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Correlation between Measurements and Monte-Carlo Calculations for the NNTE Logging-Tool

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Abstract

A correlation between Monte-Carlo simulations of the NNTE geophysical neutron logging-tool response and measurements made on the rock blocks at the calibration facility in Zielona Góra (Poland) has been examined. The NNTE tool is a recent achievement of Polish geophysicists. It is equipped with a neutron source and three detectors. The tool is designed to measure the thermal neutron absorption cross-section of geological formations *in situ*. The computer modelling is intended to complete the calibration measurements with simulated experiments in complicated borehole situations. A good correspondence between the simulated and real experiments is obvious demand. The simulations have been performed using the MCNP4C computer code. In the first approach elemental compositions of block rock matrices have been taken directly from the results of a chemical analysis. In the second approach boron B-10 has been added to the elemental compositions of rocks to compensate the difference between their absorption cross-section calculated from the elemental compositions and those known from the laboratory measurements. The very good agreement has been obtained between results of calculations and measurements. The high correlation creates the basis for further research on the influence of absorption cross-section of geological formation on the NNTE tool response.

Introduction

NNTE (Neutron – Neutron Thermal – Epithermal) logging-tool has been designed to estimate the thermal neutron absorption cross-section (Σ_a) of geological formation. It is equipped with an Am-Be source of fast neutrons, two "near" detectors and one "far" detector. One of the "near" detectors is

designed to measure thermal neutrons and is shielded from the influence of the borehole. The other "near" detector and the "far" detector are epithermal neutron detectors.

Count rates from the "near" thermal detector are used to create the neutron porosity curve. Another porosity curve is created from count rates of the "near" epithermal detector. By comparing these two porosity curves, one gets information about the neutron absorption cross-section of a formation [1].

In order to get quantitative information about Σ_a, it is essential to calibrate the logging-tool. The varying parameter would be the neutron absorption cross-section of the calibration blocks. It is rather difficult and expensive to construct several calibrating blocks and perform the empirical calibration. An alternative solution to the problem is to perform the theoretical calibration using Monte-Carlo (MC) methods. Changing the neutron and physical parameters of blocks in this method is simple and not time consuming. It is also possible to calculate the logging-tool response for any calibrating block one can think of. The first step is to model the geometry of the setup (consisting of logging-tool and its surrounding), the second one is to find correlation between measurements and calculations (for this aim, it is necessary to have several measurements on calibration blocks). This correlation is the basis for further calculations. And thirdly one can calculate tool response for purely theoretical cases (in this case, for blocks with varying Σ_a's).

Modelling of the geometry

In the following, the modelling of the geometry and calculations were performed using MCNP4C code [2].

In some cases exact geometry modelling is not important (e.g. in optimization problems), but if we want to compare results of the calculations with measurements, the geometry modelling is essential. Therefore in the presented problem the tool was modelled with great care (especially source, detectors and shieldings). Fig. 1 shows the geometry of the NNTE problem: logging-tool, block, surrounding water and concrete below the block. The dimensions used in the calculation are as follows:

- thickness of concrete layer below the block: 1 m,
- amount of water above the block: 1.5 m,
- radius of water surrounding the block: 1.7 m.

The logging-tool was placed inside the block in such way, that the source was in the middle of the block height. The tool was decentralised in hole.

