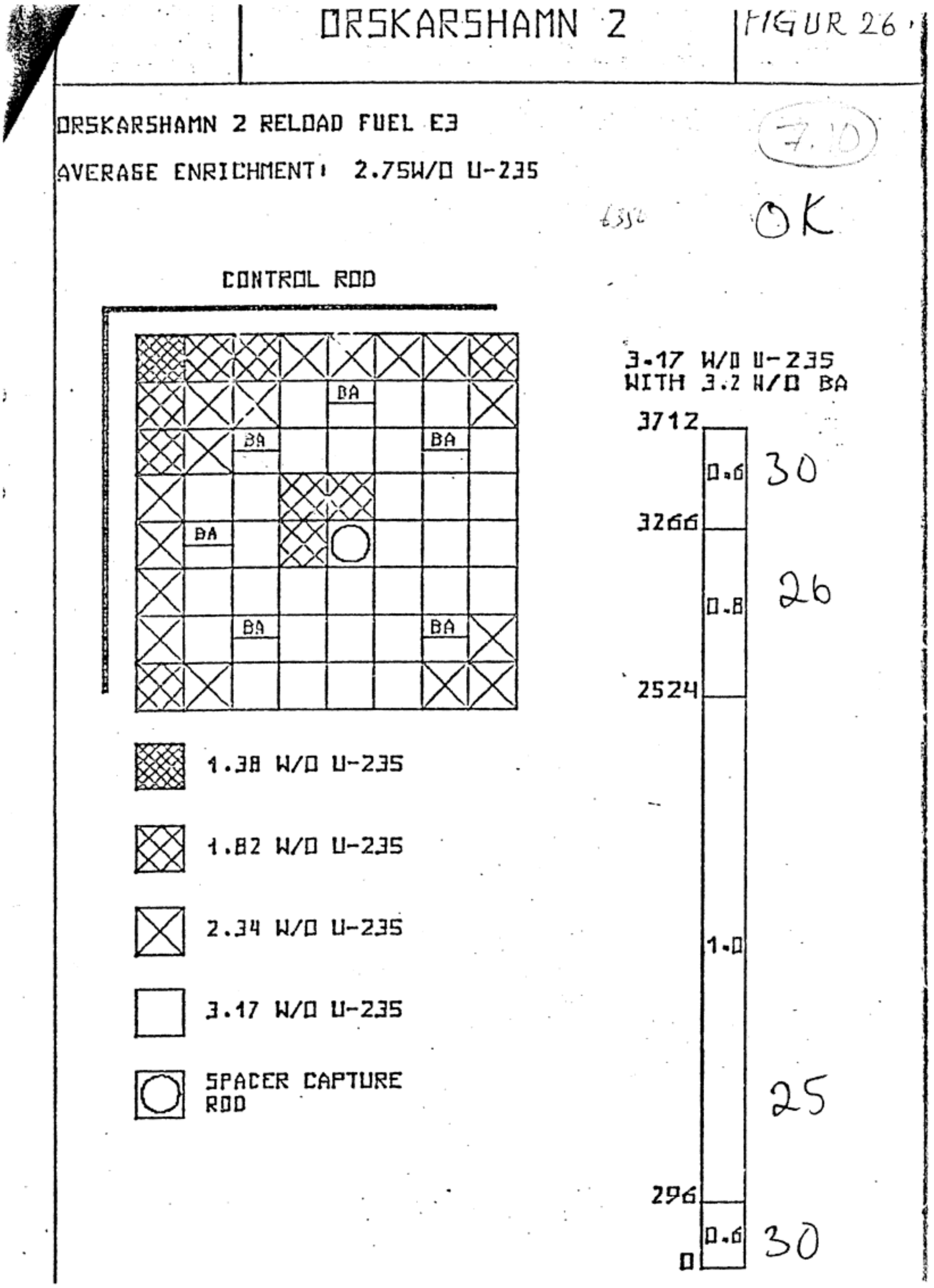
TOPPL.NR. :Z1991
BOTTPL.NR.:Z729

SPRIDARE NR.: 8383 3398 8393 8376 8259 9324
BOX NR.:4313
URSPR.LAND FÖR URAN: USA INBLANDAD MÄNGD GD2 O3=4.0%

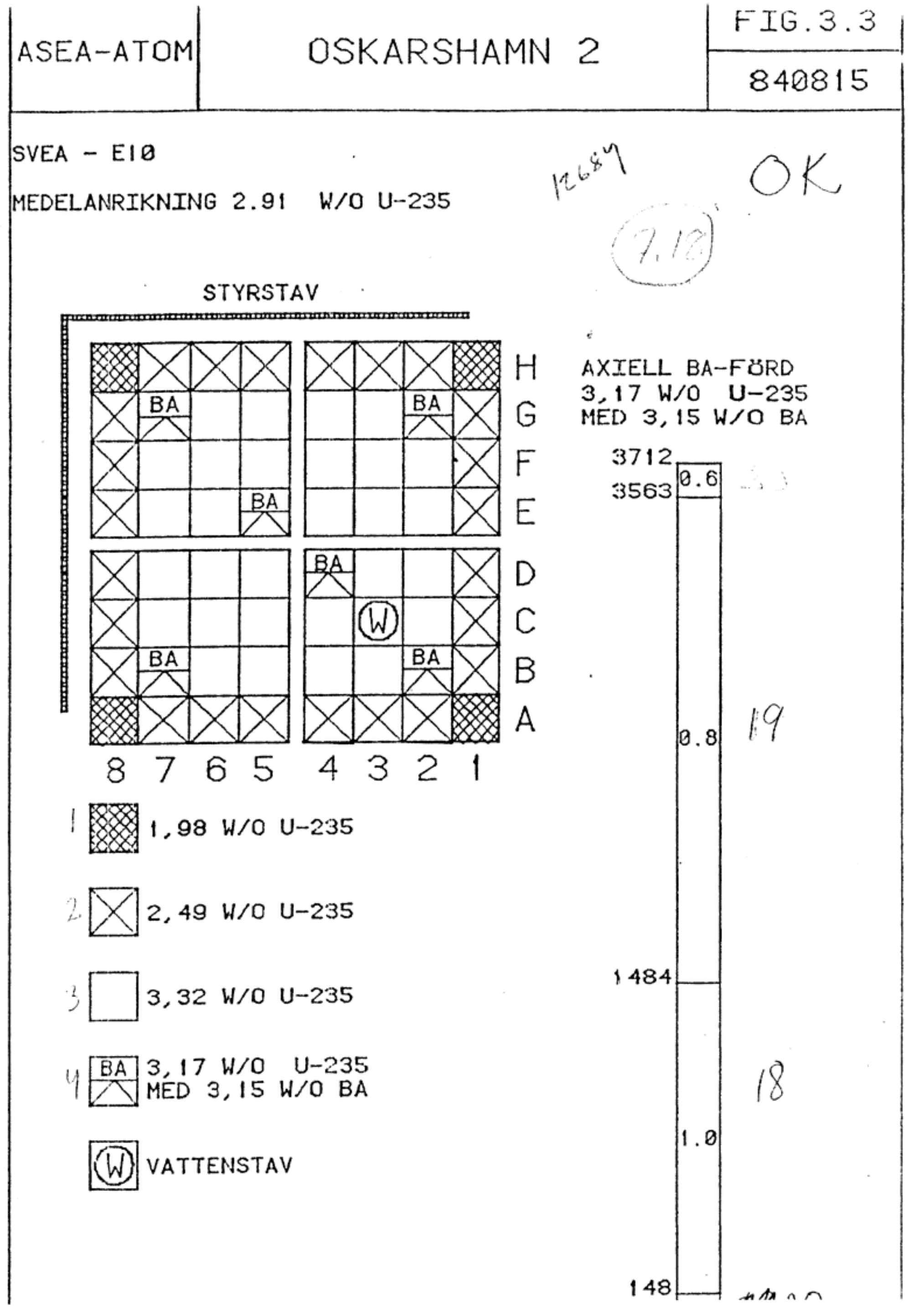
Oskarshamn 2 Enrichment diagram for assembly 3054, 3058 och 3064



Oskarshamn 2 Enrichment diagram for assembly 6350



Oskarshamn 2 Enrichment diagram for assembly 12684



2.5 Oskarshamn 3

REACTOR OSKARSHAMN 3

Reactor data	Value
Reactor pressure (MPa) at full power	7
Inlet temperature into core (C) at full power	277
Outlet temperature into core (C) at full power	286
Avg. temperature in the uranium pellets at full power (C)	507
Avg. temperature in the cladding at full power (C)	290
Temperature in the boxwall at full power (C)	286

Cycle data

Cycle no	Start	Stop	Reactor power MW	Burnup avg/cycle MWd/tU	No of assemblies in core
1	1985-03-18	1986-07-04	3,300	7,939.9	700
2	1986-07-26	1987-07-03	3,300	7,335.7	700
3	1987-07-26	1988-07-08	3,300	7,174	700
4	1988-08-14	1988-12-10	3,300	2,211	700
4B	1988-12-22	1989-06-07	3,300	3,199.7	700
5	1989-06-20	1990-06-23	3,300	7,595	700
6	1990-08-01	1991-06-24	3,300	7,718.6	700

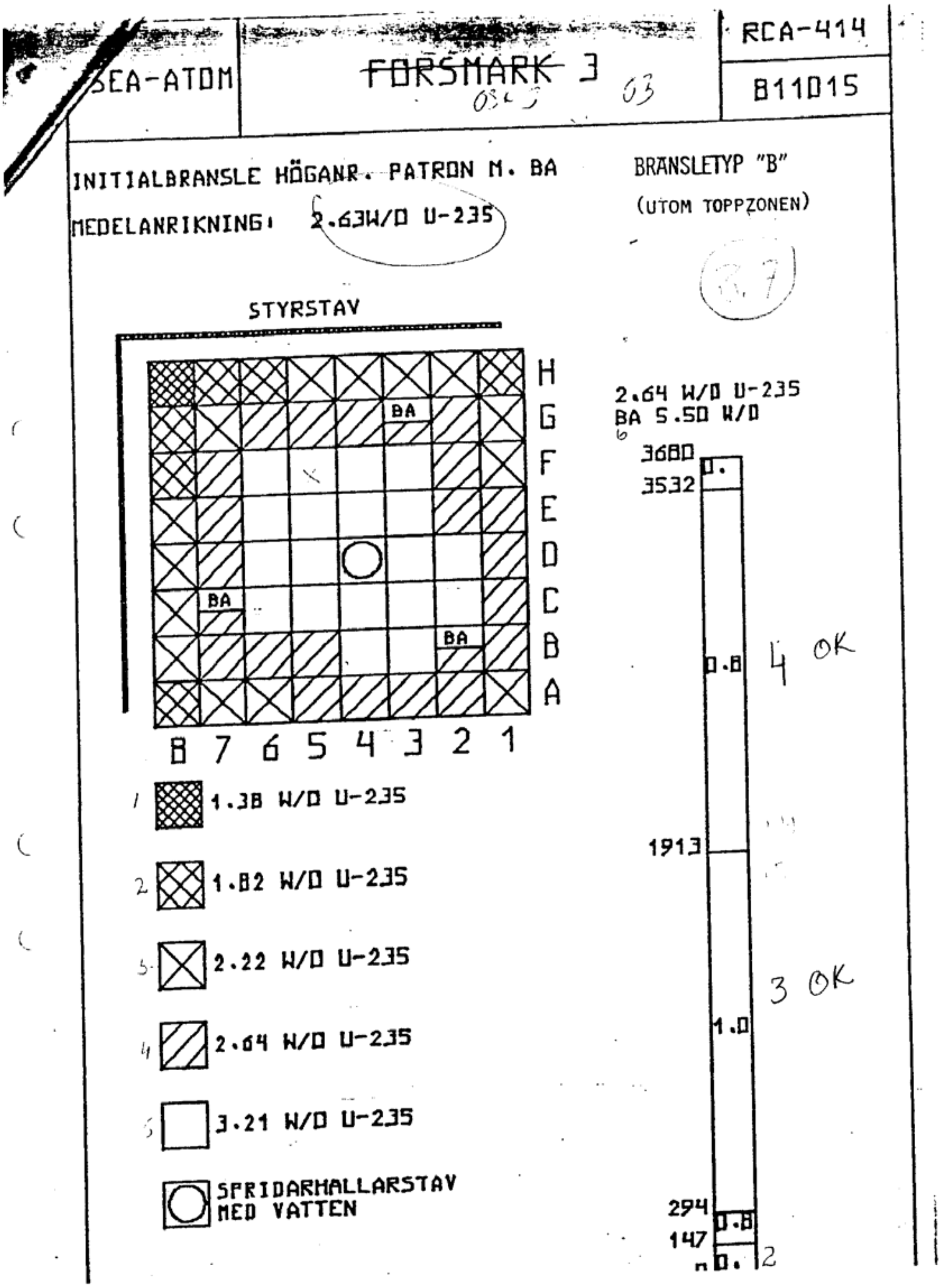
Fuel data	Fuel id 12078	13628	13630
Fuel type	8×8	Svea100	Svea100
No of fuel rods	63	100	100
Rod pitch normal rods (mm)	16.3	12.4	12.4
Rod pitch normal – corner rods (mm)	16.05		
Rod pitch corner – corner rods (mm)	15.8		
Rod diameter normal rod (mm)	12.25	9.62	9.62
Clad thickness normal rod (mm)	0.8	0.63	0.63
Pellet diameter normal rod (mm)	10.44	8.19	8.19
No of normal rods	51	100	100
Rod diameter corner rod (mm)	11.75		
Clad thickness corner rod (mm)	0.8		
Pellet diameter corner rod (mm)	9.94		
No of corner rods	12		
Active length (mm)	3680	3750	3750
Density UO2 (g/cc)	10.438	10.497	10.497
Porsity,dishing etc (%)	1	1	1
No of spacer rods		4	4
Material in spacer rods		Zr2	Zr2
Outer diameter spacer rods (mm)		9.62	9.62
Cladding thickness spacer rod		0.63	0.63
No of water rods	1 sprh		
Material in water rods	Zry		
Outer diameter water rods (mm)	12.25		
Inner diameter water rods (mm)	10.65		
No of BA rods	3	8	8
% Gd2O3	5.5	4.4	4.4
Rel poison	1	1	1
No of spacers	6	4×6	4×6
Spacer material	Inconel	Inconel	Inconel
Mass of spacer (g)	150	24	24
Box material	Zr4	Zr4	Zr4
Box outer measure square (mm)	138.6	139.6	139.6
Box wall thickness (mm)	2.3	1,1/0,8	1,1/0,8

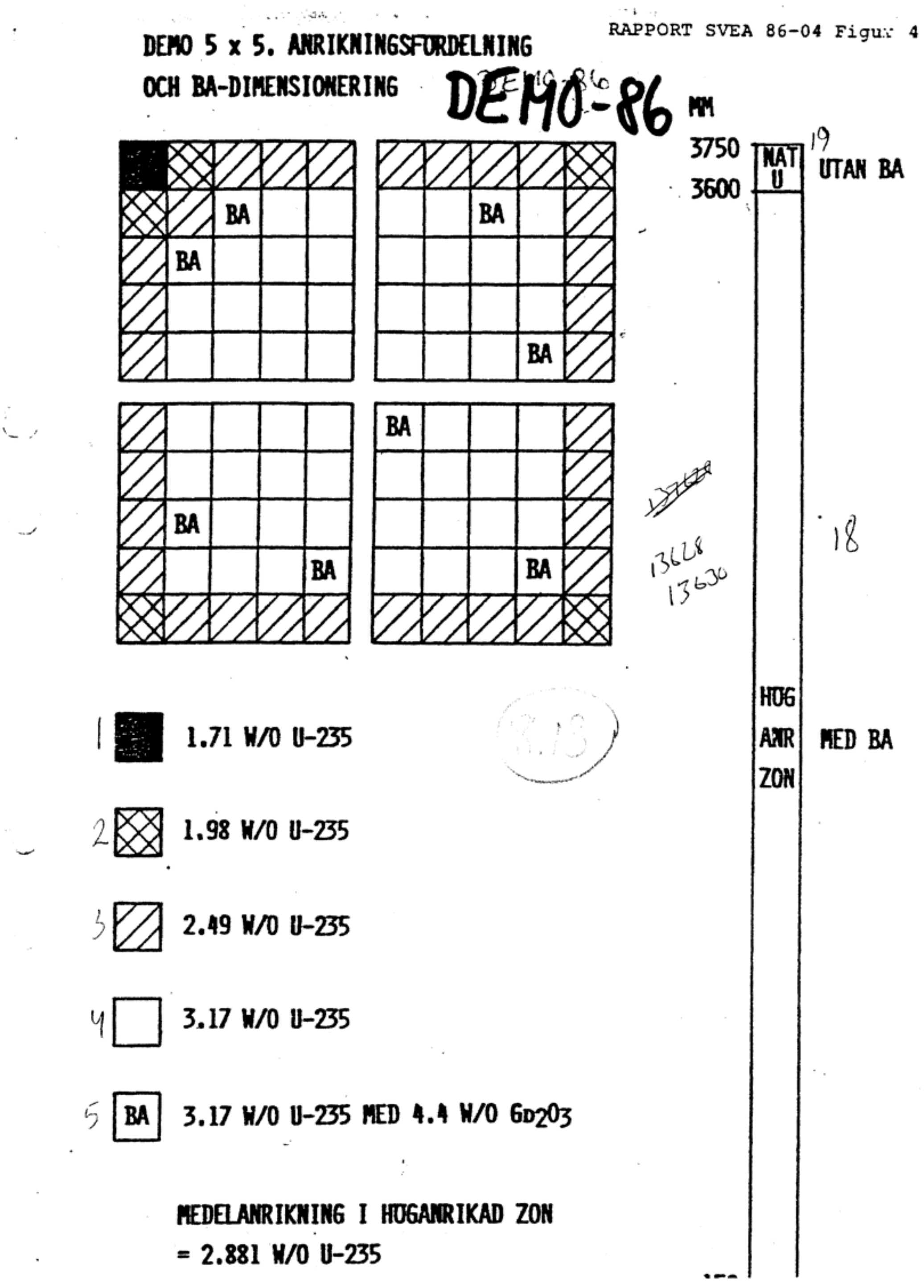
Initial data	12078	13628	13630
Initial mass Utot (g)	177,358	180,774	180,775
Initial mass U238 (g)	172,787	175,873	175,874
Initial mass U235 (g)	4,571	4,901	4,901
Avg.enrichment% U235	2.577	2.711	2.711
Data after rebuild 1			
Date of rebuild			
No of fuel rods			
No spacer rods			
No water rods			
No of water holes			
Mass Utot after rebuild (g)			
Mass U235 after rebuild (g)			
Data after rebuild 2			
Date of rebuild			
No of fuel rods			
No spacer rods			
No water rods			
No of water holes			
Mass Utot after rebuild (g)			
Mass U235 after rebuild (g)			
Cycle history burnup/cycle, MWd/tU			
1	8,690		
2	8,258	9,171	9,328
3	8,212	9,442	9,656
4		2,297	2,986
4B		3,763	3,823
5		8,212	7,073
6		2,734	7,497
Axial BU distribution, EOL MWd/tUNode no (top=25)			
1	11,300	7,800	9,400
2	19,500	27,300	31,800
3	23,600	34,100	39,200
4	25,400	37,000	42,300
5	27,000	39,100	44,700
6	27,700	40,100	45,700
7	27,900	40,400	46,200
8	27,700	40,200	46,000
9	28,300	40,900	46,700
10	28,600	41,200	47,000
11	28,600	41,200	46,900
12	28,300	40,700	46,300
13	28,900	41,100	46,700
14	29,300	41,100	46,600
15	29,200	40,900	46,200
16	28,700	40,400	45,500
17	28,900	40,800	45,700
18	28,600	40,600	45,300
19	27,900	40,100	44,500
20	26,600	38,700	42,900
21	25,700	37,500	41,500
22	23,900	34,800	38,700
23	21,000	30,500	34,100
24	16,700	24,100	27,700
25	9,400	9,800	11,500

Void history Node no (top=25)	12078	13628	13630
1	–0.03	–0.02	–0.02
2	–0.02	–0.02	–0.02
3	0.01	0.00	0.00
4	0.07	0.06	0.06
5	0.14	0.15	0.15
6	0.21	0.22	0.23
7	0.28	0.29	0.30
8	0.34	0.35	0.36
9	0.39	0.40	0.41
10	0.44	0.45	0.46
11	0.48	0.49	0.51
12	0.51	0.52	0.54
13	0.55	0.55	0.58
14	0.58	0.58	0.61
15	0.61	0.61	0.63
16	0.63	0.63	0.66
17	0.65	0.65	0.68
18	0.67	0.67	0.70
19	0.69	0.69	0.71
20	0.71	0.70	0.73
21	0.72	0.72	0.74
22	0.73	0.73	0.75
23	0.74	0.74	0.76
24	0.75	0.74	0.76
25	0.75	0.74	0.76
Density history Node no (top=25)			
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			
15			
16			
17			
18			
19			
20			
21			
22			
23			
24			
25			

Control rod history Node no (top=25)			
1	0.00	0.16	0.02
2	0.00	0.09	0.01
3	0.00	0.07	0.00
4	0.00	0.05	0.00
5	0.00	0.05	0.00
6	0.00	0.05	0.00
7	0.00	0.05	0.00
8	0.00	0.05	0.00
9	0.00	0.05	0.00
10	0.00	0.05	0.00
11	0.00	0.04	0.00
12	0.00	0.04	0.00
13	0.00	0.04	0.00
14	0.00	0.04	0.00
15	0.00	0.04	0.00
16	0.00	0.03	0.00
17	0.00	0.03	0.00
18	0.00	0.02	0.00
19	0.00	0.01	0.00
20	0.00	0.00	0.00
21	0.00	0.00	0.00
22	0.00	0.01	0.00
23	0.00	0.01	0.00
24	0.00	0.01	0.00
25	0.00	0.00	0.00

Oskarshamn 3 Enrichment diagram for assembly 12078




RAPPORT SVEA 86-04 Figur 4
DEMO 5 x 5. ANRIKNINGSFÖRDELNING
OCH BA-DIMENSIONERING
DEMO-86
MM
3750
3600
NAT U
UTAN BA
BA
13628
13630
HÖG ANR ZON
MED BA
1.71 W/O U-235
1.98 W/O U-235
2.49 W/O U-235
3.17 W/O U-235
3.17 W/O U-235 MED 4.4 W/O GD2O3
MEDELANRIKNING I HÖGANRIKAD ZON
= 2.881 W/O U-235

2.6 Ringhals 1

REACTOR RINGHALS 1

Reactor data	Value
Reactor pressure (MPa) at full power	7
Inlet temperature into core (C) at full power	272
Outlet temperature into core (C) at full power	286
Avg. temperature in the uranium pellets at full power (C)	615
Avg. temperature in the cladding at full power (C)	295
Temperature in the boxwall at full power (C)	290

Cycle data

Cycle no	Start	Stop	Reactor power MW	Burnup avg/cycle MWd/tU	No of assemblies in core
C1A	1973-08-20	1976-05-22	2,270	3,220	648
C1A	1976-09-28	1977-07-27	2,270	3,626	648
C1B	1977-11-04	1978-07-13	2,270	4,487	648
C2	1978-10-13	1979-07-12	2,270	4,280	648
C3	1979-09-30	1980-07-03	2,270	4,559	648
C4	1980-10-08	1981-07-30	2,270	5,260	648
C5	1981-11-06	1982-07-22	2,270	4,438	648
C6	1982-09-09	1983-06-18	2,270	4,490	648
C7	1983-09-30	1984-07-13	2,270	4,533	648
C8	1984-08-28	1985-08-02	2,270	5,984	648
C9	1985-09-02	1986-08-15	2,270	6,018	648
C10	1986-10-09	1987-08-21	2,270	5,508	648
C11	1987-09-24	1988-08-06	2,270	5,529	648
C12	1988-09-11	1989-09-15	2,384	5,832	648
C13	1989-10-11	1990-08-04	2,500	5,030	648
C14	1990-08-30	1991-08-09	2,500	5,566	648
C15	1991-09-06	1992-07-25	2,500	6,212	648
C16	1992-08-22	1993-10-01	2,500	3,956	648

