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**IPR-06-15**

# Äspö Hard Rock Laboratory

## Prototype Repository

## Statistical evaluation of buffer density

Martin Birgersson

Lars-Erik Johannesson

Clay Technology AB

October 2006

*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

Äspö Hard Rock Laboratory

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# Abstract

An evaluation of expected mean buffer densities and variance in PROTOTYPE REPOSITORY has been preformed using measured values of diameters of the deposition holes and masses of the emplaced bentonite blocks. The analysis gives approximate confidence intervals much smaller than 100 kg/m$^3$, which is the size of the specified density range in the KBS-3 concept /Svensk Kärnbränslehanterting AB/.

# Sammanfattning


En utvärdering av förväntade medeldensiteter och varianser i PROTOTYPE REPSOTORY har genomförts med utgångspunkt från uppmätta värden på de inplacerade bentonitblockens massor och deponeringshålens diametrar.
Analysen ger approximativa konfidensintervall betydligt mindre än 100 kg/m$^3$, vilket är storleken på det specificerade buffertdensitetsintervallet i KBS-3-konceptet /Svensk Kärnbränslehanterting AB/.

# Contents

# 1 Background

The expected average bentonite density in a KBS-3V deposit hole has been evaluated statistically using data from the six installed deposit holes within the PROTOTYPE REPOSITORY.

The buffer of a PROTOTYPE REPOSITY deposition hole at installation consists of 10 blocks of ring shape (R1 – R10), 4 blocks of disc shape (C1 – C4) and a column of bentonite pellets in between blocks and rock. The bentonite is of Wyoming type (MX-80) which is described in detail in /Karnland et al. 2006/. The configuration is schematically shown in Figure 1.

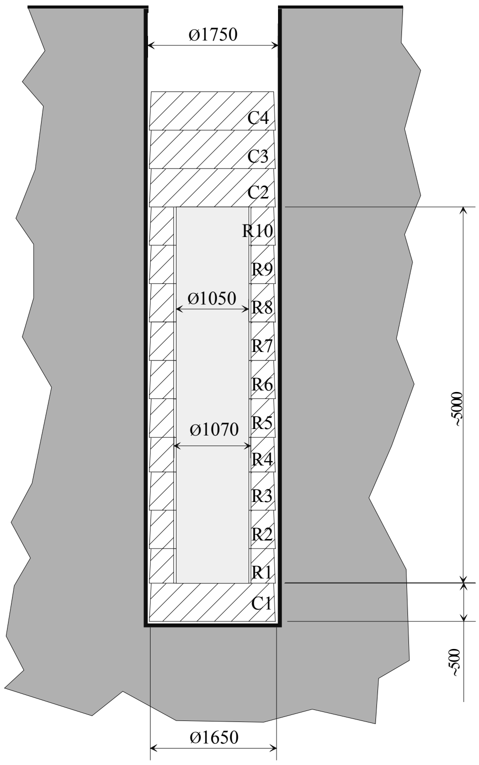


***Figure 1.*** *Schematics of a PROTOTYPE REPOSITORY deposit hole. Unit in mm.*

The mean density will have a statistical spread due to variations in the volume of the deposition holes and due to variations in the density of the emplaced bentonite.

# 2 Evaluations

## 2.1 Statistical Data

The following underlying data has been used in the evaluation

1. <u>Measurements of the deposit hole mean diameters at different depths.</u>
   These measurements have been performed at depths separated by 40 cm (see Appendix I). At each level, the diameter value is obtained by an average of three measurements in different directions. In total, 22 diameters per deposition hole are considered. Table 1 shows the sample mean and standard deviation of the hole diameter for each of the six deposition holes. Figure 2 compares a histogram of all considered mean diameters from all six deposition holes with a normal distribution, showing that the mean hole diameter is approximately normally distributed.

**Table 1: Data underlying the mean density calculations of the PROTOTYPE REPOSITORY deposition holes.**

| Hole no. | Hole diameter | | Mass of ring shaped blocks | | Mass of disc shaped blocks | | Mass of Pellets |
|---|---|---|---|---|---|---|---|
| | Mean | Std | Mean | Std | Mean | Std | |
| | (m) | (m) | (kg/m) | (kg/m) | (kg/m) | (kg/m) | (kg/m) |
| | | | | | | | |
| DA3587G05 | 1,760 | 0,0019 | 2153 | 8,1 | 3619 | 10,4 | 364 |
| DA3581G01 | 1,760 | 0,0019 | 2149 | 8,5 | 3607 | 23,4 | 374 |
| DA3575G01 | 1,761 | 0,0014 | 2152 | 9,0 | 3629 | 11,8 | 340 |
| DA3569G02 | 1,761 | 0,0018 | 2164 | 8,4 | 3621 | 35,7 | 361 |
| DA3551G01 | 1,760 | 0,0023 | 2114 | 14,8 | 3603 | 25,1 | 373 |
| DA3545G01 | 1,759 | 0,0025 | 2117 | 9,5 | 3597 | 16,0 | 357 |
| | | | | | | | |
| All holes | 1,760 | 0,0020 | 2141 | 21,5 | 3613 | 22,7 | 362 |