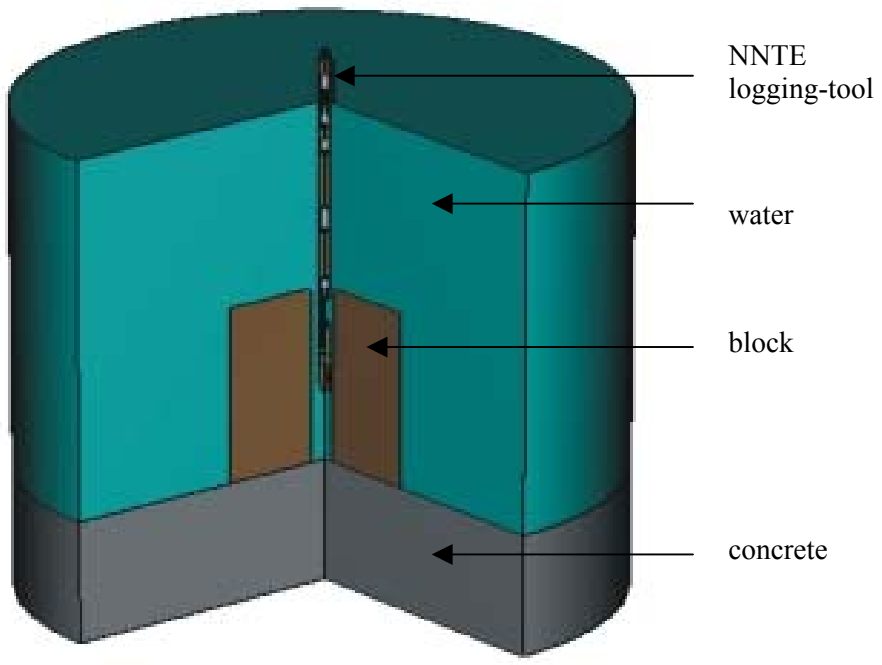


Fig.1. Cross section of the setup.

Modelling of the source

The NNTE logging-tool is equipped with an Americium 241-Beryllium neutron source. The energy spectrum of the source used in the calculations is presented in Fig.2. This is the spectrum according to ISO 8529 standard [3] (see Appendix A).

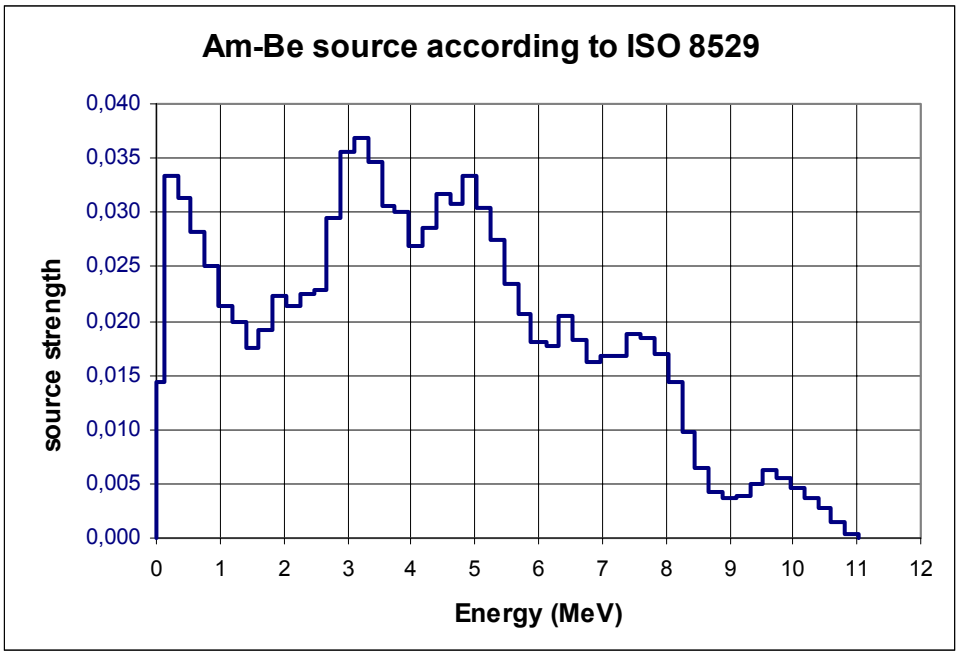


Fig.2. Am-Be source spectrum according to ISO 8529 standard [3].

Correlation between measurements and calculations.

