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**Institute of Nuclear Technology**

**Investigation on the absorbing features of the samples**

**made of concrete**

Final report

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# 1. Introduction

There are several tests available to evaluate the building units and local concretes to be applied for permanent and final storage of the nuclear wastes. The tests to determine the physical features and the chemical compositions are supposed to represent two different types varying by time: the static tests determining the conditions at a given time or the dynamic tests determining the change of the features of the related material. This report covers the test of the *absorption of the ionizing gamma radiation* of the samples made of concrete, that is the application of a static test. The dynamic test to determine the rate of the resistance to the radiation applied by the field of radiation protection can be proposed for the future test together with some physical and chemical tests depending on the volume of the doze absorbed by the sample to determine rate of the change of solidity, the porosity or the ability of being washed out in relation to different artificial and environmental materials, especially the water solutions.

# 2. APPLIED EQUIPMENTS AND PROCEDURES

The test to determine the ability of the resistance to the gamma radiation means the determination of the *linear absorption coefficient* of the absorbent or in other word used by the radiation protection or the physics of radiation, the determination of the macroscopic *absorptive efficiency cross-section* per unit volume.

In case of the photon radiation falling perpendicularly onto the surface of the absorbent, the flow of the particles passing without any weakening (intensity) or the absorbed doze generated in the measuring equipment by the intensity under the simplest conditions determined below is represented by the exponential of the layer thickness of the absorbent.

 [1]

 [2]

Where I0 and  represent the intensity [cps] that can be registered without the application of the absorbent or the dose rate [µSv/h]; µ is the absorption coefficient [m-1], that is [m2/m3], and x represents the layer thickness of the absorbent placed perpendicularly to the direction of the radiation. The validity of the [1] – [2] equations is limited, and the measured intensity, as well as the dose rate and that’s why the volume calculated by the equations is supposed to be probabilistic and stochastic.

As for the validity, it’s worth being considered without the detailed derivation of the equation that not just complete absorption but some rigid dispersion providing the decrease of energy and the change of direction can be detected during the weakening. Its intensity and dose rate can be negligible (that is, the increase of the dose rate is less than 5%), if the layer is appropriately thick, which requirement (µ×x) < 2 can be met by any absorbent practically if the tested range of energy is between 0.6 MeV and 1.3 MeV *[BENNET 04]*. We can see later that this requirement was met during our tests. In this ideal case the absorption coefficient can be transformed into the *layer-thickness of halving* applied in the practice with the following simple equation:

 [3]

We have already mentioned that the test of the absorption of the gamma radiation resulted by the radioactive decay is of stochastic nature for several reasons. It’s clear without going into details of the particle physics that the energy exchange between the photon radiation and the electrons of the medium is random. The next consideration is the inherent random nature of the source of radiation, the radioactive decay. The uncertainty featuring several phases of the process of detection, as well as the microscopic and macroscopic unhomogeneity of the material of the absorbent are not supposed to be inherent features but both of them are unavoidable increasing the nature of probability of the process.

The [1] – [3] absorption equations can be applied for the materials built up from similar atoms directly under the conditions determined above. In case of materials with clear chemical compound the resultant “effective” absorptive effective cross-section on the basis of the principles of the probability determined above makes the weighted sum of the elemental effective cross-sections of the components:

 [4]

The "i" index of the equation [4] represents the given compound or the quality of the components of the mixture, the wi represents the “atomic fragment” or the “probability of hit” of the ith element, that is the relation of the number of the atoms in the element to the total number of the atoms in the material. This parameter is supposed to be valid for the materials to be tested if the value of the wi atomic fraction is valid for the whole volume of the material, that is, the occurrence of a given type of atom in a smaller (but not infinitesimal) part is the same as in the whole volume.

At last, but not least the application of the simple relations listed above is supposed to be applicable, if the kinetic energy of the particles leaving the source of radiation is homogeneous, because if this condition is met, the arriving photons with different energy are featured by different macroscopic effective cross-section. But in this case the equation [2] can be applied for each energy components separately and not for the total (summed) dose rate. The number of the monoenergic sources of radiation is not too many, and a source of real monoenergic feature (137Cs) within the range of energy between 0.05 MeV and 3 MeV accepted for the test of the absorption of the gamma radiation and a standard source (60Co) having approximately appropriate feature were applied.

The separate analysis of the factors of probability is not necessary for the evaluation of the samples of concrete, but it is supposed to be appropriate if the test of the absorption is completed at as many points of each sample as possible. We are going to have enough data to determine the selected parameter of classification, the absorptive coefficient or the reproducibility and the empirical dispersion of the layer-thickness of halving (equations [5a] and [5b]). The relative empirical dispersion (rsd) itself is supposed to be a classifying parameter, for it is clear that the sample of two materials with the same ability of absorption having better (smaller) reproducibility is evaluated to be more beneficial.

