Designation: C1233 – 15

Standard Practice for Determining Equivalent Boron Contents of Nuclear Materials[1]

This standard is issued under the fixed designation C1233; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This standard details a recommended practice for the calculation of the Equivalent Boron Content (EBC) for nuclear materials. The EBC is used to provide a measure of the macroscopic neutron absorption cross section of a nuclear material. EBC factors for the natural elements are determined from their atomic masses and thermal neutron absorption cross sections. This practice is illustrated by using EBC factors that are based on thermal neutron (2200 m/s) absorption cross sections. Other EBC factors may be used depending upon the actual neutron energy spectrum.

1.2 The EBC is a characteristic of a homogeneous material. Characterization of inhomogeneous materials and calculation of neutron multiplication factors require techniques that are beyond the scope of this practice.

1.3 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

2. Referenced Documents

2.1 *ASTM Standards:*[2]

C696 Test Methods for Chemical, Mass Spectrometric, and Spectrochemical Analysis of Nuclear-Grade Uranium Dioxide Powders and Pellets

C698 Test Methods for Chemical, Mass Spectrometric, and Spectrochemical Analysis of Nuclear-Grade Mixed Oxides ((U, Pu)O_2)

C761 Test Methods for Chemical, Mass Spectrometric, Spectrochemical, Nuclear, and Radiochemical Analysis of Uranium Hexafluoride

C799 Test Methods for Chemical, Mass Spectrometric, Spectrochemical, Nuclear, and Radiochemical Analysis of Nuclear-Grade Uranyl Nitrate Solutions

C859 Terminology Relating to Nuclear Materials

3. Terminology

3.1 Terminology used in this practice is in accordance with Terminology C859.

4. Significance and Use

4.1 Use of this standard practice yields an equivalent boron content (EBC) that can be used to characterize the neutron-absorbing properties of a nuclear material. The elements included in the calculation are typically chosen so that the EBC represents either the entire material (for example, for a moderator) or the impurities in the material (for example, for a nuclear fuel). This practice is typically used for materials in which thermal neutron absorption is undesirable. The EBC is not intended for use as an input to any neutronic calculation. The EBC factors in Table 1 were selected to represent neutron absorption in water reactors under normal operating conditions. It is the responsibility of the user to evaluate their suitability for other purposes.

5. Procedures for EBC Determination

5.1 Agreement shall be reached between the buyer and seller as to which elements shall be analyzed for calculation of their EBC. It is recommended that B, Cd, Dy, Eu, Sm, and Gd be included in this calculation. Analytical methods for such elements shall be those given in Test Methods C696, C698, C761, and C799 as applicable or as otherwise agreed upon between buyer and seller.

5.2 The individual EBC values are calculated using the EBC factors from Table 1 as follows:

$$\textit{EBC of constituent} = \\ \textit{(EBC factor of constituent)(μg of constituent / g of material)}$$

where:

EBC factor of constituent = (atomic mass of boron)(σa of constituent)/[(atomic mass of constituent)(σa of boron)], and

σ*a* = atomic neutron absorption cross section in barns.

The EBC factors have been calculated using a value of 764 barns for the neutron absorption cross section (σ*a*) of boron. This value may vary in nature according to the isotopic

[1] This practice is under the jurisdiction of ASTM Committee C26 on Nuclear Fuel Cycle and is the direct responsibility of Subcommittee C26.02 on Fuel and Fertile Material Specifications.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