The correlation between measurements and calculations is carried out for several blocks from the calibration facility in Zielona Góra for which dimensions, elemental composition, porosity, density and neutron parameters are well known [4]. Calibration measurements were performed in Zielona Góra in 2001 and 2002 by Dr Tomasz Zorski and employees from Geofizyka Kraków Sp. z o.o.. We have obtained the results of those measurements by courtesy of Geofizyka Kraków Sp. z o.o.

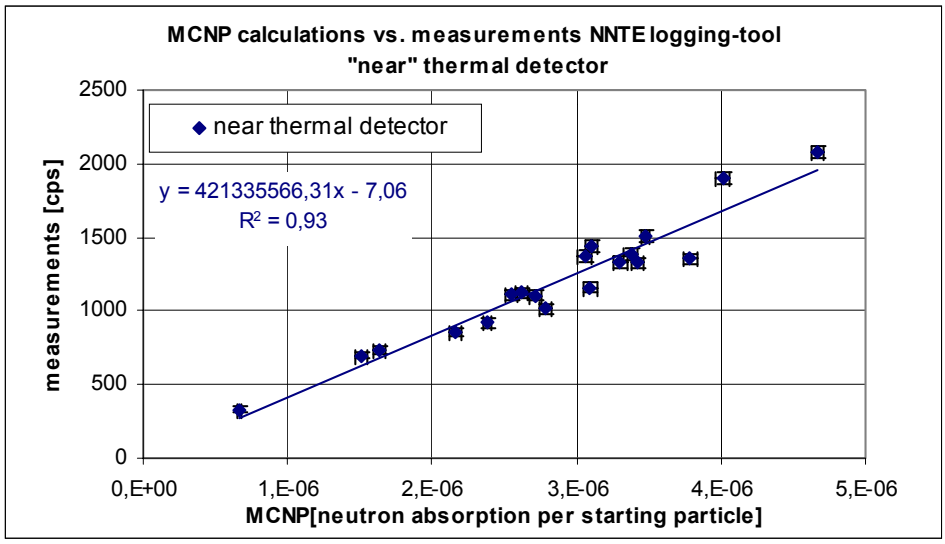
As a result of each numerical calculation we derived the number of (n,α) reactions in the given detector volume for one source neutron. All calculations were done for 15000000 histories of neutrons, except for the Biała Marianna blocks where it was 30000000 histories. The number of histories have been estimated according to the accuracy assumed less than 3 % for the near thermal detector.

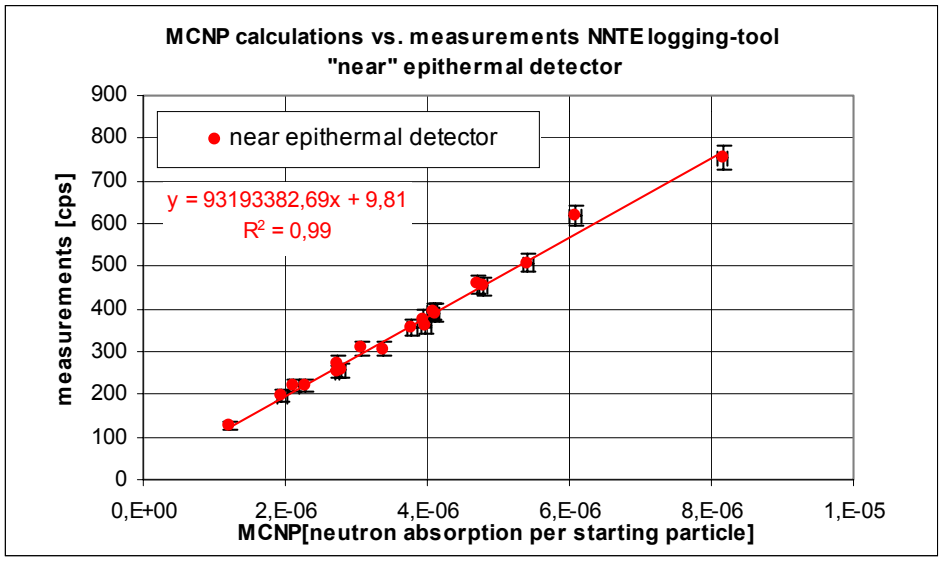
In the first approach, the calculations were performed for blocks with elemental composition taken directly from the results of a chemical analysis ([5] – except for Pińczów 220 where the rock matrix elemental composition was assumed to be the same as for Pińczów 145). Fig. 3 presents the correlation curves for such a case; the x-axis showing the calculation results, and the y-axis – measurement results. Errors of the measurements are the square root of the count rates. Errors of the calculations are the relative errors of the calculated means.