 [5a]

 [5b]

Where  represents the average of the “local” absorptive coefficients determined by all (n) stabbing points defined on the given sample. Of course, we can do the same if the layer-thickness of halving shall be applied to be a classifying parameter. 9 points of stabbing were defined on the bigger and 4 on the smaller samples. Their distribution was uniform. The distance between the source and the detector was 1 m and the unreduced dose rate of two sources of radiation formed into point source by shadowing and collimation was determined. Afterwards, the samples with know thickness were located - equally - 80 cm far from the source of radiation for the effect of the rate of the spread radiation cannot be eliminated but unified to provide minimised effect on the results. The following arrangement (Figure 1.) was applied to measure the reduced dose rate by each sample with 9 or 4 settings.



Source of radiation

Absorbent

Detector

1. Figure 1.

Test arrangement to measure the absorption of the samples

It can be seen in the figure that the measurement was completed by dose rate gauge of FH-40-G type having type test and valid calibration completed in Hungary by the Hungarian Authority of Commercial Permission. The equipment is facilitated with proportional counter and its detailed description can be found in the internet as well [THERMO 07]. It’s an important feature that the reading of the gauge represents the dose rate calculated by the integrated microprocessor on the basis of the direct results of the measurements (number of the response signals (counts) collected during a given but varying on the basis of the measurements period of time). The data processing algorithm completed by the converting program is able to follow the quick positive changes (jumps) and applies program fragments to damp the statistical effect of the decreasing or permanent level. The gauge and the samples were placed on a test bench providing a positioning of mm precision made by us.

# 3. Findings of the tests

The tests were completed between 13th July and 9th August 2007. applying 60Co and 137Cs sources of radiation by the equipments described above.

3.1. Absorption tests in the dose area of 60Co source of radiation

The energy of the two gamma lines with gamma frequency is 1.17 MeV and 1.33 MeV. These two energies being close to each other are considered to be a fictive gamma line featured by an average value of 1.25 MeV provided by the common frequency of the two gamma lines for it is accepted in measuring technology of the radiation protection. The activity of the source of radiation was 8.19 MBq at the time of tests and the dose rate of the unreduced and collimated radiation after the correction of the background in 1 m was 1.81 ± 0.02 µSv/h.

3.1.1. Reference tests

There were 9 points of stabbing distributed evenly on the surface of the reference sample defined.

*Test of reference sample X.I.*

|  |  |
| --- | --- |
| Dose area of 60Co | |
| Code of the sample: X.I. [etalon] | |
| Average layer-thickness: 10.2 cm | |
| Background dose rate: 99 ± 6 µSv/h | |
| Number of the test point | Dose rate [µSv/h] |
| 1 | 1.09 |
| 2 | 0.98 |
| 3 | 1.00 |
| 4 | 1.04 |
| 5 | 1.04 |
| 6 | 1.08 |
| 7 | 1.01 |
| 8 | 1.04 |
| 9 | 1.01 |
| **Average ± empirical dispersion (with the correction of the background)** | **0.933 ± 0.036** |

Chart 1/a.:

The findings of the test of X. I. reference sample with the application of 60Co source of radiation

The average rate of transmission measured by the test above (the ratio of the dose rate measured by the absorbent and the unreduced dose rate measured with the same arrangement of the source and the detector by equation [2] ), as well as its relative uncertainty calculated from the empirical dispersion can be seen in Chart 1/b.

|  |  |  |  |
| --- | --- | --- | --- |
| Code of the sample: | Thickness [cm] | Rate of transmission | Relative uncertainty [%] |
| X I. | 10.2 | 0.515 | 3.9 |

Chart 1/b.:

The rate of transmission of the X.I. reference sample with the application of 60Co source of radiation

The absorption coefficient µ [cm-1] can be calculated from the rate of transmission with the help of a bit modified equation [2], as well as the X1/2 layer-thickness of halving calculated with the equation [3] and the estimated σ dispersion of this later value calculated by applying the method of the approximate propagation of errors (analysis of variance) known from the uncertainty of the measuring given earlier. The findings of the tests can be seen in Chart 1/c.

|  |  |  |
| --- | --- | --- |
| **Code of the sample:** | **µ [cm-1]** | **X1/2 ± σ [cm]** |
| **X I.** | **0.0651** | **10.65 ± 0.63** |

Chart 1/c.:

The absorption coefficient and the layer-thickness of halving of the X.I. reference sample with the application of 60Co source of radiation