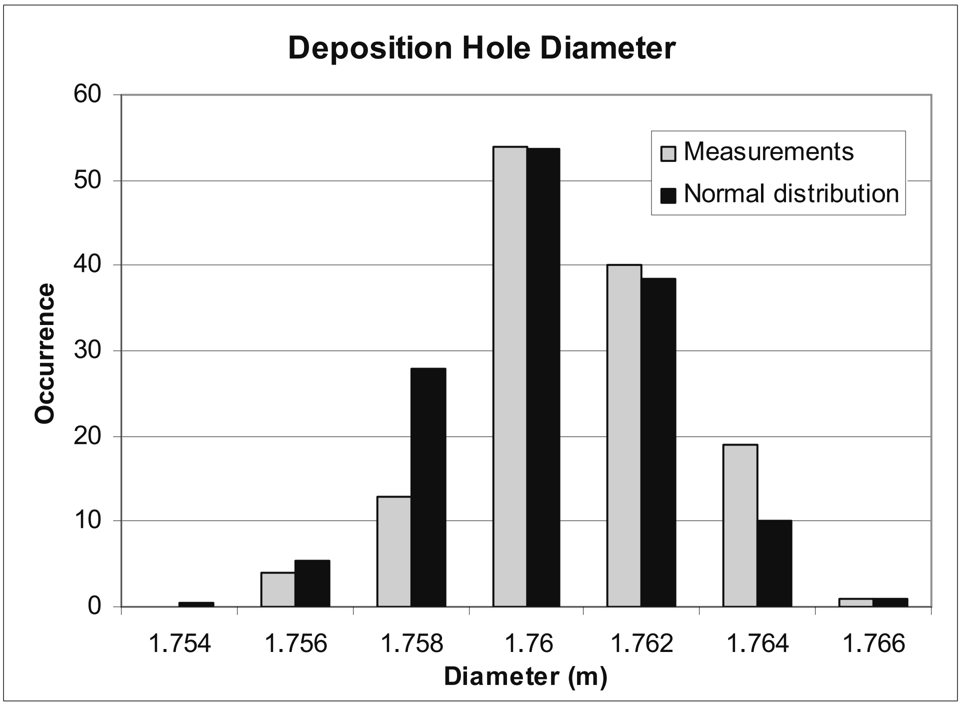


***Figure 2.*** *Histogram of the mean diameters at different depths for all of the six deposition holes. For comparison, a normal distribution with the same mean (1.760 m) and standard deviation (0.0204 m) is also plotted.*

2. The amount of bentonite in the blocks described as dry mass per unit length. This quantity has been measured for all the installed disc and ring formed blocks (see Appendix II). Sample means and standard deviations for each deposition hole are found in Table 1. These quantities have been calculated using all available blocks, i.e. 10 rings and 4 discs per deposition hole. In the table it can also be seen that the sample standard deviation for all blocks (from all six deposition holes) is usually larger than the sample standard deviation from individual holes. The reason for this is that blocks in different deposition holes have been compacted at different occasions, resulting in a rather large difference in mean value between the holes.

3. The amount of bentonite pellets expressed as mass per unit length (see Appendix II). The contribution to the final density variation due to variations in this quantity will only be minor since the total mass of pellets is small compared to the mass of bentonite contained in blocks. This quantity is therefore assumed to be non-stochastic in the following evaluations. The mass of pellets per unit length for each deposition hole is listed in Table 1.

## 2.2 Calculations

The following estimations of the mean density in the deposition holes has been performed:

1. Estimation of the mean density at a specific depth of each individual deposition hole.

For these estimations the diameter of the deposition hole and the amount of bentonite in the blocks are assumed to be normally distributed stochastic variables with parameters (mean and variance) according to Table 1. The dry density is then also a stochastic variable

$$\rho_d(M,D) = \frac{M_{tot}}{V_{bent}} = \frac{(M+m_p)h}{A_{bent}h} = \frac{(M+m_p)}{\pi([D/2]^2 - r_c^2)} \qquad (1)$$

Where stochastic variables are indicated by capital letters, and

| | | |
|---|---|---|
| $\rho_d$ | = | Dry density at a specific depth (either at a cut across a ring shaped or a disc shaped block, see Figure 1.). |
| $M$ | = | The amount of dry bentonite of the block of interest expressed as kg/m. |
| $m_p$ | = | The amount of dry bentonite of the pellets expressed as kg/m. |
| $M_{tot}$ | = | $M+ m_p$; total amount of dry bentonite expressed as kg/m. |
| $D$ | = | Diameter of the deposition hole. |
| $h$ | = | An arbitrary height of the cut (included in order to get the correct dimension in the equation). |
| $r_c$ | = | 0.525 m; Radius of the copper canister, when this is included in the cut of interest. When calculating a cut across disc shaped blocks, $r_c$ is put to 0. |
| $A_{bent}$ | = | $\pi((D/2)^2 - r_c^2)$; the area of the cross section of the swollen bentonite. When calculating a cut across disc shaped blocks, $r_c$ is put to 0. |
| $V_{bent}$ | = | $A_{bent} \cdot h$; the volume of the swollen bentonite. |

An exact treatment of the distribution of $\rho_d$ is complicated due to the form of equation 1, and is here treated approximately by linearization. The variance of $\rho_d$ is then (the delta method, see e.g. /Casella and Berger 2002/)

$$\operatorname{var}(\rho_d) \approx \left(\frac{\partial \rho_d(\overline{M},\overline{D})}{\partial M}\right)^2 \operatorname{var}(M) + \left(\frac{\partial \rho_d(\overline{M},\overline{D})}{\partial D}\right)^2 \operatorname{var}(D)$$

$$= \frac{1}{\pi^2([\overline{D}/2]^2 - r_c^2)^2}\left(\operatorname{var}(M) + \left[\frac{\overline{D}(\overline{M}+m_p)}{([\overline{D}/2]^2 - r_c^2)}\right]^2 \operatorname{var}(D)\right) = \qquad (2)$$

$$\frac{1}{\overline{A}^2}\left(\operatorname{var}(M) + [\pi\overline{D}\overline{\rho}_d]^2 \operatorname{var}(D)\right),$$

Where bared quantities denotes mean values.

The results of the calculations are presented in Table 2, where both mean values and standard deviations are listed, as well as approximate 95% confidence intervals for the expected mean *bulk* densities, $\rho_{m,}$ in each deposition hole.

**Table 2: Results of calculations of the mean density in the six deposition holes in PROTOTYPE REPOSITORY.**

| Hole no. | Ring Shaped Blocks | | | | Disc Shaped Blocks | | | |
|---|---|---|---|---|---|---|---|---|
| | mean | std | 95% C.I. | | mean | std | 95% C.I. | |
| | $\rho_d$ | $\rho_d$ | $\rho_m$ | | $\rho_d$ | $\rho_d$ | $\rho_m$ | |
| | (kg/m$^3$) | (kg/m$^3$) | (kg/m$^3$) | | (kg/m$^3$) | (kg/m$^3$) | (kg/m$^3$) | |
| DA3587G05 | 1605 | 7,5 | 2018 | 2037 | 1636 | 5,6 | 2041 | 2055 |
| DA3581G01 | 1610 | 7,6 | 2021 | 2040 | 1636 | 10,2 | 2035 | 2060 |
| DA3575G01 | 1589 | 7,0 | 2009 | 2026 | 1630 | 5,5 | 2037 | 2051 |
| DA3569G02 | 1608 | 7,4 | 2021 | 2039 | 1635 | 15,0 | 2028 | 2066 |
| DA3551G01 | 1587 | 11,4 | 2002 | 2030 | 1634 | 11,1 | 2032 | 2060 |
| DA3545G01 | 1581 | 9,2 | 2000 | 2023 | 1626 | 8,0 | 2031 | 2051 |
| | | | | | | | | |
| All Holes | 1597 | 14,9 | 2003 | 2041 | 1633 | 10,1 | 2033 | 2058 |

The saturated bulk density is obtained from the dry density according to

$$\rho_m = \rho_d + \rho_w \left(1 - \frac{\rho_d}{\rho_s}\right) \tag{3}$$

where

$\rho_m$ = Mean density of water saturated bentonite

$\rho_s$ = Grain density of Wyoming type bentonite, 2780 kg/m$^3$ /Karnland et al. 2006/

$\rho_w$ = Water density, 1000 kg/m$^3$

2. Estimation of the mean density for a complete deposition hole.

The calculations is made with the assumption that the bentonite in the deposition hole consists of four disc- and ten ring-shaped 0.50 m blocks and a 7.0 m column of pellets. The hole diameter and the block mass per unit length are treated as stochastic variables as before (with parameters from Table 1).