Fuel data	Fule id																
	582	**596**	**710**	**900**	**1136**	**1177**	**1186**	**5829**	**6423**	**6432**	**6454**	**6478**	**8327**	**8331**	**8332**	**8338**	**8341**
Fuel type	AA8×8	AA8×8	AA8×8	AA8×8	AA8×8	AA8×8	AA8×8	AA8×8	AA8×8	AA8×8	AA8×8	AA8×8	AA8×8	AA8×8	AA8×8	AA8×8	AA8×8
No of fuel rods	64	64	64	64	64	63	63	63	63	63	63	63	63	63	63	63	63
Rod pitch normal rods (mm)	16.3	16.3	16.3	16.3	16.3	16.3	16.3	16.3	16.3	16.3	16.3	16.3	16.3	16.3	16.3	16.3	16.3
Rod pitch normal – corner rods (mm)	16.05	16.05	16.05	16.05	16.05	16.05	16.05	16.05	16.05	16.05	16.05	16.05	16.05	16.05	16.05	16.05	16.05
Rod pitch corner – corner rods (mm)	15.8	15.8	15.8	15.8	15.8	15.8	15.8	15.8	15.8	15.8	15.8	15.8	15.8	15.8	15.8	15.8	15.8
																	0
Rod diameter normal rod (mm)	12.25	12.25	12.25	12.25	12.25	12.25	12.25	12.25	12.25	12.25	12.25	12.25	12.25	12.25	12.25	12.25	12.25
Clad thickness normal rod (mm)	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Pellet diameter normal rod (mm)	10.58	10.58	10.58	10.58	10.58	10.58	10.58	10.44	10.44	10.44	10.44	10.44	10.44	10.44	10.44	10.44	10.44
No of normal rods	52	52	52	52	52	51	51	51	51	51	51	51	51	51	51	51	51
Rod diameter corner rod (mm)	11.75	11.75	11.75	11.75	11.75	11.75	11.75	11.75	11.75	11.75	11.75	11.75	11.75	11.75	11.75	11.75	11.75
Clad thickness corner rod (mm)	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Pellet diameter corner rod (mm)	10.08	10.08	10.08	10.08	10.08	10.08	10.08	9.94	9.94	9.94	9.94	9.94	9.94	9.94	9.94	9.94	9.94
No of corner rods	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
																	0
Active length (mm)	3,650	3,650	3,650	3,650	3,650	3,650	3,650	3,680	3,680	3,680	3,680	3,680	3,680	3,680	3,680	3,680	3,680
Density UO2 (g/cc)	10.245	10.235	10.242	10.249	10.232	10.43	10.426	10.1	10.457	10.447	10.457	10.45	10.448	10.457	10.447	10.451	10.385
Porsity,dishing etc (%)	1	1	1	1	1	1	1	1.83	1	1	1	1	1	1	1	1	1
No of spacer rods																	
Material in spacer rods						1	1	1	1	1	1	1	1	1	1	1	1
Outer diameter spacer rods (mm)						Zr	Zr	Zr	Zr	Zr	Zr	Zr	Zr	Zr	Zr	Zr	Zr
Cladding thickness spacer rod						12.25	12.25	12.25	12.25	12.25	12.25	12.25	12.25	12.25	12.25	12.25	12.25
No of water rods																	
Material in water rods																	
Outer diameter water rods (mm)																	
Inner diameter water rods (mm)																	
No of BA rods						3	3	4	4	4	4	4	4	4	4	4	4
% Gd2O3						2	2	2	2	2	2	2	2	2	2	2	2
Rel poison						1	1	1	1	1	1	1	1	1	1	1	1
No of spacers	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
Spacer material	Inconel	Inconel	Inconel		Inconel	Inconel	Inconel	Inconel	Inconel	Inconel	Inconel	Inconel	Inconel	Inconel	Inconel	Inconel	Inconel
Mass of spacer (g)	135	135	135	135	135	135	135	135	135	135	135	135	135	135	135	135	135
																	0
Box material	Zr–4	Zr–4	Zr–4	Zr–4	Zr–4	Zr–4	Zr–4	Zr–4	Zr–4	Zr–4	Zr–4	Zr–4	Zr–4	Zr–4	Zr–4	Zr–4	Zr–4
Box outer measure square (mm)	139	139	139	139	139	139	139	139	139	139	139	139	139	139	139	139	139
Box wall thickness (mm)	2	2	2	2	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3

Initial data	**582**	**596**	**710**	**900**	**1136**	**1177**	**1186**	**5829**	**6423**	**6432**	**6454**	**6478**	**8327**	**8331**	**8332**	**8338**	**8341**
Initial mass Utot (g)	180,265	180,057	180,181	180,321	180,016	180,587	180,515	170,200	177,701	177,520	177,683	177,568	177,544	177,690	177,519	177,596	176,475
Initial mass U238 (g)	176,193	175,991	176,107	176,244	175,942	175,816	175,750	165,591	172,547	172,382	172,534	172,419	172,389	172,520	172,380	172,426	171,376
Initial mass U235 (g)	4,072	4,066	4,074	4,077	4,074	4,771	4,765	4,609	5,154	5,138	5,149	5,149	5,155	5,170	5,139	5,170	5,099
Avg.enrichment% U235	2.259	2.258	2.261	2.261	2.263	2.642	2.640	2.708	2.900	2.894	2.898	2.900	2.904	2.910	2.895	2.911	2.889
Data after rebuild 1																	
Date of rebuild	1978-08-23	1978-09-01	1978-09-11	1978-08-22	1978-09-06			81-10-14				1988-01-21					
No of fuel rods	63	63	63	63	63			62				44					
No spacer rods	zr homo	zr homo	zr homo	zr homo	zr homo												
No water rods																	
No of water holes																	
Mass Utot after rebuild (g)	177,394	177,199	177,308	177,362	177,162			167,335				126,675					
Mass U235 after rebuild (g)	4,000	3,995	4,003	4,004	4,003			4,557				3,673					
Data after rebuild 2																	
Date of rebuild					1981-09-14			87-09-22									
No of fuel rods					60			58									
No spacer rods																	
No water rods																	
No of water holes																	
Mass Utot after rebuild (g)					171,581			156,410									
Mass U235 after rebuild (g)					4,274			4,294									
Cycle history burnup/cycle, MWd/tU																	
C1A	3,300	3,100	3,300	3,600	3,500												
C1A	3,970	4,100	3,660	4,020	3,940												
C1B	5,013	5,305	4,747	4,528	4,178												
C2	3,972	4,777	4,630	4,035	4,956	4,486	4,554										
C3	5,015	4,974	5,054	4,662		4,883	5,060	6,254									
C4						6,965	5,845	7,354			7,120	6,709					
C5			1,223	2,307	2,472	4,096	4,508	5,478		5,502	5,880	5,678			5,755	5,660	5,358
C6					3,184	5,068	4,625	4,154	5,401	4,942	5,936	4,324			5,713	5,470	5,245
C7						4,822	3,428	4,669	6,663	5,737	5,895	5,421	3,212	6,974	5,090	5,152	5,213
C8						5,922	2,478	5,826	7,376	7,085	6,087	6,934	6,270	8,158	6,849	6,738	6,082
C9								5,864	6,749	6,813	6,318	6,117	6,474	7,361	6,486	6,943	4,508
C10								5,262	5,446	4,667			5,622	4,155	2,758	2,671	6,392
C11									3,474	2,115			6,487	6,671	2,326	2,196	1,301
C12													6,755	2,584			
C13													1,321				
C14													1,710				

Axial BU distribution, EOL MWd/t UNode no (top=25)	582	596	710	900	1136	1177	1186	5829	6423	6432	6454	6478	8327	8331	8332	8338	8341
1						–0.01	0.00	–0.01									
2						0.00	0.00	0.00									
3						0.02	0.02	0.02									
4						0.05	0.06	0.06									
5						0.10	0.11	0.10									
6						0.16	0.15	0.15									
7						0.22	0.20	0.21									
8						0.27	0.25	0.26									
9						0.32	0.30	0.31									
10						0.37	0.34	0.35									
11						0.42	0.37	0.40									
12						0.45	0.41	0.43									
13						0.49	0.43	0.47									
14						0.52	0.46	0.50									
15						0.54	0.49	0.53									
16						0.57	0.51	0.55									
17						0.59	0.53	0.58									
18						0.61	0.55	0.60									
19						0.63	0.57	0.61									
20						0.65	0.59	0.63									
21						0.66	0.60	0.65									
22						0.67	0.62	0.66									
23						0.68	0.63	0.67									
24						0.69	0.63	0.68									
25						0.70	0.64	0.68									
Void history Node no (top=25)																	
1																	
2																	
3																	
4																	
5																	
6																	
7																	
8																	
9																	
10																	
11																	
12																	
13																	
14																	
15																	
16																	
17																	
18																	
19																	
20																	

21
22
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24
25

Control rod history **Node no (top=25)**
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25

Ringhals 1 Fuel rod diagram for assembly 582

M O N T E R I N G S P R O T O K O L L

PATRON NR. 582. DATUM:05-01-73 REF.NORN

1.85 2.950 5230	1.85 2.969 5233	1.85 3.252 19219	1.85 3.232 19169	1.85 3.253 19231	1.40 3.242 18002	1.40 2.932 6419	1.40 2.942 6442
2.50 2.944 11571	2.50 3.253 24298	2.50 3.253 24286	2.50 3.241 24244	1.85 3.230 19149	1.85 3.248 647	1.85 3.256 19196	1.40 2.949 6401
2.50 3.266 24445	2.50 3.254 1493	2.50 3.250 24246	2.50 3.265 24426	2.50 3.264 24407	2.50 3.259 24302	1.85 3.246 19096	1.40 3.230 18009
2.50 3.264 24283	2.50 3.256 24425	2.50 3.259 24285	2.50 3.252 24249	2.50 3.267 24314	2.50 3.265 24326	1.85 3.249 19103	1.85 3.228 19125
2.50 3.260 24257	2.50 3.258 24313	2.50 3.259 24363	2.50 3.259 24237	2.50 3.271 24339	2.50 3.268 24393	2.50 3.269 24317	1.85 3.250 19232
2.50 3.253 24321	2.50 3.267 24263	2.50 3.254 24394	2.50 3.257 24344	2.50 3.263 24353	2.50 3.241 24241	2.50 3.251 1448	1.85 3.216 19161
2.50 2.954 11577	2.50 3.255 24398	2.50 3.252 1572	2.50 3.269 24360	2.50 3.257 24294	2.50 3.248 24387	2.50 3.261 24350	1.85 2.957 5556
1.85 2.952 5264	2.50 2.945 11567	2.50 3.262 24247	2.50 3.261 24320	2.50 3.266 24351	2.50 3.261 24417	2.50 2.948 11532	1.85 2.959 5475

ANRIKN.% NOM	VERKL.	ANTAL STAVAR	KG UO2	KG U	KG U-235
1.40	1.412	5	15.295	13.475	0.190
1.85	1.853	16	50.438	44.436	0.824
2.50	2.499	43	138.881	122.354	3.058
S:A	2.259	64	204.614	180.265	4.072

TOPPL.NR.:4065A

BOTTPL.NR.:3892B

SPRIDARE NR.: 2075 2558 964 2931 2059 2526 URSPR.LAND FÖR URAN: US.
BOXNR.: 1150

Ringhals 1 Fuel rod diagram for assembly 582

M O N T E R I N G S P R O T O K O L L

PATRON NR. 582. DATUM:05-01-73 REF.NÖRH

SPRIDARHÅLLARSTAV 78-08-23

1.85 2.950 5230	1.85 2.969 5233	1.85 3.252 19219	1.85 3.232 19169	1.85 3.253 19231	1.40 3.242 18002	1.40 2.932 6419	1.40 2.942 6442
2.50 2.944 11571	2.50 3.253 24298	2.50 3.253 24286	2.50 3.241 24244	1.85 3.230 19149	1.85 3.248 647	1.85 3.256 19196	1.40 2.949 6401
2.50 3.266 24445	2.50 3.254 1493	2.50 3.250 24246	2.50 3.265 24426	2.50 3.264 24407	2.50 3.259 24302	1.85 3.246 19096	1.40 3.230 18009
2.50 3.264 24283	2.50 3.256 24425	2.50 3.259 24285	2.50 3.252 24249	2.50 3.267 24314	2.50 3.265 24326	1.85 3.249 19103	1.85 3.228 19125
2.50 3.260 24257	2.50 3.258 24313	2.50 3.259 24363		2.50 3.271 24339	2.50 3.268 24393	2.50 3.269 24317	1.85 3.250 19232
2.50 3.253 24321	2.50 3.267 24263	2.50 3.254 24394	2.50 3.257 24344	2.50 3.263 24353	2.50 3.241 24241	2.50 3.251 1448	1.85 3.216 19161
2.50 2.954 11577	2.50 3.255 24398	2.50 3.252 1572	2.50 3.269 24360	2.50 3.257 24294	2.50 3.248 24387	2.50 3.261 24350	1.85 2.957 5556
1.85 2.952 5264	2.50 2.945 11567	2.50 3.262 24247	2.50 3.261 24320	2.50 3.266 24351	2.50 3.261 24417	2.50 2.948 11532	1.85 2.959 5475

ANRIKN.% NOM	VERKL.	ANTAL STAVAR	KG UO2	KG U	KG U-235	
1.40	1.412	5	15.295	13.475	0.190	TOPPL.NR.:4065A
1.85	1.853	16	50.438	44.436	0.824	
2.50	2.499	42	135.622	119.483	2.986	BOTTPL.NR.:3892B
S:A	2.255	63	201.355	177.394	4.000	

SPRIDARE NR.: 2075 2558 964 2931 2059 2026 URSPR.LAND FÖR URAN: USA
BOXNR.: 1150

Ringhals 1 Fuel rod diagram for assembly 596

MONTERINGSPROTOKOLL

PATRON NR. 596. DATUM:12-01-73 REF.HÖRN

1.85 2.951 5403	1.85 2.951 5428	1.85 3.238 19186	1.85 3.236 19095	1.85 3.234 19065	1.40 3.250 18146	1.40 2.956 6399	1.40 2.952 6390
2.50 2.933 11615	2.50 3.245 25465	2.50 3.257 25497	2.50 3.258 25446	1.85 3.245 19164	1.85 3.239 471	1.85 3.234 19060	1.40 2.960 6368
2.50 3.250 25564	2.50 3.247 2000	2.50 3.254 25561	2.50 3.247 25565	2.50 3.261 25422	2.50 3.248 25556	1.85 3.226 19072	1.40 3.252 18060
2.50 3.246 25529	2.50 3.250 25566	2.50 3.248 25541	2.50 3.251 25571	2.50 3.254 25551	2.50 3.256 25552	1.85 3.238 19133	1.85 3.245 19132
2.50 3.256 25559	2.50 3.254 25474	2.50 3.258 25523	2.50 3.244 25563	2.50 3.256 25554	2.50 3.256 25506	2.50 3.259 25555	1.85 3.227 19121
2.50 3.254 25488	2.50 3.255 25542	2.50 3.252 25560	2.50 3.263 25360	2.50 3.257 25568	2.50 3.253 25558	2.50 3.256 1982	1.85 3.245 19097
2.50 2.948 11676	2.50 3.256 25451	2.50 3.261 1954	2.50 3.247 25414	2.50 3.251 25487	2.50 3.256 25409	2.50 3.259 25483	1.85 2.959 5385
1.85 2.957 5351	2.50 2.940 11684	2.50 3.246 23436	2.50 3.255 25557	2.50 3.251 25435	2.50 3.247 25518	2.50 2.930 11742	1.85 2.957 5382

ANRIKN.% NOM	VERKL.	ANTAL STAVAR	KG UO2	KG U	KG U-235
1.40	1.412	5	15.370	13.541	0.191
1.85	1.854	16	50.382	44.387	0.823
2.50	2.499	43	138.625	122.129	3.052
S:A	2.258	64	204.377	180.057	4.066

TOPPL.NR.:3872H

BOTTPL.NR.:3199C

SPRIDARE NR.: 2592 2596 2581 2249 2456 2274 UPSPR.LAND FÖR URAN: USA
BOXNR.: 522

Ringhals 1 Fuel rod diagram for assembly 596

MONTERINGSPROTOKOLL

PATRON NR. 596.   DATUM:12-01-73   REF.HÖRN

SPRIDARHALLARSTAV 780901

1,85	1.85	1.85	1.85	1.85	1.40	1.40	1.40
2.951	2.951	3.238	3.236	3,234	3.250	2.956	2.952
5403	5428	19186	19095	19065	18146	6399	6390
2.50	2.50	2.50	2.50	1.85	1.85	1.85	1.40
2,933	3.245	3.257	3.258	3.245	3.239	3.234	2.960
11615	25465	25497	25446	19164	471	19060	6368
2.50	2.50	2.50	2.50	2,50	2.50	1.85	1.40
3.250	3.247	3.254	3.247	3.261	3.248	3.226	3.252
25564	2000	25561	25565	25422	25556	19072	18060
2.50	2.50	2.50	2.50	2.50	2.50	1.85	1.85
3,246	3.250	3.248	3.251	3.254	3.256	3.238	3.245
25529	25566	25541	25571	25551	25552	19133	19132
2.50	2.50	2.50		2.50	2.50	2.50	1.85
3.256	3.254	3.258		3.256	3.256	3.259	3.227
25559	25474	25523		25554	25506	25555	19121
2.50	2.50	2.50	2.50	2.50	2.50	2.50	1.85
3.254	3.255	3.252	3.263	3.257	3.253	3.256	3.245
25488	25542	25560	25360	25568	25558	1982	19097
2.50	2.50	2.50	2.50	2.50	2,50	2.50	1.85
2.948	3.256	3.261	3.247	3.251	3.256	3.259	2.959
11676	25451	1954	25414	25487	25409	25483	5385
1.85	2.50	2.50	2.50	2.50	2.50	2.50	1.85
2.957	2.940	3.246	3.255	3.251	3.247	2.930	2.957
5351	11684	23436	25557	25435	25518	11742	5382

ANRIKN.% NOM	VERKL.	ANTAL STAVAR	KG UO2	KG U	KG U-235	
1.40	1.412	5	15.370	13.541	0.191	TOPPL.NR.:3872H
1.85	1.854	16	50.382	44.387	0,823	
2.50	2.499	42	135.331	119.271	2.981	BOTTPL.NR.:3199C
S:A	2.254	63	201.133	177.199	3.995	

SPRIDARE NR.: 2592 2596 2581 2249 2406 2274 UPSPR.LAND FÖR URAN: USA
BOXNR.: 522

Ringhals 1 Fuel rod diagram for assembly 710

PATRON NR. 710. DATUM:12-02-73 REF,HÖRN

1.85 2.941 9117	1.85 2.955 9217	1.85 3.251 27485	1.85 3.259 27421	1.85 3.255 27420	1.40 3.236 21438	1.40 2.951 7116	1.40 2.943 7032
2.50 2.941 11[illegible]55	2.50 3.253 31649	2.50 3.247 31629	2.50 3.255 31429	1.85 3.264 27474	1.85 3.241 479	1.85 3.267 27483	1.40 2.941 7163
2.50 3.257 31641	2.50 3.242 1610	2.50 3.259 31634	2.50 3.245 31492	2.50 3.247 31643	2.50 3.250 31518	1.85 3.253 27501	1.40 3.255 21498
2.50 3.259 31603	2.50 3.253 31556	2.50 3.250 31540	2.50 3.256 31642	2.50 3.246 31648	2.50 3.257 31646	1.85 3.258 27430	1.85 3.261 27504
2.50 3.256 31572	2.50 3.250 31609	2.50 3.261 31537	2.50 3.261 31578	2.50 3.253 31615	2.50 3.251 31588	2.50 3.255 31613	1.85 3.255 27449
2.50 3.255 31536	2.50 3.248 31597	2.50 3.251 31636	2.50 3.262 31520	2.50 3.244 31539	2.50 3.260 31577	2.50 3.257 1693	1.85 3.256 27464
2.50 2.948 11[illegible]74	2.50 3.261 31631	2.50 3.252 1600	2.50 3.251 31529	2.50 3.261 31527	2.50 3.250 31517	2.50 3.254 31535	1.85 2.942 9170
1.85 2.945 9268	2.50 2.933 11044	2.50 3.247 31426	2.50 3.249 31530	2.50 3.255 31614	2.50 3.260 31617	2.50 2.943 11073	1.85 2.946 9241

ANRIKN.% NOM	VERKL.	ANTAL STAVAR	KG UO2	KG U	KG U-235
1.40	1.412	5	15.326	13.502	0.191
1.85	1.853	16	50.549	44.534	0.825
2.50	2.504	43	138.644	122.145	3.058
S:A	2.261	64	204.519	180.181	4.074

TOPPL.NR.:36770

BOTTPL.NR.:36450

SPRIDARE NR.: 3180 3258 3209 3106 3265 3182 URSPR.LAND FÖR URAN: US

BOXNR.: 662

Ringhals 1 Fuel rod diagram for assembly 710

MONTERINGSPROTOKOLL

PATRON NR. 710. DATUM:12-02-73 REF.HÖR!

SPRIDARHÅLLARSTAV 780911

1.85 2.941 9117	1.85 2.955 9217	1.85 3.251 27485	1.85 3.259 27421	1.85 3.255 27420	1.40 3.236 21438	1.40 2.951 7116	1.40 2.943 7032
2.50 2.941 11[illegible]55	2.50 3.253 31649	2.50 3.247 31629	2.50 3.255 31429	1.85 3.264 27474	1.85 3.241 479	1.85 3.267 27483	1.40 2.941 7163
2.50 3.257 31641	2.50 3.242 1610	2.50 3.259 31634	2.50 3.245 31492	2.50 3.247 31643	2.50 3.250 31518	1.85 3.253 27501	1.40 3.255 21498
2.50 3.259 31603	2.50 3.253 31556	2.50 3.250 31540	2.50 3.256 31642	2.50 3.246 31648	2.50 3.257 31646	1.85 3.258 27430	1.85 3.261 27504
2.50 3.256 31572	2.50 3.250 31609	2.50 3.260 31537		2.50 3.253 31615	2.50 3.251 31588	2.50 3.255 31613	1.85 3.255 27449
2.50 3.255 31536	2.50 3.248 31597	2.50 3.251 31636	2.50 3.262 31520	2.50 3.244 31539	2.50 3.260 31577	2.50 3.257 1693	1.85 3.256 27484
2.50 2.948 11[illegible]74	2.50 3.261 31631	2.50 3.252 1600	2.50 3.251 31529	2.50 3.261 31527	2.50 3.250 31517	2.50 3.254 31535	1.85 2.942 9170
1.85 2.945 9268	2.50 2.933 11044	2.50 3.247 31426	2.50 3.249 31530	2.50 3.255 31614	2.50 3.260 31617	2.50 2.943 11073	1.85 2.946 9241

ANRIKN.% NOM	VERKL.	ANTAL STAVAR	KG UO2	KG U	KG U-235	
1.40	1.412	5	15.326	13.502	0.191	TOPPL.NR.:36770
1.85	1.853	16	50.549	44.534	0.825	
2.50	2.504	42	135.383	119.272	2.987	BOTTPL.NR.:36450
S:A	2.257	63	201.258	177.308	4.003	

SPRIDARE NR.: 3180 3258 3200 3186 3265 3182 URSPR.LAND FÖR URAN: US
BOXNR.: 662

Ringhals 1 Fuel rod diagram for assembly 900

MONTERINGSPROTOKOLL

PATRON NR, 900. DATUM:19-03-73 REF.4588

1.85	1.85	1.85	1.85	1.85	1.40	1.40	1.40
2.945	2.942	3.254	3.257	3.255	3.252	2.948	2.967
8739	3777	10297	16031	17150	22555	7589	7590
2.50	2.50	2.50	2.50	1.85	1.85	1.85	1.40
2.937	3.252	3.255	3.258	3.256	3.250	3.257	2.960
12076	40185	40180	40190	16857	343	15222	7574
2.50	2.50	2.50	2.50	2.50	2.50	1.85	1.40
3.263	3.240	3.262	3.246	3.259	3.260	3.261	3.255
40118	1205	40120	40116	40103	40147	17253	22511
2.50	2.50	2.50	2.50	2.50	2.50	1.85	1.85
3.263	3.251	3.257	3.254	3.248	3.259	3.265	3.248
40117	40177	40171	40167	40181	40168	16335	15567
2.50	2.50	2.50	2.50	2.50	2.50	2.50	1.85
3.247	3.255	3.254	3.256	3.249	3.255	3.251	3.265
39983	40006	39984	39981	40108	40189	40150	15071
2.50	2.50	2.50	2.50	2.50	2.50	2.50	1.85
3.267	3.266	3.250	3.262	3.259	3.252	3.246	3.249
39999	39976	39995	39998	40003	40187	1266	17002
2.50	2.50	2.50	2.50	2.50	2.50	2.50	1.85
2.944	3.249	3.246	3.242	3.255	3.256	3.255	2.942
12059	39997	1207	39994	40026	39996	39987	8716
1.85	2.50	2.50	2.50	2.50	2.50	2.50	1.85
2.950	2.939	3.253	3.245	3.254	3.251	2.948	2.936
8654	12026	40090	40178	40191	40018	12035	8697

ANRIKN.% NOM	VERKL.	ANTAL STAVAR	KG UO2	KG U	KG U-235	
1.40	1.409	5	15.392	13.552	0.191	TOPPL.NR.:40663
1.85	1.858	16	50.512	44.501	0.827	
2.50	2.503	43	138.481	122.178	3.059	BOTTPL.NR.:40690
S:A	2.262	64	204.575	180.231	4.077	

SPRIDARE NR.: 1592 1738 1653 1056 1023 1024 URSPR.LAND FÖR URAN: US
BOXNR.: 971

Ringhals 1 Fuel rod diagram for assembly 900

M O N T E R I N G S P R O T O K O L L

PATRON NR, 900.　　DATUM:15-03-73　　REF.HORN

SPRIDARHALLARSTAV 78-08-22

1.85 2.945 8739	1.85 2.942 8777	1.85 3.254 16297	1.85 3.257 16031	1.85 3.255 17158	1.40 3.252 22555	1.40 2.948 7569	1.40 2.967 7590
2.50 2.937 12076	2.50 3.252 40185	2.50 3.255 40188	2.50 3.258 40190	1.85 3.256 16857	1.85 3.230 343	1.85 3.257 15222	1.40 2.960 7574
2.50 3.263 40118	2.50 3.240 1205	2.50 3.262 40120	2.50 3.246 40116	2.50 3.259 40103	2.50 3.260 40147	1.85 3.261 17253	1.40 3.255 22511
2.50 3.263 40117	2.50 3.251 40177	2.50 3.257 40171	2.50 3.254 40167	2.50 3.248 40181	2.50 3.259 40168	1.85 3.265 16335	1.85 3.248 15567
2.50 3.247 39983	2.50 3.255 40006	2.50 3.254 39984		2.50 3.249 40108	2.50 3.255 40189	2.50 3.251 40156	1.85 3.265 15071
2.50 3.267 39999	2.50 3.266 39976	2.50 3.258 39995	2.50 3.262 39998	2.50 3.259 40008	2.50 3.252 40187	2.50 3.246 1266	1.85 3.249 17002
2.50 2.944 12059	2.50 3.249 39997	2.50 3.246 1207	2.50 3.242 39994	2.50 3.255 40026	2.50 3.256 39996	2.50 3.255 39987	1.85 2.942 8716
1.85 2.950 8654	2.50 2.939 12026	2.50 3.253 40090	2.50 3.248 40178	2.50 3.254 40191	2.50 3.251 40018	2.50 2.948 12035	1.85 2.936 8697