Several points in this picture are not lined exactly along the correlation curve. The reason for this fact seems to be the difference between the Σ_a's of the rock matrices used for calculations and the

real Σ_a's. The differences of Σ_a's are specially significant for sandstone blocks of Mucharz and Brenna (Table 1). The Σ_a's obtained from laboratory measurements (made on samples taken from blocks) are always higher values than that obtained from the elemental analysis. It seems that some of strong neutron absorbers (like boron and/or Rare Earth Elements) have been omitted in the analysis. The experimental results seems to be more reliable. The direct application of the experimental data of macroscopic parameters (like Σ_a) is impossible for the MCNP calculations. The input data for the given material have to be done as its elemental composition. The following trick has been used: the lack in the absorption cross section calculated from the elemental composition has been compensated by adding the adequate amount of boron to the elemental composition of the block rock matrix. The amount of boron has been calculated to obtain the same Σ_a from the elemental composition and from the measurement. In the Table 1, we have:

- Σ_a's calculated from the elemental compositions of the block rock matrices (using the SIGSA computer programme [6, 7], and these are the Σ_a's used in the first approach of our calculations;
- Σ_a's experimentally known from measurement using the neutron generator;
- the amounts of B-10 added to the chemical compositions of the block rock matrices, and
- Σ_a's of the block rock matrices with B-10 added.





