



Designation: E 523 – 92 (Reapproved 1996)

Standard Test Method for Measuring Fast-Neutron Reaction Rates by Radioactivation of Copper¹

This standard is issued under the fixed designation E 523; 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 test method covers procedures for measuring reaction rates by the activation reaction $^{63}\text{Cu}(n,\alpha)^{60}\text{Co}$. The cross section for ^{60}Co produced in this reaction increases rapidly with neutrons having energies greater than about 5 MeV. ^{60}Co decays with a half-life of 5.271 years² and emits two gamma rays having energies of 1.1732 and 1.3325 MeV². The isotopic content of natural copper is 69.17 % ^{63}Cu and 30.83 % ^{65}Cu .³ The neutron reaction, $^{63}\text{Cu}(n,\gamma)^{64}\text{Cu}$, produces a radioactive product that emits gamma rays which might interfere with the counting of the ^{60}Co gamma rays.

1.2 With suitable techniques, fission-neutron fluence rates above $10^9 \text{ cm}^{-2}\cdot\text{s}^{-1}$ can be determined. The $^{63}\text{Cu}(n,\alpha)^{60}\text{Co}$ reaction can be used to determine fast-neutron fluences for irradiation times up to about 15 years (for longer irradiations, see Practice E 261).

1.3 Detailed procedures for other fast-neutron detectors are referenced in Practice E 261.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 ASTM Standards:

- E 170 Terminology Relating to Radiation Measurements and Dosimetry⁴
- E 181 Test Methods for Detector Calibration and Analysis of Radionuclides⁴
- E 261 Practice for Determining Neutron Fluence Rate, Fluence, and Spectra by Radioactivation Techniques⁴
- E 262 Test Method for Determining Thermal Neutron Reaction and Fluence Rates by Radioactivation Techniques⁴
- E 844 Guide for Sensor Set Design and Irradiation for

Reactor Surveillance, E706 (IIC)⁴

E 944 Guide for Application of Neutron Spectrum Adjustment Methods in Reactor Surveillance, (IIA)⁴

E 1005 Test Method for Application and Analysis of Radiometric Monitors for Reactor Vessel Surveillance, E706 (IIIA)⁴

E 1018 Guide for Application of ASTM Evaluated Cross Section Data File, Matrix E 706 (IIB)⁴

3. Terminology

3.1 Definitions:

3.1.1 Refer to Terminology E 170.

4. Summary of Test Method

4.1 High-purity copper (<1 ppm cobalt) is irradiated in a neutron field, thereby producing radioactive ^{60}Co from the $^{63}\text{Cu}(n,\alpha)^{60}\text{Co}$ reaction.

4.2 The gamma rays emitted by the radioactive decay of ^{60}Co are counted in accordance with Test Methods E 181 and the reaction rate, as defined by Practice E 261, is calculated from the decay rate and irradiation conditions.

4.3 The neutron fluence rate above about 5 MeV can then be calculated from the spectral-weighted neutron activation cross section as defined by Practice E 261.

5. Significance and Use

5.1 Refer to Guide E 844 for the selection, irradiation, and quality control of neutron dosimeters.

5.2 Refer to Practice E 261 for a general discussion of the measurement of fast neutron fluence rate with threshold detectors. The general shape of the $^{63}\text{Cu}(n,\alpha)^{60}\text{Co}$ cross section is also shown in Fig. 1.⁵ This figure is for illustrative purposes only to indicate the range of response of the $^{63}\text{Cu}(n,\alpha)$ reaction. Refer to Guide E 1018 for descriptions of recommended tabulated dosimetry cross sections.

5.3 The chief advantages of copper for measuring fast-neutron fluence rate are that it has good strength, is easily fabricated, has excellent corrosion resistance, has a melting temperature of 1083°C, and can be obtained pure. The half-life of ^{60}Co is long and its decay scheme is simple and well known.

5.4 The disadvantages of copper for measuring fast neutron

¹ This test method is under the jurisdiction of ASTM Committee E-10 on Nuclear Technology and Applications and is the direct responsibility of Subcommittee E10.05 on Nuclear Radiation Metrology.

Current edition approved Oct. 15, 1992. Published May 1993. Originally published as E 523 – 76. Last previous edition E 523 – 87.

² *Nuclear Data Sheets for A = 60*, National Nuclear Data Center, Vol 48, June 1986, p. 251.

³ "Isotopic Compositions of the Elements 1983," International Union of Pure and Applied Chemistry, Vol 56, Pergamon Press, 1984.

⁴ *Annual Book of ASTM Standards*, Vol 12.02.

⁵ "ENDF-201, ENDF/B-VI Summary Documentation," edited by P.F. Rose, Brookhaven National Laboratory Report BNL-NCS-1741, 4th ed., October 1991.