ANRIKN,% NOM	VERKL,	ANTAL STAVAR	KG UO2	KG U	KG U-235	
1.40	1.499	5	15.382	13.552	0.191	TOPPL.NR.:40663
1.85	1.858	16	50.512	44.501	0.827	
2.50	2.503	42	135.425	119.309	2.986	BOTTPL.NR.:40690
S:A	2.258	63	201.319	177.362	4.004	

SPRIDARE NR.: 1592 1739 1053 1056 1023 1024　URSPR.LAND FÖR URAN: US

BOX NR.: 971

Ringhals 1 Fuel rod diagram for assembly 1136

MONTERINGSPROTOKOLL

PATRON NR,1136. DATUM:03-06-73 REF.4SRS

1.85	1.85	1.85	1.85	1.85	1.40	1.40	1.40
2.951	2.941	3.260	3.262	3.247	3.251	2.940	2.950
9373	9319	45913	45902	45877	18247	7721	7717
2.50	2.50	2.50	2.50	1.85	1.85	1.85	1.40
2.945	3.254	3.251	3.236	3.260	3.262	3.242	2.954
11871	29233	29368	29304	45910	194	45852	7741
2.50	2.50	2.50	2.50	2.50	2.50	1.85	1.40
3.250	3.241	3.251	3.236	3.239	3.244	3.261	3.266
29280	866	29220	29364	29326	29178	45923	18211
2.50	2.50	2.50	2.50	2.50	2.50	1.85	1.85
3.243	3.258	3.253	3.246	3.247	3.256	3.251	3.262
29219	29301	29225	29217	29401	29330	45913	45970
2.50	2.50	2.50	2.50	2.50	2.50	2.50	1.85
3.248	3.248	3.245	3.239	3.246	3.241	3.253	3.263
29250	29230	29270	29369	29365	29185	29337	45925
2.50	2.50	2.50	2.50	2.50	2.50	2.50	1.85
3.243	3.244	3.243	3.232	3.259	3.250	3.259	3.254
29389	29277	29353	29245	29301	29223	872	45965
2.50	2.50	2.50	2.50	2.50	2.50	2.50	1.85
2.951	3.240	3.256	3.241	3.245	3.242	3.237	2.959
11956	29248	869	29406	29307	29267	29410	9348
1.85	2.50	2.50	2.50	2.50	2.50	2.50	1.85
2.951	2.939	3.243	3.233	3.250	3.260	2.951	2.944
9409	11963	29379	29284	29293	29346	11973	9436

ANRIKN.% NOM	VERKL,	ANTAL STAVAR	KG UO2	KG U	KG U-235
1,40	1.407	5	15,361	13,533	0,190
1,85	1.853	16	50,563	44,546	0,825
2.50	2.509	43	138,407	121,937	3,059
S:A	2.263	64	204,331	180,016	4,074

TOPPL,NR,:58490

BOTTPL,NR.:5609W

SPRIDARE NR.: 237 137 107 202 231 3230 ANSPR,LAND FOR BRACI JSA

BOX NR.: 856

Ringhals 1 Fuel rod diagram for assembly 1136

MONTERINGSPROTOKOLL RINGHALS 1

PATRON NR 1136 810403

1.85	1.85	1.85	1.85	1.85	1.40	1.40	1.40
2.951	2.941	3.260	3.262	3.247	3.251	2.940	2.950
9373	9319	45913	45902	45877	18247	7721	7717
2.50	2.50	2.50	2.50	1.85	1.85	1.85	1.40
2.945	3.254	3.251	3.236	3.260	3.262	3.242	2.954
11871	29233	29368	29304	45910	194	45852	7740
2.50	2.50	2.50	2.50	2.50	2.50	1.85	1.40
3.250	3.241	3.251	3.236	3.239	3.244	3.261	3.266
29280	866	29220	29364	29326	29178	45923	18211
2.50	2.50	2.50	2.50	2.50	2.50	1.85	1.85
3.243	3.258	3.253	3.246	3.247	3.256	3.251	3.262
29219	29301	29225	29217	29401	29330	45918	45970
2.50	2.50	2.50	.00	2.50	2.50	2.50	1.85
3.248	3.248	3.245	.000	3.246	3.241	3.253	3.265
29250	29230	29278		29365	29185	29337	45925
2.50	2.50	2.50	2.50	2.50	2.50	2.50	1.85
3.243	3.244	3.243	3.232	3.259	3.250	3.259	3.254
29389	29277	29353	29246	29300	29223	872	45965
2.50	2.50	2.50	2.50	2.50	2.50	2.50	1.85
2.951	3.240	3.256	3.241	3.245	3.242	3.237	2.950
11956	29248	869	29406	29307	29267	29410	9348
1.85	2.50	2.50	2.50	2.50	2.50	2.50	1.85
2.951	2.939	3.243	3.253	3.250	3.260	2.950	2.944
9409	11963	29379	29284	29293	29346	11973	9436

UO2(KG)	U(KG)	U235(KG)
201.092	177.161	4.008

Ringhals 1 Fuel rod diagram for assembly 1136

MONTERINGSPROTOKOLL *Ringhals 1*

PATRON NR 1136 810914 *CA*

2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50
3.250	3.250	3.256	3.257	3.254	3.250	3.247	2.945
29280	44710	44721	44701	44702	44722	44781	11871
2.50	2.50	2.50	2.50	2.50	1.85	2.50	2.50
3.255	3.243	3.251	3.261	3.243	3.262	3.254	3.248
44707	29219	29368	44706	29389	194	44769	44727
2.50	2.50	2.50	2.50	2.50	2.50	1.85	2.50
3.256	3.241	3.251	3.236	3.239	3.258	3.261	3.261
44763	866	29220	29364	29326	44703	45923	44724
2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50
3.249	3.258	3.253	3.246	3.247	3.256	3.243	3.255
44736	29301	29225	29217	29401	29330	29379	44709
2.50	2.50	.00	.00	2.50	2.50	2.50	2.50
3.248	3.248	.000	.000	3.246	3.241	3.260	3.263
29250	29230			29365	29185	44776	44784
2.50	2.50	.00	.00	2.50	2.50	2.50	2.50
3.253	3.244	.000	.000	3.259	3.250	3.259	3.246
44718	29277			29300	29223	872	44726
2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50
3.245	3.258	3.256	3.241	3.245	3.242	3.250	3.251
29278	44723	869	29406	29307	29267	29293	44730
2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50
3.243	3.232	3.262	3.253	3.259	3.260	3.248	3.260
29353	29246	44788	29284	44786	44791	44740	29346

UO2(KG)	U(KG)	U235(KG)
194.758	171.581	4.274

Ringhals 1 Fuel rod diagram for assembly 1136

M O N T E R I N G S P R O T O K O L L

PATRON NR.1136. DATUM:03-06-73 REF.45RN

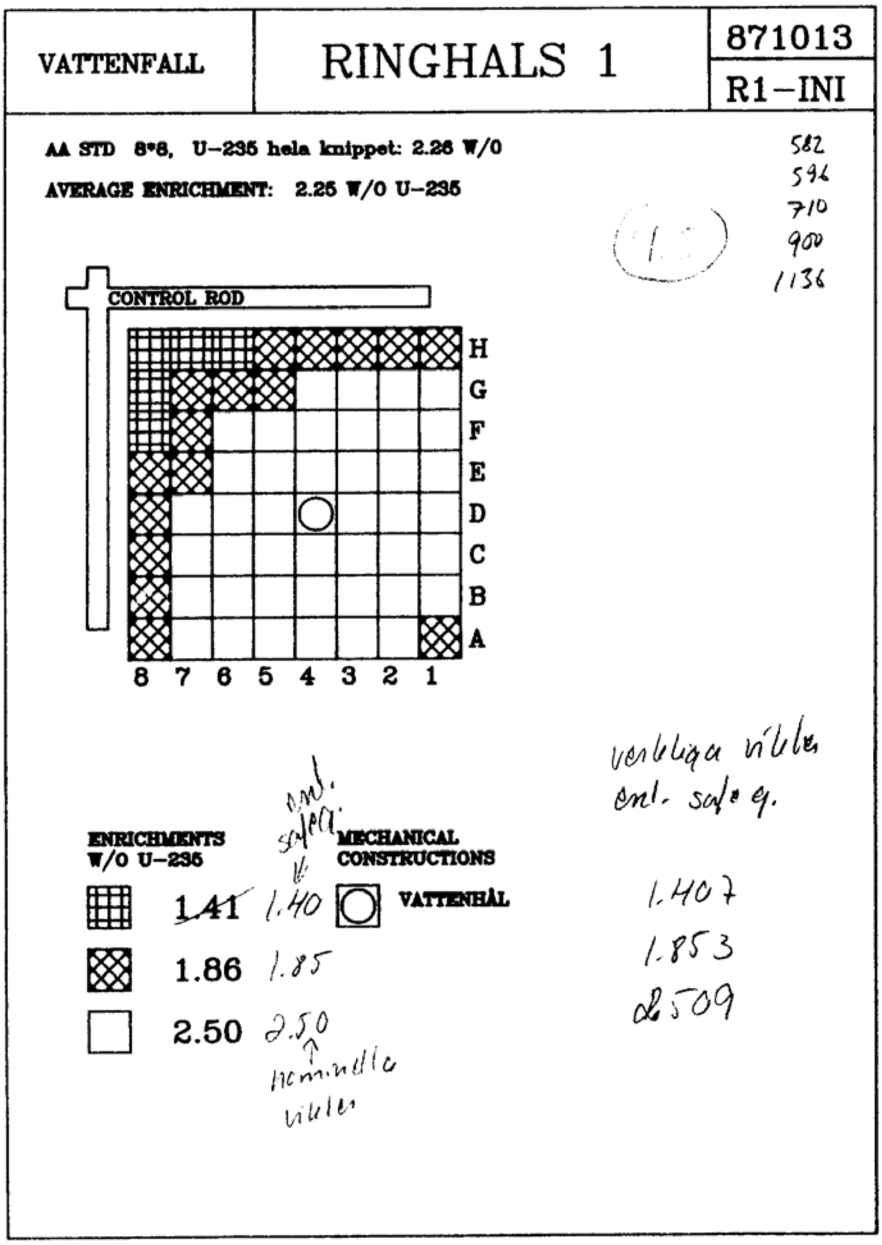
SPRIDARHÅLLARSTAV 780906

1.85 2.951 9373	1.85 2.941 9319	1.85 3.260 45913	1.85 3.262 45902	1.85 3.247 45877	1.40 3.251 18247	1.40 2.940 7721	1.40 2.950 7717
2.50 2.945 11671	2.50 3.254 29233	2.50 3.251 29368	2.50 3.236 29304	1.85 3.260 45910	1.85 3.262 194	1.85 3.242 45852	1.40 2.954 7740
2.50 3.250 29280	2.50 3.241 866	2.50 3.251 29220	2.50 3.236 29364	2.50 3.239 29326	2.50 3.244 29178	1.85 3.261 45923	1.40 3.266 18211
2.50 3.243 29219	2.50 3.258 29301	2.50 3.253 29225	2.50 3.246 29217	2.50 3.247 29401	2.50 3.256 29330	1.85 3.251 45918	1.85 3.262 45970
2.50 3.248 29250	2.50 3.246 29230	2.50 3.245 29278		2.50 3.246 29365	2.50 3.241 29185	2.50 3.253 29337	1.85 3.255 45925
2.50 3.243 29389	2.50 3.244 29277	2.50 3.243 29353	2.50 3.232 29245	2.50 3.259 29380	2.50 3.250 29223	2.50 3.259 872	1.85 3.254 45965
2.50 2.951 11956	2.50 3.240 29248	2.50 3.256 869	2.50 3.241 29406	2.50 3.245 29307	2.50 3.242 29267	2.50 3.237 29410	1.85 2.950 9348
1.85 2.951 9409	2.50 2.939 11963	2.50 3.243 29379	2.50 3.253 29284	2.50 3.250 29293	2.50 3.260 29346	2.50 2.950 11973	1.85 2.944 9436

ANRIKN.% NOM	VERKL.	ANTAL STAVAR	KG UO2	KG U	KG U-235	
1.40	1.407	5	15.361	13.533	0.190	TOPPL.NR.:58190
1.85	1.853	16	50.563	44.546	0.825	
2.50	2.509	42	135.168	119.083	2.988	BOTTPL.NR.:5601W
S:A	2.259	63	201.092	177.162	4.003	

SPRIDARE NR.: 237 137 107 202 231 3930 ANSPR.LAND FOR URAN: JS.
BOX.NR.: 856

Ringhals 1 Enrichment diagram for assemblies 582, 596, 710, 900 och 1177



Ringhals 1 Fuel rod diagram for assembly 1177

PATRON NR 1177 [illegible]

	A	B	C	D	E	F	G	H
8	1.40 3.013 5296	2.05 3.005 5478	2.05 3.323 15644	2.05 3.320 15736	2.05 3.321 15432	2.05 3.327 15705	1.40 3.012 5228	1.4[illegible] 3.0[illegible] 52[illegible]
7	2.05 3.004 5479	2.05 3.329 15299	2.82 3.304 15700	3.10 3.313 16742	3.10 3.319 16331	2.82 3.300 4	2.05 3.322 15418	1.40 3.014 5293
6	2.82 3.314 15713	3.10 3.303 93	3.10 3.330 16307	3.10 3.312 16642	3.10 3.308 16618	3.100A 3.293 19043	2.82 3.318 15699	2.05 3.331 15439
5	3.10 3.314 16696	3.103A 3.292 19346	3.10 3.313 16456	3.10 3.326 16261	3.10 3.314 16173	3.10 3.311 16728	3.10 3.317 16641	2.05 3.323 15419
4	3.10 3.328 16794	3.10 3.311 16721	3.10 3.314 16653	 7074	3.10 3.317 16706	3.10 3.307 16660	3.10 3.325 16349	2.05 3.323 15440
3	2.82 3.311 15783	3.10 3.316 16176	3.10 3.308 16577	3.10 3.315 16719	3.10 3.304 16620	3.10 3.310 16640	2.82 3.309 178	2.05 3.320 15421
2	2.05 3.005 5519	2.82 3.315 15680	3.10 3.312 101	3.10 3.313 16713	3.100A 3.283 19047	3.10 3.311 16712	2.05 3.321 15404	2.05 3.014 5460
1	2.05 3.009 5528	2.05 3.010 5488	2.82 3.312 15781	3.10 3.312 16720	3.10 3.302 16659	2.82 3.324 15733	2.05 3.005 5457	1.40 3.016 5254

ANRIKN.% NOM	VERKL	ANTAL STAVAR	KG UO2	KG U	KG U-235
1.40	1.409	5	15.059	13.267	0.187
2.05	2.086	18	57.618	50.751	1.059
2.82	2.813	9	29.137	26.260	0.739
3.10	3.084	28	92.727	81.749	2.521
3.100	3.100	3	9.573	8.534	0.265
SUM	2.[illegible]	63	[illegible]	[illegible]	[illegible]

TOPPPL.NR. : [illegible]
BOTTPL.NR. : [illegible]

SPRIDARE NR.: 16-0092 16-0079 16-1147 16-0083 16-0076 16-0509
KOK NR.: 2567 [illegible]
URSPR.LAND FÖR URAN: USA
[illegible]

Ringhals 1 Fuel rod diagram for assembly 1186

M O N T E R I N G S P R O T O K O L L

RINGHALS 1 ERS. 1 BA

PATRON NR 1186 DATUM:76-05-07 REF. HÖRN

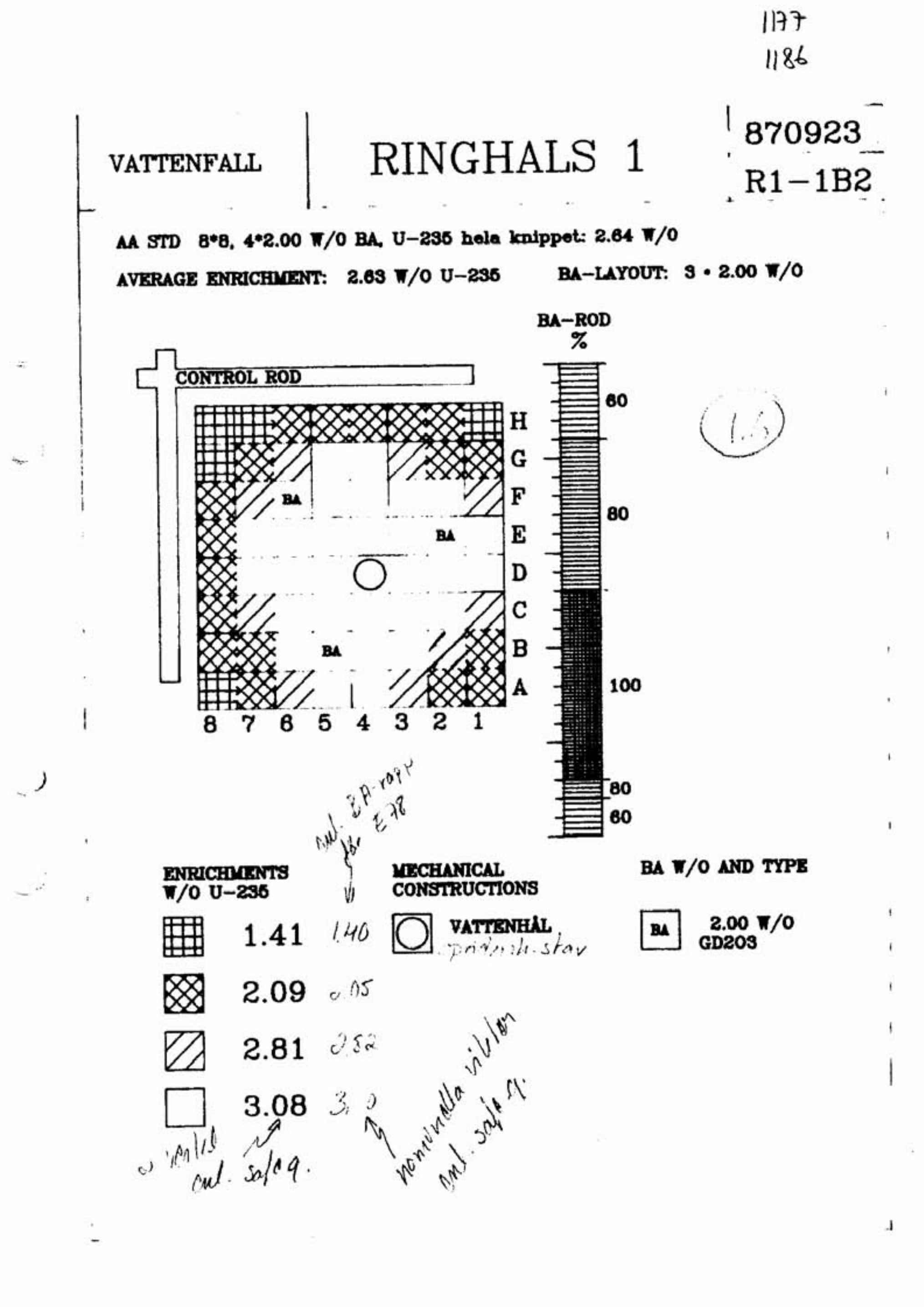
	A	B	C	D	E	F	G	H
8	1.40 3.012 5393	2.05 3.006 5115	2.05 3.325 15229	2.05 3.322 15230	2.05 3.307 15268	2.05 3.329 15328	1.40 3.014 5298	1.40 3.010 5305
7	2.05 3.004 5096	2.05 3.308 15329	2.82 3.302 15826	3.10 3.328 16303	3.10 3.323 16786	2.82 3.306 40	2.05 3.314 15377	1.40 3.002 5242
6	2.82 3.311 15678	3.10 3.306 139	3.10 3.312 16678	3.10 3.327 15995	3.10 3.312 16658	3.10BA 3.282 19033	2.82 3.308 15700	2.05 3.312 15293
5	3.10 3.312 16690	3.10BA 3.290 19132	3.10 3.313 16800	3.10 3.304 16747	3.10 3.318 16133	3.10 3.323 16175	3.10 3.303 16673	2.05 3.331 15431
4	3.10 3.313 16756	3.10 3.323 16325	3.10 3.314 16186	7065	3.10 3.308 16592	3.10 3.318 16135	3.10 3.317 16688	2.05 3.323 15346
3	2.82 3.310 15834	3.10 3.325 16208	3.10 3.318 16167	3.10 3.314 16629	3.10 3.320 16631	3.10 3.307 16657	2.82 3.311 57	2.05 3.319 15348
2	2.05 3.005 5086	2.82 3.312 15716	3.10 3.302 190	3.10 3.311 16674	3.10BA 3.288 19024	3.10 3.315 16342	2.05 3.320 15361	2.05 3.002 5112
1	2.05 3.019 5081	2.05 3.003 5045	2.82 3.323 15868	3.10 3.308 16760	3.10 3.307 16598	2.82 3.312 15734	2.05 3.009 5031	1.40 3.008 5418

ANRIKN.% NOM	VERKL	ANTAL STAVAR	KG UO2	KG U	KG U-235
1.40	1.409	5	15.046	13.256	0.187
2.05	2.086	18	57.558	50.739	1.058
2.82	2.813	9	29.795	26.249	0.738
3.10	3.079	28	92.801	81.758	2.517
3.10BA	3.100	3	9.860	8.543	0.265
S:A	2.640	63	205.060	180.515	4.765

TOPPL.NR. : 6036B
BOTTPL.NR.: 4586D

SPRIDARE NR.: 14-005 14-098 14-028 14-110 14-009 14-414
BOX NR.: 2653
URSPR.LAND FÖR URAN: USA
INBLANDAD MÄNGD GD2 O3=2.0%

Ringhals 1 Enrichment diagram for assembly 1177 and 1186



Ringhals 1 Fuel rod diagram for assembly 5829

	PBB2	R1 ers 2. , Exp - patr.		5829 sid 1

Toppl.mont.sign.datum 79 06 07	Toppl.mont.godk. 790615	Mont.Sign.Dat. 790618	PATRON Kontr.Sign.Dat. 790618	Dokum.Sign.Dat.
Benämning	Materialkod			
Mid-Grip M5 ritn.nr AA 131.650-2	81 BM 8541 pos 2:3	Toppl.nr M 203	XX / XXXX	Anrikning / Stavnr.
Skruv M5 ritn.nr AA 131.691	81 BM 8485:5/895	Spridare nr 130 6		Bärande stav
Bladfjäder tunn ritn.nr AA 131.730	81 BM 8381 pos 3:2/255	195 5		
Bladfjäder tjock ritn.nr AA 131.721	81 BM 8381 pos 2:2/239	211 4		
Bladfjäder tjock ritn.nr AA 147.718	81 BM 8381 pos 4:2/218	225 3		Spridarhållarstav
Låsfjäder ritn.nr AA 147 782	92 RF 3534 pos 1/255			
Mutter M8 ritn.nr AA 101 538	M8-8	187 2		
Tryckfjäder yttre ritn.nr AA 147.760	81 BM 8551:1/232	226 1		
Mutter Topplatta ritn.nr AA 172 598	92 RF 3534 pos 2	Bottenpl.nr Z 2103		Stav med mindre diameter
Mutter M6 ritn.nr AA 147.753	M6-2	Box nr. 71B 080		Pilens riktning på topplattan=Referens-hörn

	A	B	C	D	E	F	G	H
8	1.82 2940 6680	2.34 2941 6673	2.34 3258 25534	2.34 3263 25494	2.34 3254 25883	1.82 3248 25857	1.82 2944 6670	1.38 2956 6687
7	2.34 2956 6659	3.17/1.28 2311/344 79T 8	3.17 3260 25906	3.17 2796 541	3.17 3263 25914	2.34 3258 25852	2.34 3263 25923	1.82 2936 6661
6	3.17/1.28 2087/346 79T 24	3.17 Ba 3244 25911	3.17 3251 25853	3.17 3016 25550	3.17 2787 25555	3.17 Ba 3242 25957	2.34 3254 25873	1.82 3251 25875
5	3.17/1.28 2300/346 79T 19	3.17 3253 546	3.17 3253 25890	1.82 3246 25888	1.82 3251 25874	3.17 2790 25563	3.17 3261 25934	2.34 3261 25881
4	3.17 3253 25920	3.17 3262 25889	3.17 3261 25905	39 063	1.82 3254 25951	3.17 2983 25559	3.17 2794 537	2.34 3256 25880
3	3.17/1.28 2309/344 79T 9	3.17 3007 25560	3.17 3259 25921	3.17 3263 25936	3.17 3252 25944	3.17 3253 25876	3.17 3260 25931	2.34 3261 25540
2	2.34 2944 6367	3.17 Ba 3248 25913	3.17 2977 [illegible]	3.17 3261 [illegible]	3.17 3261 [illegible]	3.17 Ba 3243 [illegible]	3.17/1.28 2302/344 [illegible]	2.34 2944 [illegible]
1	2.34 2952 6678	2.34 2948 6653	3.17/1.28 2306/347 79T 11	3.17 3261 25954	3.17/1.28 2311/344 79T 14	3.17/1.28 2169/346 79T 22	2.34 2952 6652	1.82 2948 6664