The blocks of the two sections of the PROTOTYPE REPOSITORY are manufactured at different occasions at which deliveries of bentonite with slightly different water content were used. The variance of the block mass has therefore been calculated using the residuals, i.e. the difference between the actual mass and the section mean, in order to make use of all available data. The resulting standard deviations are 10.7 kg/m for ring shaped blocks and 20.8 kg/m for disc shaped blocks (compare last row of Table 1).

Histograms of the residuals are plotted in Figure 3 and Figure 4. It is seen that these are approximately normally distributed.

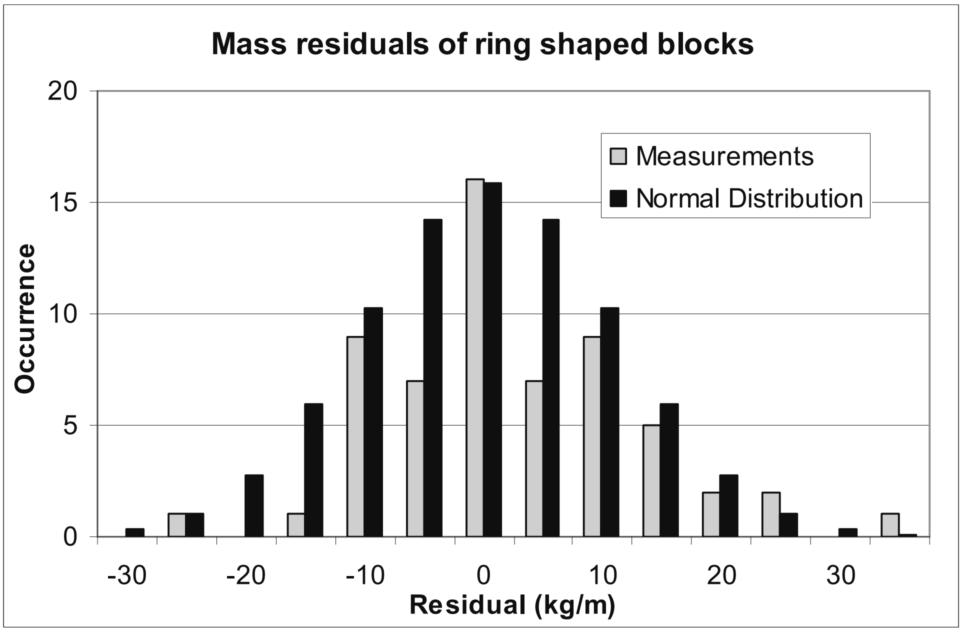


***Figure 3.*** *Histogram of residuals of mass of ring shaped blocks. A normal distribution with the same mean (0 kg/m) and standard deviation (10.7 kg/m) is plotted for comparison.*

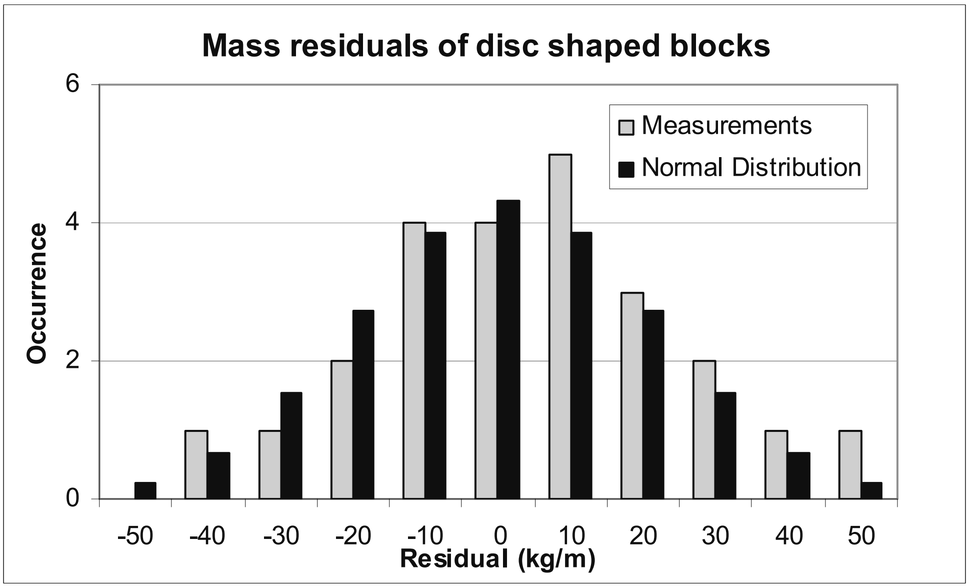


***Figure 4.*** *Histogram of residuals of mass of disc shaped blocks. A normal distribution with the same mean (0 kg/m) and standard deviation (20.8 kg/m) is plotted for comparison.*