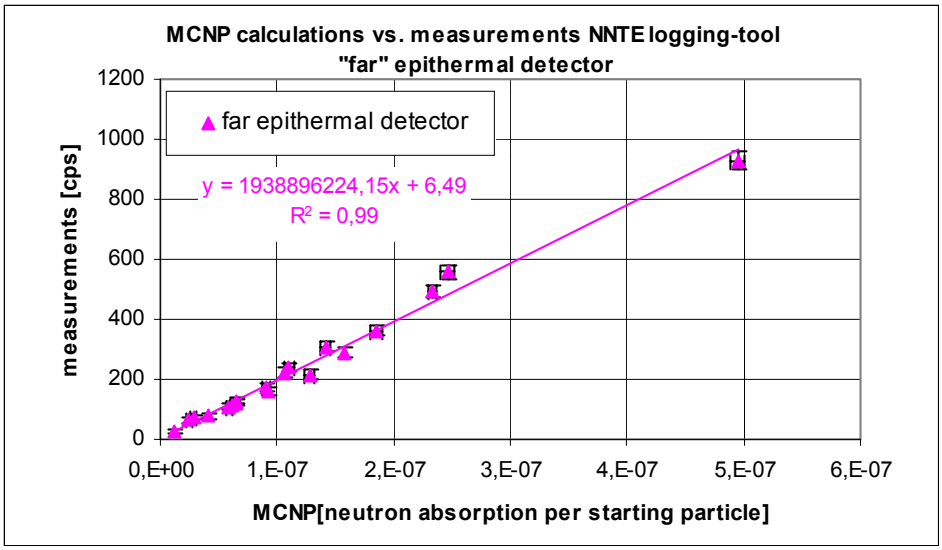


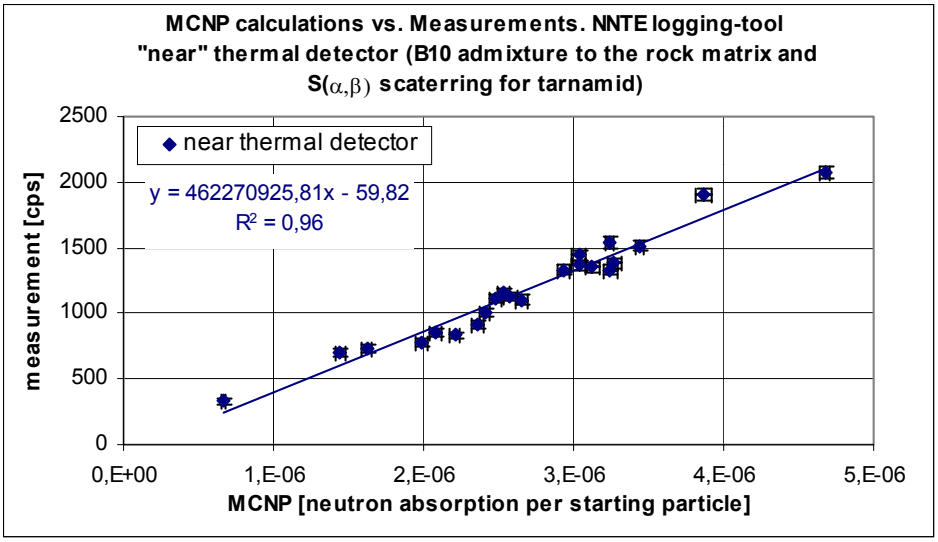
Fig.3. Correlation between calculations and measurements for each detector (first approach).

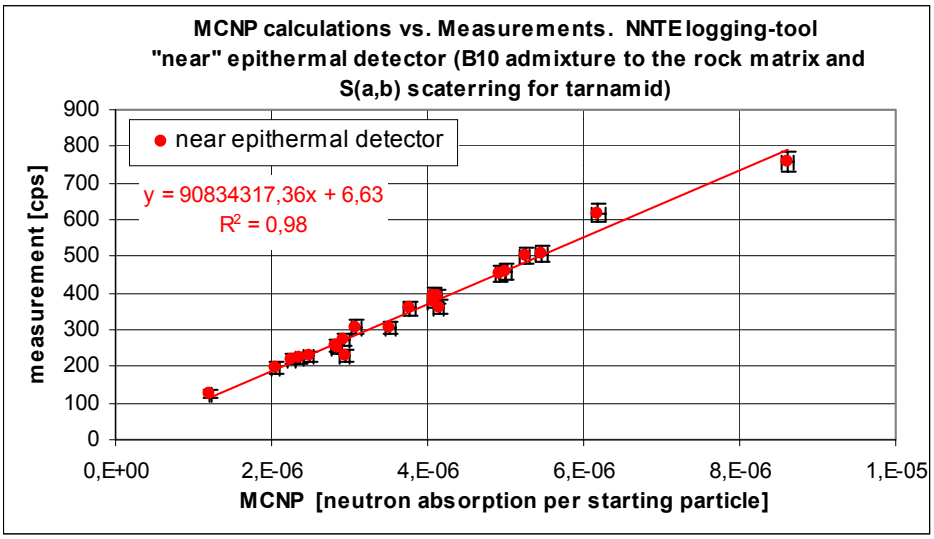
Table.1. Measured and calculated Σ_a's for calibration block rock matrices. Σ_a is given for neutron speed v = 2200 m/s. Calculation of the B-10 amount is made on the assumption that B-10 content in B-nat is 19.9%.