Ringhals 1 Fuel rod diagram for assembly 5829

sid 2

MONTERINGSPROTOKOLL RINGHALS 1

PATRON NR 5829 810731

1.82 2.940 30- 6660	2.34 2.941 30- 6673	2.34 3.258 30-25534	2.34 3.263 30-25494	2.34 3.254 30-25883	1.82 3.248 30-25857	1.82 2.944 30- 6670	1.38 2.956 30- 6667
2.34 2.956 30- 6659	3.17 2.311 30-79T8A 1.28 0.344 30-79T8B	3.17 3.260 30-25906	3.17 2.796 30- 541	3.17 3.263 30-25914	2.34 3.258 30-25852	2.34 3.263 30-25923	1.82 2.936 30- 6661
3.17 2.087 3079T24A 1.28 0.346 30-79T24B	3.17 3.244 30-25911	3.17 3.251 30-25853	3.17 3.016 30-25550	3.17 2.787 30-25555	3.17 3.242 30-25957	2.34 3.254 30-25873	1.82 3.251 30-25875
3.17 2.300 3079T19A 1.28 0.346 30-79T19B	3.17 3.253 30- 546	3.17 3.253 30-25890	1.82 3.245 30-25888	1.82 3.251 30-25874	3.17 2.790 30-25563	3.17 3.261 30-25934	2.34 3.261 30-25881
3.17 3.255 30-25920	3.17 3.262 30-25889	3.17 3.261 30-25905	.00 .000	1.82 3.254 30-25951	3.17 2.983 30-25559	3.17 2.794 30- 537	2.34 3.256 30-25860
3.17 2.309 30-79T9A 1.28 0.344 30-79T9B	3.17 3.307 30-25560	3.17 3.259 30-25921	3.17 3.263 30-25936	3.17 3.252 30-25944	3.17 3.253 30-25876	3.17 3.260 30-25931	2.34 3.261 30-25540
2.34 2.944 30- 6367	3.17 3.245 30-25916	3.17 2.977 30-25558	3.17 3.261 30-25933	3.17 3.261 30- 549	3.17 3.243 30-25962	3.17 2.302 3079T10A 1.28 0.344 30-79T10B	2.34 2.944 30- 6663
2.34 2.952 30- 6678	2.34 2.948 30- 6653	3.17 2.306 3079T11A 1.28 0.347 30-79T11B	3.17 3.261 30-25954	3.17 2.311 3079T14A 1.28 0.344 30-79T14B	3.17 2.169 3079T22A 1.28 0.346 30-79T22B	2.34 2.952 30- 6652	1.82 2.948 30- 6664

UO2(KG)	U(KG)	U235(KG)
195.309	170.200	4.809

Ringhals 1 Fuel rod diagram for assembly 5829

sid 3

MONTERINGSPROTOKOLL RINGHALS 1

PATRON NR 5829 611014

1.82 2.940 30- 6680	2.34 2.941 30- 6673	2.34 3.258 30-25534	2.34 3.263 30-25494	2.34 3.254 30-25883	1.82 3.248 30-25857	1.82 2.944 30- 6670	1.38 2.956 30- 6667
2.34 2.956 30- 6659	3.17 2.311 30-79T8A 1.28 0.344 30-79T8B	3.17 3.260 30-25906	3.17 2.796 30- 541	3.17 3.263 30-25914	2.34 3.258 30-25852	2.34 3.263 30-25923	1.82 2.936 30- 6661
3.17 2.087 3079T24A 1.28 0.346 30-79T24B	3.17 3.244 30-25911	3.17 3.251 30-25853	3.17 3.016 30-25550	3.17 2.787 30-25555	3.17 3.242 30-25957	2.34 3.254 30-25873	1.82 3.251 30-25875
3.17 2.300 3079T19A 1.28 0.346 30-79T19B	3.17 3.253 30- 546	3.17 3.253 30-25890	1.82 3.246 30-25868	.00 .000	3.17 2.790 30-25563	3.17 3.261 30-25934	2.34 3.261 30-25881
3.17 3.255 30-25920	3.17 3.262 30-25869	3.17 3.261 30-25905	.00 .000	1.82 3.254 30-25951	3.17 2.963 30-25559	3.17 2.794 30- 537	2.34 3.256 30-25880
3.17 2.309 30-79T9A 1.28 0.344 30-79T9B	3.17 3.007 30-25560	3.17 3.259 30-25921	3.17 3.263 30-25936	3.17 3.252 30-25944	3.17 3.253 30-25876	3.17 3.260 30-25931	2.34 3.201 30-25540
2.34 2.944 30- 6367	3.17 3.248 30-25916	3.17 2.977 30-25558	3.17 3.201 30-25933	3.17 3.241 30- 549	3.17 3.243 30-25962	3.17 2.302 3079T10A 1-28 0-344 30-79T10B	2.34 2.944 30- 6683
2.34 2.952 30- 6678	2.34 2.948 30- 6655	3.17 2.306 3079T11A 1.28 0.347 30-79T11B	3.17 3.261 30-25954	3.17 2.311 3079T14A 1.28 0.344 30-79T14B	3.17 2.169 3079T22A 1.28 0.346 30-79T22B	2.34 2.952 30- 6652	1.82 2.948 30- 6604

UO2(KG)	U(KG)	U235(KG)
[illegible].055	167.555	4.557

Ringhals 1 Fuel rod diagram for assembly 5829

sid 4

R[illegible]GHALS [illegible]LOCK 1 MONTERINGSPROTOKOLL FÖR PATRON: 5829 UTSKRIFTSDATUM: 1987-09-30
DATUM: 870922 OMR: B POS IT65 BOX-NR:

	A	B	C	D	E	F	G	H
8	1.82 30-6680	2.34 30-6673	2.34 30-25534	2.34 30-25494	2.34 30-25983		1.82 30-6670	1.38 30-6687
7	2.34 30-6659	3.17 30-79T8	3.17 30-25906	3.17 30-541	3.17 30-25914	2.34 30-25852	2.34 30-25923	1.82 30-6601
6	3.17 30-79T24	3.17 30-25911	3.17 30-25853	3.17 30-25550	3.17 30-25555	3.17 30-25957	2.34 30-25873	
5		3.17 30-546	3.17 30-25890	1.82 30-25898		3.17 30-25563	3.17 30-25934	2.34 30-25881
4	3.17 30-25926	3.17 30-25889	3.17 30-25905		1.82 30-25951	3.17 30-25559	3.17 30-537	2.34 30-25880
3	3.17 30-79T9	3.17 30-25560	3.17 30-25921	3.17 30-25936	3.17 30-25944	3.17 30-25876	3.17 30-25931	2.34 30-25540
2	2.34 30-6367	3.17 30-25916	3.17 30-25558	3.17 30-25933	3.17 30-549	3.17 30-25962	3.17 30-79T10	2.34 30-6683
1	2.34 30-6678	2.34 30-6653	3.17 30-79T11	3.17 30-25954	3.17 30-79T14	3.17 30-79T22	2.34 30-6652	1.82 30-6664

Ringhals 1 Fuel rod diagram for assembly 5829

sid 5

RINGHALS BLOCK 1 MONTER: ISPROTO LL FÖR PATRON: 5829 'SKRIFT ATUM: 1989-10-06
DATUM: 880113 OMR: BB POS: E165 BOX-NR:

	A	B	C	D	E	F	G	H
8	1.82 30-6680	2.34 30-6673	2.34 30-25534	2.34 30-25494	2.34 30-25883		1.82 30-6670	1.38 30-6687
7	2.34 30-6659	3.17 30-79T8	3.17 30-25906	3.17 30-541	3.17 30-25914	2.34 30-25852	2.34 30-25923	1.82 30-6661
6	3.17 30-79T24	3.17 30-25911	3.17 30-25853	3.17 30-25550	3.17 30-25555	3.17 30-25957	2.34 30-25873	
5		3.17 30-546	3.17 30-25890	1.82 30-25888		3.17 30-25563	3.17 30-25934	2.34 30-25881
4	3.17 30-25920	3.17 30-25889	3.17 30-25905		1.82 30-25951	3.17 30-25559	3.17 30-537	2.34 30-25880
3	3.17 30-79T9	3.17 30-25560	3.17 30-25921	3.17 30-25936	3.17 30-25944	3.17 30-25876	3.17 30-25931	2.34 30-25540
2	2.34 30-6367	3.17 30-25918	3.17 30-25558	3.17 30-25933	3.17 30-549	3.17 30-25962	3.17 30-79T10	2.34 30-6683
1	2.34 30-6678	2.34 30-6653	3.17 30-79T11	3.17 30-25954	3.17 30-79T14	3.17 30-79T22	2.34 30-6652	1.82 30-6664

Ringhals 1 Fuel rod diagram for assembly 5829

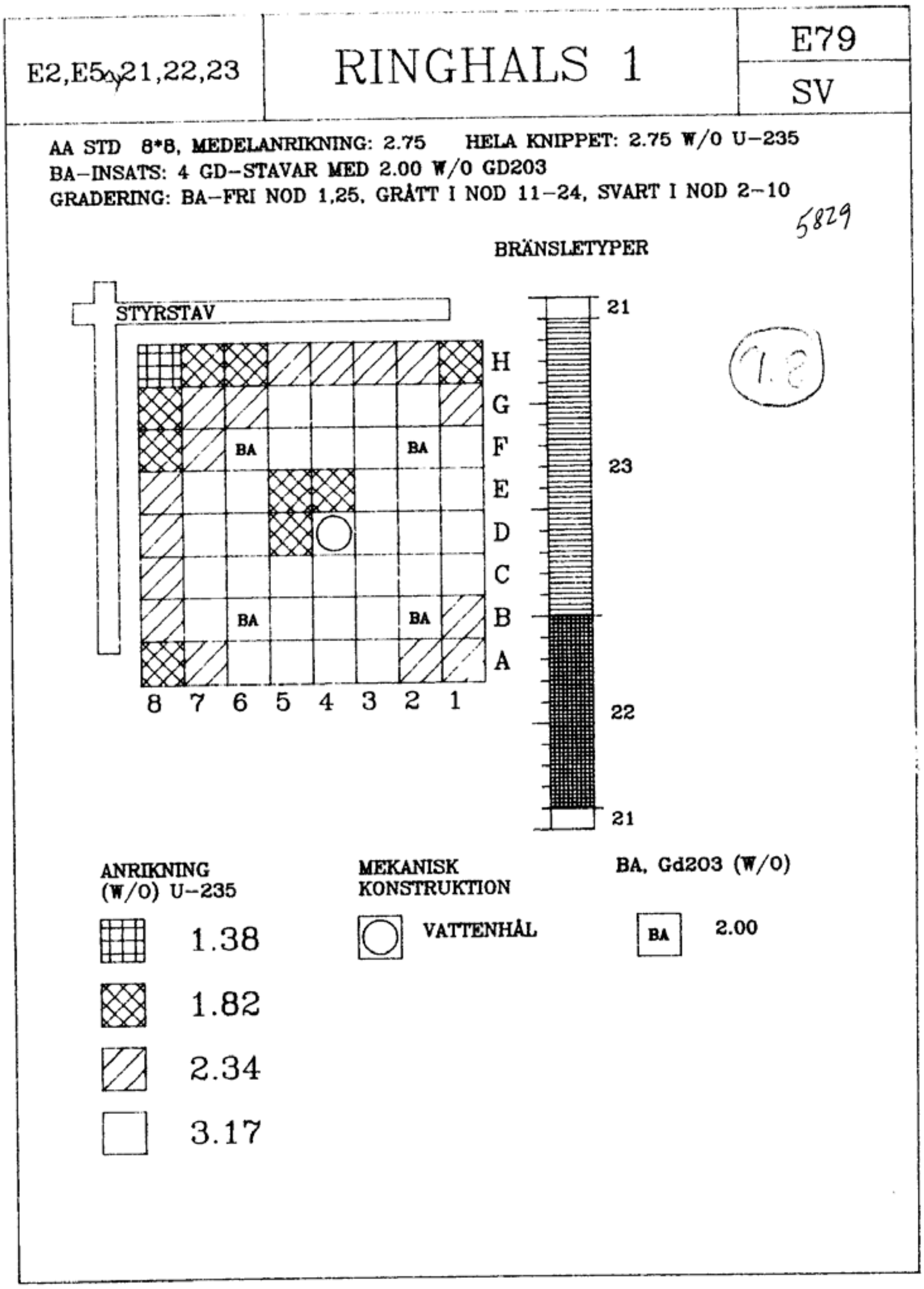
RINGHALS BLOCK 1 MONTER GSPROTC OLL FÖR PATRON: 5829 TSKRIFT DATUM: 1989-10-12
DATUM: 891011 OMR: 8b POS: E.65 BOX-NR:

	A	B	C	D	E	F	G	H
8	1.82 30-6680	2.34 30-6673	2.34 30-25534	2.34 30-25494	2.34 30-25883	6	1.82 30-6670	1.38 30-6687
7	2.34 30-6659	3.17 30-79T8	3.17 30-25906	3.17 30-541	3.17 30-25914	2.34 30-25852	2.34 30-25923	1.82 30-6661
6	3.17 30-79T24	3.17 30-25911	2	3.17 30-25550	3.17 30-25555	3.17 30-25957	2.34 30-25873	5
5	1	3.17 30-546	3.17 30-25890	1.82 30-25888	4	3.17 30-25563	3.17 30-25934	2.34 30-25881
4	3.17 30-25920	3.17 30-25889	3.17 30-25905	3	1.82 30-25951	3.17 30-25559	3.17 30-537	2.34 30-25880
3	3.17 30-79T9	3.17 30-25560	3.17 30-25921	3.17 30-25936	3.17 30-25944	3.17 30-25876	3.17 30-25931	2.34 30-25540
2	2.34 30-6367	3.17 30-25918	3.17 30-25558	3.17 30-25933	3.17 30-549	3.17 30-25962	3.17 30-79T10	2.34 30-6683
1	2.34 30-6678	2.34 30-6653	3.17 30-79T11	3.17 30-25954	3.17 30-79T14	3.17 30-79T22	2.34 30-6652	1.82 30-6664

5829

sid 6

Ringhals 1 Enrichment diagram for assembly 5829



Ringhals 1 Fuel rod diagram for assembly 6423

M O N T E R I N G S P R O T O K O L L   PATRON NR 6423

033   R1E3

REF.HÖRN

	A	B	C	D	E	F	G	H
8	1.98 2.963 5203	2.49 2.949 5116	2.49 3.256 21570	2.49 3.257 21549	2.49 3.253 21538	1.98 3.250 20559	1.98 2.963 5191	1.38 2.958 5488
7	2.49 2.954 5132	3.37 3.264 21276	3.17 3.250 20494	3.37 3.264 73	3.37 3.263 21238	2.49 3.252 21571	2.49 3.254 21514	1.98 2.959 5199
6	3.37 3.268 21305	3.17BA 3.262 15102	3.37 3.261 21215	3.37 3.265 21197	3.37 3.263 21192	3.17BA 3.263 15113	2.49 3.261 21560	1.98 3.263 20549
5	3.37 3.262 21329	3.37 3.266 30	3.37 3.263 21287	1.98 3.270 20545	1.98 3.264 20599	3.37 3.264 21156	3.37 3.266 21217	2.49 3.250 21545
4	3.37 3.270 21182	3.37 3.260 21298	3.37 3.261 21308	53117	1.98 3.265 20551	3.37 3.260 21310	3.37 3.271 60	2.49 3.258 21559
3	3.37 3.267 21267	3.37 3.270 21285	3.17 3.258 20508	3.37 3.260 21335	3.37 3.262 21333	3.37 3.269 21315	3.17 3.249 20483	2.49 3.251 21544
2	2.49 2.950 5169	3.17BA 3.270 15060	3.37 3.263 21317	3.37 3.260 21350	3.37 3.265 100	3.17BA 3.266 15132	3.37 3.265 21343	2.49 2.951 5155
1	2.49 2.950 5131	2.49 2.955 5147	3.37 3.262 21334	3.37 3.260 21316	3.37 3.264 21264	3.37 3.262 21332	2.49 2.953 5139	1.98 2.965 5215

ANRIKN.% NOM	VERKL	ANTAL STAVAR	KG UO2	KG U	KG U-235
1.38	1.407	1	2.953	2.607	0.037
1.98	1.984	9	28.162	24.822	0.493
2.49	2.503	16	49.954	44.029	1.102
3.17BA	3.177	4	13.061	11.336	0.360
3.17	3.170	3	9.757	8.600	0.273
3.37	3.347	30	97.920	86.307	2.889
S:A	2.900	63	201.812	177.701	5.154

TOPPL.NR : M647
BOTTPL.NR: M1072
BOX NR : 738026

INBLANDAD MÄNGD GD 2.00%
SPRIDARE NR.: 33776 34011 34019 34024 34204 34220

GODK. FÖR INFRYSNING OCH LEVERANS DAT..1980-12-22 SIGN:...

Ringhals 1 Fuel rod diagram for assembly 6432

M O N T E R I N G S P R O T O K O L L

PATRON NR 6432

033 R1E3

REF.HÖRN

	A	B	C	D	E	F	G	H
8	1.98 2.956 6283	2.49 2.949 6087	2.49 3.256 23042	2.49 3.258 23064	2.49 3.264 23068	1.98 3.253 22848	1.98 2.965 6362	1.38 2.955 6269
7	2.49 2.957 6177	3.37 3.263 22197	3.17 3.251 22676	3.37 3.269 249	3.37 3.255 22179	2.49 3.264 23100	2.49 3.269 23070	1.98 2.963 6290
6	3.37 3.254 22050	3.17BA 3.249 16112	3.37 3.255 22148	3.37 3.257 22048	3.37 3.258 22165	3.17BA 3.249 16116	2.49 3.261 23093	1.98 3.250 22824
5	3.37 3.263 22175	3.37 3.269 207	3.37 3.254 22101	1.98 3.250 22841	1.98 3.256 22815	3.37 3.257 22188	3.37 3.254 22120	2.49 3.263 22646
4	3.37 3.256 22105	3.37 3.261 22084	3.37 3.254 22090	53094	1.98 3.255 22805	3.37 3.263 22160	3.37 3.264 241	2.49 3.257 22649
3	3.37 3.265 22161	3.37 3.260 22088	3.17 3.258 22707	3.37 3.252 22072	3.37 3.255 22021	3.37 3.264 22046	3.17 3.248 22680	2.49 3.259 22675
2	2.49 2.951 6080	3.17BA 3.252 16117	3.37 3.253 22083	3.37 3.256 22017	3.37 3.262 257	3.17BA 3.252 16115	3.37 3.256 22074	2.49 2.952 6015
1	2.49 2.953 6121	2.49 2.953 6045	3.37 3.262 22113	3.37 3.254 22103	3.37 3.252 22019	3.37 3.262 22020	2.49 2.959 6093	1.98 2.960 6264

ANRIKN.% NOM	VERKL	ANTAL STAVAR	KG UO2	KG U	KG U-235
1.38	1.407	1	2.955	2.605	0.037
1.98	1.984	9	28.108	24.774	0.492
2.49	2.503	16	50.025	44.092	1.104
3.17BA	3.177	4	13.002	11.284	0.359
3.17	3.170	3	9.757	8.600	0.273
3.37	3.334	30	97.759	86.165	2.873
S:A	2.893	63	201.606	177.520	5.138

TOPPL.NR : M630
BOTTPL.NR: M1075
BOX NR : 73B162

INBLANDAD MÄNGD GD 2.00%
SPRIDARE NR.: 32766 32902 32930 32939 32940 34799

GODK. FÖR INFRYSNING OCH LEVERANS DAT. 1980-12-22 SIGN: HU

Ringhals 1 Fuel rod diagram for assembly 6454

MONTERINGSPROTOKOLL

PATRON NR 6454

033 R1E3

REF.HÖRN

	A	B	C	D	E	F	G	H
	1.98	2.49	2.49	2.49	2.49	1.98	1.98	1.38
	2.963	2.954	3.258	3.267	3.255	3.252	2.957	2.958
8	6324	6185	23359	23376	23374	23247	6375	6237
	2.49	3.37	3.17	3.37	3.37	2.49	2.49	1.98
	2.961	3.261	3.250	3.263	3.263	3.258	3.260	2.951
7	6030	23291	23346	323	23268	23362	23365	6359
	3.37	3.17BA	3.37	3.37	3.37	3.17BA	2.49	1.98
	3.257	3.267	3.260	3.262	3.266	3.268	3.260	3.256
6	23269	16020	23305	23275	23292	16044	23356	23241
	3.37	3.37	3.37	1.98	1.98	3.37	3.37	2.49
	3.260	3.260	3.306	3.256	3.252	3.254	3.264	3.258
5	23265	319	23331	23254	23242	23303	23284	23355
	3.37	3.37	3.37		1.98	3.37	3.37	2.49
	3.267	3.263	3.259		3.257	3.266	3.265	3.261
4	23289	23309	23285	53067	23244	23290	322	23370
	3.37	3.37	3.17	3.37	3.37	3.37	3.17	2.49
	3.259	3.264	3.251	3.265	3.257	3.258	3.250	3.262
3	23307	23259	23347	23280	23293	23297	23340	23363
	2.49	3.17BA	3.37	3.37	3.37	3.17BA	3.37	2.49
	2.949	3.269	3.261	3.259	3.264	3.266	3.267	2.961
2	6215	16011	23270	23278	326	16059	23276	6216
	2.49	2.49	3.37	3.37	3.37	3.37	2.49	1.98
	2.946	2.946	3.259	3.263	3.265	3.264	2.950	2.962
1	6138	6035	23277	23281	23271	23264	6126	6365

ANRIKN.% NOM	VERKL	ANTAL STAVAR	KG UO2	KG U	KG U-235
1.38	1.407	1	2.953	2.607	0.037
1.98	1.984	9	28.106	24.773	0.492
2.49	2.503	16	50.006	44.075	1.103
3.17BA	3.177	4	13.070	11.343	0.360
3.17	3.170	3	9.751	8.595	0.272
3.37	3.343	30	97.901	86.290	2.885
S:A	2.898	63	201.792	177.683	5.149

TOPPL.NR : M517
BOTTPL.NR: Z4197
BOX NR : 73B008

INBLANDAD MÄNGD GD 2.00%

SPRIDARE NR.: 33738 36158 36418 36429 36437 36442

GODK. FÖR INFRYSNING OCH LEVERANS DAT. 1980-12-22 SIGN: [illegible]

Ringhals 1 Fuel rod diagram for assembly 6478

sid 1

MONTERINGSPROTOKOLL

PATRON NR 6478

033 R1E3

REF.NORN

	A	B	C	D	E	F	G	H
8	1.98 2.953 8028	2.49 2.963 3031	2.49 3.267 25308	2.49 3.255 25317	2.49 3.262 25374	1.98 3.256 25425	1.98 2.953 8030	1.38 2.954 8003
7	2.49 2.959 8089	3.37 3.262 25093	3.17 3.256 25515	3.37 3.234 504	3.37 3.261 25001	2.49 3.262 25316	2.49 3.258 25354	1.98 2.950 8026
6	3.37 3.259 25008	3.17BA 3.244 18016	3.37 3.260 25002	3.37 3.258 25016	3.37 3.265 25004	3.17BA 3.250 18027	2.49 3.255 25328	1.98 3.261 25430
5	3.37 3.261 25087	3.37 3.237 539	3.37 3.262 25023	1.98 3.255 25453	1.98 3.260 25432	3.37 3.259 25031	3.37 3.261 25117	2.49 3.263 25312
4	3.37 3.260 25044	3.37 3.265 25137	3.37 3.264 25015	53065	1.98 3.264 25458	3.37 3.262 25022	3.37 3.235 535	2.49 3.265 25356
3	3.37 3.262 25017	3.37 3.264 25021	3.17 3.257 25532	3.37 3.262 25101	3.37 3.264 25102	3.37 3.260 25061	3.17 3.268 25523	2.49 3.261 25338
2	2.49 2.964 8149	3.17BA 3.244 18037	3.37 3.264 25089	3.37 3.264 25092	3.37 3.237 531	3.17BA 3.248 18026	3.37 3.264 25069	2.49 2.963 8124
1	2.49 2.956 8123	2.49 2.960 3152	3.37 3.257 25110	3.37 3.266 25109	3.37 3.267 25139	3.37 3.265 25076	2.49 2.962 3133	1.98 2.950 8042

ANRIKN.% NOM	VERKL	ANTAL STAVAR	KG UO2	KG U	KG U-235
1.38	1.407	1	2.954	2.604	0.037
1.98	1.980	9	28.102	24.769	0.490
2.49	2.506	16	50.075	44.136	1.106
3.17BA	3.177	4	12.986	11.271	0.358
3.17	3.172	3	9.781	8.621	0.273
3.37	3.348	30	97.761	86.167	2.885
S:A	2.900	63	201.659	177.568	5.149

TOPPL.NR : M565
BOTTPL.NR: Z4203
BOX NR : 73B270

INBLANDAD MÄNGD GD 2.00%

SPRIDARE NR.: 33767 34805 34807 34831 34833 34847

GODK. FÖR INFRYSNING OCH LEVERANS DAT. 1980-12-22 SIGN: ....