*Test of reference sample X. II.*

|  |  |
| --- | --- |
| Dose area of 60Co | |
| Code of the sample: X.II. [etalon] | |
| Average layer-thickness: 9.9 cm | |
| Background dose rate: 99 ± 6 µSv/h | |
| Number of the test point | Dose rate [µSv/h] |
| 1 | 0.87 |
| 2 | 0.80 |
| 3 | 0.73 |
| 4 | 0.96 |
| 5 | 0.93 |
| 6 | 0.94 |
| 7 | 0.90 |
| 8 | 0.88 |
| 9 | 0.87 |
| **Average ± empirical dispersion (with the correction of the background)** | **0.777 ± 0.072** |

Chart 2/a.:

The findings of the test of X. II. references sample with the application of 60Co source of radiation

The average rate of transmission found by the tests above, as well as its relative uncertainty calculated from the empirical dispersion can be seen in Chart 2/b. The absorption coefficient of the sample, as well as the layer-thickness of halving and the estimated dispersion can be seen in Chart 2/c.

|  |  |  |  |
| --- | --- | --- | --- |
| Code of the sample | Thickness [cm] | Rate of transmission | Relative uncertainty [%] |
| X. II. | 9.9 | 0.429 | 9.3 |

Chart 2/b.:

The rate of transmission of the X.II. reference sample with the application of 60Co source of radiation

|  |  |  |
| --- | --- | --- |
| **Code of the sample:** | **µ [cm-1]** | **X1/2 ± σ [cm]** |
| **X. II.** | **0.0855** | **8.11 ± 0.89** |

Chart 2/c.:

The absorption coefficient and the layer-thickness of halving of the X.II. reference sample with the application of 60Co source of radiation

3.1.2. Tests of “N1” samples

There were 4 points of stabbing distributed evenly on the surface of N1 samples for their smaller dimension defined.

|  |  |
| --- | --- |
| Dose area of 60Co | |
| Code of the sample: N1 - 1/1 | |
| Average layer-thickness: 7.3 cm | |
| Background dose rate: 99 ± 6 µSv/h | |
| Number of the test point | Dose rate [µSv/h] |
| 1 | 0.91 |
| 2 | 0.84 |
| 3 | 0.92 |
| 4 | 0.87 |
| **Average ± empirical dispersion (with the correction of the background)** | **0.786 ± 0.037** |

Chart 3/a.:

The findings of the test of N1 – 1/1 sample with the application of 60Co source of radiation

|  |  |
| --- | --- |
| Dose area of 60Co | |
| Code of the sample: N1 - 2/1 | |
| Average layer-thickness: 7.7 cm | |
| Background dose rate: 99 ± 6 µSv/h | |
| Number of the test point | Measured dose rate [µSv/h] |
| 1 | 0.94 |
| 2 | 0.93 |
| 3 | 0.869 |
| 4 | 0.83 |
| **Average ± empirical dispersion (with the correction of the background)** | **0.791 ± 0.054** |

Chart 3/b.:

The findings of the test of N1 – 2/1 sample with the application of 60Co source of radiation

|  |  |
| --- | --- |
| Dose area of 60Co | |
| Code of the sample: N1 - 3/1 | |
| Average layer-thickness: 7.6 cm | |
| Background dose rate: 99 ± 6 µSv/h | |
| Number of the test point | Measured dose rate [µSv/h] |
| 1 | 0.89 |
| 2 | 0.98 |
| 3 | 0.91 |
| 4 | 0.98 |
| **Average ± empirical dispersion (with the correction of the background)** | **0.841 ± 0.047** |

Chart 3/c.:

The findings of the test of N1 – 3/1 sample with the application of 60Co source of radiation

The average rate of transmission of three samples made in the similar way found by the tests above, as well as its relative uncertainty calculated from the empirical dispersion can be seen in Chart 3/d. The absorption coefficient of the samples, as well as the layer-thickness of halving and the estimated dispersion can be seen in Chart 3/e.

|  |  |  |  |
| --- | --- | --- | --- |
| Code of the sample | Thickness [cm] | Rate of transmission | Relative uncertainty [%] |
| N1 - 1/1 | 7.3 | 0.434 | 4.7 |
| N1 - 2/1 | 7.7 | 0.437 | 6.8 |
| N1 - 3/1 | 7.6 | 0.464 | 5.6 |

Chart 3/d.:

The rate of transmission of N1 samples with the application of 60Co source of radiation

|  |  |  |
| --- | --- | --- |
| Code of the sample | µ [cm-1] | X1/2 [cm] |
| N1 - 1/1 | 0.114 | 6.06 |
| N1 - 2/1 | 0.108 | 6.44 |
| N1 - 3/1 | 0.101 | 6.87 |
| **Average layer-thickness of halving and dispersion of N1 samples** | | **6.46 ± 0.41 [cm]** |

Chart 3/e.:

The absorption coefficient and the layer-thickness of halving of the N.I. samples with the application of 60Co source of radiation

3.1.3. Tests of “N2” samples

There were 9 points of stabbing distributed evenly on the surface of the N2 samples defined.

|  |  |
| --- | --- |
| Dose area of 60Co | |
| Code of the sample: N2 - ½ | |
| Average layer-thickness: 6.9 cm | |
| Background dose rate: 99 ± 6 µSv/h | |
| Number of the test point | Dose rate [µSv/h] |
| 1 | 1.02 |
| 2 | 1.01 |
| 3 | 1.03 |
| 4 | 1.04 |
| 5 | 1.02 |
| 6 | 1.04 |
| 7 | 0.98 |
| 8 | 1.00 |
| 9 | 1.02 |
| **Average ± empirical dispersion (with the correction of the background)** | **0.919 ± 0.019** |

Chart 4/a.:

The findings of the test of N2 – 1/2 sample with the application of 60Co source of radiation

|  |  |
| --- | --- |
| Dose area of 60Co | |
| Code of the sample: N2 - 2/2 | |
| Average layer-thickness: 6.7 cm | |
| Background dose rate: 99 ± 6 µSv/h | |
| Number of the test point | Measured dose rate [µSv/h] |
| 1 | 1.08 |
| 2 | 1.02 |
| 3 | 1.09 |
| 4 | 1.15 |
| 5 | 1.04 |
| 6 | 0.89 |
| 7 | 0.89 |
| 8 | 1.10 |
| 9 | 0.97 |
| **Average ± empirical dispersion (with the correction of the background)** | **0.927 ± 0.092** |

Chart 4/b.:

The findings of the test of N2 – 2/2 sample with the application of 60Co source of radiation

|  |  |
| --- | --- |
| Dose area of 60Co | |
| Code of the sample: N2 - 3/2 | |
| Average layer-thickness: 6.8 cm | |
| Background dose rate: 99 ± 6 µSv/h | |
| Number of the test point | Measured dose rate [µSv/h] |
| 1 | 0.95 |
| 2 | 0.85 |
| 3 | 1.04 |
| 4 | 1.01 |
| 5 | 1.06 |
| 6 | 1.14 |
| 7 | 1.01 |
| 8 | 1.1 |
| 9 | 1.06 |
| **Average ± empirical dispersion (with the correction of the background)** | **0.925 ± 0.085** |

Chart 4/c.:

The findings of the test of N2 – 3/2 sample with the application of 60Co source of radiation

The average rate of transmission of three samples made in the similar way found by the tests above, as well as its relative uncertainty calculated from the empirical dispersion can be seen in Chart 4/d. The absorption coefficient of the samples, as well as the layer-thickness of halving and the estimated dispersion can be seen in Chart 4/e.

|  |  |  |  |
| --- | --- | --- | --- |
| Code of the sample | Thickness [cm] | Rate of transmission | Relative uncertainty [%] |
| N2 - 1/1 | 6.9 | 0.507 | 2.1 |
| N2 - 2/2 | 6.7 | 0.512 | 9.9 |
| N2 - 3/2 | 6.8 | 0.482 | 5.5 |

Chart 4/d.:

The rate of transmission of N2 samples with the application of 60Co source of radiation

|  |  |  |
| --- | --- | --- |
| Code of the sample | µ [cm-1] | X1/2 [cm] |
| N2 - 1/2 | 0.0983 | 7.05 |
| N2 - 2/2 | 0.100 | 6.93 |
| N2 - 3/2 | 0.107 | 6.46 |
| **Average layer-thickness of halving and dispersion of N2 samples** | | **6.81 ± 0.31 [cm]** |

Chart 4/e.:

The absorption coefficient and the layer-thickness of halving of the N2. samples with the application of 60Co source of radiation

3.1.4. Tests of N/3 samples

These samples differ from the others (N1/3, N2/3, N3/3) a bit and all of them are called N/3 samples to make the identification easier. There were 9 points of stabbing distributed evenly on the surface of the N/3 samples defined.

|  |  |
| --- | --- |
| Dose area of 60Co | |
| Code of the sample: N 1/3 | |
| Average layer-thickness: 6.8 cm | |
| Background dose rate: 99 ± 6 µSv/h | |
| Number of the test point | Measured dose rate [µSv/h] |
| 1 | 0.94 |
| 2 | 1.01 |
| 3 | 0.96 |
| 4 | 1.00 |
| 5 | 0.97 |
| 6 | 0.98 |
| 7 | 0.88 |
| 8 | 0.91 |
| 9 | 0.90 |
| **Average ± empirical dispersion (with the correction of the background)** | **0.851 ± 0.046** |

Chart 5/a.:

The findings of the test of N 1/3 sample with the application of 60Co source of radiation

|  |  |
| --- | --- |
| Dose area of 60Co | |
| Code of the sample: N 2/3 | |
| Average layer-thickness: 6.6 cm | |
| Background dose rate: 99 ± 6 µSv/h | |
| Number of the test point | Measured dose rate [µSv/h] |
| 1 | 1.06 |
| 2 | 1.12 |
| 3 | 1.10 |
| 4 | 1.08 |
| 5 | 1.05 |
| 6 | 1.06 |
| 7 | 1.03 |
| 8 | 1.04 |
| 9 | 1.08 |
| **Average ± empirical dispersion (with the correction of the background)** | **0.970 ± 0.029** |

Chart 5/b.:

The findings of the test of N 2/3 sample with the application of 60Co source of radiation

|  |  |
| --- | --- |
| Dose area of 60Co | |
| Code of the sample: N 3/3 | |
| Average layer-thickness: 6.6 cm | |
| Background dose rate: 99 ± 6 µSv/h | |
| Number of the test point | Measured dose rate [µSv/h] |
| 1 | 1.01 |
| 2 | 1.08 |
| 3 | 1.13 |
| 4 | 1.02 |
| 5 | 1.03 |
| 6 | 1.04 |
| 7 | 1.10 |
| 8 | 0.96 |
| 9 | 0.92 |
| **Average ± empirical dispersion (with the correction of the background)** | **0.934 ± 0.071** |

Chart 5/c.:

The findings of the test of N 3/3 sample with the application of 60Co source of radiation

The average rate of transmission of three samples made in the similar way found by the tests above, as well as its relative uncertainty calculated from the empirical dispersion can be seen in Chart 5/d. The absorption coefficient of the samples, as well as the layer-thickness of halving and the estimated dispersion of the layer-thickness of halving can be seen in Chart 5/e.

|  |  |  |  |
| --- | --- | --- | --- |
| Code of the sample | Thickness [cm] | Rate of transmission | Relative uncertainty [%] |
| N 1/3 | 6.8 | 0.470 | 5.4 |
| N 2/3 | 6.6 | 0.534 | 3.0 |
| N 3/3 | 6.6 | 0.516 | 7.6 |

Chart 5/d.:

The rate of transmission of N/3 samples with the application of 60Co source of radiation

|  |  |  |
| --- | --- | --- |
| Code of the sample | µ [cm-1] | X1/2 [cm] |
| N 1/3 | 0.111 | 6.24 |
| N 2/3 | 0.0946 | 7.33 |
| N 3/3 | 0.100 | 6.91 |
| **Average layer-thickness of halving and dispersion of N/3 samples** | | **6.83 ± 0.55 [cm]** |

Chart 5/e.:

The absorption coefficient and the layer-thickness of halving of the N/3 samples with the application of 60Co source of radiation

3.2. Absorption tests in the dose area of 137Cs source of radiation

The gamma energy of 137Cs makes 0.66 MeV. The activity of the source of radiation was 526 MBq at the time of tests and the dose rate of the unreduced and collimated radiation after the correction of the background in 1 m was 34.0 ± 0.03 µSv/h.

3.2.1. Reference tests

*Test of reference sample X.I.*

|  |  |
| --- | --- |
| Dose area of 137Cs | |
| Code of the sample: X.I. [etalon] | |
| Average layer-thickness: 10.2 cm | |
| Background dose rate: 0.13 ± 0.01 µSv/h | |
| Number of the test point | Measured dose rate [µSv/h] |
| 1 | 9.50 |
| 2 | 10.4 |
| 3 | 10.4 |
| 4 | 10.1 |
| 5 | 9.6 |
| 6 | 10.6 |
| 7 | 9.6 |
| 8 | 9.5 |
| 9 | 10.3 |
| **Average ± empirical dispersion (with the correction of the background)** | **9.87 ± 0.45** |

Chart 6/a.:

The findings of the test of X. I. references sample with the application of 137Cs source of radiation

The average rate of transmission found by the tests above, as well as its relative uncertainty calculated from the empirical dispersion can be seen in Chart 6/b. The absorption coefficient of the sample, as well as the layer-thickness of halving and the estimated dispersion can be seen in Chart 6/c.

|  |  |  |  |
| --- | --- | --- | --- |
| Code of the sample: | Thickness [cm] | Rate of transmission | Relative uncertainty [%] |
| X I. | 10.2 | 0.291 | 4.6 |

Chart 6/b.:

The rate of transmission of the X.I. reference sample with the application of 137Cs source of radiation

|  |  |  |
| --- | --- | --- |
| **Code of the sample:** | **µ [cm-1]** | **X1/2 ± σ [cm]** |
| **X I.** | **0.121** | **5.73 ± 0.21** |