TABLE 1 Equivalent Boron Content Factors

Element	Neutron Absorption Cross Section[A] (Barns) at 2200 m/s	Atomic Mass[B]	EBC Factor
Aluminium[C]	0.231	26.98	1.21E-04
Antimony	5.1[D]	121.75	5.93E-04
Argon	0.68	39.95	2.41E-04
Arsenic	4.5	74.92	8.50E-04
Barium[C]	1.2[D]	137.33	1.24E-04
Beryllium[C]	0.0076[D]	9.01	1.19E-05
Bismuth[C]	0.0338	208.98	2.29E-06
Boron	764[E]	10.81	1.00E+00
Bromine	6.9	79.91	1.22E-03
Cadmium	2520	112.41	3.17E-01
Calcium[C]	0.43	40.08	1.52E-04
Carbon[C]	0.0035	12.01	4.12E-06
Cerium[C]	0.63[D]	140.12	6.36E-05
Cesium	29	132.91	3.09E-03
Chlorine	33.5	35.45	1.34E-02
Chromium	3.07	52.00	8.35E-04
Cobalt	37.2	58.93	8.93E-03
Copper	3.78	63.54	8.42E-04
Dysprosium	940	162.50	8.18E-02
Erbium	159.2	167.26	1.35E-02
Europium	4565	151.97	4.25E-01
Fluorine[C]	0.0096[D]	19.00	7.15E-06
Gadolinium	48890	157.25	4.40E+00
Gallium	2.9	69.72	5.89E-04
Germanium	2.3[D]	72.59	4.48E-04
Gold	98.65	196.97	7.09E-03
Hafnium	104.1	178.49	8.25E-03
Helium[C]	0.0073	4.00	2.58E-05
Holmium	64.7	164.93	5.55E-03
Hydrogen	0.33	1.01	4.62E-03
Indium	193.8[D]	114.82	2.39E-02
Iodine	6.2	126.90	6.91E-04
Iridium	425.30	192.22	3.13E-02
Iron	2.56[D]	55.85	6.49E-04
Krypton	25.00	83.80	4.22E-03
Lanthanum	8.97[D]	138.91	9.14E-04
Lead[C]	0.171	207.2	1.17E-05
Lithium	70.6[F]	6.94	1.44E-01
Lutetium	76.4	174.97	6.18E-03
Magnesium[C]	0.063	24.31	3.67E-05
Manganese	13.3	54.94	3.43E-03
Mercury	372.3	200.59	2.63E-02
Molybdenum	2.55[D]	95.94	3.76E-04
Neodymium	50.5[D]	144.24	4.95E-03
Neon[C]	0.039	20.18	2.73E-05
Nickel	4.49[D]	58.69	1.08E-03
Niobium[C]	1.15	92.91	1.75E-04
Nitrogen	1.90	14.01	1.92E-03
Osmium	16.00	190.20	1.19E-03
Oxygen[C]	0.00019[D]	16.00	1.68E-07
Palladium	6.90	106.42	9.17E-04
Phosphorus[C]	0.172	30.97	7.86E-05
Platinum	10.30	195.08	7.47E-04
Potassium	2.1[D]	39.10	7.60E-04
Praseodymium	11.5	140.91	1.15E-03
Rhenium	89.70	186.21	6.82E-03
Rhodium	145.20	102.91	2.00E-02
Rubidium[C]	0.38[D]	85.47	6.29E-05
Ruthenium	2.56[D]	101.07	3.58E-04
Samarium	5670	150.36	5.34E-01
Scandium	27.20	44.96	8.56E-03
Selenium	11.70	78.96	2.10E-03
Silicon[C]	0.171	28.09	8.61E-05
Silver	63.3	107.87	8.30E-03
Sodium	0.53	22.99	3.26E-04
Strontium	1.28[D]	87.62	2.07E-04
Sulfur	0.52	32.06	2.29E-04
Tantalum	20.6	180.95	1.61E-03
Tellurium	4.70	127.60	5.21E-04
Terbium	23.4	158.92	2.08E-03
Thallium	3.43	204.37	2.37E-04
Thorium	7.37	232.04	4.49E-04
Thulium	105	168.93	8.79E-03
Tin[C]	0.626[D]	118.71	7.46E-05

TABLE 1 *Continued*

Element	Neutron Absorption Cross Section^{A} (Barns) at 2200 m/s	Atomic Mass^{B}	EBC Factor
Titanium	6.1	47.88	1.80E-03
Tungsten	18.4	183.85	1.42E-03
Vanadium	5.08	50.94	1.41E-03
Xenon	23.90	131.29	2.58E-03
Ytterbium	35.5	173.04	2.90E-03
Yttrium	1.28	88.91	2.04E-04
Zinc	1.11	65.39	2.40E-04
Zirconium^{C}	0.185^{D}	91.22	2.87E-05

^{A} *Neutron Cross Sections*, Vol 1, Parts A and B, Academic Press, New York, 1981 and 1984, respectively.
^{B} Holden, N. E., and Martin, R. L., *Pure and Applied Chemistry*, Vol 56, p. 653, 1984.
^{C} When present in small concentrations, this element should be excluded from determinations of the total EBC.
^{D} In the absence of other data, the neutron capture cross section for a Maxwellian flux is used.
^{E} Cross section is primarily due to a single isotope, whose isotopic abundance is variable in nature. The value can vary between 733 and 779 barns depending upon the source. See Holden, N. E., *Neutron Capture Cross Section Standards* for BNL-325, Fourth Ed., BNL-NCS-51388, January 1981.
^{F} Cross section is primarily due to a single isotope, whose isotopic abundance is variable in nature. The value can vary between 69 and 72 barns depending upon the source. See Holden, N. E., *Neutron Capture Cross Section Standards* for BNL-325, Fourth Ed., BNL-NCS-51388, January 1981.

composition of the elements. If an alternative value is chosen the EBC factors must be recalculated using the chosen value.

5.3 If the concentration of any of the elements used in the calculation is reported as a "less than" value, that value shall be used in calculating the EBC.

5.4 A total EBC value, if required, is determined by the summation of individual EBC values.

5.5 Plutonium and uranium have not been included, as they are fissionable elements.

5.6 Table 1 includes elements that may provide a negligible contribution to the total EBC. In particular, elements with both small concentrations and very small EBC factors (less than 2E-4) will generally provide a negligible contribution to the EBC of the material as a whole. Such elements should be excluded from determinations of the total EBC.

6. Keywords

6.1 boron; neutron absorption; nuclear materials; nuclear poisons