The same approximate method as used in the previous calculation is adopted here for the variance evaluation. In this case the mean density of a complete deposition hole is expressed as

$$\rho_d(\vec{M},D) = \frac{M_{tot}}{V} = \frac{0.5\sum_{i=1}^{10} M_R^i + 0.5\sum_{j=1}^{4} M_D^j + 7m_p}{\pi\left(7/4\,D^2 - 5r_c^2\right)}, \tag{4}$$

where $M_R^i$ and $M_D^j$ are stochastic variables describing the mass of ring shaped block *i* and disc shaped block *j* respectively. These are collected as components in a stochastic mass vector $\vec{M}$ . For the rest of equation 4, the symbols have the same meaning as in equation 1. The variance of the mean density is approximately

$$\begin{aligned}
\mathrm{var}(\rho_d) &\approx \sum_{i=1}^{10}\left(\frac{\partial\rho_d(\overline{\vec{M}},\overline{D})}{\partial M_R^i}\right)^2 \mathrm{var}(M_R) + \sum_{j=1}^{4}\left(\frac{\partial\rho_d(\overline{\vec{M}},\overline{D})}{\partial M_O^j}\right)^2 \mathrm{var}(M_O) + \\
&+\left(\frac{\partial\rho_d(\overline{\vec{M}},\overline{D})}{\partial D}\right)^2 \mathrm{var}(D) = \\
&=\left(\frac{1}{\overline{V}}\right)^2\left(0.5\,\mathrm{var}(M_R)\sum_{i=1}^{10}1 + 0.5\,\mathrm{var}(M_O)\sum_{j=1}^{4}1\right)+\left(\frac{\overline{M}_{tot}}{\overline{V}^2}\frac{7\pi\overline{D}}{2}\right)^2 \mathrm{var}(D) = \\
&\left(\frac{1}{\overline{V}}\right)^2\left(5\,\mathrm{var}(M_R) + 2\,\mathrm{var}(M_O) + \left[\frac{7\pi\overline{D}\overline{\rho}_d}{2}\right]^2 \mathrm{var}(D)\right),
\end{aligned} \tag{5}$$

and is presented in Table 3.

**Table 3: Results from calculation of mean density of a complete deposition hole.**

| **Deposition hole PROTOTYPE** | | | | |
|---|---|---|---|---|
| mean | std | mean | 95% C.I. | |
| ρd | ρd | ρm | ρm | |
| (kg/m$^3$) | (kg/m$^3$) | (kg/m$^3$) | (kg/m$^3$) | |
| 1610 | 5,8 | 2031 | 2024 | 2038 |

# 3 Conclusions and final remarks

- The mean density is in general larger in cross sections over disc shaped blocks as compared to ring shaped blocks.
- The evaluated confidence intervals for the mean density are of the same size for both types of blocks.
- The evaluated confidence intervals are much less than 100 $kg/m^3$.
- The diameter of the deposition holes in section 2 of PROTOTYPE REPOSITORY (DA3551G01 and DA3545G01) has a larger standard deviation as compared to section 1. Also the block mass standard deviation is larger in this section. The resulting mean density confidence interval is consequently larger in these deposition holes.
- The calculated mean density of a complete deposition hole (2031 $kg/m^3$) is larger than specified within the KBS-3 concept (2000 $kg/m^3$) /Svensk Kärnbränslehanterting AB/. The reason for this is that when planning the PROTOTYPE REPOSITORY, all data on hole diameter and block mass variances where not available. Furthermore, what density of the pellets column which could be achieved during installation was uncertain. The mean density in future installations can probably be better adopted to the concept specifications by adjusting the compaction stress during block manufacturing. It is also possible to adjust the final density by changing the diameters of the blocks.
- The calculation gives a mean density 95 % confidence interval for a complete deposition hole of 2024 – 2038 $kg/m^3$. This could be compared to the specified interval for the saturated density in the KBS-3 concept, 1950-2050 $kg/m^3$ /Svensk Kärnbränslehanterting AB/.
- Assuming a capacity of a final repository of 6000 canisters, the present analysis gives an approximate 1/6000 confidence interval of 2017 – 2045 $kg/m^3$. I.e. the mean density of one out of 6000 deposition holes is expected to lie outside of this range.
- Examining the various terms in the last equality in equation 5 reveals that the largest contribution to the mean density variation stems from the hole diameter variance. To achieve less density variance in future installations better boring precision is demanded.
- However, a reason for the hole diameter variance to dominate the final mean density variance is that its variation with depth has not been considered in the present analysis. Since the diameter variation at two different depths (not too close) can be assumed to be independent, this will contribute to lower the impact of the diameter variance on the final mean density variance. From this perspective, the present analysis is based on pessimistic assumptions.
- The quality on the presented results depends on how well the underlying distribution parameters for hole diameter and blocks masses has been estimated. From this view calculation 2, which is based on 132 diameter measurements, 60 ring block measurements and 24 disc block measurements (Table 3), is the most reliable. Most uncertain are the calculations of mean density in cross sections of disc shaped blocks in an individual deposition hole (the right part of Table 2) which is based on 4 disc block measurements and 22 diameter measurements.

# References


**Casella G. and Berger R.L 2002**, Statistical Interference, $2^{nd}$ ed., Duxbury 2002, p.240ff.

**Karnland O, Olsson S, Nilsson U, 2006**. Mineralogy and sealing properties of various bentonites and smectite-rich clay materials, SKB TR-06-30, Svensk Kärnbränslehantering AB.

**Svensk Kärnbränslehantering AB**, **2006.** Initial state report for the safety assessment SR-Can. SKB TR-06-21, Svensk Kärnbränslehantering AB.

# APPENDIX I

**Measured diameters of the deposition holes**

| **SKB Äspö HRL** | | | |
|---|---|---|---|
| **Hole No:** | **DA3587G01** | | |
| **Date** | 990721 | **Time** | 13:00 - 15:00 |
| **Measurements made by:** | | | Robert Nyberg |

| Depth (m) | Diam 1 (m) | Diam 2 (m) | Diam 3 (m) |
|---|---|---|---|
| 0,00 | 1,755 | 1,770 | 1,755 |
| 0,40 | 1,755 | 1,755 | 1,770 |
| 0,80 | 1,745 | 1,760 | 1,760 |
| 1,20 | 1,755 | 1,765 | 1,760 |
| 1,60 | 1,755 | 1,765 | 1,760 |
| 2,00 | 1,755 | 1,765 | 1,765 |
| 2,40 | 1,760 | 1,770 | 1,760 |
| 2,80 | 1,755 | 1,765 | 1,760 |
| 3,20 | 1,760 | 1,765 | 1,760 |
| 3,60 | 1,755 | 1,765 | 1,760 |
| 4,00 | 1,755 | 1,765 | 1,765 |
| 4,40 | 1,755 | 1,770 | 1,765 |
| 4,80 | 1,755 | 1,765 | 1,760 |
| 5,20 | 1,755 | 1,760 | 1,760 |
| 5,60 | 1,755 | 1,765 | 1,760 |
| 6,00 | 1,760 | 1,765 | 1,760 |
| 6,40 | 1,755 | 1,765 | 1,760 |
| 6,80 | 1,755 | 1,760 | 1,760 |
| 7,20 | 1,755 | 1,770 | 1,760 |
| 7,60 | 1,755 | 1,770 | 1,765 |
| 8,00 | 1,755 | 1,760 | 1,760 |
| 8,15 | 1,755 | 1,765 | 1,760 |