Block name borehole diameter mm	**Σ_a calculated from chemical analysis c.u.**	**Σ_a from experiment c.u.**	**Σ_a after adding B-10 c.u.**	**Amount of B-nat. wgt. %**	**Amount of B-10 wgt. %**
Biała Marianna 141	7.08	7.92	7.89	0.0007	0.000139
Biała Marianna 220	7.19	7.83	7.76	0.0005	0.000100
Morawica 141	7.34	8.66	8.71	0.0012	0.000239
Morawica 220	7.29	8.53	8.55	0.0011	0.000219
Józefów 143	7.34	8.17	8.15	0.0007	0.000139
Józefów 216	7.34	8.06	8.03	0.0006	0.000119
Pińczów 145	7.20	7.96	8.01	0.0007	0.000139
Pińczów 220	7.14	8.13	8.17	0.0009	0.000179
Libiąż 145	5.03	6.02	6.00	0.0008	0.000159
Libiąż 216	5.03	5.92	5.88	0.0007	0.000139
Mucharz 143	8.57	17.48	17.43	0.0078	0.001552
Mucharz 220	8.51	16.54	16.49	0.0069	0.001373
Brenna 140	9.20	16.58	16.56	0.0065	0.001294
Brenna 215	9.17	15.57	15.57	0.0057	0.001124
Radków 143	6.26	6.92	6.93	0.0006	0.000119
Radków 216	6.44	7.13	7.11	0.0006	0.000119
Żerkowice 135	5.03	6.40	6.38	0.0012	0.000239
Żerkowice 220	5.08	6.40	6.43	0.0012	0.000239

In the second approach, all the MCNP calculations were repeated once again for blocks with the admixture of B-10 (see Appendix B for elemental composition of the blocks with an admixture of B-10) and with the special correction which is needed when hydrogenous materials are present in the structure of the modelled logging tool. The so-called S(α,β) thermal scattering treatment [2] for tarnamid (several parts of the NNTE logging tool are made of this material) has to be applied to the proper simulation of the thermal neutron transport process. The resulting correlation curves are presented in Fig. 4. The correlation coefficient for the "near" thermal detector is better than in the first approach. The greatest influence of admixture of B-10 on the "near" thermal detector tool response is observed for the blocks Mucharz and Brenna. This effect was earlier noticed during calculations performed for the PKNN-3 (thermal neutron) logging-tool [8]. For the blocks Mucharz and Brenna the difference in measured and calculated Σ_a of the block rock matrix is significant (Table 3).

Despite these facts not all points are lined exactly along the correlation curve. This is caused by uncertainties in elemental composition of the blocks, their porosity or density. On the other hand the worse correlation for the thermal detector in comparison to the epithermal detectors can be caused by narrow collimation slot influencing the repeatibility of measurements in rock blocks.





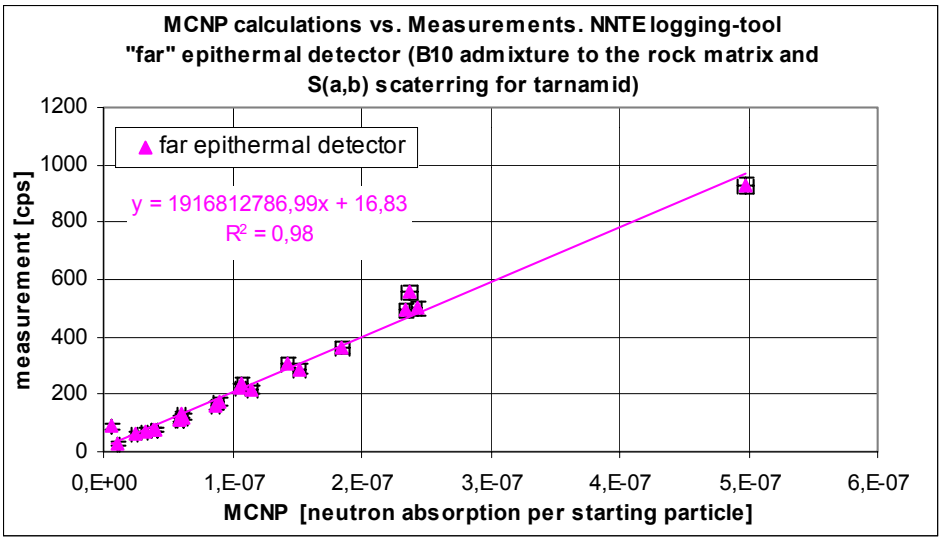


Fig.4. Correlation between calculations and measurements for each detector. Rock matrix of the blocks with admixture of B-10 and S(α,β) thermal scattering treatment for tarnamid (second approach).