Ringhals 1 Fuel rod diagram for assembly 6478

DATUM: 860824 OMR: BB POS: CC38 BOX-NR: 31B271 EJ GILTIGT - HISTORIK

	A	B		D	E			H	
8	1.98 33-8028	2.49 33-8081	2.49 33-25308	2.49 33-25317	2.49 33-25374	1.98 33-25425	1.98 33-8030	1.38 33-8003	Före omräkn
7	2.49 33-8039	3.37 33-25093	3.17 33-25515	3.37 33-504	3.37 33-25001	2.49 33-25316	2.49 33-25354	1.98 33-8026	
6	3.37 33-25008	3.17 33-18016	3.37 33-25002	3.37 33-25016	3.37 33-25004	3.17 33-18027	2.49 33-25328	1.98 33-25430	
5	3.37 33-25087	3.37 33-539	3.37 33-25023	1.98 33-25453	1.98 33-25432	3.37 33-25031	3.37 33-25117	2.49 33-25312	
4	3.37 33-25044	3.37 33-25137	3.37 33-25015		1.98 33-25458	3.37 33-25022	3.37 33-535	2.49 33-25356	
3	3.37 33-25017	3.37 33-25021	3.17 33-25532	3.37 33-25101	3.37 33-25102	3.37 33-25061	3.17 33-25523	2.49 33-25338	
2	2.49 33-8149	3.17 33-18037	3.37 33-25089	3.37 33-25092	3.37 33-531	3.17 33-18026	3.37 33-25069	2.49 33-8124	
1	2.49 33-8123	2.49 33-8152	3.37 33-25110	3.37 33-25109	3.37 33-25139	3.37 33-25076	2.49 33-8133	1.98 33-8042	

sid 2

Ringhals 1 Fuel rod diagram for assembly 6478

sid 3

RINGHALS BLOCK 1 MONTERINGSPROTOKOLL FÖR PATRON: 6478 UTSKRIFTSDATUM: 1986-09-02
DATUM: 860826 OMR: B POS: ' 8 ' BOX-NR: 31B271

	A	B	C	D	E	F	G	H
8	1.98 33-8028	2.49 33-8081	2.49 33-25308	2.49 33-25317	2.49 33-25374	1.98 33-25425	1.98 33-8030	1.38 33-8003
7	2.49 33-8039	3.37 33-25093	3.17 33-25515	3.37 33-504	3.37 33-25001	2.49 33-25316	2.49 33-25354	1.98 33-8026
6	3.37 33-25008	3.17 33-18016	3.37 33-25002	3.37 33-25016	3.37 33-25004	3.17 33-18027	2.49 33-25328	1.98 33-25430
5	3.37 33-25087	3.37 33-539		1.98 33-25453	1.98 33-25432	3.37 33-25031	3.37 33-25117	2.49 33-25312
4	3.37 33-25044				1.98 33-25458		3.37 33-535	2.49 33-25356
3	3.37 33-25017		3.17 33-25532	3.37 33-25101	3.37 33-25102	3.37 33-25061	3.17 33-25523	2.49 33-25338
2	2.49 33-8149	3.17 33-18037	3.37 33-25089		3.37 33-531	3.17 33-18026	3.37 33-25069	2.49 33-8124
1	2.49 33-8123	2.49 33-8152	3.37 33-25110	3.37 33-25109	3.37 33-25139	3.37 33-25076	2.49 33-8133	1.98 33-8042

Ringhals 1 Fuel rod diagram for assembly 6478

sid 4

RINGHALS BLOCK 1 MONTERINGSPROTOKOLL FÖR PATRON: 6478 UTSKRIFTSDATUM: 1987-09-30
DATUM: 870929 ONR: POS: 62 BOX-NR:

	A	B	C	D	E	F	G	H
8	1.98 33-8028	2.49 33-8081				1.98 33-25425	1.98 33-8030	
7	2.49 33-8089	3.37 33-25093	3.17 33-25515	3.37 33-504	3.37 33-25001	2.49 33-25316	2.49 33-25354	1.98 33-8026
6			3.37 33-25002	3.37 33-25016	3.37 33-25004	3.17 33-18027	2.49 33-25323	1.98 33-25430
5	3.37 33-25087	3.37 33-539		1.98 33-25453	1.98 33-25432	3.37 33-25031	3.37 33-25117	
4	3.37 33-25044				1.98 33-25458		3.37 33-535	
3	3.37 33-25017		3.17 33-25532	3.37 33-25101	3.37 33-25102	3.37 33-25061	3.17 33-25523	2.49 33-25338
2	2.49 33-8149	3.17 33-18037	3.37 33-25087		3.37 33-531	3.17 33-18026	3.37 33-25069	2.49 33-8124
1	2.49 33-8135	2.49 33-8152	3.37 33-25110	3.37 33-25109	3.37 33-25139	3.37 33-25076	2.49 33-8133	1.98 33-8042

Ringhals 1 Fuel rod diagram for assembly 6478

sid 5

RINGHALS BLOCK 1 MONTERINGSPROTOKOLL FÖR PATRON: 6478 UTSKRIFTSDATUM: 1988-01-21
DATUM: 880113 OMR: POS: 52' BOX-NR:

	A	B	C	D	E	F	G	H
8	1.98 33-8028	2.49 33-8031				1.98 33-25425	1.98 33-8030	
7	2.49 33-8089	3.37 33-25093	3.17 33-25515	3.37 33-504	3.37 33-25001	2.49 33-25316	2.49 33-25354	1.98 33-8026
6			3.37 33-25002	3.37 33-25016	3.37 33-25004	3.17 33-18027	2.49 33-25328	1.98 33-25430
5	3.37 33-25087	3.37 33-539		1.98 33-25453	1.98 33-25432	3.37 33-25031	3.37 33-25117	
4	3.37 33-25044				1.98 33-25458		3.37 33-535	
3	3.37 33-25017		3.17 33-25552	3.37 33-25101	3.37 33-25102	3.37 33-25061	3.17 33-25523	2.49 33-25338
2	2.49 33-8149	3.17 33-18037	3.37 33-25089		3.37 33-531	3.17 33-18026	3.37 33-25069	2.49 33-8124
1	2.49 33-8123	2.49 33-8152	3.37 33-25110	3.37 33-25109	3.37 33-25139	3.37 33-25076	2.49 33-8133	1.98 33-8042

Ringhals 1 Fuel rod diagram for assembly 6478

sid 6

UT UR HÅRD 860815

RINGHALS BLOCK 1 MONTERINGSPROTOKOLL FÖR PATRON: 6478 UTSKRIFTSDATUM: 1988-01-21
DATUM: 880113 OMR: POS: 2 BOX-NR:

	A	B	C	D	E	F	G	H
8	1.98 33-8028	2.49 33-8081	9	5		2	1.98 33-8030	
7	2.49 33-8089	3.37 33-25093	3.17 33-25515	3.37 33-504	3.37 33-25001	2.49 33-25316	2.49 33-25354	1.98 33-8026
6	6	5	3.37 33-25002	3.37 33-25016	3.37 33-25004	3.17 33-18027	2.49 33-25328	
5	3.37 33-25087	3.37 33-539	10	1.98 33-25453	1.98 33-25432	3.37 33-25031	3.37 33-25117	
4	3.37 33-25044	11	12		1.98 33-25458		3.37 33-535	
3	3.37 33-25017	18	3.17 33-25532	3.37 33-25101	3.37 33-25102	3.37 33-25061	3.17 33-25523	2.49 33-25338
2	2.49 33-8149	3.17 33-18037	3.37 33-25089		3.37 33-531	3.17 33-18026	3.37 33-25069	2.49 33-8124
1	2.49 33-8123	1	3.37 33-25110	3.37 33-25109	3.37 33-25139	3.37 33-25076	2	1.98 33-8042

Ringhals 1 Fuel rod diagram for assembly 8327

8327

M O N T E R I N G S P R O T O K O L L   PATRON NR 8327

047   RIE4

TOPPL: M476   BOTTPL: Z3713   BOX: 73B139   REF.NORM

	A	B	C	D	E	F	G	H
8	1.98 2.971 6547	2.49 2.966 6493	2.49 3.249 22267	2.49 3.257 22738	2.49 3.261 22781	1.98 3.253 25744	1.98 2.958 6576	1.38 2.956 6213
7	2.49 2.963 6526	3.37 3.265 25320	3.17 3.268 24991	3.37 3.263 467	3.37 3.266 25376	2.49 3.255 22740	2.49 3.257 22848	1.98 2.960 6582
6	3.37 3.261 25504	3.17BA 3.241 15537	3.37 3.263 25364	3.37 3.252 24593	3.37 3.252 24590	3.17BA 3.241 15522	2.49 3.263 22713	1.98 3.257 25786
5	3.37 3.260 24506	3.37 3.268 537	3.37 3.254 24553	1.98 3.259 25781	1.98 3.257 25785	3.37 3.255 24544	3.37 3.250 24596	2.49 3.264 22793
4	3.37 3.258 24541	3.37 3.257 24604	3.37 3.258 24552	47133	1.98 3.256 25758	3.37 3.254 24527	3.37 3.263 547	2.49 3.257 22729
3	3.37 3.252 24621	3.37 3.253 24620	3.17 3.269 22783	3.37 3.260 24509	3.37 3.259 24587	3.37 3.261 24526	3.17 3.271 24995	2.49 3.258 22839
2	2.49 2.950 6653	3.17BA 3.238 15547	3.37 3.254 24642	3.37 3.259 24601	3.37 3.260 542	3.17BA 3.241 15475	3.37 3.261 24574	2.49 2.966 6522
1	2.49 2.950 6617	2.49 2.962 6513	3.37 3.261 24629	3.37 3.256 24659	3.37 3.260 24676	3.37 3.259 24623	2.49 2.964 6482	1.98 2.953 6588

ANRIKN.% NOM	VERKL	ANTAL STAVAR	KG UO2	KG U	KG U-235	UFAKTOR
1.38	1.399	1	2.956	2.605	0.036	0.8814
1.98	1.997	9	28.124	24.789	0.495	0.8814
2.49	2.485	16	50.044	44.109	1.094	0.8814
3.17BA	3.179	4	12.961	11.250	0.356	0.8680
3.17	3.186	3	9.808	8.644	0.276	0.8814
3.37	3.364	30	97.754	86.157	2.898	0.8814
S:A	2.906	63	201.647	177.554	5.155	

INBLANDAD MÄNGD GD 2.00%

SPRIDARE NR.: 51003 51286 51260 51262 51259 51281

GODK. FÖR INFRYSNING OCH LEVERANS DAT.....1981-09-13.....SIGN:..........

Ringhals 1 Fuel rod diagram for assembly 8331

8331

MONTERINGSPROTOKOLL　　PATRON NR 8331

047　* R1E4 *

TOPPL: A502　BOTTPL: Z3715　BOX: 73B491　REF.HORN

	A	B	C	D	E	F	G	H
8	1.98 2.965 6542	2.49 2.964 6525	2.49 3.251 25326	2.49 3.259 25673	2.49 3.257 25605	1.98 3.259 25619	1.98 2.969 6569	1.38 2.965 6380
7	2.49 2.957 6640	3.37 3.261 25513	3.17 3.278 25057	3.37 3.263 507	3.37 3.262 25471	2.49 3.254 25609	2.49 3.257 23057	1.98 2.966 6553
6	3.37 3.264 25485	3.17BA 3.241 15485	3.37 3.264 25500	3.37 3.262 25484	3.37 3.261 25456	3.17BA 3.245 15487	2.49 3.257 25710	1.98 3.258 25791
5	3.37 3.266 25470	3.37 3.263 459	3.37 3.259 25424	1.98 3.257 25811	1.98 3.258 25745	3.37 3.259 25512	3.37 3.265 25371	2.49 3.250 23139
4	3.37 3.265 25430	3.37 3.266 25447	3.37 3.260 25402	47052	1.98 3.262 25742	3.37 3.258 25407	3.37 3.260 487	2.49 3.255 23025
3	3.37 3.265 25406	3.37 3.266 25398	3.17 3.277 24988	3.37 3.261 25491	3.37 3.265 25506	3.37 3.261 25497	3.17 3.266 25026	2.49 3.263 25683
2	2.49 2.958 6635	3.17BA 3.241 15463	3.37 3.263 25505	3.37 3.262 25482	3.37 3.256 509	3.17BA 3.241 15489	3.37 3.266 25472	2.49 2.952 6637
1	2.49 2.966 6518	2.49 2.969 6523	3.37 3.263 25509	3.37 3.258 25503	3.37 3.261 25473	3.37 3.264 25466	2.49 2.948 6618	1.98 2.965 6551

ANRIKN.% NOM	VERKL	ANTAL STAVAR	KG UO2	KG U	KG U-235	UFAKTOR
1.38	1.394	1	2.965	2.613	0.036	0.8814
1.98	1.992	9	28.159	24.819	0.495	0.8814
2.49	2.485	16	50.017	44.084	1.094	0.8814
3.17BA	3.179	4	12.968	11.256	0.357	0.8680
3.17	3.186	3	9.821	8.656	0.276	0.8814
3.37	3.384	30	97.869	86.262	2.912	0.8814
S:A	2.915	63	201.799	177.690	5.170	

INBLANDAD MÄNGD GD 2.00%

SPRIDARE NR.: 51030　51299　51277　51297　51289　51273

Ringhals 1 Fuel rod diagram for assembly 8332

8332

M O N T E R I N G S P R O T O K O L L   PATRON NR [illegible]

047   * R1E4 *

TOPPL: M484   BOTTPL: M423   BOX: 73B439   REF/HORN

	A	B	C	D	E	F	G	H
8	1.98	2.49	2.49	2.49	2.49	1.98	1.98	1.38
	2.968	2.953	3.267	3.265	3.256	3.258	2.966	2.961
	8042	8023	30156	30153	30148	30171	8039	8054
7	2.49	3.37	3.17	3.37	3.37	2.49	2.49	1.98
	2.955	3.251	3.273	3.261	3.255	3.254	3.261	2.963
	8024	30085	30117	602	30017	30149	30181	8036
6	3.37	3.17BA	3.37	3.37	3.37	3.17BA	2.49	1.98
	3.261	3.244	3.260	3.254	3.256	3.241	3.261	3.260
	30067	17013	30026	30102	30062	17001	30132	30180
5	3.37	3.37	3.37	1.98	1.98	3.37	3.37	2.49
	3.251	3.264	3.253	3.258	3.262	3.252	3.251	3.263
	30090	605	30084	30167	30161	30083	30108	30128
4	3.37	3.37	3.37		1.98	3.37	3.37	2.49
	3.250	3.255	3.258		3.261	3.254	3.259	3.257
	30098	30092	30054	47060	30162	30101	604	30150
3	3.37	3.37	3.17	3.37	3.37	3.37	3.17	2.49
	3.259	3.252	3.266	3.253	3.251	3.254	3.267	3.270
	30076	30106	30129	30089	30104	30105	30118	30155
2	2.49	3.17BA	3.37	3.37	3.37	3.17BA	3.37	2.49
	2.956	3.244	3.252	3.259	3.256	3.247	3.255	2.959
	8021	17012	30096	30093	609	17005	30097	8028
1	2.49	2.49	3.37	3.37	3.37	3.37	2.49	1.98
	2.949	2.958	3.257	3.261	3.253	3.254	2.953	2.969
	8005	8029	30040	30013	30002	30024	8009	8044

ANRIKN.% NOM	VERKL	ANTAL STAVAR	KG U02	KG U	KG U-235	UFAKTOR
1.38	1.407	1	2.961	2.610	0.037	0.8814
1.98	1.984	9	28.165	24.825	0.493	0.8814
2.49	2.467	16	50.037	44.103	1.087	0.8814
3.17BA	3.175	4	12.976	11.263	0.356	0.8680
3.17	3.186	3	9.806	8.644	0.276	0.8814
3.37	3.362	30	97.661	86.074	2.890	0.8814
S:A	2.898	63	201.606	177.519	5.139	

INBLANDAD MANGD GD 2.00%

SPRIDARE NR.: 51048 51293 51288 51256 51272 51292

SODK. FÖR INFRYSNING OCH LEVERANS DAT..........SIGN:..........

Ringhals 1 Fuel rod diagram for assembly 8338

8338

M O N T E R I N G S P R O T O K O L L   PATRON NR [illegible]

047 * R1E4 *

TOPPL: Z2926   BOTTPL: M422   BOX: 73B471   REF/HORN

	A	B	C	D	E	F	G	H
8	1.98 2.970 6559	2.49 2.962 6521	2.49 3.255 32101	2.49 3.255 32111	2.49 3.258 32121	1.98 3.256 32131	1.98 2.952 6573	1.38 2.952 6190
7	2.49 2.952 6648	3.37 3.266 25428	3.17 3.277 24992	3.37 3.266 489	3.37 3.261 25292	2.49 3.258 22782	2.49 3.264 22291	1.98 2.963 6538
6	3.37 3.253 32071	3.17BA 3.238 15457	3.37 3.267 25433	3.37 3.257 25316	3.37 3.262 25295	3.17BA 3.240 15465	2.49 3.257 25686	1.98 3.253 32074
5	3.37 3.252 32026	3.37 3.261 499	3.37 3.261 25349	1.98 3.252 25770	1.98 3.258 25743	3.37 3.261 25354	3.37 3.267 25408	2.49 3.253 32023
4	3.37 3.261 32076	3.37 3.260 25502	3.37 3.271 25415	47004	1.98 3.257 25772	3.37 3.264 25386	3.37 3.266 466	2.49 3.258 32075
3	3.37 3.261 32025	3.37 3.264 25372	3.17 3.267 24968	3.37 3.257 25440	3.37 3.267 25414	3.37 3.262 25365	3.17 3.277 25008	2.49 3.259 32024
2	2.49 2.954 6644	3.17BA 3.237 15491	3.37 3.267 25370	3.37 3.262 25385	3.37 3.262 498	3.17BA 3.241 15482	3.37 3.270 25298	2.49 2.951 6650
1	2.49 2.762 6532	2.49 2.949 6611	3.37 3.246 32102	3.37 3.251 32112	3.37 3.253 32122	3.37 3.252 32132	2.49 2.954 6614	1.98 2.966 6556

ANRIKN.% NOM	ANRIKN.% VERKL	ANTAL STAVAR	KG UO2	KG U	KG U-235	UFAKTOR
1.38	1.399	1	2.952	2.602	0.036	0.8814
1.98	1.991	9	28.127	24.792	0.495	0.8814
2.49	2.488	16	50.001	44.073	1.094	0.8814
3.17BA	3.179	4	12.956	11.246	0.356	0.8680
3.17	3.186	3	9.821	8.656	0.276	0.8814
3.37	3.383	30	97.830	86.227	2.913	0.8814
S:A	2.915	63	201.687	177.596	5.170	

INBLANDAD MÄNGD GD 2.00%

SPRIDARE NR.: 51032 51227 51239 51228 51235 51101

GODK. FÖR INFRYSNING OCH LEVERANS DAT..........SIGN:......

Ringhals 1 Fuel rod diagram for assembly 8341

8341

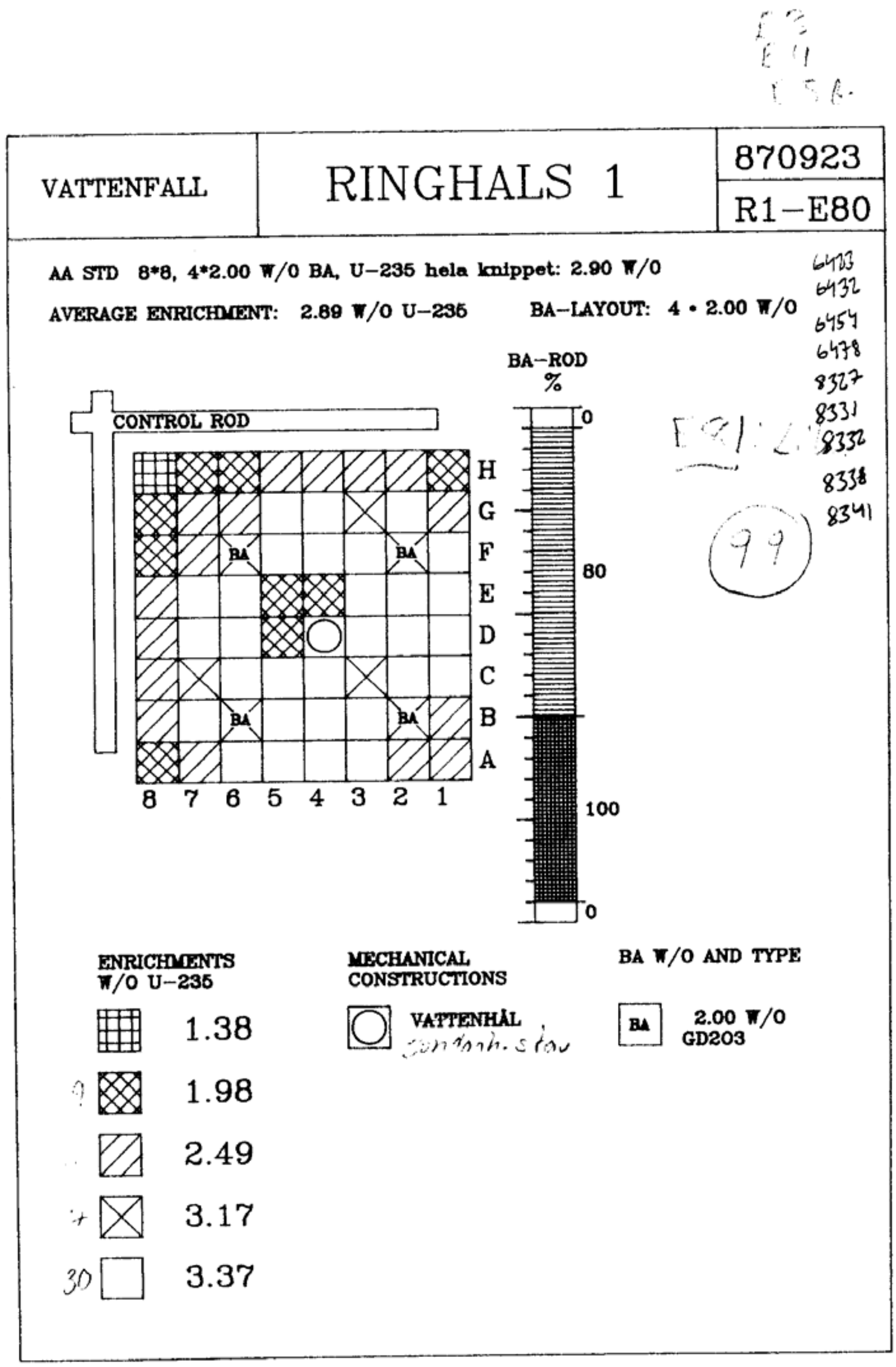
	A	B	C	D	E	F	G	H
8	1.98 2.964 0115	2.49 2.957 0114	2.49 3.267 31015	2.49 3.262 31007	2.49 3.269 31036	1.98 3.261 31035	1.98 2.958 0125	1.38 2.957 0122
7	2.49 2.940 0117	3.37 3.253 31012	3.17 3.263 31076	3.37 3.256 702	3.17 3.247 31048	2.49 3.263 31071	2.49 3.261 31082	1.98 2.961 0119
6	3.37 3.247 31041	3.17BA 3.243 18008	3.37 3.249 31022	3.37 3.262 31032	3.37 3.250 31064	3.17BA 3.249 18007	2.49 3.263 31052	1.98 3.254 31081
5	3.37 3.261 31067	3.37 3.262 709	3.37 3.263 31061	1.98 3.260 31054	1.98 3.250 31026	3.37 3.257 31019	3.37 3.256 31066	2.49 3.244 31083
4	1.38/3.17/3.37 2.665 81B1	3.37 3.254 31035	3.37 3.259 31044	 47030	1.98 3.260 31027	3.37 3.256 31045	3.37 3.256 704	2.49 3.260 31057
3	3.37 3.254 31060	3.37 3.256 31020	3.17 3.263 31010	3.37 3.256 31018	3.37 3.264 31070	3.37 3.254 31034	3.17 3.264 31013	2.49 3.258 31021
2	2.49 2.949 0109	3.17BA 3.244 18009	3.37 3.258 31062	3.37 3.250 31073	3.37 3.256 706	3.17BA 3.248 18004	3.37 3.258 31025	2.49 2.957 0116
1	2.49 2.951 0103	2.49 2.946 0107	3.37 3.247 31069	1.38/3.17/3.37 2.680 81B2	3.37 3.264 31002	3.37 3.256 31072	2.49 2.960 0104	1.98 2.959 0123

INBLANDAD MANGD GD 2.00%
SPRIDARE NR.: 51121 51133 51147 51115 51138 51139
STRILGER STAVAR I POS A4, D1

Anr	UO_2	U	U-235
1,38	3 665	3 230	45
1,98	28 135	24 797	493
2,49	50 043	44 108	1 094
3,17 BA	12 984	11 270	358
3,17	10 027	8 838	279
3,37	95 563	84 232	2 830
S:A	200 417	176 475	5 099

81-05-11 / [illegible]

Ringhals 1 Enrichment diagram sssemblies 6423, 6432, 6454, 6478, 8327, 8331, 8332, 8338 and 8341



2.7 Ringhals 2

REACTOR RINGHALS 2

Reactor data	Value
Reactor pressure (MPa) at full power	15.4
Average temperature into core (C) at full power	303.7
Pitch between assemblies in the core (c–c , mm)	215.0
Avg. temperature in the uranium pellets at full power (C)	614
No of BP-rods/ assembly	12
BP material	B2O3
w/o BP	12.5