Appendix 1:2

# SKB Äspö HRL

**Hole No:** **DA3581G01**

**Date** 990722 **Time** 11:30 - 13:30

**Measurements made by:** Robert Nyberg

| Depth (m) | Diam 1 (m) | Diam 2 (m) | Diam 3 (m) |
|---|---|---|---|
| 0,00 | 1,760 | 1,760 | 1,765 |
| 0,40 | 1,755 | 1,755 | 1,760 |
| 0,80 | 1,755 | 1,755 | 1,765 |
| 1,20 | 1,760 | 1,760 | 1,765 |
| 1,60 | 1,755 | 1,765 | 1,765 |
| 2,00 | 1,755 | 1,760 | 1,760 |
| 2,40 | 1,755 | 1,760 | 1,760 |
| 2,80 | 1,755 | 1,760 | 1,760 |
| 3,20 | 1,755 | 1,760 | 1,770 |
| 3,60 | 1,755 | 1,760 | 1,760 |
| 4,00 | 1,755 | 1,760 | 1,765 |
| 4,40 | 1,760 | 1,765 | 1,765 |
| 4,80 | 1,755 | 1,760 | 1,765 |
| 5,20 | 1,755 | 1,760 | 1,765 |
| 5,60 | 1,760 | 1,765 | 1,765 |
| 6,00 | 1,760 | 1,760 | 1,765 |
| 6,40 | 1,755 | 1,760 | 1,765 |
| 6,80 | 1,755 | 1,760 | 1,765 |
| 7,20 | 1,755 | 1,760 | 1,765 |
| 7,60 | 1,755 | 1,760 | 1,765 |
| 8,00 | 1,760 | 1,760 | 1,765 |
| 8,15 | 1,750 | 1,760 | 1,760 |

Appendix I:3

# SKB Äspö HRL

**Hole No:** **DA3575G01**

**Date** 990722 **Time** 15:30 - 17:30

**Measurements made by:** Robert Nyberg

| Depth (m) | Diam 1 (m) | Diam 2 (m) | Diam 3 (m) |
|---|---|---|---|
| 0,00 | 1,760 | 1,765 | 1,760 |
| 0,40 | 1,755 | 1,765 | 1,760 |
| 0,80 | 1,755 | 1,765 | 1,755 |
| 1,20 | 1,755 | 1,765 | 1,755 |
| 1,60 | 1,760 | 1,765 | 1,760 |
| 2,00 | 1,755 | 1,760 | 1,760 |
| 2,40 | 1,760 | 1,765 | 1,760 |
| 2,80 | 1,760 | 1,765 | 1,760 |
| 3,20 | 1,755 | 1,765 | 1,765 |
| 3,60 | 1,755 | 1,770 | 1,760 |
| 4,00 | 1,760 | 1,765 | 1,755 |
| 4,40 | 1,755 | 1,760 | 1,760 |
| 4,80 | 1,755 | 1,760 | 1,765 |
| 5,20 | 1,760 | 1,765 | 1,765 |
| 5,60 | 1,755 | 1,765 | 1,760 |
| 6,00 | 1,760 | 1,765 | 1,760 |
| 6,40 | 1,755 | 1,765 | 1,765 |
| 6,80 | 1,755 | 1,765 | 1,760 |
| 7,20 | 1,760 | 1,765 | 1,760 |
| 7,60 | 1,755 | 1,765 | 1,765 |
| 8,00 | 1,760 | 1,765 | 1,760 |
| 8,15 | 1,755 | 1,765 | 1,760 |

**Appendix I:4**

# SKB Äspö HRL

**Hole No:** **DA3569G01**

**Date:** 990723 **Time:** 10:00 - 12:00

**Measurements made by:** Robert Nyberg

| Depth (m) | Diam 1 (m) | Diam 2 (m) | Diam 3 (m) |
|---|---|---|---|
| 0,00 | 1,755 | 1,765 | 1,765 |
| 0,40 | 1,760 | 1,765 | 1,765 |
| 0,80 | 1,755 | 1,765 | 1,760 |
| 1,20 | 1,755 | 1,770 | 1,765 |
| 1,60 | 1,755 | 1,765 | 1,765 |
| 2,00 | 1,750 | 1,765 | 1,765 |
| 2,40 | 1,755 | 1,765 | 1,760 |
| 2,80 | 1,760 | 1,765 | 1,760 |
| 3,20 | 1,755 | 1,765 | 1,765 |
| 3,60 | 1,755 | 1,770 | 1,765 |
| 4,00 | 1,755 | 1,765 | 1,760 |
| 4,40 | 1,755 | 1,765 | 1,765 |
| 4,80 | 1,755 | 1,765 | 1,760 |
| 5,20 | 1,755 | 1,770 | 1,760 |
| 5,60 | 1,755 | 1,770 | 1,760 |
| 6,00 | 1,755 | 1,770 | 1,765 |
| 6,40 | 1,755 | 1,770 | 1,760 |
| 6,80 | 1,755 | 1,770 | 1,760 |
| 7,20 | 1,760 | 1,765 | 1,755 |
| 7,60 | 1,755 | 1,765 | 1,765 |
| 8,00 | 1,755 | 1,765 | 1,760 |
| 8,15 | 1,750 | 1,760 | 1,755 |

**Appendix I:5**

# SKB Äspö HRL

**Hole No:** **DA3551G01**

**Date:** ??? **Time:** ???

**Measurements made by:** ???

| Depth (m) | Diam 1 0 degr | Diam 2 60 degr | Diam 3 120 degr |
|---|---|---|---|
| 0.00 | 1,752 | 1,762 | 1,761 |
| 0.40 | 1,752 | 1,767 | 1,756 |
| 0.80 | 1,752 | 1,758 | 1,761 |
| 1.20 | 1,752 | 1,762 | 1,767 |
| 1.60 | 1,757 | 1,767 | 1,767 |
| 2.00 | 1,747 | 1,756 | 1,767 |
| 2.40 | 1,747 | 1,767 | 1,766 |
| 2.80 | 1,747 | 1,767 | 1,767 |
| 3.20 | 1,742 | 1,772 | 1,776 |
| 3.60 | 1,747 | 1,767 | 1,766 |
| 4.00 | 1,747 | 1,767 | 1,766 |
| 4.40 | 1,742 | 1,772 | 1,761 |
| 4.80 | 1,747 | 1,772 | 1,767 |
| 5.20 | 1,747 | 1,767 | 1,772 |
| 5.60 | 1,737 | 1,771 | 1,767 |
| 6.00 | 1,742 | 1,782 | 1,767 |
| 6.40 | 1,742 | 1,771 | 1,776 |
| 6.80 | 1,742 | 1,772 | 1,767 |
| 7.20 | 1,737 | 1,767 | 1,767 |
| 7.60 | 1,742 | 1,771 | 1,772 |
| 8.00 | 1,747 | 1,767 | 1,771 |
| 8.15 | 1,742 | 1,762 | 1,767 |