Chart 6/c.:

The absorption coefficient and the layer-thickness of halving of the X.I. reference sample with the application of 137Cs source of radiation

*Test of reference sample X. II.*

|  |  |
| --- | --- |
| Dose area of 137Cs | |
| Code of the sample: X.II. [etalon] | |
| Average layer-thickness: 9.9 cm | |
| Background dose rate: 0.13 ± 0.01 µSv/h | |
| Number of the test point | Measured dose rate [µSv/h] |
| 1 | 7.40 |
| 2 | 8.20 |
| 3 | 7.20 |
| 4 | 8.20 |
| 5 | 8.00 |
| 6 | 8.30 |
| 7 | 7.80 |
| 8 | 7.90 |
| 9 | 7.90 |
| **Average ± empirical dispersion (with the correction of the background)** | **7.75 ± 0.37** |

Chart 7/a.:

The findings of the test of X. II. references sample with the application of 137Cs source of radiation

The average rate of transmission found by the tests above, as well as its relative uncertainty calculated from the empirical dispersion can be seen in Chart 7/b. The absorption coefficient of the sample, as well as the layer-thickness of halving and the estimated dispersion can be seen in Chart 7/c.

|  |  |  |  |
| --- | --- | --- | --- |
| Code of the sample: | Thickness [cm] | Rate of transmission | Relative uncertainty [%] |
| X. II. | 10.2 | 0.229 | 4.8 |

Chart 7/b.:

The rate of transmission of the X.II. reference sample with the application of 137Cs source of radiation

|  |  |  |
| --- | --- | --- |
| **Code of the sample:** | **µ [cm-1]** | **X1/2 ± σ [cm]** |
| **X. II.** | **0.149** | **4.65 ± 0.15** |

Chart 7/c.:

The absorption coefficient and the layer-thickness of halving of the X.II. reference sample with the application of 137Cs source of radiation

3.2.2. Tests of “N1” samples

|  |  |
| --- | --- |
| Dose area of 137Cs | |
| Code of the sample: N1 - 1/1 | |
| Average layer-thickness: 7.3 cm | |
| Background dose rate: 0.13 ± 0.01 µSv/h | |
| Number of the test point | Dose rate [µSv/h] |
| 1 | 9.40 |
| 2 | 8.60 |
| 3 | 9.10 |
| 4 | 8.90 |
| **Average ± empirical dispersion (with the correction of the background)** | **8.87 ± 0.34** |

Chart 8/a.:

The findings of the test of N1 – 1/1 sample with the application of 137Cs source of radiation

|  |  |
| --- | --- |
| Dose area of 137Cs | |
| Code of the sample: N1 - 2/1 | |
| Average layer-thickness: 7.7 cm | |
| Background dose rate: 0.13 ± 0.01 µSv/h | |
| Number of the test point | Measured dose rate [µSv/h] |
| 1 | 8.60 |
| 2 | 9.10 |
| 3 | 8.40 |
| 4 | 8.50 |
| **Average ± empirical dispersion (with the correction of the background)** | **8.52 ± 0.31** |

Chart 8/b.:

The findings of the test of N1 – 2/1 sample with the application of 137Cs source of radiation

|  |  |
| --- | --- |
| Dose area of 137Cs | |
| Code of the sample: N1 - 3/1 | |
| Average layer-thickness: 7.6 cm | |
| Background dose rate: 0.13 ± 0.01 µSv/h | |
| Number of the test point | Measured dose rate [µSv/h] |
| 1 | 9.50 |
| 2 | 9.10 |
| 3 | 8.40 |
| 4 | 9.20 |
| **Average ± empirical dispersion (with the correction of the background)** | **8.92 ± 0.47** |

Chart 8/c.:

The findings of the test of N1 – 3/1 sample with the application of 137Cs source of radiation

The average rate of transmission of three samples made in the similar way found by the tests above, as well as its relative uncertainty calculated from the empirical dispersion can be seen in Chart 8/d. The absorption coefficient of the samples, as well as the layer-thickness of halving and the estimated dispersion can be seen in Chart 8/e.

|  |  |  |  |
| --- | --- | --- | --- |
| Code of the sample | Thickness [cm] | Rate of transmission | Relative uncertainty [%] |
| N1 - 1/1 | 7.3 | 0.262 | 3.9 |
| N1 - 2/1 | 7.7 | 0.252 | 3.4 |
| N1 - 3/1 | 7.6 | 0.263 | 5.3 |

Chart 8/d.:

The rate of transmission of N1 samples with the application of 137Cs source of radiation

|  |  |  |
| --- | --- | --- |
| Code of the sample | µ [cm-1] | X1/2 [cm] |
| N1 - 1/1 | 0.183 | 3.79 |
| N1 - 2/1 | 0.179 | 3.87 |
| N1 - 3/1 | 0.176 | 3.94 |
| **Average layer-thickness of halving and dispersion of N1 samples** | | **3.87 ± 0.08 [cm]** |