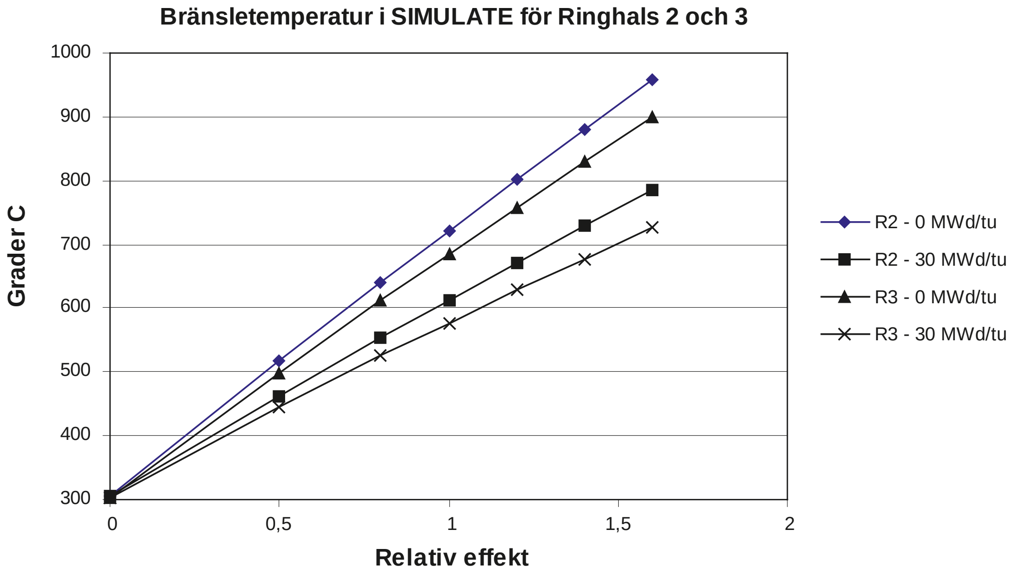
Cycle data

Cycle no	Start	Stopp	Reactor power, MW	Burnup avg/cycle, MWd/tU	No of assemblies in core	Boron content avg., ppm
1	1974-06-19	1977-04-13	2432	16,388	157	
2	1977-07-07	1978-03-31	2432	7,746	157	
3	1978-05-26	1979-04-03	2432	7,615	157	342
4	1979-06-25	1980-04-01	2432	6,856.1	157	530
5	1980-06-18	1981-04-04	2432	8,753.3	157	350
6	1981-06-23	1982-05-06	2432	8,557.8	157	395
7	1982-07-29	1983-04-28	2432	8,287.4	157	308
8	1983-07-28	1984-04-13	2432	7,059.6	157	323
9	1984-07-12	1985-04-04	2432	7,720.9	157	299
10	1985-06-14	1986-04-30	2432	8,261.8	157	340
11	1986-07-02	1987-04-25	2432	7,794.9	157	277
12	1987-06-18	1988-05-12	2432	8,482.5	157	302

Fuel data	Fuel id C01	C12	C20	C42	D27	D38	E38	E40	F14	F21	F25	F32	G11	G23	I09	I20	I24	I25
Fuel type	W15x15	W15x15	W15x15	W15x15	KWU15x15	KWU15x15	KWU15x15	KWU15x15	KWU15x15	KWU15x15	KWU15x15	KWU15x15	KWU15x15	KWU15x15	KWU15x15	KWU15x15	KWU15x15	KWU15x15
No of fuel rods	204	204	204	204	204	204	204	204	204	204	204	204	204	204	204	204	204	204
Rod pitch (mm)	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3
Rod diameter (mm)	10.72	10.72	10.72	10.72	10.75	10.75	10.75	10.75	10.75	10.75	10.75	10.75	10.75	10.75	10.75	10.75	10.75	10.75
Clad thickness (mm)	0.618	0.618	0.618	0.618	0.725	0.725	0.725	0.725	0.725	0.725	0.725	0.725	0.725	0.725	0.725	0.725	0.725	0.725
Pelletdiameter (mm)	9.29	9.29	9.29	9.29	9.11	9.11	9.11	9.11	9.11	9.11	9.11	9.11	9.11	9.11	9.11	9.11	9.11	9.11
Cladding material	Zr4	Zr4	Zr4	Zr4	Zr4	Zr4	Zr4	Zr4	Zr4	Zr4	Zr4	Zr4	Zr4	Zr4	Zr4	Zr4	Zr4	Zr4
Active length (mm)	3,658	3,658	3,658	3,658	3,658	3,658	3,658	3,658	3,658	3,658	3,658	3,658	3,658	3,658	3,658	3,658	3,658	3,658
Density UO2 (g/cc)	10.41	10.41	10.41	10.41	10.41	10.41	10.41	10.41	10.41	10.41	10.41	10.41	10.41	10.41	10.41	10.41	10.41	10.41
Density incl. porsity,dishing etc	10.228	10.182	10.205	10.2364	10.095	10.133	10.1185	10.1335	10.1835	10.173	10.2045	10.1976	10.1788	10.1774	10.206	9.99	10.025	10.106
No of guide tubes	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
Material in guide tubes	Zr4	Zr4	Zr4	Zr4	Zr4	Zr4	Zr4	Zr4	Zr4	Zr4	Zr4	Zr4	Zr4	Zr4	Zr4	Zr4	Zr4	Zr4
Outer diameter guide tube (mm)	13.87	13.87	13.87	13.87	13.89	13.89	13.89	13.89	13.89	13.89	13.89	13.89	13.89	13.89	13.89	13.89	13.89	13.89
Cladding thickness guide tube	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43
No of instrument tubes	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Material in instrument tubes	Zr4	Zr4	Zr4	Zr4	Zr4	Zr4	Zr4	Zr4	Zr4	Zr4	Zr4	Zr4	Zr4	Zr4	Zr4	Zr4	Zr4	Zr4
Outerdiameter instrument tubes (mm)	13.87	13.87	13.87	13.87	13.89	13.89	13.89	13.89	13.89	13.89	13.89	13.89	13.89	13.89	13.89	13.89	13.89	13.89
Cladding thickness instrument tubes (mm)	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43
Burnable poison rods?	No	No	No	Yes, 12	No	No	No	No	No	No	No	No	No	No	No	No	No	No
No of spacers	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
Spacer material	Inconel	Inconel	Inconel	Inconel	Inc/Zr4	Inc/Zr4	Inc/Zr4	Inc/Zr4	Inc/Zr4	Inc/Zr4	Inc/Zr4	Inc/Zr4	Inc/Zr4	Inc/Zr4	Inc/Zr4	Inc/Zr4	Inc/Zr4	Inc/Zr4
Mass of spacer (g)	788	788	788	788	720/160	720/160	720/160	720/160	720/160	720/160	720/160	720/160	720/160	720/160	720/160	720/160	720/160	720/160

Initialdata	C01	C12	C20	C42	D27	D38	E38	E40	F14	F21	F25	F32	G11	G23	I09	I20	I24	I25
Initial mass Utot (g)	455,789	453,736	454,758	456,159	432,589	434,214	433,593	434,244	436,382	435,939	437,286	436,993	436,180	436,125	437,353	428,147	429,597	433,062
Initial mass U235 (g)	14,107	14,043	14,075	14,118	14,066	14,119	13,869	13,890	13,953	13,939	13,982	13,972	13,906	13,981	14,007	13,712	13,759	13,870
Avg.enrichment% U235	3.095	3.095	3.095	3.095	3.252	3.252	3.199	3.199	3.197	3.197	3.197	3.197	3.188	3.206	3.203	3.203	3.203	3.203
Data after rebuild 1																		
Date of rebuild				810,302													870,122	
No if fuel rods				–1													–2	
No water rods				0													0	
No water holes				0													0	
No of homgeneous rods			1													0		
Mass Utot after rebuild (g)			453,923													423,896		
Mass U235 after rebuild (g)			14,049													13,576		
Data after rebuild 2																		
Date of rebuild																		
No if fuel rods																		
No water rods																		
No water holes																		
No of homgeneous rods																		
Mass Utot after rebuild (g)																		
Mass U235 after rebuild (g)																		
Cycle history burnup/cycle, MWd/tU																		
1	11,247	11,247	11,247	16,565														
2	9,403	9,318	9,377			6,367												
3	7,569	7,390	7,454		9,510	9,331	7,568	7,705										
4					12,889	7,358	8,458	7,249	5,069	4,767	8,307							
5	8,469	8,430			9,267	8,701	9,879	10,655	10,755	6,317	10,749	10,553	6,890					
6				7,619		7,646	8,068	8,730	9,898	10,046	8,316	10,609	10,422	1,0268				
7				8,126	8,010				8,287	8,255	7,980	8,391	7,868	1,0035		8,300	8,245	5,207
8										6,888			6,943	7,618	6,727	9,010	8,967	4,991
9			7,642										3,340	7,712	8,950	9,108	9,144	9,803
10												7,761			9,065	7,895	7,938	8,998
11												6,629			7,568			7,860
12				3,329								7,019			7,878			

Axial BU distribution, EOL MWd/kgU																		
1	20.94	20.89	20.32	18.61	22.79	22.42	17.15	20.16	19.08	21.23	19.89	32.23	19.84	21.05	24.21	19.66	19.59	22.73
2	30.06	29.98	29.21	27.43	33.10	32.17	26.47	28.76	27.51	30.09	28.53	44.46	28.65	29.75	34.16	28.14	28.04	31.98
3	35.08	34.98	34.14	32.76	38.57	37.50	31.56	33.33	32.20	34.78	33.30	50.50	33.54	34.37	39.28	32.81	32.69	36.68
4	37.37	37.25	36.43	35.56	40.89	39.96	34.12	35.32	34.38	36.86	35.53	52.96	35.87	36.41	41.48	35.01	34.87	38.62
5	38.32	38.19	37.41	37.00	41.81	41.05	35.41	36.12	35.38	37.77	36.54	53.88	36.95	37.28	42.38	36.04	35.89	39.33
6	38.68	38.53	37.80	37.73	42.15	41.54	36.14	36.40	35.85	38.15	37.02	54.17	37.46	37.64	42.70	36.52	36.36	39.55
7	38.79	38.63	37.93	38.10	42.29	41.77	36.52	36.49	36.07	38.31	37.25	54.21	37.71	37.78	42.79	36.75	36.58	39.58
8	38.81	38.65	37.97	38.28	42.31	41.89	36.71	36.51	36.17	38.37	37.38	54.18	37.84	37.84	42.79	36.86	36.68	39.54
9	38.81	38.64	37.98	38.38	42.30	41.96	36.83	36.50	36.24	38.39	37.46	54.13	37.93	37.87	42.77	36.92	36.75	39.49
10	38.81	38.64	37.98	38.44	42.29	42.02	36.93	36.50	36.29	38.41	37.52	54.07	37.99	37.89	42.75	36.97	36.79	39.44
11	38.82	38.64	38.00	38.48	42.28	42.08	37.02	36.50	36.33	38.42	37.57	54.01	38.04	37.90	42.73	37.00	36.82	39.40
12	38.83	38.65	38.02	38.52	42.29	42.13	37.11	36.51	36.37	38.42	37.62	53.96	38.10	37.92	42.72	37.04	36.86	39.36
13	38.85	38.67	38.04	38.57	42.30	42.19	37.20	36.53	36.42	38.43	37.68	53.92	38.15	37.94	42.71	37.07	36.89	39.33
14	38.88	38.69	38.07	38.62	42.31	42.24	37.29	36.54	36.46	38.44	37.73	53.88	38.21	37.95	42.70	37.11	36.92	39.30
15	38.91	38.73	38.11	38.68	42.32	42.29	37.38	36.56	36.51	38.45	37.78	53.84	38.26	37.97	42.70	37.15	36.96	39.28
16	38.96	38.77	38.16	38.74	42.33	42.34	37.46	36.57	36.55	38.46	37.82	53.81	38.31	38.00	42.70	37.18	36.99	39.27
17	39.02	38.82	38.22	38.78	42.36	42.38	37.54	36.60	36.59	38.47	37.86	53.78	38.36	38.02	42.70	37.21	37.01	39.26
18	39.08	38.88	38.27	38.76	42.39	42.40	37.58	36.62	36.62	38.46	37.87	53.75	38.38	38.03	42.70	37.21	37.01	39.25
19	39.11	38.91	38.29	38.61	42.40	42.36	37.54	36.62	36.58	38.41	37.82	53.68	38.32	38.00	42.66	37.14	36.94	39.21
20	38.98	38.79	38.15	38.16	42.28	42.14	37.29	36.50	36.39	38.21	37.59	53.45	38.07	37.83	42.48	36.90	36.71	39.06
21	38.40	38.21	37.55	37.07	41.72	41.43	36.53	35.99	35.77	37.62	36.92	52.76	37.35	37.28	41.89	36.22	36.05	38.53
22	36.64	36.46	35.79	34.66	39.96	39.49	34.58	34.45	34.08	35.97	35.15	50.75	35.49	35.69	40.18	34.48	34.32	36.95
23	32.13	31.97	31.35	29.60	35.29	34.68	30.02	30.36	29.89	31.73	30.83	45.37	31.02	31.55	35.66	30.23	30.10	32.73
24	23.16	23.04	22.57	20.74	25.66	25.09	21.35	21.97	21.55	23.08	22.28	33.75	22.30	23.04	26.14	21.84	21.75	23.92



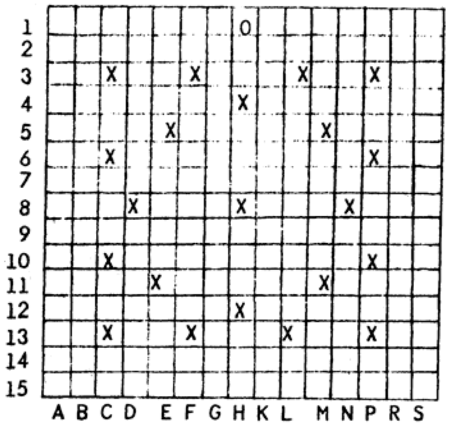
Ringhals 2. Temperature program.

Cykel	HZP Tavg	HFP Tin	Tavg	Tout	100% DT	
R2 Cy01	286.0	286.3	303.7	320.4	34.1	
R2 Cy02	286.0	286.3	303.7	320.4	34.1	
R2 Cy03	286.0	286.3	303.7	320.4	34.1	
R2 Cy04	286.0	286.3	303.7	320.4	34.1	
R2 Cy05	286.0	286.3	303.7	320.4	34.1	
R2 Cy06	286.0	286.3	303.7	320.4	34.1	
R2 Cy07	286.0	286.3	303.7	320.4	34.1	
R2 Cy08	286.0	286.3	303.7	320.4	34.1	
R2 Cy09	286.0	286.3	303.7	320.4	34.1	
R2 Cy10	286.0	286.3	303.7	320.4	34.1	
	286.0	277.1	294.5	311.2	34.1	81% 1986-02-18
R2 Cy11	286.0	277.1	294.5	311.2	34.1	ÅG-probl: 80,7%
R2 Cy12	271.0	271.3	288.7	305.4	34.1	ÅG-probl: 80,7%

Ringhals 2 Fuel rod diagram assembly C42

STATENS VATTENFALLSVERK
VATTENFALL

RINGHALS 2
MONTERINGSPROTOKOLL
PATRON NR: C42



O = Stav av homogen zircaloy
X = Ej möjlig stavposition

Anrikning nominell 3,10
verklig 3,095

Medelstavvikt (g) UO_2 2538 U 2236 U-235 69

Uttagna stavar

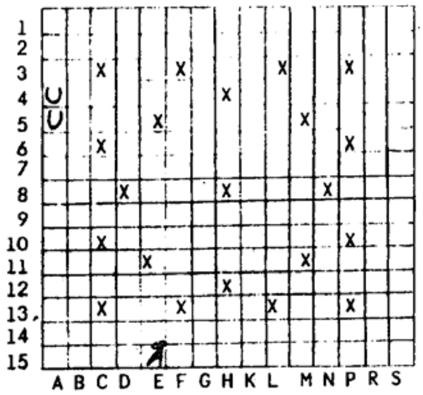
datum	pos.	UO_2	vikter i g U	U-235
810302	H01	2538	2236	69

Patronvikt efter stavbyte (g)

datum	UO_2	U	U-235
810302	515142	453923	14049

STATENS VATTENFALLSVERK
VATTENFALL

RINGHALS 2
MONTERINGSPROTOKOLL
PATRON NR: T20



O = Stav av homogen zircaloy
X = Ej möjlig stavposition
U = Uttagen, ej ersatt stav
Å = Återinsatt stav

A5: Skruv 02503

Anrikning nominell
verklig

Medelstavvikt (g) UO_2 U U-235

Uttagna stavar

datum	pos.	UO_2 (vikter i g)	U	U-235
870122	A5	2422	2135	68 → uttagen
870122	E15	2403	2118	68 → Återinsatt

Patronvikt efter stavbyte (g)

datum	UO_2	U	U-235
	480961	423896	13576

2.8 Ringhals 3

REACTOR RINGHALS 3

Reactor data	Value
Reactor pressure (MPa) at full power	15.5
Average temperature into core (C) at full power	303.3
Pitch between assemblies in the core (c–c , mm)	215.0
Avg. temperature in the uranium pellets at full power (C)	577
No of BP-rods/ assembly	12
BP material	B2O3
w/o BP	12.5

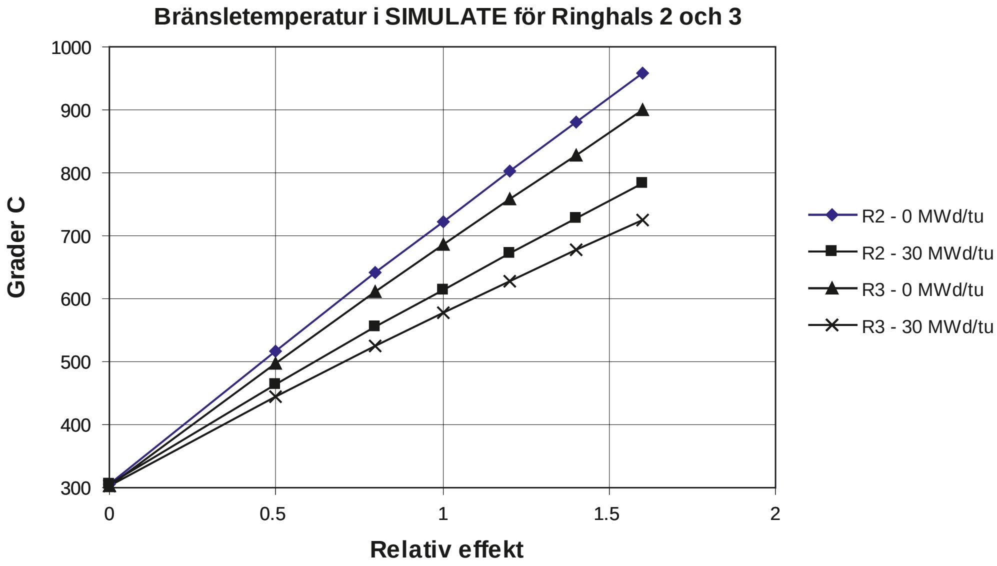
Cycle data

Cycle no	Start	Stopp	Reactor power, MW	Burnup avg/cycle, MWd/tU	No of assemblies in core	Boron content avg., ppm
1A	1980-07-29	1983-06-02	2,775	10,521.50	157	
1B	1983-09-14	1984-05-11	2,775	7,696.40	157	270
2	1984-07-24	1985-05-25	2,775	10,090.60	157	389
3	1985-07-11	1986-05-30	2,775	11,142.30	157	452
4	1986-07-18	1987-06-18	2,775	11,248.00	157	402
5	1987-08-04	1988-07-07	2,775	11,269.10	157	401
6	1988-08-14	1989-06-22	2,775	10,039.40	157	412
7	1989-08-01	1990-06-07	2,775	9,953.70	157	482
8	1990-07-11	1991-06-13	2,775	10,243.10	157	457

Fuel data	Fuel id															
	2A5	**5A3**	**0C9**	**1C2**	**1C5**	**2C2**	**3C1**	**3C4**	**3C5**	**3C9**	**4C4**	**4C7**	**0E2**	**0E6**	**1E5**	**5F2**
Fuel type	W17×17	W17×17	W17×17	W17×17	W17×17	W17×17	W17×17	W17×17	W17×17	W17×17	W17×17	W17×17	W17×17	W17×17	W17×17	AA17×17
No of fuel rods	264	264	264	264	264	264	264	264	264	264	264	264	264	264	264	264
Rod pitch (mm)	12.6	12.6	12.6	12.6	12.6	12.6	12.6	12.6	12.6	12.6	12.6	12.6	12.6	12.6	12.6	12.6
Rod diameter (mm)	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5
Clad thickness (mm)	0.571	0.571	0.571	0.571	0.571	0.571	0.571	0.571	0.571	0.571	0.571	0.571	0.572	0.572	0.572	0.572
Pelletdiameter (mm)	8.191	8.191	8.191	8.191	8.191	8.191	8.191	8.191	8.191	8.191	8.191	8.191	8.191	8.191	8.191	8.191
Cladding material	Zr4	Zr4	Zr4	Zr4	Zr4	Zr4	Zr4	Zr4	Zr4	Zr4	Zr4	Zr4	Zr4	Zr4	Zr4	Zr2
Active length (mm)	3,658	3,658	3,658	3,658	3,658	3,658	3,658	3,658	3,658	3,658	3,658	3,658	3,658	3,658	3,658	3,658
Density UO2 (g/cc)	10.45	10.45	10.45	10.45	10.45	10.45	10.45	10.45	10.45	10.45	10.45	10.45	10.45	10.45	10.45	10.45
Density incl. porsity,dishing etc	10.31	10.3	10.21	10.24	10.22	10.25	10.23	10.22	10.24	10.25	10.24	10.23	10.35	10.31	10.35	10.32
No of guide tubes	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24
Material in guide tubes	Zr4	Zr4	Zr4	Zr4	Zr4	Zr4	Zr4	Zr4	Zr4	Zr4	Zr4	Zr4	Zr4	Zr4	Zr4	Zr4
Outer diameter guide tube (mm)	12.24	12.24	12.24	12.24	12.24	12.24	12.24	12.24	12.24	12.24	12.24	12.24	12.24	12.24	12.24	12.09
Cladding thickness guide tube	0.406	0.406	0.406	0.406	0.406	0.406	0.406	0.406	0.406	0.406	0.406	0.406	0.406	0.406	0.406	0.455
No of instrument tubes	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Material in instrument tubes	Zr4	Zr4	Zr4	Zr4	Zr4	Zr4	Zr4	Zr4	Zr4	Zr4	Zr4	Zr4	Zr4	Zr4	Zr4	Zr4
Outerdiameter instrument tubes (mm)	12.24	12.24	12.24	12.24	12.24	12.24	12.24	12.24	12.24	12.24	12.24	12.24	12.24	12.24	12.24	12.24
Cladding thickness instrument tubes (mm)	0.406	0.406	0.406	0.406	0.406	0.406	0.406	0.406	0.406	0.406	0.406	0.406	0.406	0.406	0.406	0.406
Burnable poison rods?	No	No	Yes, 12	No	Yes, 12	No	No	Yes, 12	Yes, 12	No	No	Yes, 12	No	No	No	No
No of spacers	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
Spacer material	Inc 718	Inc 718	Inc 718	Inc 718	Inc 718	Inc 718	Inc 718	Inc 718	Inc 718	Inc 718	Inc 718	Inc 718	Inc 718	Inc 718	Inc 718	Zr4
Mass of spacer (g)	753	753	753	753	753	753	753	753	753	753	753	753	753	753	753	1,350

Initialdata	2A5	5A3	0C9	1C2	1C5	2C2	3C1	3C4	3C5	3C9	4C4	4C7	0E2	0E6	1E5	5F2
Initial mass Utot (g)	462,026	461,477	457,639	459,050	457,992	459,490	458,433	457,904	458,873	459,138	459,050	458,256	463,598	463,898	462,248	
Initial mass U238 (g)	452,284	451,787	443,448	444,815	443,790	445,241	444,217	443,704	444,643	444,900	444,815	444,045	449,111	449,506	446,414	
Initial mass U235 (g)	9,742	9,690	14,191	14,235	14,202	14,249	14,216	14,200	14,230	14,238	14,235	14,211	14,487	14,316	14,392	15,834
Avg.enrichment% U238	97.900	97.900	96.899	96.899	96.899	96.899	96.899	96.899	96.899	96.899	96.899	96.899	96.897	96.897	96.596	
Avg.enrichment% U235	2.100	2.100	3.101	3.101	3.101	3.101	3.101	3.101	3.101	3.101	3.101	3.101	3.103	3.103	3.103	3.404
Data after rebuild 1																
Date of rebuild								1987-08-27								911,123
No if fuel rods								–1								–3
No water rods								0								0
No water holes								0								0
No of homgeneous rods								0								0
Mass Utot after rebuild (g)							456,170								456,996	
Mass U235 after rebuild (g)							14,146								15,654	
Data after rebuild 2																
Date of rebuild																920,404
No if fuel rods																–3
No water rods																0
No water holes																0
No of homgeneous rods																0
Mass Utot after rebuild (g)															451,743	
Mass U235 after rebuild (g)															15474	
Cycle history burnup/cycle, MWd/tU																
C1A	12,228	11,696	9,884	6,249	9,884	7,783	7,783	9,884	9,884	7,783	6,249	9,884				
C1B	7,879	8,003	8,192	5,019	8,102	8,345	8,341	8,192	8,113	8,377	4,991	8,101				
C2			10,350	11,509	10,411	99,32	9,931	10,354	10,343	9,876	11,030	10,347	7,496			
C3			10,016	10,541	10,087	10,517	10,517	10,017	10,033	10,524	11,063	10,038	13,034	12,490	10,556	
C4													11,308	13,031	13,134	13,475
C5													9,790	10,472	10,948	6,922
C6																10,337
C7																8,930
C8																7,644
C9																