Conclusion

In spite of the the incomplete knowledge of the elemental composition of the calibration blocks applied both in the measurements and in the MC simulations the very good agreement has been obtained. This means that the calculation procedure has been correctly prepared and executed. The correlation curve (measurement – simulation) of the NNTE logging-tool is the basis for further calculations of the influence of Σ_a on the response of each detector of the tool. It is also a good starting point for an analysis of other parameters, such as the vertical resolution or the penetration range of the tool. The influence of the flush zone can be also examined. We have then a valuable solution for a complete testing of the new geophysical tool characteristics and parameters.

Acknowledgment

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Project No 8 T12B 046 21 (2001 – 2004).

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Appendix A

Am-Be source N0.1617 in vacuum. ISO 8529 standard [3]. Total source strength B=1/sec.
The values of group source strength correspond to the upper limit of the particular energy interval.

E(MeV)	delta B (1/sec)	E(MeV)	delta B (1/sec)	E(MeV)	delta B (1/sec)
4.14E-07	0.00E+00	3.75	3.07E-02	7.61	1.88E-02
0.11	1.44E-02	3.97	3.00E-02	7.82	1.84E-02
0.33	3.34E-02	4.18	2.69E-02	8.03	1.69E-02
0.54	3.13E-02	4.39	2.86E-02	8.25	1.44E-02
0.75	2.81E-02	4.61	3.18E-02	8.46	9.68E-03
0.97	2.50E-02	4.82	3.07E-02	8.68	6.52E-03
1.18	2.14E-02	5.04	3.33E-02	8.89	4.26E-03
1.40	1.98E-02	5.25	3.04E-02	9.11	3.67E-03
1.61	1.75E-02	5.47	2.74E-02	9.32	3.81E-03
1.82	1.93E-02	5.68	2.33E-02	9.53	5.06E-03
2.04	2.23E-02	5.89	2.06E-02	9.75	6.25E-03
2.25	2.15E-02	6.11	1.82E-02	9.96	5.52E-03
2.47	2.25E-02	6.32	1.77E-02	10.18	4.68E-03
2.68	2.28E-02	6.54	2.04E-02	10.39	3.70E-03
2.90	2.95E-02	6.75	1.83E-02	10.60	2.78E-03
3.11	3.56E-02	6.96	1.63E-02	10.82	1.51E-03
3.32	3.69E-02	7.18	1.68E-02	11.03	3.63E-04
3.54	3.46E-02	7.39	1.68E-02	11.09	0.00E+00

Appendix B

Elemental composition (weight content) of the calibrating blocks from Zielona Góra (including water in rock pores). Rock pores 100% saturated with fresh water. Rock matrices elemental compositions according to Zorski *et al.* [5] except for Pińczów 220 where rock matrix composition was assumed to be the same as for Pińczów 145.