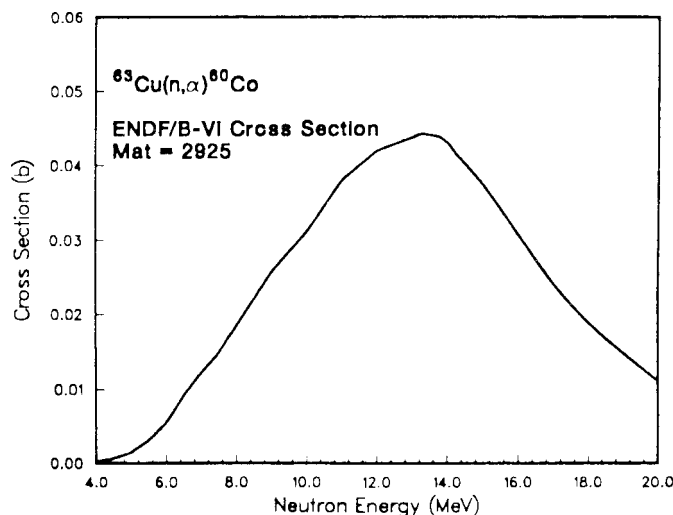


FIG. 1 $^{63}\text{Cu}(n,\alpha)^{60}\text{Co}$ Cross Section

fluence rate are the high reaction apparent threshold of 5 MeV, the possible interference from cobalt impurity ($>1 \mu\text{g/g}$), the reported possible thermal component of the (n,α) reaction, and the possibly significant cross sections for thermal neutrons for ^{63}Cu and ^{60}Co (that is 4.5 and 2.0 barns, respectively),⁶ which will require burnout corrections at high fluences.

6. Apparatus

6.1 NaI(Tl) or High Resolution Gamma-Ray Spectrometer—Because of its high resolution, the germanium detector is useful when contaminant activities are present or when it is necessary to analyze before the 12.7 h ^{64}Cu has decayed.

6.2 Precision Balance, able to achieve the required accuracy.

6.3 Digital Computer, useful for data analysis (optional).

7. Materials

7.1 Copper Metal—Pure copper metal in the form of wire or foil is available.

7.1.1 The metal should be tested for impurities by a neutron activation technique. If the measurement is to be made in a thermal-neutron environment, there must be no cobalt impurity ($<1 \mu\text{g/g}$) because the reaction $^{59}\text{Co}(n,\gamma)^{60}\text{Co}$ produces the same product as produced in the subject reaction. To reduce this interference, the use of a thermal-neutron shield during irradiation would be advisable if cobalt impurity is suspected.

7.2 Encapsulating Materials—Brass, stainless steel, copper, aluminum, quartz, or vanadium have been used as primary encapsulating materials. The container should be constructed in such a manner that it will not create significant flux perturbation and that it may be opened easily, especially if the capsule is to be opened remotely (see Guide E 844).

8. Procedure

8.1 Decide on the size and shape of the copper sample to be irradiated, taking into consideration the size and shape of the

irradiation space. The mass and exposure time are parameters that can be varied to obtain a desired disintegration rate for a given neutron fluence rate level (see Guide E 844).

8.2 Weigh the sample.

8.3 Irradiate the sample for the predetermined time period. Record the power level and any changes in power during the irradiation, the time at the beginning and end of the irradiation, and the relative position of the monitors in the irradiation facility.

8.4 A waiting period of about 6 days is recommended between termination of the exposure and analyzing the sample for ^{60}Co content. This allows the 12.7 h ^{64}Cu to decay so that there is no interference from the gamma rays emitted by ^{64}Cu , that is, the 0.511 and 1.346 MeV gamma rays. However, analysis may be performed sooner if a suitable gamma-ray or peak analysis technique is used.

8.5 Check the sample for activity from cross-contamination by other irradiated materials. Clean, if necessary and reweigh.

8.6 Analyze the sample for ^{60}Co content in disintegrations per second using the gamma-ray spectrometer (see Test Methods E 181 and E 1005).

8.7 Disintegration of ^{60}Co nuclei produces 1.1732 MeV and 1.3325 MeV gamma rays with probabilities per decay of 0.9990 and 0.9998 respectively.² When analyzing either peak in the gamma-ray spectrum, a correction for coincidence summing may be required if the sample is placed close to the detector (10 cm or less) (see Test Methods E 181).

9. Calculations

9.1 Calculate the saturation activity A_s , as follows:

$$A_s = A / [(1 - \exp[-\lambda t_i]) (\exp[-\lambda t_w])] \quad (1)$$

where:

A = ^{60}Co disintegrations per second measured by counting,

λ = decay constant for $^{60}\text{Co} = 4.167 \times 10^{-9} \text{s}^{-1}$,

t_i = irradiation duration s,

t_w = elapsed time between the end of irradiation and counting, s.

⁶ "Chart of the Nuclides," Knolls Atomic Power Laboratory, 14th Edition, April 1988.