**Appendix I:6**

# SKB Äspö HRL

**Hole No:** **DA3545G01**

**Date:** ??? **Time:** ???

**Measurements made by:** ???

| Depth (m) | Diam 1 0 degr | Diam 2 60 degr | Diam 3 120 degr |
|---|---|---|---|
| 0.00 | 1,755 | 1,757 | 1,756 |
| 0.40 | 1,760 | 1,762 | 1,756 |
| 0.80 | 1,760 | 1,762 | 1,756 |
| 1.20 | 1,760 | 1,757 | 1,756 |
| 1.60 | 1,760 | 1,757 | 1,756 |
| 2.00 | 1,755 | 1,761 | 1,756 |
| 2.40 | 1,765 | 1,751 | 1,761 |
| 2.80 | 1,765 | 1,767 | 1,756 |
| 3.20 | 1,765 | 1,747 | 1,756 |
| 3.60 | 1,765 | 1,767 | 1,756 |
| 4.00 | 1,765 | 1,757 | 1,756 |
| 4.40 | 1,770 | 1,763 | 1,761 |
| 4.80 | 1,765 | 1,757 | 1,762 |
| 5.20 | 1,765 | 1,757 | 1,756 |
| 5.60 | 1,765 | 1,762 | 1,756 |
| 6.00 | 1,760 | 1,757 | 1,751 |
| 6.40 | 1,765 | 1,752 | 1,756 |
| 6.80 | 1,765 | 1,757 | 1,751 |
| 7.20 | 1,770 | 1,761 | 1,756 |
| 7.60 | 1,770 | 1,761 | 1,756 |
| 8.00 | 1,765 | 1,757 | 1,752 |
| 8.15 | 1,765 | 1,757 | 1,751 |

# APPENDIX II

**Data of the installed blocks**

## Used Blocks in DA3587G01

| Block ID | Block No | w | Weight (kg) | Height (m) | Diam D1 (m) | Diam D2 (m) | Dim D3 (m) | Volume block (m3) | Bulk Density (kg(m3) | Dry Densiity (kg/m3) | Dry weight/m (kg/m) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| PRC8 | C1 | 0,182 | 2146 | 504,0 | 1651,7 | 1630,4 | | 1,0660 | 2013 | 1704 | 3603 |
| PRR15 | R1 | 0,175 | 1266 | 500,5 | 1644,1 | 1626,4 | 1070,8 | 0,6004 | 2109 | 1794 | 2153 |
| PRR12 | R2 | 0,174 | 1290 | 513,3 | 1645,4 | 1625,5 | 1068,8 | 0,6177 | 2088 | 1779 | 2141 |
| PRR19 | R3 | 0,172 | 1270 | 502,5 | 1646,9 | 1626,4 | 1066,7 | 0,6081 | 2088 | 1782 | 2157 |
| PRR11 | R4 | 0,168 | 1284 | 506,4 | 1646,9 | 1625,2 | 1069,9 | 0,6093 | 2107 | 1804 | 2170 |
| PRR6 | R5 | 0,174 | 1266 | 500,3 | 1646,6 | 1626,0 | 1069,3 | 0,6027 | 2101 | 1790 | 2156 |
| PRR16 | R6 | 0,175 | 1288 | 509,3 | 1645,0 | 1625,4 | 1067,6 | 0,6136 | 2099 | 1786 | 2152 |
| PRR17 | R7 | 0,173 | 1276 | 504,6 | 1645,9 | 1626,4 | 1070,2 | 0,6071 | 2102 | 1791 | 2155 |
| PRR18 | R8 | 0,173 | 1268 | 502,6 | 1645,5 | 1626,0 | 1070,0 | 0,6043 | 2098 | 1788 | 2150 |
| PRR9 | R9 | 0,173 | 1276 | 507,8 | 1645,5 | 1626,3 | 1070,8 | 0,6099 | 2092 | 1784 | 2143 |
| PRR5 | R10 | 0,172 | 1266 | 502,5 | 1649,2 | 1626,5 | 1069,5 | 0,6072 | 2085 | 1779 | 2149 |
| PRC4 | C2 | 0,178 | 2164 | 506,5 | 1651,5 | 1629,7 | | 1,0707 | 2021 | 1715 | 3626 |
| PRC6 | C3 | 0,179 | 2166 | 507,3 | 1652,0 | 1631,1 | | 1,0735 | 2018 | 1712 | 3622 |
| PRC2 | C4 | 0,173 | 2128 | 500,6 | 1651,2 | 1630,9 | | 1,0587 | 2010 | 1714 | 3624 |

Installed Pellets: 364 (dry weight /m)