Axial BU distribution, EOL MWd/tU																
1	9.65	8.66	21.14	18.08	21.16	20.09	20.09	21.14	21.12	20.09	18.08	21.12	24.59	20.54	18.93	28.28
2	14.88	14.07	30.64	26.61	30.67	29.19	29.19	30.64	30.60	29.18	26.61	30.60	34.69	29.34	27.56	39.72
3	18.29	17.62	36.17	31.54	36.21	34.45	34.45	36.18	36.13	34.44	31.54	36.12	40.17	34.27	32.45	45.78
4	20.21	19.66	38.93	33.88	38.97	37.03	37.02	38.94	38.88	37.01	33.89	38.87	42.65	36.57	34.84	48.49
5	21.23	20.90	40.25	34.93	40.29	38.21	38.21	40.26	40.19	38.20	34.94	40.19	43.72	37.60	36.02	49.63
6	21.73	21.42	40.85	35.37	40.89	38.72	38.72	40.86	40.78	38.71	35.38	40.78	44.17	38.05	36.56	50.09
7	21.95	21.62	41.10	35.58	41.14	38.94	38.94	41.11	41.03	38.92	35.59	41.03	44.35	38.25	36.84	50.27
8	22.03	21.67	41.20	35.66	41.24	39.02	39.02	41.21	41.13	39.01	35.67	41.13	44.41	38.35	36.99	50.34
9	22.04	21.66	41.25	35.69	41.28	39.06	39.05	41.25	41.17	39.04	35.71	41.17	44.44	38.41	37.07	50.37
10	22.03	21.63	41.28	35.72	41.31	39.08	39.07	41.28	41.20	39.06	35.74	41.19	44.44	38.45	37.14	50.38
11	22.01	21.61	41.30	35.75	41.34	39.11	39.10	41.31	41.22	39.09	35.77	41.22	44.44	38.48	37.19	50.39
12	22.01	21.61	41.33	35.78	41.37	39.15	39.14	41.34	41.25	39.13	35.80	41.25	44.43	38.52	37.25	50.40
13	22.02	21.62	41.37	35.82	41.41	39.20	39.20	41.38	41.29	39.18	35.83	41.29	44.42	38.55	37.30	50.41
14	22.05	21.65	41.42	35.86	41.46	39.27	39.26	41.42	41.34	39.25	35.87	41.34	44.41	38.58	37.35	50.42
15	22.10	21.69	41.47	35.90	41.51	39.35	39.34	41.48	41.39	39.33	35.92	41.39	44.40	38.62	37.40	50.43
16	22.15	21.75	41.53	35.94	41.57	39.44	39.43	41.54	41.45	39.42	35.96	41.45	44.39	38.66	37.45	50.44
17	22.20	21.81	41.59	35.99	41.63	39.54	39.53	41.59	41.50	39.52	36.01	41.50	44.38	38.70	37.50	50.46
18	22.22	21.84	41.61	36.02	41.66	39.63	39.62	41.62	41.53	39.61	36.04	41.53	44.36	38.73	37.52	50.46
19	22.15	21.78	41.55	35.99	41.61	39.65	39.64	41.56	41.47	39.63	36.01	41.47	44.29	38.71	37.48	50.40
20	21.85	21.52	41.25	35.78	41.31	39.47	39.46	41.26	41.17	39.45	35.80	41.17	44.07	38.51	37.26	50.11
21	21.11	20.82	40.37	35.09	40.44	38.74	38.73	40.38	40.29	38.72	35.11	40.29	43.37	37.83	36.57	49.28
22	19.49	19.26	38.18	33.25	38.25	36.74	36.73	38.18	38.10	36.72	33.27	38.10	41.42	35.99	34.71	47.05
23	16.25	16.09	33.14	28.87	33.20	31.96	31.95	33.14	33.07	31.94	28.89	33.07	36.49	31.48	30.26	41.50
24	10.92	10.83	23.69	20.55	23.73	22.84	22.83	23.69	23.64	22.82	20.57	23.64	26.58	22.68	21.67	30.32



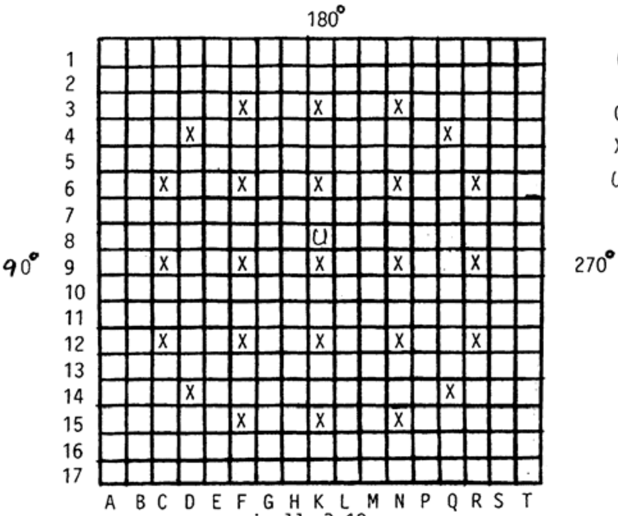
Ringhals 3. Temperature program.

Cykel	HZP Tavg	Tin	HFP Tavg	Tout	100% DT	
R3 C01A	291.7	285.3	303.3	321.8	36.5	
R3 C01B	291.7	285.3	303.3	321.8	36.5	
R3 C02	291.7	285.3	303.3	321.8	36.5	
R3 C03	291.7	285.3	303.3	321.8	36.5	
R3 C04	291.7	285.3	303.3	321.8	36.5	
R3 C05	291.7	285.3	303.3	321.8	36.5	
R3 C06	291.7	285.3	303.3	321.8	36.5	
	291.7	273.3	292.0	309.8	36.5	Max 88%
R3 C07	291.7	273.3	292.0	309.8	36.5	Max 88%
R3 C08	291.7	273.3	291.9	309.8	36.5	Maz 88%

Ringhals 3 – Fuel rod diagram assembly 3C4

Vattenfall
RINGHALSVERKET

RINGHALS 3
MONTERINGSPROTOKOLL
PATRON NR: 3C4



(Patronen sedd ovanifrån)

0 = Stav av homogen zircaloy
X = Ej möjlig stavposition
U = uttagen stav

Anrikning nominell: 3.10
verklig: 3.101

Medelstavvikt (g) UO_2 1968 U 1734 U-235 54

Uttagna stavar (vikter i g)

datum	pos.	UO_2	U	U-235	
870827	K8	1968	1734	54	Anm. Inga dummystavar insatta.

Patronvikt efter stavbyte (g)

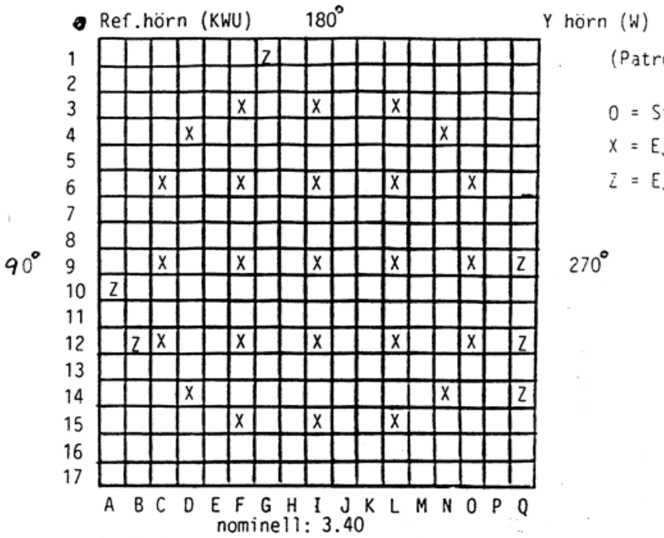
datum	UO_2	U	U-235
870827	517592	456170	14146

Ringhals 3 Fuel rod diagram assembly 5F2

B/R3

Vattenfall
RINGHALSVERKET

RINGHALS 3
MONTERINGSPROTOKOLL
PATRON NR: 5F2



(Patronen sedd ovanifrån)

0 = Stav av homogen zircaloy
X = Ej möjlig stavposition
Z = Ej ersatt uttagen stav

Anrikning nominell: 3.40
verklig: 3.404

Uttagna stavar (vikter i g)

datum	pos.	UO_2	U	U-235	stav nr.
911123	B12	1984	1749	60	096-33846
911123	Q14	1988	1752	60	096-40003
911123	Q12	1987	1751	60	096-40015
920404	A10	1984	1749	60	096-33831
920404	G1	1988	1752	60	096-33949
920404	Q9	1988	1752	60	096-40064

Patronvikt efter stavbyte (g)

datum	UO_2	U	U-235
911123	518493	456996	15654
920404	512533	451743	15474

2.9 Barsebäck 1

REACTOR BARSEBÄCK 1

Parameter	Value
Reactor pressure (MPa) at full power	7
Inlet temperature into core (C) at full power	260
Outlet temperature into core (C) at full power	286
Pitch between assemblies in the core (c–c, mmm)	153
Avg. temperature in the uranium pellets at full power (C)	650
Avg. temperature in the cladding at full power (C)	290
Temperature in the boxwall at full power (C)	286

Cycle data

Cycle no	Start	Stop	Reactor power MW	Burnup avg/cycle MWd/tU	No of assemblies in core
1	1975-05-15	1977-07-16	1,800	11,140	444
2	1977-10-10	1978-05-08	1,800	3,878	444
3	1978-05-30	1979-04-13	1,800	5,738	444
4	1979-09-05	1980-09-03	1,800	6,441	444
5	1980-10-26	1981-06-22	1,800	4,919	444
6	1981-07-19	1982-06-30	1,800	6,864	444
7	1982-08-14	1983-07-06	1,800	6,745	444
8	1983-08-06	1984-06-28	1,800	6,666	444
9	1984-07-26	1985-08-07	1,800	7,572	444
10	1985-09-02	1986-07-17	1,800	6,653	444
11	1986-08-18	1987-07-01	1,800	6,940	444
12	1987-07-29	1988-09-17	1,800	8,750	444

Fuel data	Fuel id 2014	2018	2048	2074	2118	9329	10288
Fuel type	AA8×8	AA8×8	AA8×8	AA8×8	AA8×8	AA8×8	AA8×8
No of fuel rods	63	63	63	63	63	63	63
Rod pitch normal rods (mm)	16.3	16.3	16.3	16.3	16.3	16.3	16.3
Rod pitch normal – corner rods (mm)	16.05	16.05	16.05	16.05	16.05	16.05	16.05
Rod pitch corner – corner rods (mm)	15.8	15.8	15.8	15.8	15.8	15.8	15.8
Rod diameter normal rod (mm)	12.25	12.25	12.25	12.25	12.25	12.25	12.25
Clad thickness normal rod (mm)	0.8	0.8	0.8	0.8	0.8	0.8	0.77
Pellet diameter normal rod (mm)	10.46	10.46	10.46	10.46	10.46	10.44	10.44
No of normal rods	51	51	51	51	51	51	51
Rod diameter corner rod (mm)	11.75	11.75	11.75	11.75	11.75	11.75	11.75
Clad thickness corner rod (mm)	0.8	0.8	0.8	0.8	0.8	0.8	0.77
Pellet diameter corner rod (mm)	9.96	9.96	9.96	9.96	9.96	9.94	9.94
No of corner rods	12	12	12	12	12	12	12
Active length (mm)	3,712	3,712	3,712	3,712	3,712	3,712	3,712
Density UO2 (g/cc)	10.5	10.5	10.5	10.5	10.5	10.5	10.5
Porsity,dishing etc (%)	1.49	1.5	1.56	1.61	1.63	1.71	1.50
No of spacer rods	1	1	1	1	1	1	1
Material in spacer rods	Zr2	Zr2	Zr2	Zr2	Zr2	Zr2	Zr2
Outer diameter spacer rods (mm)	12.25	12.25	12.25	12.25	12.25	12.25	12.25
Cladding thickness spacer rod							
No of water rods							
Material in water rods							
Outer diameter water rods (mm)							
Inner diameter water rods (mm)							
No of BA rods						5	5
% Gd2O3						2.55	2.55
Rel poison						1	1
No of spacers	6	6	6	6	6	6	6
Spacer material	Inconel	Inconel	Inconel	Inconel	Inconel	Inconel	Inconel
Mass of spacer (g)	135	135	135	135	135	135	135
Box material	Zr4	Zr4	Zr4	Zr4	Zr4	Zr4	Zr4
Box outer measure square (mm)	139	139	139	139	139	139	139
Box wall thickness (mm)	2.3	2.3	2.3	2.3	2.3	2.3	2.3

Initial data	**2014**	**2018**	**2048**	**2074**	**2118**	**9329**	**10288**
Initial mass Utot (g)	179,878	179,852	179,741	179,657	179,607	178,771	179,159
Initial mass U235 (g)	4,183	4,183	4,190	4,179	4,485	5,223	5,291
Avg.enrichment% U235	2.320	2.320	2.320	2.320	2.500	2.920	2.950
Fuel rod diagram	X	X	X	X	X	X	X
Enrichment diagram						X	X
Data after rebuild 1							
Date of rebuild	1977	1977	1977	1977	1977		
No of fuel rods	63	63	63	63	63		
No spacer rods	1	1	1	1	1		
No water rods							
No of water holes							
Mass Utot after rebuild (g)							
Mass U235 after rebuild (g)							
Data after rebuild 2							
Date of rebuild							
No of fuel rods							
No spacer rods							
No water rods							
No of water holes							
Mass Utot after rebuild (g)							
Mass U235 after rebuild (g)							
Cycle history burnup/cycle, MWd/tU							
1	13,200	12,700	11,800	11,500	12,000		
2		1,900	4,500	4,100	4,500		
3	6,448	3,081	6,259				
4		2,924		7,323			
5							
6					4,154		
7							
8						8,219	
9						9,508	9,726
10						7,307	7,714
11						6,924	8,147
12						9,136	9,593
Axial BU distribution, EOL MWd/tUNode no (top=25)							
1						30,200	18,300
2						31,900	29,600
3						37,700	35,100
4						40,300	37,300
5						42,600	39,200
6						43,900	40,000
7						44,700	40,200
8						44,700	39,700
9						45,800	40,300
10						46,200	40,400
11						46,500	40,300
12						46,200	39,600
13						46,700	39,900
14						46,800	37,700
15						46,500	39,200
16						45,800	38,200
17						46,000	38,100
18						45,700	37,600
19						44,900	36,700
20						43,500	35,100
21						42,400	33,900
22						39,900	31,600
23						35,700	28,000
24						22,900	23,300
25						22,400	17,600

Void history Node no (top=25)	2014	2018	2048	2074	2118	9329	10288
1						0.00	0.00
2						0.00	0.00
3						0.00	0.00
4						0.03	0.05
5						0.08	0.12
6						0.15	0.19
7						0.21	0.26
8						0.28	0.31
9						0.33	0.37
10						0.38	0.42
11						0.43	0.46
12						0.47	0.50
13						0.51	0.54
14						0.54	0.57
15						0.57	0.60
16						0.60	0.63
17						0.63	0.65
18						0.65	0.67
19						0.67	0.68
20						0.68	0.70
21						0.70	0.71
22						0.71	0.73
23						0.72	0.73
24						0.73	0.74
25						0.74	0.75
Density history Node no (top=25)							
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							
21							
22							
23							
24							
25							

Average density	0.41	0.41	0.41	0.41	0.41	0.39	0.40
Control rod history **Node no (top=25)**							
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							
21							
22							
23							
24							
25							

Barsebäck 1 Fuel rod diagram assembly 2014

M O N T E R I N G S P R O T O K O L L
****
B A R S E B Ä C K I

PATRON NR.2014. DATUM:24-09-74 REF.HÖRN

1.85	1.85	1.35	1.35	1.17	1.17	1.17	1.17
2.988	2.996	3.291	3.303	3.302	3.307	2.996	2.994
7397	7453	19252	19236	16059	16082	5301	5749
1.85	2.50	2.50	2.50	1.85	1.85	1.17	1.17
2.988	3.296	3.293	3.283	3.294	3.299	3.311	3.005
7467	27002	27080	782	19262	19253	16013	5733
2.50	2.50	3.05	2.50	2.50	1.85	1.85	1.17
3.304	3.292	3.309	3.297	3.308	3.293	3.301	3.299
27017	27106	24660	27015	27129	19249	19240	16001
3.05	3.05	3.05	1.85	1.85	2.50	1.85	1.17
3.300	3.296	3.297	3.298	3.304	3.297	3.303	3.302
24557	1459	24534	19263	19223	27130	19244	16020
3.05	3.05	3.05	~~1.85~~	1.85	2.50	2.50	1.85
3.296	3.302	3.297	~~3.300~~	3.298	3.294	3.301	3.289
24542	24539	24529	~~19248~~	19247	26980	872	19246
3.05	3.05	3.05	3.05	3.05	3.05	2.50	1.85
3.306	3.304	3.297	3.306	3.301	3.299	3.293	3.303
24663	24651	24533	24623	24550	24632	27004	19132
2.50	3.05	3.05	3.05	3.05	2.50	2.50	1.85
2.994	3.291	3.304	3.302	3.291	3.295	3.296	2.992
10303	24577	24886	24783	1373	27090	26996	7464
1.85	2.50	3.05	3.05	3.05	2.50	1.85	1.85
2.990	2.993	3.305	3.298	3.310	3.292	2.992	2.992
7471	10275	24900	24882	24885	26942	7474	7424

ANRIKN.% NOM	VERKL.	ANTAL STAVAR	KG UO2	KG U	KG U-235
1.17	1.176	8	25.516	22.480	0.264
~~1.35~~	~~1.350~~	~~20~~	~~63.814~~	~~56.220~~	~~1.040~~
2.50	2.499	16	52.133	45.929	1.148
3.05	3.069	20	66.011	58.156	1.785
1.85	1.850	19	60.514	53.313	0.986
S:A	~~2.318~~	~~64~~	~~207.474~~	~~182.785~~	~~4.237~~
	2.325	63	204.174	179.878	4.183

TOPPL.NR.: Z914

BOTTPL.NR.: K867

SPRIDARE NR.: 834 2598 2428 2633 1015 1011 URSPR.LAND FÖR URAN: US,
BOXNR.: 1977

Avsänt
21 OKT
6/2

M O N T E R I N G S P R O T O K O L L

B A R S E B Ä C K I

PATRON NR.2018. DATUM:25-09-74 REF.HÖRN

1.85	1.85	1.85	1.85	1.17	1.17	1.17	1.17
2.978	2.992	3.293	3.291	3.310	3.298	3.003	2.995
7359	7384	19168	19086	15940	15931	5827	5828
1.85	2.50	2.50	2.50	1.85	1.85	1.17	1.17
2.989	3.288	3.286	3.285	3.294	3.306	3.300	2.993
7440	26969	26987	792	19196	19225	15938	5757
2.50	2.50	3.05	2.50	2.50	1.85	1.85	1.17
3.289	3.299	3.306	3.298	3.305	3.289	3.298	3.298
26985	27097	24559	26981	26944	19126	19264	15937
3.05	3.05	3.05	1.85	1.85	2.50	1.85	1.17
3.309	3.293	3.304	3.294	3.294	3.296	3.295	3.299
24619	1393	24618	19123	19204	26935	19109	15951
3.05	3.05	3.05	~~1.85~~	1.85	2.50	2.50	1.85
3.305	3.303	3.306	~~3.298~~	3.293	3.301	3.296	3.302
24664	24616	24603	~~19118~~	19084	27000	844	19116
3.05	3.05	3.05	3.05	3.05	3.05	2.50	1.85
3.299	3.300	3.298	3.305	3.306	3.303	3.286	3.302
24568	24569	24585	24533	24606	24560	26986	19087
2.50	3.05	3.05	3.05	3.05	2.50	2.50	1.85
2.983	3.305	3.306	3.306	3.294	3.294	3.302	2.990
10341	24600	24631	24602	1402	26948	27128	7406
1.85	2.50	3.05	3.05	3.05	2.50	1.85	1.85
2.988	3.000	3.303	3.305	3.306	3.301	2.996	2.934
7376	10293	24615	24614	24601	26957	7356	7408

ANRIKN.% NOM	VERKL.	ANTAL STAVAR	KG UO2	KG U	KG U-235
1.17	1.176	8	25.496	22.462	0.264
~~1.85~~	~~1.850~~	~~20~~	~~63.771~~	~~56.182~~	~~1.039~~
2.50	2.499	16	52.109	45.908	1.147
3.05	3.069	20	66.067	58.205	1.786
1.85	1.850	19	60.473	53.277	0.986
S:A	~~2.318~~	~~64~~	~~207.443~~	~~182.757~~	~~4.236~~
	2.325	63	204.145	179.852	4.183

TOPPL.NR.: Z971

BOTTPL.NR.: K759

SPRIDARE NR.: 2442 2426 1497 2433 1546 1022 URSPR.LAND FÖR URAN: US

BOXNR.: 1843

175669

Avsänt

21 OKT 1974

612

Barsebäck 1 Fuel rod diagram assembly 2048

MONTERINGSPROTOKOLL
****
BARSEBÄCK I

PATRON NR.2048. DATUM:11-10-74 REF.HÖRN

1.85	1.85	1.35	1.85	1.17	1.17	1.17	1.17
2.986	2.982	3.296	3.298	3.320	3.310	3.004	2.994
8074	8123	19379	19369	16277	16273	5730	5735
1.85	2.50	2.50	2.50	1.85	1.35	1.17	1.17
2.983	3.299	3.301	3.303	3.292	3.294	3.314	2.993
7987	26886	26350	703	19427	19460	16276	5739
2.50	2.50	3.05	2.50	2.50	1.85	1.85	1.17
3.292	3.291	3.293	3.299	3.295	3.298	3.294	3.316
26839	26345	24973	26729	26739	19478	19390	16335
3.05	3.05	3.05	1.85	1.85	2.50	1.85	1.17
3.297	3.301	3.288	3.297	3.307	3.293	3.295	3.306
25104	1638	25120	19444	19350	26751	19498	16255
3.05	3.05	3.05	~~1.85~~	1.85	2.50	2.50	1.85
3.291	3.303	3.290	~~3.290~~	3.295	3.284	3.291	3.298
25099	25095	25118	~~19319~~	19472	26783	730	19389
3.05	3.05	3.05	3.05	3.05	3.05	2.50	1.85
3.291	3.298	3.301	3.297	3.301	3.293	3.291	3.296
24940	25124	25121	24963	25009	25080	26757	19480
2.50	3.05	3.05	3.05	3.05	2.50	2.50	1.85
2.998	3.298	3.293	3.296	3.300	3.282	3.301	2.982
10037	25107	24983	25065	1669	26785	26747	7978
1.85	2.50	3.05	3.05	3.05	2.50	1.85	1.35
2.990	2.994	3.287	3.294	3.291	3.291	2.982	2.983
7992	10039	24953	24931	25090	26760	7980	7982

ANRIKN.% NOM	VERKL.	ANTAL STAVAR	KG UO2	KG U	KG U-235
1.17	1.176	8	25.557	22.516	0.265
~~1.85~~	~~1.850~~	~~20~~	~~63.743~~	~~56.158~~	~~1.039~~
2.50	2.501	16	52.105	45.905	1.148
3.05	3.086	20	65.903	58.061	1.792
1.85	1.850	19	60.453	53.259	0.985
S:A	~~2.323~~	~~64~~	~~207.308~~	~~182.640~~	~~4.244~~
	2.331	63	204.018	179.741	4.190

TOPPL.NR.: Z922

BOTTPL.NR.: K802

SPRIDARE NR.: 2552 1951 2344 2279 2342 2553 URSPR.LAND FÖR URAN: US
BOXNR.: 1908

Avstämt
2 5 OKT 1974
Sign.........

