Designation: E264 – 08 (Reapproved 2013)

Standard Test Method for Measuring Fast-Neutron Reaction Rates by Radioactivation of Nickel[1]

This standard is issued under the fixed designation E264; 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.

This standard has been approved for use by agencies of the U.S. Department of Defense.

1. Scope

1.1 This test method covers procedures for measuring reaction rates by the activation reaction ^{58}Ni(n,p)^{58}Co.

1.2 This activation reaction is useful for measuring neutrons with energies above approximately 2.1 MeV and for irradiation times up to about 200 days in the absence of high thermal neutron fluence rates (for longer irradiations, see Practice E261).

1.3 With suitable techniques fission-neutron fluence rates densities above 10^7 $cm^{-2}·s^{-1}$ can be determined.

1.4 Detailed procedures for other fast-neutron detectors are referenced in Practice E261.

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

1.6 *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:*[2]

E170 Terminology Relating to Radiation Measurements and Dosimetry

E181 Test Methods for Detector Calibration and Analysis of Radionuclides

E261 Practice for Determining Neutron Fluence, Fluence Rate, and Spectra by Radioactivation Techniques

E844 Guide for Sensor Set Design and Irradiation for Reactor Surveillance, E 706 (IIC)

E944 Guide for Application of Neutron Spectrum Adjustment Methods in Reactor Surveillance, E 706 (IIA)

E1005 Test Method for Application and Analysis of Radiometric Monitors for Reactor Vessel Surveillance, E 706 (IIIA)

E1018 Guide for Application of ASTM Evaluated Cross Section Data File, Matrix E706 (IIB)

3. Terminology

3.1 *Definitions:*

3.1.1 Refer to Terminology E170.

4. Summary of Test Method

4.1 High-purity nickel is irradiated in a neutron field, thereby producing radioactive^{58}Co from the ^{58}Ni(n,p)^{58}Co activation reaction.

4.2 The gamma rays emitted by the radioactive decay of ^{58}Co are counted in accordance with Test Methods E181 and the reaction rate, as defined by Practice E261, is calculated from the decay rate and irradiation conditions.

4.3 The neutron fluence rate above about 2.1 MeV can then be calculated from the spectral-weighted neutron activation cross section as defined by Practice E261.

5. Significance and Use

5.1 Refer to Guide E844 for the selection, irradiation, and quality control of neutron dosimeters.

5.2 Refer to Practice E261 for a general discussion of the determination of fast-neutron fluence rate with threshold detectors.

5.3 Pure nickel in the form of foil or wire is readily available, and easily handled.

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[1] This test method is under the jurisdiction of ASTM Committee E10 on Nuclear Technology and Applicationsand is the direct responsibility of Subcommittee E10.05 on Nuclear Radiation Metrology.

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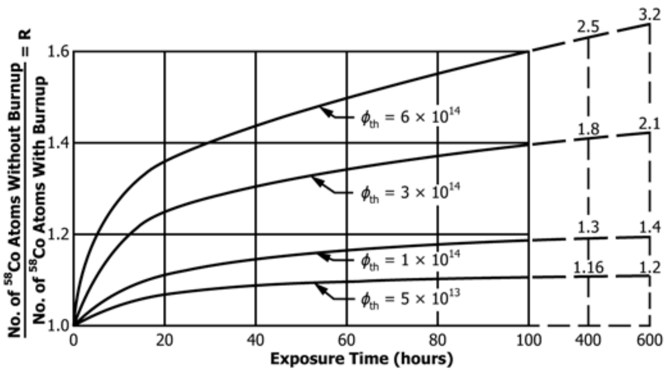
[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.



NOTE 1—The burnup corrections were computed using effective burn-up cross sections of 1650 b for $^{58}Co(n,\gamma)$ and 1.4E5 b for $^{58m}Co(n,\gamma)$.

FIG. 1 *R* Correction Values as a Function of Irradiation Time and Neutron Flux

5.4 ^{58}Co has a half-life of 70.86 days[3] and emits a gamma ray with an energy of 0.8107593-MeV.[4]

5.5 Competing activities ^{65}Ni(2.5172 h) and ^{57}Ni(35.60 h) are formed by the reactions $^{64}Ni(n,\gamma)$ ^{65}Ni, and $^{58}Ni(n,2n)^{57}Ni$, respectively.