**Appendix II:2**

## Used Blocks in DA3581G01

| Block ID | Block No | w | Weight (kg) | Height (m) | Diam D1 (m) | Diam D2 (m) | Dim D3 (m) | Volume block (m3) | Bulk Density (kg(m3) | Dry Densiity (kg/m3) | Dry weight/m (kg/m) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| PRC9 | C1 | 0,179 | 2154 | 501,9 | 1651,1 | 1630,4 | | 1,0610 | 2030 | 1722 | 3641 |
| CRTR3 | R1 | 0,169 | 1276 | 509,6 | 1645,6 | 1625,0 | 1069,0 | 0,6129 | 2082 | 1781 | 2142 |
| CRTR4 | R2 | 0,172 | 1278 | 507,1 | 1646,2 | 1626,0 | 1068,7 | 0,6113 | 2091 | 1784 | 2151 |
| CRTR5 | R3 | 0,171 | 1298 | 514,8 | 1648,4 | 1626,4 | 1070,0 | 0,6210 | 2090 | 1785 | 2153 |
| CRTR6 | R4 | 0,172 | 1274 | 508,0 | 1646,0 | 1625,5 | 1068,3 | 0,6122 | 2081 | 1776 | 2140 |
| CRTR9 | R5 | 0,174 | 1296 | 514,8 | 1647,1 | 1624,8 | 1067,5 | 0,6213 | 2086 | 1777 | 2144 |
| CRTR10 | R6 | 0,172 | 1290 | 512,3 | 1646,0 | 1628,4 | 1071,2 | 0,6167 | 2092 | 1785 | 2148 |
| CRTR18 | R7 | 0,172 | 1304 | 514,9 | 1646,1 | 1624,6 | 1069,4 | 0,6190 | 2107 | 1797 | 2160 |
| CRTR19 | R8 | 0,167 | 1284 | 508,2 | 1645,3 | 1625,9 | 1068,9 | 0,6117 | 2099 | 1798 | 2165 |
| CRTR21 | R9 | 0,172 | 1294 | 515,1 | 1649,9 | 1624,7 | 1068,5 | 0,6226 | 2078 | 1773 | 2143 |
| PRR1 | R10 | 0,174 | 1264 | 503,1 | 1647,5 | 1626,0 | 1069,3 | 0,6068 | 2083 | 1775 | 2140 |
| CRTC3 | C2 | 0,173 | 2116 | 501,0 | 1652,0 | 1631,8 | | 1,0607 | 1995 | 1701 | 3602 |
| CRTC5 | C3 | 0,177 | 2096 | 496,5 | 1652,2 | 1630,5 | | 1,0505 | 1995 | 1696 | 3588 |
| CRTC7 | C4 | 0,170 | 2122 | 504,3 | 1654,05 | 1632,25 | | 1,0693 | 1985 | 1696 | 3596 |

Installed Pellets: 374 (dry weight /m)

**Appendix II:3**

## Used Blocks in DA3575G01

| Block ID | Block No | w | Weight (kg) | Height (m) | Diam D1 (m) | Diam D2 (m) | Dim D3 (m) | Volume block (m3) | Bulk Density (kg(m3) | Dry Densiity (kg/m3) | Dry weight/m (kg/m) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| PRC1 | C1 | 0,174 | 2116 | 495,3 | 1648,3 | 1630,5 | | 1,0454 | 2024 | 1725 | 3641 |
| PRR8 | R1 | 0,175 | 1280 | 506,2 | 1644,7 | 1626,5 | 1068,9 | 0,6094 | 2101 | 1788 | 2152 |
| PRR7 | R2 | 0,172 | 1266 | 501,9 | 1643,8 | 1625,6 | 1069,7 | 0,6024 | 2102 | 1793 | 2152 |
| PRR22 | R3 | 0,168 | 1278 | 505,5 | 1646,3 | 1627,8 | 1070,5 | 0,6090 | 2099 | 1797 | 2165 |
| PRR21 | R4 | 0,174 | 1286 | 509,6 | 1648,5 | 1627,2 | 1070,0 | 0,6154 | 2090 | 1780 | 2150 |
| PRR2 | R5 | 0,170 | 1266 | 504,0 | 1647,0 | 1627,0 | 1069,1 | 0,6083 | 2081 | 1779 | 2147 |
| PRR27 | R6 | 0,172 | 1284 | 509,1 | 1647,9 | 1627,8 | 1069,7 | 0,6151 | 2087 | 1781 | 2152 |
| PRR20 | R7 | 0,167 | 1282 | 507,8 | 1647,3 | 1627,5 | 1070,9 | 0,6119 | 2095 | 1795 | 2163 |
| PRR14 | R8 | 0,174 | 1270 | 505,1 | 1647,0 | 1626,6 | 1069,9 | 0,6088 | 2086 | 1776 | 2141 |
| PRR29 | R9 | 0,170 | 1278 | 505,0 | 1647,0 | 1626,6 | 1069,9 | 0,6086 | 2100 | 1795 | 2163 |
| PRR4 | R10 | 0,176 | 1274 | 506,5 | 1645,4 | 1625,9 | 1069,3 | 0,6094 | 2090 | 1778 | 2139 |
| PRC10 | C2 | 0,180 | 2158 | 503,6 | 1650,2 | 1630,7 | | 1,0644 | 2027 | 1718 | 3632 |
| PRC3 | C3 | 0,174 | 2146 | 503,4 | 1651,0 | 1631,1 | | 1,0647 | 2016 | 1717 | 3631 |
| PRC5 | C4 | 0,175 | 2130 | 501,9 | 1650,3 | 1630,4 | | 1,0606 | 2008 | 1710 | 3613 |

Installed Pellets: 340 (dry weight /m)

**Appendix II:4**

## Used Blocks in DA3569G01

| Block ID | Block No | w | Weight (kg) | Height (m) | Diam D1 (m) | Diam D2 (m) | Dim D3 (m) | Volume block (m3) | Bulk Density (kg(m3) | Dry Densiity (kg/m3) | Dry weight/m (kg/m) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| PRC7 | C1 | 0,179 | 2144 | 502,1 | 1649,2 | 1630,3 | | 1,0602 | 2022 | 1715 | 3621 |
| CRTR22 | R1 | 0,168 | 1276 | 508,6 | 1648,4 | 1627,9 | 1070,5 | 0,6142 | 2078 | 1778 | 2147 |
| PRR32 | R2 | 0,168 | 1284 | 507,8 | 1648,2 | 1628,0 | 1070,2 | 0,6133 | 2093 | 1793 | 2166 |
| PRR24 | R3 | 0,168 | 1292 | 511,1 | 1646,8 | 1628,2 | 1070,1 | 0,6167 | 2095 | 1793 | 2164 |
| PRR28 | R4 | 0,168 | 1284 | 506,8 | 1646,8 | 1627,9 | 1070,1 | 0,6112 | 2101 | 1799 | 2170 |
| PRR23 | R5 | 0,170 | 1290 | 510,8 | 1648,5 | 1626,5 | 1069,5 | 0,6167 | 2092 | 1788 | 2158 |
| PRR10 | R6 | 0,163 | 1266 | 500,4 | 1648,5 | 1627,7 | 1069,4 | 0,6051 | 2092 | 1798 | 2175 |
| PRR30 | R7 | 0,169 | 1292 | 510,9 | 1648,2 | 1627,5 | 1070,8 | 0,6163 | 2096 | 1793 | 2163 |
| PRR25 | R8 | 0,171 | 1284 | 508,5 | 1647,8 | 1627,4 | 1070,3 | 0,6135 | 2093 | 1788 | 2157 |
| PRR26 | R9 | 0,166 | 1284 | 506,4 | 1648,6 | 1628,2 | 1070,6 | 0,6117 | 2099 | 1801 | 2176 |
| PRR3 | R10 | 0,169 | 1264 | 499,5 | 1645,4 | 1626,1 | 1068,6 | 0,6017 | 2101 | 1797 | 2164 |
| CRTC8 | C2 | 0,171 | 2110 | 503,8 | 1652,2 | 1631,6 | | 1,0665 | 1978 | 1690 | 3577 |
| PRC13 | C3 | 0,181 | 2140 | 500,5 | 1650,0 | 1630,9 | | 1,0578 | 2023 | 1712 | 3619 |
| PRC12 | C4 | 0,178 | 2174 | 503,8 | 1650,4 | 1630,9 | | 1,0650 | 2041 | 1734 | 3665 |