Chart 8/e.:

The absorption coefficient and the layer-thickness of halving of the N1 samples with the application of 137Cs source of radiation

3.2.3. Tests of “N2” samples

|  |  |
| --- | --- |
| Dose area of 137Cs | |
| Code of the sample: N2 - ½ | |
| Average layer-thickness: 6.9 cm | |
| Background dose rate: 0.13 ± 0.01 µSv/h | |
| Number of the test point | Dose rate [µSv/h] |
| 1 | 9.92 |
| 2 | 10.8 |
| 3 | 9.80 |
| 4 | 10.4 |
| 5 | 9.60 |
| 6 | 10.7 |
| 7 | 10.6 |
| 8 | 11.2 |
| 9 | 11.2 |
| **Average ± empirical dispersion (with the correction of the background)** | **10.34 ± 0.59** |

Chart 9/a.:

The findings of the test of N2 – 1/2 sample with the application of 137Cs source of radiation

|  |  |
| --- | --- |
| Dose area of 137Cs | |
| Code of the sample: N2 - 2/2 | |
| Average layer-thickness: 6.7 cm | |
| Background dose rate: 0.13 ± 0.01 µSv/h | |
| Number of the test point | Measured dose rate [µSv/h] |
| 1 | 10.2 |
| 2 | 9.91 |
| 3 | 10.2 |
| 4 | 11.8 |
| 5 | 10.6 |
| 6 | 10.6 |
| 7 | 11.4 |
| 8 | 10.9 |
| 9 | 10.4 |
| **Average ± empirical dispersion (with the correction of the background)** | **10.54 ± 0.61** |

Chart 9/b.:

The findings of the test of N2 – 2/2 sample with the application of 137Cs source of radiation

|  |  |
| --- | --- |
| Dose area of 137Cs | |
| Code of the sample: N2 - 3/2 | |
| Average layer-thickness: 6.8 cm | |
| Background dose rate: 0.13 ± 0.01 µSv/h | |
| Number of the test point | Measured dose rate [µSv/h] |
| 1 | 9.78 |
| 2 | 10.2 |
| 3 | 10.8 |
| 4 | 10.9 |
| 5 | 10.2 |
| 6 | 10.6 |
| 7 | 9.70 |
| 8 | 9.70 |
| 9 | 9.50 |
| **Average ± empirical dispersion (with the correction of the background)** | **10.02 ± 0.52** |

Chart 9/c.:

The findings of the test of N2 – 3/2 sample with the application of 137Cs source of radiation

The average rate of transmission of three samples made in the similar way found by the tests above, as well as its relative uncertainty calculated from the empirical dispersion can be seen in Chart 9/d. The absorption coefficient of the samples, as well as the layer-thickness of halving and the estimated dispersion can be seen in Chart 9/e.

|  |  |  |  |
| --- | --- | --- | --- |
| Code of the sample | Thickness [cm] | Rate of transmission | Relative uncertainty [%] |
| N2 - 1/1 | 6.9 | 0.305 | 5.7 |
| N2 - 2/2 | 6.7 | 0.311 | 5.8 |
| N2 - 3/2 | 6.8 | 0.296 | 5.2 |

Chart 9/d.:

The rate of transmission of N2 samples with the application of 137Cs source of radiation

|  |  |  |
| --- | --- | --- |
| Code of the sample | µ [cm-1] | X1/2 [cm] |
| N2 - 1/2 | 0.172 | 4.03 |
| N2 - 2/2 | 0.174 | 3.98 |
| N2 - 3/2 | 0.179 | 3.87 |
| **Average layer-thickness of halving and dispersion of N2 samples** | | **3.96 ± 0.08 [cm]** |

Chart 9/e.:

The absorption coefficient and the layer-thickness of halving of the N2. samples with the application of 137Cs source of radiation

3.2.4. Tests of N/3 samples

|  |  |
| --- | --- |
| Dose area of 137Cs | |
| Code of the sample: N 1/3 | |
| Average layer-thickness: 6.8 cm | |
| Background dose rate: 0.13 ± 0.01 µSv/h | |
| Number of the test point | Measured dose rate [µSv/h] |
| 1 | 10.9 |
| 2 | 10.5 |
| 3 | 10.8 |
| 4 | 11.1 |
| 5 | 10.4 |
| 6 | 11.8 |
| 7 | 11.2 |
| 8 | 10.7 |
| 9 | 11.1 |
| **Average ± empirical dispersion (with the correction of the background)** | **10.81 ± 0.42** |

Chart 10/a.:

The findings of the test of N 1/3 sample with the application of 137Cs source of radiation

|  |  |
| --- | --- |
| Dose area of 137Cs | |
| Code of the sample: N 2/3 | |
| Average layer-thickness: 6.6 cm | |
| Background dose rate: 0.13 ± 0.01 µSv/h | |
| Number of the test point | Measured dose rate [µSv/h] |
| 1 | 10.1 |
| 2 | 10.6 |
| 3 | 10.7 |
| 4 | 10.9 |
| 5 | 10.9 |
| 6 | 11.7 |
| 7 | 12.1 |
| 8 | 11.2 |
| 9 | 10.8 |
| **Average ± empirical dispersion (with the correction of the background)** | **10.87 ± 0.60** |

Chart 10/b.:

The findings of the test of N 2/3 sample with the application of 137Cs source of radiation

|  |  |
| --- | --- |
| Dose area of 137Cs | |
| Code of the sample: N 3/3 | |
| Average layer-thickness: 6.6 cm | |
| Background dose rate: 0.13 ± 0.01 µSv/h | |
| Number of the test point | Measured dose rate [µSv/h] |
| 1 | 10.3 |
| 2 | 12.0 |
| 3 | 10.8 |
| 4 | 10.8 |
| 5 | 10.1 |
| 6 | 11.4 |
| 7 | 9.87 |
| 8 | 11.9 |
| 9 | 11.2 |
| **Average ± empirical dispersion (with the correction of the background)** | **10.80 ± 0.76** |

Chart 10/c.:

The findings of the test of N 3/3 sample with the application of 137Cs source of radiation

The average rate of transmission of three samples made in the similar way found by the tests above, as well as its relative uncertainty calculated from the empirical dispersion can be seen in Chart 10/d. The absorption coefficient of the samples, as well as the layer-thickness of halving and the estimated dispersion can be seen in Chart 10/e.

|  |  |  |  |
| --- | --- | --- | --- |
| Code of the sample | Thickness [cm] | Rate of transmission | Relative uncertainty [%] |
| N 1/3 | 6.8 | 0.319 | 3.9 |
| N 2/3 | 6.6 | 0.321 | 5.5 |
| N 3/3 | 6.6 | 0.319 | 7.0 |

Chart 10/d.:

The rate of transmission of N/3 samples with the application of 137Cs source of radiation

|  |  |  |
| --- | --- | --- |
| Code of the sample | µ [cm-1] | X1/2 [cm] |
| N 1/3 | 0.168 | 4.13 |
| N 2/3 | 0.167 | 4.15 |
| N 3/3 | 0.173 | 4.01 |
| **Average layer-thickness of halving and dispersion of N/3 samples** | | **4.10 ± 0.08 [cm]** |

Chart 10/e.:

The absorption coefficient and the layer-thickness of halving of the N/3 samples with the application of 137Cs source of radiation

# 4. EVALUATION, SUMMARY

The final results summarised according to the detailed findings of the tests listed in Chapter 3. can be found in Chart 11. The characteristic features of the samples are the layer-thickness of halving (X1/2, equation [4]) and its dispersion.

|  |  |  |
| --- | --- | --- |
| Code of the sample | **X1/2 [cm] 137Cs Eγ 0.66 MeV** | **X1/2 [cm] 60Co Eγ 1.25 MeV** |
| X.I. etalon | 5.73 ± 0.21 | 10.65 ± 0.63 |
| X.II. etalon | 4.65 ± 0.15 | 8.11 ± 0.89 |
| **N1** | **3.87 ± 0.08** | **6.46 ± 0.41** |
| N2 | 3.96 ± 0.08 | 6.81 ± 0.31 |
| N3 (N1/3, N2/3, N3/3) | 4.10 ± 0.08 | 6.83 ± 0.55 |

The smaller is the layer-thickness of halving the more beneficial is the ability of the concrete to absorb (to attenuate the radiation). *The best were the N1 samples in both ranges of energy*, their findings are in bold. All the three samples have better absorptive feature than of X. II. reference sample and much better ability to absorb the radiation than of X.I. reference sample.

The relevantly bigger variation of the test completed with radiation source of 60Co type is caused by the “statistic of decay” resulting in bigger relative uncertainty for the smaller source activity. Furthermore, the unhomogeneity of the material covered in details earlier has a kind of effect to increase uncertainty, but we can see no change of the sequence determined on the basis of the classifying parameter.

# List of literature

[BENNET 04] *D. J. Bennet, J. R. Thomson: The Elements of Nuclear Power (4th Ed.) Longman/Wiley, New York, 2004.*

[THERMO 07] *Thermo Scientific web page*

*http://www.thermo.com/com/cda/product/detail/1,,15715,00.html*