5.6 A second 9.04 h isomer, ^{58m}Co, is formed that decays to 70.86-day ^{58}Co. Loss of ^{58}Co and ^{58m}Co by thermal-neutron burnout will occur in environments[5,6] having thermal fluence rates of 3×10^{12} $cm^{-2} \cdot s^{-1}$ and above. Burnout correction factors, *R*, are plotted as a function of time for several thermal fluxes in Fig. 1. Tabulated values for a continuous irradiation time are provided in Hogg, et al.[6]

5.7 Fig. 2 shows a plot of cross section[7] versus energy for the fast-neutron reaction $^{58}Ni(n,p)$ ^{58}Co. This figure is for illustrative purposes only to indicate the range of response of the $^{58}Ni(n,p)$ reaction. Refer to Guide E1018 for descriptions of recommended tabulated dosimetry cross sections.

NOTE 1—The data is taken from the Evaluated Nuclear Data File, ENDF/B-VI, rather than the later ENDF/B-VII. This is in accordance with E1018, section 6.1, since the later ENDF/B-VII data files do not include covariance information. For more details see Section H of reference 8.[8]

6. Apparatus

6.1 *NaI (T1) or High Resolution Gamma-Ray Spectrometer.* Because of its high resolution, the germanium detector is useful when contaminant activities are present (see Test Methods E181 and E1005).

6.2 *Precision Balance,* able to achieve the required accuracy.

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

7. Materials

7.1 The nickel metal must be low in contained cobalt to prevent the production of ^{60}Co by thermal-neutron capture. Nickel produced by the carbonyl (Mond) process is sufficiently free of cobalt for even the most adverse conditions. Whenever possible, all nickel should be tested for interfering impurities by neutron activation.

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 E844).

8. Procedure

8.1 Decide on the size and shape of nickel sample to be irradiated. This is influenced by the irradiation space and the expected production of ^{58}Co. Calculate the expected production rate of ^{58}Co from the activation equation described in Section 9, and adjust the sample size and irradiation time so that the ^{58}Co may be counted accurately.

8.2 Determine the level of thermal-neutron fluence rate by including a thermal-fluence rate monitor. Place the sample in a boron or cadmium shield if required.

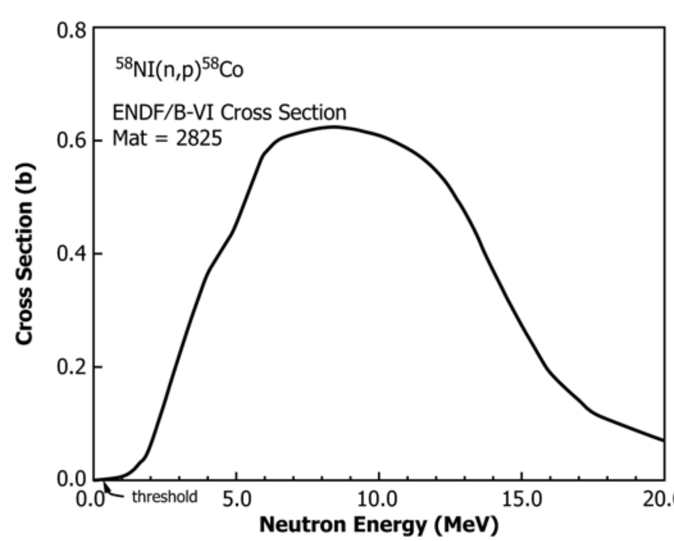


FIG. 2 $^{58}Ni(n,p)^{58}Co$ Cross Section

8.3 Weigh the sample.

[3] J. K. Tulti, "Nuclear Wallet Cards," National Nuclear Data Center, Brookhaven National Laboratory, Upton, New York, April 2005.