616
631

Barsebäck 1 Fuel rod diagram assembly 2074

M O N T E R I N G S P R O T O K O L L

B A R S E B Ä C K I

PATRON NR.2074. DATUM:31-10-74 REF.HÖRN

1.85 2.980 8292	1.85 2.984 8293	1.85 3.311 20761	1.85 3.301 20759	1.17 3.299 16620	1.17 3.305 16629	1.17 2.985 6224	1.17 2.980 6274
1.85 2.981 8249	2.50 3.288 29056	2.50 3.283 29040	2.50 3.297 1130	1.85 3.305 20729	1.85 3.304 20757	1.17 3.305 16643	1.17 2.988 6335
2.50 3.284 29052	2.50 3.291 29053	3.05 3.293 33205	2.50 3.279 29004	2.50 3.310 28981	1.85 3.305 20758	1.85 3.306 20781	1.17 3.308 16735
3.05 3.295 33204	3.05 3.301 164	3.05 3.279 33162	1.85 3.309 20769	1.85 3.301 20792	2.50 3.282 29113	1.85 3.314 20636	1.17 3.310 16616
3.05 3.302 33073	3.05 3.300 33031	3.05 3.284 33044	~~1.85~~ ~~3.302~~ ~~20637~~	1.85 3.303 20699	2.50 3.285 28999	2.50 3.306 1265	1.85 3.312 20742
3.05 3.297 33035	3.05 3.294 33034	3.05 3.291 33029	3.05 3.282 33046	3.05 3.279 33089	3.05 3.295 33159	2.50 3.293 29034	1.85 3.307 20771
2.50 2.995 10651	3.05 3.289 33030	3.05 3.287 33091	3.05 3.286 33090	3.05 3.294 169	2.50 3.286 29131	2.50 3.298 29161	1.85 2.993 8269
1.85 2.989 8299	2.50 2.996 10724	3.05 3.278 33038	3.05 3.286 33037	3.05 3.235 33086	2.50 3.286 29002	1.85 2.932 8213	1.85 2.991 8285

ANRIKN.% NOM	VERKL.	ANTAL STAVAR	KG UO2	KG U	KG U-235
1.17	1.179	3	25.430	22.446	0.265
~~1.35~~	~~1.350~~	~~20~~	~~63.335~~	~~56.283~~	~~1.041~~
2.50	2.501	16	52.064	45.368	1.147
3.05	3.071	20	65.797	57.967	1.780
1.85		19	[illegible]	[illegible]	[illegible]
S:A	~~2.319~~	~~64~~	~~207.226~~	~~182.500~~	~~4.233~~
	[illegible]	63	[illegible]	[illegible]	[illegible]

TOPPL.NR.: Z505

BOTTPL.NR.:K1050

SPRIDARE NR.: 814 371 308 772 804 470 URSPR.LAND FÖR URAN: USA
BOKNR.: 1062

Barsebäck 1 Fuel rod diagram assembly 2118

M O N T E R I N G S P R O T O K O L L

B A R S E B Ä C K I

PATRON NR.2118. DATUM:04-11-74 REF.HÖRN

1.85	1.85	1.85	1.85	1.17	1.17	1.17	1.17
2.983	2.986	3.303	3.296	3.304	3.306	2.985	2.978
8353	8361	20773	20772	16731	16740	6262	6209
1.85	2.50	2.50	2.50	1.85	1.85	1.17	1.17
2.977	3.298	3.298	3.307	3.303	3.303	3.310	2.981
8313	29099	29091	1232	20715	20714	16631	6126
2.50	2.50	3.05	2.50	2.50	1.85	1.85	1.17
3.292	3.287	3.293	3.295	3.281	3.305	3.312	3.303
29062	29117	33190	29084	29063	20812	20691	16715
3.05	3.05	3.05	1.85	1.85	2.50	1.85	1.17
3.292	3.301	3.286	3.306	3.297	3.296	3.299	3.297
33189	137	33143	20780	20798	29042	20836	16664
3.05	3.05	3.05	1.85	1.85	2.50	2.50	1.85
3.292	3.279	3.287	3.311	3.306	3.301	3.307	3.305
33181	33065	33156	20628	20749	29074	1323	20777
3.05	3.05	3.05	3.05	3.05	3.05	2.50	1.85
3.298	3.286	3.275	3.295	3.286	3.283	3.301	3.311
33158	33078	33122	33157	33072	33150	29150	20627
2.50	3.05	3.05	3.05	3.05	2.50	2.50	1.85
2.990	3.281	3.287	3.285	3.293	3.297	3.291	2.992
10671	33054	33136	33041	180	29069	29073	8177
1.85	2.50	3.05	3.05	3.05	2.50	1.85	1.85
2.983	2.995	3.286	3.288	3.297	3.292	2.991	2.995
8254	10668	33109	33045	33108	29072	8236	8199

ANRIKN.% NOM	VERKL.	ANTAL STAVAR	KG UO2	KG U	KG U-235
1.17	1.179	8	25.464	22.434	0.264
1.85	1.850	20	63.869	56.269	1.041
2.50	2.501	16	52.128	45.925	1.148
3.05	3.071	20	65.730	57.952	1.780
S:A	2.319	64	207.241	182.580	4.233

TOPPL.NR.: Z813

BOTTPL.NR.:K1098

SPRIDARE NR.: 2052 1451 1468 2047 1464 1486 URSPR.LAND FÖR URAN: USA
BOXNR.: 1987

Barsebäck 1 Enrichment diagram assemblies 2014, 2018, 2048, 2074 and 2118

Initialhärden B1.

BIL. 1

PATRONLAYOUT

ANRIKNINGSFÖRDELNING

UTBRÄNNINGSREGIONER

	1	2	3	4	5	6	7	8
1	1							
2	2	3						
3	3	4	4					
4	3	4	7	6				
5	4	7	8	6	6			
6	4	8	10	10	11	11		
7	5	8	8	11	11	11	10	
8	5	5	8	11	11	10	9	5

KOORDINATER

Stavtyp nr	Typ	Anrikn. W % U235	Utbrännings-region
1	Smal	1,17	1
2	"	1,17	2
3	Normal	1,17	2
4	"	1,85	3
5	Smal	1,85	3
6	Normal	1,85	4
7	"	2,50	5
8	"	2,50	5
9	Smal	2,50	5
10	Normal	3,05	6
11	"	3,05	7

Barsebäck 1 Enrichment diagram assemblies 2014, 2018, 2048, 2074 and 2118

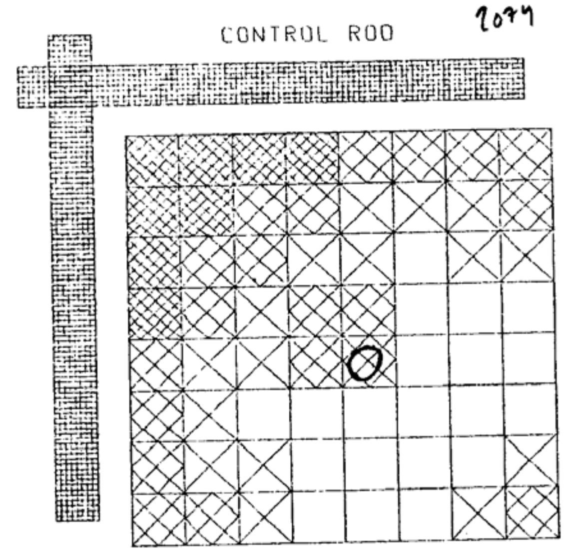
ASEA-ATOM	BARSEBECK 1	BEA-327 7C0902

BARSEBECK 1 INITIAL CORE

AVERAGE ENRICHMENT: 2.31 ~~2.30~~ W/O U-235

2014
2018
2048
2118
2074

(17)



1.17 W/O U-235 | 1.85 W/O U-235

2.50 W/O U-235 | 3.05 W/O U-235

O = spacer capture rod (SOLID Zr ROD REPLACED FUEL ROD AFTER 1ST CYCLE)

MONTERINGSPROTOKOLL 9329

058 * 9187 *

TOPPL: Z4190 BOTTPL: Z49C4 BOX: TRPSKY REF/HORN

	A	B	C	D	E	F	G	H
8	1.98 2.936 5561	2.49 2.974 5170	2.49 3.288 21892	2.49 3.280 25186	2.49 3.236 25190	1.98 3.285 20529	1.98 2.986 5533	1.38 2.991 6353
7	2.49 2.976 5198	3.50 3.280 24332	3.50 3.282 24407	3.50 3.298 485	3.17BA 3.263 15427	2.49 3.284 21876	2.49 3.285 21887	1.98 2.981 5638
6	3.50 3.283 24301	3.17BA 3.260 15496	3.50 3.288 24385	2.49 3.277 21812	2.49 3.278 21851	3.17 3.288 25044	2.49 3.283 21822	1.98 3.288 20534
5	3.50 3.285 25134	3.50 3.297 458	3.50 3.286 24499	1.38 3.280 20162	1.38 3.287 20003	2.49 3.279 21982	3.17BA 3.262 15464	2.49 3.284 25178
4	3.50 3.287 25188	3.50 3.290 24469	3.50 3.284 24446	 58042	1.38 3.295 20201	2.49 3.281 21859	3.50 3.294 477	2.49 3.283 25182
3	3.50 3.278 24304	3.50 3.281 24459	3.50 3.279 24337	3.50 3.280 24336	3.50 3.282 24338	3.50 3.279 24280	3.50 3.289 24395	2.49 3.280 21834
2	3.50 2.985 6121	3.17BA 3.262 15574	3.50 3.279 24343	3.50 3.281 24322	3.50 3.299 451	3.17BA 3.255 15485	3.50 3.279 24350	2.49 2.977 5092
1	2.49 2.987 5076	3.50 2.990 6076	3.50 3.280 24282	3.50 3.282 25180	3.50 3.282 25176	3.50 3.280 24348	2.49 2.971 5196	1.98 2.981 5520

ANRIKN.% NOM	VERKL	ANTAL STAVAR	KG UO2	KG U	KG U-235	UFAKTOR
1.38	1.395	4	12.853	11.328	0.159	0.8814
1.98	1.990	6	18.507	16.311	0.324	0.8814
2.49	2.496	18	57.553	50.728	1.262	0.8814
3.17BA	3.180	5	16.302	14.073	0.448	0.8633
3.17	3.172	1	3.288	2.898	0.092	0.8814
3.50	3.517	29	94.659	83.433	2.938	0.8814
S:A	2.922	63	203.162	178.771	5.223	

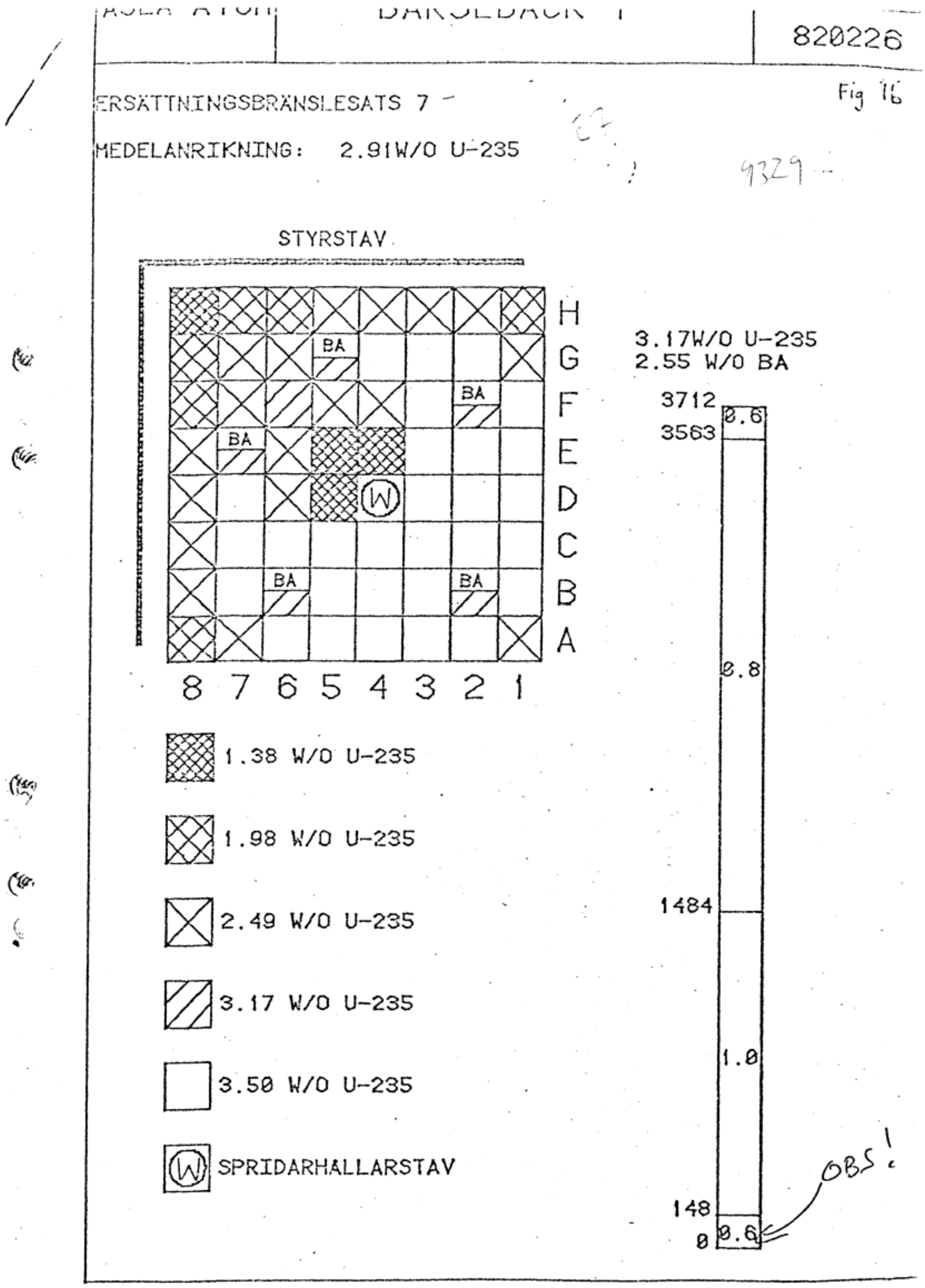
BA-HALT = 2,55 W/O I BA-KUTSAR

SPRIDARE NR.: 56820 56737 56748 56712 56734 56731

1983 -02- 16

GODK. FOR INFRYSNING OCH LEVERANS DAT..........SIGN:.........

Barsebäck 1 Enrichment diagram assembliy 9329



MONTERINGSPROTOKOLL BWR STANDARD
MONTERAD DEN: 84-01-02 AV GE

PATRON-NUMMER/-TYP : 10288 1
PROJEKT-NUMMER/-NAMN: 071 B1E8

REF-HöRN

	A	B	C	D	E	F	G	H
8	5174 / 02	6287 / 04	20689 / 05	20825 / 05	20718 / 05	24405 / 03	5205 / 02	5982 / 01
7	6261 / 04	22785 / 06	22722 / 06	443 / 07	15289 / 08	20728 / 05	20775 / 05	5166 / 02
6	22746 / 06	15313 / 08	22668 / 06	22647 / 06	22579 / 06	22700 / 06	20869 / 05	24467 / 03
5	22690 / 06	412 / 07	22675 / 06	22626 / 06	22560 / 06	22642 / 06	15281 / 08	20807 / 05
4	22666 / 06	22627 / 06	22659 / 06	71034 / 09	22667 / 06	22676 / 06	251 / 07	20813 / 05
3	22678 / 06	22657 / 06	22614 / 06	22604 / 06	22695 / 06	22694 / 06	22681 / 06	20842 / 05
2	6220 / 04	15272 / 08	22692 / 06	22664 / 06	387 / 07	15271 / 08	22774 / 06	6195 / 04
1	6216 / 04	6191 / 04	22658 / 06	22663 / 06	22802 / 06	22843 / 06	6215 / 04	5087 / 02

KAT	TYP	ANRIKNINGAR
01	H	1,38
02	H	1,98
03	N	1,98
04	H	2,49
05	N	2,49
06	N	3,32
07	B	3,32
08	BA	3,17 3,17 3,17
09	SP	

SPRIDARE 1(TOP): 63532
SPRIDARE 2 : 63515
SPRIDARE 3 : 63516
SPRIDARE 4 : 63547
SPRIDARE 5 : 63333
SPRIDARE 6(BOT): 63503

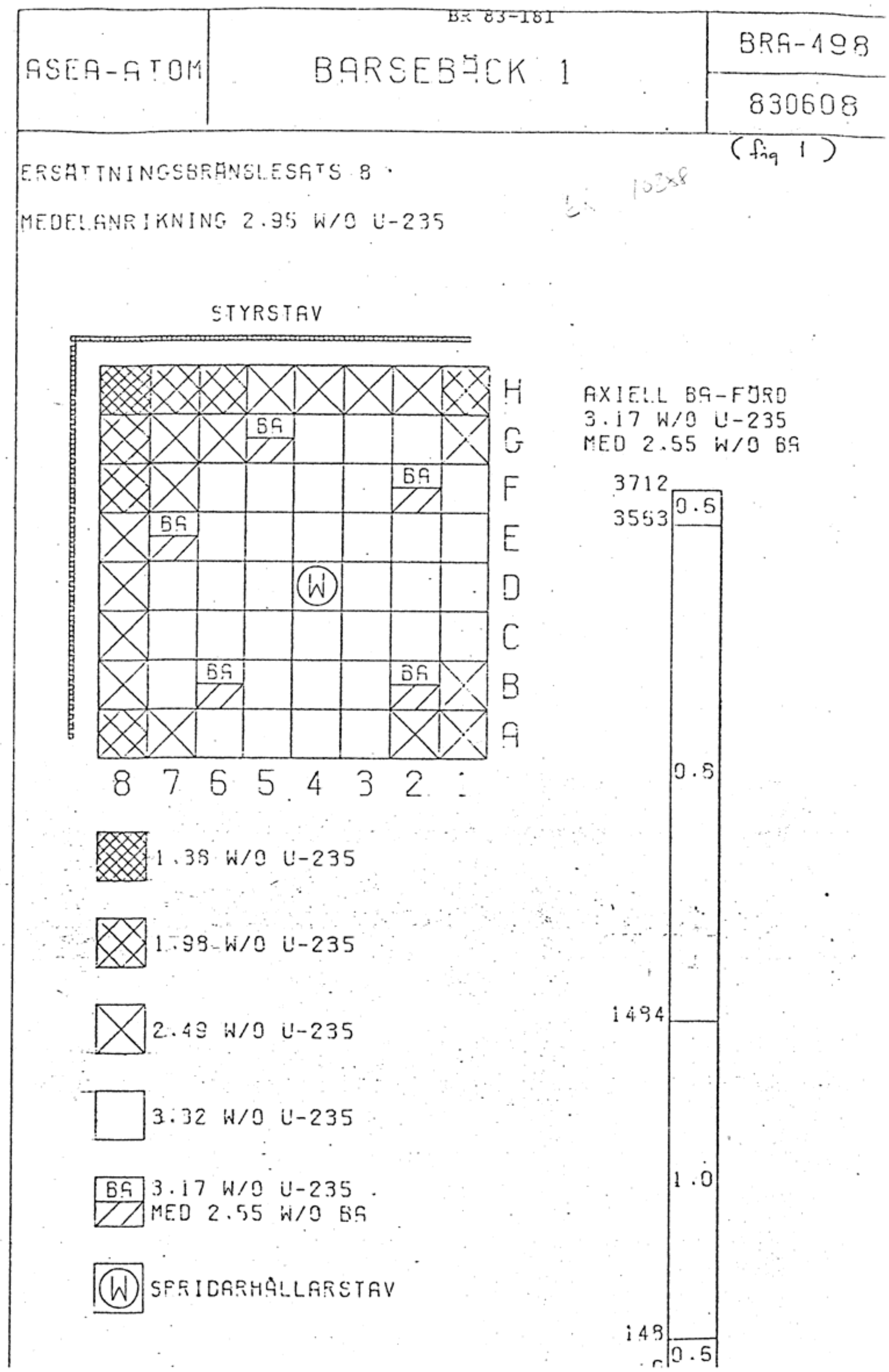
TOPPLATTA: Z4382
TJ.BLADFJ 1: 9198/3:2/578
TJ.BLADFJ 2: 9198/1:2/572
TUNN.BLADFJ: 9198/5:3/610
M7-SKRUV LANG: 9306/2:3
M7-SKRUV KORT: 9306/1:3

BOTTENPLATTA: M2394
M8-MUTTER: M8-49
Y.TR.FJÄDER: 9075:1/518
BOX: 31B012L

LEVERANS GODKÄND (ATOM/PCB) DATUM: 1984-02-01 SIGNATUR:

10288

Barsebäck 1 Enrichment diagram assembly 10288



2.10 Barsebäck 2

REACTOR BARSEBÄCK 2

Parameter	Value
Reactor pressure (MPa) at full power	7
Inlet temperature into core (C) at full power	260
Outlet temperature into core (C) at full power	286
Pitch between assemblies in the core (c–c, mmm)	153
Avg. temperature in the uranium pellets at full power (C)	650
Avg. temperature in the cladding at full power (C)	290
Temperature in the boxwall at full power (C)	286

Cycle data

Cycle no	Start	Stop	Reactor power MW	Burnup avg/cycle MWd/tU	No of assemblies in core
9	1987-09-19	1988-07-06	1,800	6,050	444
10	1988-08-07	1989-09-08	1,800	8,090	444
11	1989-09-28	1990-07-11	1,800	5,630	444
12	1990-08-18	1991-09-06	1,800	8,110	444
13	1991-09-22	1992-07-02	1,800	5,600	444
14	1992-08-08	1993-09-30	1,800	5,350	444
15	1994-01-29	1994-06-29	1,800	2,820	444

Fuel data	Fuel id 14076
Fuel type	AA8×8
No of fuel rods	63
Rod pitch normal rods (mm)	16.3
Rod pitch normal – corner rods (mm)	16.05
Rod pitch corner – corner rods (mm)	15.8
Rod diameter normal rod (mm)	12.25
Clad thickness normal rod (mm)	0.8
Pellet diameter normal rod (mm)	10.44
No of normal rods	51
Rod diameter corner rod (mm)	11.75
Clad thickness corner rod (mm)	0.8
Pellet diameter corner rod (mm)	9.94
No of corner rods	12
Active length (mm)	3,712
Density UO2 (g/cc)	10.44
Porsity,dishing etc (%)	1
	10.3356
No of spacer rods	1
Material in spacer rods	Zr2
Outer diameter spacer rods (mm)	12.25
Cladding thickness spacer rod	
No of water rods	
Material in water rods	
Outer diameter water rods (mm)	
Inner diameter water rods (mm)	
No of BA rods	5
% Gd2O3	2
Rel poison	0.8–1
No of spacers	6
Spacer material	Inconel
Mass of spacer (g)	0135
Box material	Zr4
Box outer measure square (mm)	139
Box wall thickness (mm)	2.3

Initial data	17076
Initial mass Utot (g)	179,571.00
Initial mass U235 (g)	5,665.00
Avg.enrichment% U235	3.15
Fuel rod diagram	X
Enrichment diagram	X
Data after rebuild 1	
Date of rebuild	
No of fuel rods	
No spacer rods	
No water rods	
No of water holes	
Mass Utot after rebuild (g)	
Mass U235 after rebuild (g)	
Data after rebuild 2	
Date of rebuild	
No of fuel rods	
No spacer rods	
No water rods	
No of water holes	
Mass Utot after rebuild (g)	
Mass U235 after rebuild (g)	
Cycle history burnup/cycle, MWd/tU	
4	
5	
6	
7	
8	
9	8,398
10	10,218
11	5,514
12	9,993
13	5,884
Axial BU distribution, EOL MWd/tUNode	
1	21,600
2	34,500
3	40,500
4	42,800
5	44,700
6	45,600
7	45,700
8	45,200
9	45,600
10	45,500
11	45,100
12	44,400
13	44,600
14	44,300
15	43,700
16	42,700
17	42,600
18	42,000
19	41,000
20	39,300
21	38,000
22	35,600
23	31,700
24	26,500
25	20,400

Void history Node no (top=25)	14076
1	0.00
2	0.00
3	0.00
4	0.05
5	0.13
6	0.20
7	0.27
8	0.33
9	0.39
10	0.44
11	0.49
12	0.53
13	0.56
14	0.59
15	0.62
16	0.64
17	0.66
18	0.68
19	0.70
20	0.72
21	0.73
22	0.74
23	0.75
24	0.76
25	0.76
Density history Node no (top=25)	
1	0.76
2	0.76
3	0.74
4	0.70
5	0.65
6	0.60
7	0.55
8	0.50
9	0.46
10	0.42
11	0.39
12	0.37
13	0.34
14	0.32
15	0.31
16	0.29
17	0.28
18	0.26
19	0.25
20	0.24
21	0.23
22	0.23
23	0.22
24	0.22
25	0.21

Control rod history Node no (top=25)
1
2
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MONTERINGSPROTOKOLL BWR STANDARD
MONTERAD DEN: 87-01-26 AV IE

PATRON-NUMMER/-TYP : 14076 1
PROJEKT-NUMMER/-NAMN: 114 B2E7

REF-HöRN

	A	B	C	D	E	F	G	H
8	5209	5703	22201	22221	22200	22543	5190	5415
	02	04	05	05	05	03	02	01
7	5825	20409	15146	237	20426	22162	22157	5193
	04	06	08	07	06	05	05	02
6	20268	15061	20403	20337	20273	15057	22042	22476
	06	08	06	06	06	08	05	03
5	20245	244	20394	20345	20397	20329	20242	22101
	06	07	06	06	06	06	06	05
4	20231	20391	20432	114039	20422	20372	232	22123
	06	06	06	09	06	06	07	05
3	20331	20375	20256	20427	20361	20228	15068	22037
	06	06	06	06	06	06	08	05
2	5729	15038	20448	20301	239	15036	20343	5865
	04	08	06	06	07	08	06	04
1	5737	5788	20234	20366	20373	20271	5738	5212
	04	04	06	06	06	06	04	02

KAT	TYP	ANRIKNINGAR
01	H	1,38
02	H	2,10
03	N	2,10
04	H	2,64
05	N	2,64
06	N	3,60
07	B	3,60
08	BA	3,17 3,17 3,17 3,17
09	SP	

SPRIDARE 1(TOP): 80028
SPRIDARE 2 : 80008
SPRIDARE 3 : 80488
SPRIDARE 4 : 80436
SPRIDARE 5 : 80505
SPRIDARE 6(BOT): 80800

TOPPLATTA: M772
TJ.BLADFJ 1: 9507/4:1/660
TJ.BLADFJ 2: 9507/1:1/667
TUNN.BLADFJ: 9507/6:2/692
M7-SKRUV LANG: 9504/2:2
M7-SKRUV KORT: 9504/1:2

BOTTENPLATTA: Z7641
M8-MUTTER: M8-65
Y.TR.FJÄDER: 9946/2:1/741
BOX: 55B102L

LEVERANS GODKÄND (ATOM/PCB) DATUM: 1987-03-28 SIGNATUR: [signature] 14076

A-66/87

Barsebäck 2 Enrichment diagram assembly14076