LIMESTONES AND DOLOMITES

Block name borehole diameter, mm	Biała Marianna 141	Biała Marianna 220	Morawica 141	Morawica 220	Józefów 143	Józefów 216	Pińczów 145	Pińczów 220	Libiąż 145	Libiąż 216
Rock matrix density g/ccm	2.712	2.713	2.677	2.674	2.691	2.686	2.716	2.694	2.823	2.824
Bulk density g/ccm	2.710	2.711	2.627	2.631	2.502	2.454	2.084	2.103	2.620	2.587
porosity %	0.10	0.12	2.99	2.57	11.19	13.77	36.82	34.89	11.11	13.00
Si	0.0130227	0.0129928	0.0112295	0.0112478	0.0069659	0.0068829	0.0043874	0.0044447	0.0025514	0.0025305
Al	-	-	-	-	-	-	-	-	-	-
Fe	0.0007459	0.0007436	0.0012295	0.0012315	0.0008168	0.0008071	0.0006400	0.0006483	0.0011910	0.0011812
Mn	0.0002162	0.0002154	0.0002291	0.0002295	0.0002952	0.0002917	0.0000636	0.0000644	0.0001480	0.0001467
Mg	0.0084575	0.0084406	0.0031597	0.0031649	0.0044933	0.0044397	0.0034755	0.0035209	0.1223657	0.1213617
Ca	0.3762717	0.3754798	0.3789649	0.3799066	0.3673098	0.3628637	0.3198742	0.3241125	0.2102465	0.2085217
Na	0.0001038	0.0001038	-	-	0.0002835	0.0002801	0.0002443	0.0002475	0.0002842	0.0002818
K	0.0005145	0.0005128	-	-	0.0000793	0.0000784	0.0001367	0.0001385	0.0000795	0.0000788
H	0.0001509	0.0003851	0.0018988	0.0016349	0.0055396	0.0068287	0.0199717	0.0187614	0.0050550	0.0059316
C	0.1168890	0.1166471	0.1150750	0.1153451	0.1125232	0.1111560	0.0975439	0.0988182	0.1228336	0.1218258
B-10	0.0000014	0.0000010	0.0000024	0.0000022	0.0000013	0.0000011	0.0000011	0.0000015	0.0000015	0.0000013
O	0.4836263	0.4844780	0.4882111	0.4872375	0.5016921	0.5063707	0.5536616	0.5492420	0.5352437	0.5381387

SANDSTONES

Block name borehole diameter, mm	Mucharz 143	Mucharz 220	Brenna 140	Brenna 215	Radków 143	Radków 216	Żerkowice 135	Żerkowice 220
Rock matrix density g/ccm	2.670	2.710	2.649	2.651	2.620	2.620	2.643	2.645
Bulk density g/ccm	2.632	2.667	2.535	2.533	2.397	2.383	2.241	2.242
porosity %	2.30	2.54	6.91	7.14	13.74	14.63	24.47	24.47
Si	0.2814803	0.2812581	0.3487020	0.3483698	0.4008143	0.3990789	0.4024889	0.4025222
Al	0.0548757	0.0548323	0.0459738	0.0459299	0.0211042	0.0210129	0.0066004	0.0066010
Fe	0.0120201	0.0120105	0.0167103	0.0166944	0.0024181	0.0024076	0.0018696	0.0018697
Mn	0.0003829	0.0003826	0.0001503	0.0001502	0.0000728	0.0000725	-	-
Mg	0.0227151	0.0226971	0.0059246	0.0059190	0.0010801	0.0010754	0.0001074	0.0001074
Ca	0.0613522	0.0613035	0.0193271	0.0193087	0.0022233	0.0022137	0.0018463	0.0018465
Na	0.0137515	0.0137406	0.0173193	0.0173027	0.0009791	0.0009748	0.0001983	0.0001983
K	0.0134134	0.0134027	0.0215611	0.0215405	0.0139300	0.0138697	0.0001479	0.0001479
H	0.0030634	0.0027949	0.0045850	0.0046113	0.0069829	0.0077522	0.0127672	0.0128388
C	0.0252678	0.0261128	0.0049910	0.0051719	0.0038334	0.0030483	0.0018477	0.0016533
B-10	0.0000154	0.0000136	0.0000126	0.0000109	0.0000011	0.0000011	0.0000021	0.0000021
O	0.5116623	0.5114511	0.5147429	0.5149907	0.5465606	0.5484927	0.5721241	0.5722128