[4] Evaluated Nuclear Structure Data File (ENSDF), a computer file of evaluated nuclear structure and radioactive decay data, which is maintained by the National Nuclear Data Center (NNDC), Brookhaven National Laboratory (BNL), on behalf of the International Network for Nuclear Structure Data Evaluation, which functions under the auspices of the Nuclear Data Section of the International Atomic Energy Agency (IAEA). The URL is http://www.nndc.bnl.gov/nndc/ensdf. The data quoted here comes from the database as of January 1, 2002.

[5] Hogg, C. H., Weber, L. D., and Yates, E. C., "Isomers and the Effects on Fast Flux Measurements Using Nickel," *Atomic Energy Commission R and D Report* IDO-16744, 1962.

[6] Hogg, C. H., Weber, L. D., Yates, E.C., "Thermal Neutron Cross Sections of the Co^{58} Isomers and the Effect on Fast Flux Measurements Using Nickel," IDO-16744 AEC Research & Development Report, Physics TID-4500, June 18, 1962.

[7] *ENDF-201, ENDF/B-VI Summary Documentation*, edited by P. F. Rose, Brookhaven National Laboratory Report BNL-NCS-1741, 4th Edition, October 1991.

[8] "Special Issue on Evaluated Nuclear Data File ENDF/B-VII.0," Nuclear Data Sheets, J. K. Tuli, Editor, Vol. 107, December 2006.

8.4 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 period, and the relative position of the monitors in the irradiation facility.

8.5 A waiting period of at least 4 days is recommended between termination of the exposure and start of counting. This allows the 9.04-h ^{58m}Co to decay entirely to the 70.86-day ^{58}Co ground state. Activated impurities such as 2.52-h ^{65}Ni, 35.6-h ^{57}Ni, and 23.72-h ^{187} W, sometimes observed in nickel prepared by high-temperature sintering in tungsten, will also be eliminated by allowing the sample to decay over an extended period.

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

8.7 Analyze the sample for ^{58}Co content in disintegrations per second using the gamma-ray spectrometer (see Test Methods E181 and E1005).

8.8 Disintegration of ^{58}Co nuclei produces 0.8107593-MeV gamma rays with a probability per decay of 0.9945.[4] When analyzing the 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 E181).

9. Calculations

9.1 Calculate the saturation activity, A_s, as follows:

$$A_s = A/[(1 - e^{-\lambda t_i})(e^{-\lambda t_w})] \quad (1)$$

where:

A = ^{58}Co disintegrations per second measured by counting,

λ = decay constant for ^{58}Co = 1.132×10^{-7} s^{-1},

t_i = irradiation duration, s, and

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

NOTE 2—The equation for A_s is valid if the reactor operated at essentially constant power and if corrections for other reactions (for example, impurities, burnout, etc.) are negligible. Refer to Practice E261 for more generalized treatments.

9.2 Calculate the reaction rate, R_s, as follows:

$$R_s = A_s/N_o \quad (2)$$

where:

A_s = saturation activity, and

N_o = number of ^{58}Ni atoms.

9.3 Refer to Practice E261 and Guide E944 for a discussion of fast-neutron fluence rate and fluence.

10. Report

10.1 Practice E261 describes how data should be reported.

11. Precision and Bias

NOTE 3—Measurement uncertainty is described by a precision and bias statement in this standard. Another acceptable approach is to use Type A and B uncertainty components.[9,10] This Type A/B uncertainty specification is now used in International Organization for Standardization (ISO) Standards and this approach can be expected to play a more prominent role in future uncertainty analyses.

11.1 General practice indicates that disintegration rates can be determined with a bias of ± 3 % (1S %) and with a precision of ± 1 % (1S %).

12. Keywords

12.1 activation; activation reaction; cross section; dosimetry; fast-neutron monitor; neutron metrology; nickel; pressure vessel surveillance; reaction rate

[9] B. N. Taylor, C.E. Kuyatt, *Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results*, NIST Technical Note 1297, National Institute of Standards and Technology, Gaithersburg, MD, 1994.

[10] *Guide in the Expression of Uncertainty in Measurements*, International Organization for Standardization, 1995, ISBN 92–67–10188–9.