Installed Pellets: 361 (dry weight /m)

**Appendix II.5**

## Used Blocks in DA3551G01

| Block ID | Block No | w | Weight (kg) | Height (m) | Diam D1 (m) | Diam D2 (m) | Dim D3 (m) | Volume block (kg(m3) | Bulk Density (kg/m3) | Dry Densiity (kg/m) | Dry weight/m (kg/m) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| PRC19 | 5-C1 | 0,172 | 2102 | 500,0 | 1650,1 | 1631,2 | | 1,0570 | 1989 | 1696 | 3586 |
| PRR50 | 5-R1 | 0,170 | 1248 | 504,5 | 1646,5 | 1627,0 | 1069,8 | 0,6080 | 2053 | 1754 | 2114 |
| PRR37 | 5-R2 | 0,174 | 1266 | 511,0 | 1645,8 | 1626,1 | 1070,2 | 0,6144 | 2060 | 1755 | 2111 |
| PRR43 | 5-R3 | 0,174 | 1256 | 512,0 | 1647,0 | 1626,9 | 1067,5 | 0,6193 | 2028 | 1728 | 2090 |
| PRR13 | 5-R4 | 0,173 | 1274 | 505,8 | 1645,4 | 1625,8 | 1070,7 | 0,6073 | 2098 | 1789 | 2148 |
| PRR41 | 5-R5 | 0,174 | 1258 | 508,6 | 1645,2 | 1625,8 | 1069,7 | 0,6114 | 2057 | 1753 | 2107 |
| PRR35 | 5-R6 | 0,176 | 1260 | 508,5 | 1646,2 | 1626,6 | 1070,2 | 0,6120 | 2059 | 1751 | 2108 |
| PRR40 | 5-R7 | 0,169 | 1278 | 516,5 | 1646,4 | 1626,6 | 1069,1 | 0,6227 | 2052 | 1755 | 2116 |
| PRR39 | 5-R8 | 0,172 | 1280 | 514,3 | 1646,1 | 1626,6 | 1069,8 | 0,6192 | 2067 | 1764 | 2124 |
| PRR47 | 5-R9 | 0,171 | 1262 | 510,0 | 1645,8 | 1627,0 | 1070,5 | 0,6136 | 2057 | 1756 | 2113 |
| PRR49 | 5-R10 | 0,171 | 1256 | 508,8 | 1646,8 | 1628,0 | 1071,4 | 0,6126 | 2050 | 1751 | 2108 |
| PRC11 | 5-C2 | 0,177 | 2148 | 501,4 | 1652,2 | 1631,0 | | 1,0611 | 2024 | 1720 | 3640 |
| PRC22 | 5-C3 | 0,173 | 2120 | 502,3 | 1652,4 | 1631,2 | | 1,0633 | 1994 | 1700 | 3598 |
| PRC20 | 5-C4 | 0,173 | 2110 | 501,3 | 1650,9 | 1630,4 | | 1,0596 | 1991 | 1697 | 3588 |

Installed Pellets: 373 (dry weight /m)

**Appendix II:6**

## Used Blocks in DA3545G01

| Block ID | Block No | w | Weight (kg) | Height (m) | Diam D1 (m) | Diam D2 (m) | Dim D3 (m) | Volume block (kg(m3) | Bulk Density (kg/m3) | Dry Densiity (kg/m) | Dry weight/m (kg/m) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| PRC18 | 6-C1 | 0,173 | 2128 | 507,0 | 1650,9 | 1630,5 | | 1,0718 | 1985 | 1693 | 3579 |
| PRR33 | 6-R1 | 0,172 | 1264 | 510,8 | 1648,4 | 1625,6 | 1068,9 | 0,6166 | 2050 | 1748 | 2111 |
| PRR44 | 6-R2 | 0,172 | 1276 | 514,5 | 1646,6 | 1626,2 | 1069,5 | 0,6198 | 2059 | 1756 | 2116 |
| PRR56 | 6-R3 | 0,175 | 1260 | 503,8 | 1647,0 | 1626,9 | 1070,3 | 0,6069 | 2076 | 1767 | 2129 |
| PRR55 | 6-R4 | 0,178 | 1250 | 499,5 | 1648,1 | 1626,2 | 1071,3 | 0,6012 | 2079 | 1765 | 2124 |
| PRR36 | 6-R5 | 0,175 | 1258 | 510,0 | 1646,4 | 1627,7 | 1070,9 | 0,6141 | 2048 | 1744 | 2100 |
| PRR46 | 6-R6 | 0,172 | 1256 | 506,8 | 1644,3 | 1626,2 | 1070,9 | 0,6078 | 2066 | 1762 | 2114 |
| PRR34 | 6-R7 | 0,171 | 1264 | 512,3 | 1646,1 | 1625,8 | 1070,3 | 0,6159 | 2052 | 1752 | 2107 |
| PRR38 | 6-R8 | 0,173 | 1272 | 510,8 | 1645,6 | 1625,6 | 1070,4 | 0,6135 | 2073 | 1767 | 2123 |
| PRR45 | 6-R9 | 0,172 | 1270 | 509,3 | 1647,3 | 1626,7 | 1070,0 | 0,6139 | 2069 | 1765 | 2128 |
| PRR48 | 6-R10 | 0,171 | 1274 | 514,3 | 1647,5 | 1626,8 | 1070,5 | 0,6197 | 2056 | 1755 | 2115 |
| PRC14 | 6-C2 | 0,180 | 2150 | 503,5 | 1651,0 | 1630,3 | | 1,0644 | 2020 | 1711 | 3618 |
| PRC15 | 6-C3 | 0,170 | 2110 | 501,3 | 1651,3 | 1631,3 | | 1,0605 | 1990 | 1700 | 3597 |
| PRC16 | 6-C4 | 0,174 | 2136 | 506,5 | 1650,5 | 1631,1 | | 1,0710 | 1994 | 1699 | 3593 |

Installed Pellets: 357 (dry weight /m)