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

This standard is issued under the fixed designation E 264; 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 Department of Defense.

[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.

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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 E 261).

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

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

1.5 *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 Dosimetry[2]

E 181 Test Methods for Detector Calibration and Analysis of Radionuclides[2]

E 261 Practice for Determining Neutron Fluence Rate, Fluence, and Spectra by Radioactivation Techniques[2]

E 844 Guide for Sensor Set Design and Irradiation for Reactor Surveillance, E 706 (IIC)[2]

E 944 Guide for Application of Neutron Spectrum Adjustment Methods in Reactor Surveillance, E 706 (IIA)[2]

E 1005 Test Method for Application and Analysis of Radiometric Monitors for Reactor Vessel Surveillance, E 706 (IIIA)[2]

E 1018 Guide for Application of ASTM Evaluated Cross Section Data File, Matrix E 706 (IIB)[2]

3. Terminology

3.1 *Definitions:*

3.1.1 Refer to Terminology E 170.

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 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 2.1 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 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.

[2] *Annual Book of ASTM Standards*, Vol 12.02.

5.4 ^{58}Co has a half-life of 70.82~~6~~ days and emits a gamma ray with an energy of 0.810~~8~~7593-MeV.[3]

5.5 Competing activities ^{65}Ni(2.51~~7~~2 h) and ^{57}Ni(36~~5~~.1~~6~~0 h) are formed by the reactions ^{64}Ni(n,γ) ^{65}Ni, and ^{58}Ni(n,2n) ^{57}Ni, respectively.

5.6 A second ~~9.15–h~~ 9.04–h isomer, ^{58m}Co, is formed that decays to 70.82-day ^{58}Co. Loss of ^{58}Co and ^{58m}Co by thermal-neutron burnout will occur in environments having thermal fluence rates of 3×10^{12} $cm^{-2} \cdot s^{-1}$ and above. The ^{58}Co(n,γ) ^{59}Co and ^{58m}Co(n,γ) ^{59}Co cross sections have been measured at 1650 and 1.4×10^5 barns, respectively.[4] Burnout correction factors, *R*, are plotted as a function of time for several thermal fluxes in Fig. 1.

5.7 Fig. 2 shows a plot of cross section versus energy for the fast-neutron reaction ^{58}Ni(n,p) ^{58}Co.[5] This figure is for illustrative purposes only to indicate the range of response of the ^{58}Ni(n,p) reaction. Refer to Guide E 1018 for descriptions of recommended tabulated dosimetry cross sections.

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 E 181 and E 1005).

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 E 844).

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.

8.3 Weigh the sample.

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 ~~9.15-h~~ 9.04-h ^{58m}Co to decay entirely to the 70.82~~6~~-day ^{58}Co ground state. Activated impurities such as 2.52-h ^{65}Ni,

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[3] "*Evaluated Nuclear Structure Data Sheets for A = 58*," File (ENSDF), a computer file of evaluated nuclear structure and radioactive decay data, which is maintained by the National Nuclear Data Center, Vol 42, 1984, p. 457. 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.

[4] 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.

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

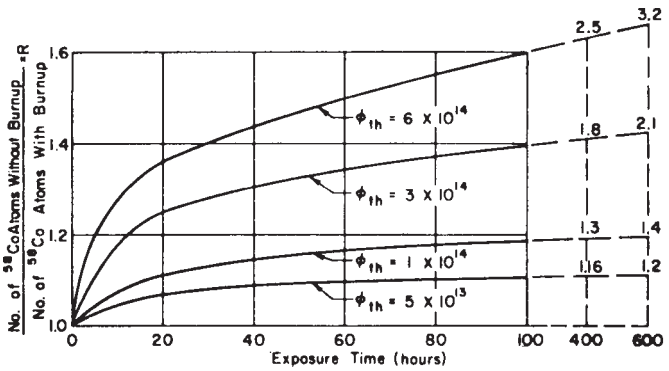

FIG. 1 *R* Correction Values as a Function of Irradiation Time and Neutron Flux

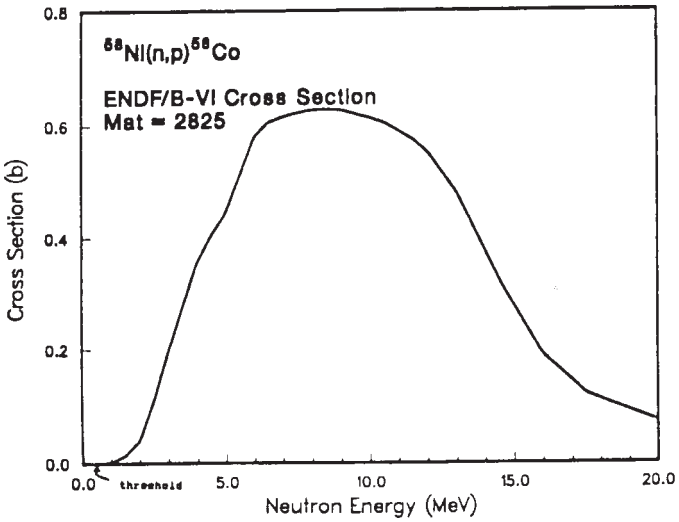

FIG. 2 ^{58}Ni(n,p)^{58}Co Cross Section

365.16-h ^{57}Ni, and 23.872-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 E 181 and E 1005).

8.8 Disintegration of ^{58}Co nuclei produces 0.810875593-MeV gamma rays with a probability per decay of 0.9945.[6] 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 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 = ^{58}Co disintegrations per second measured by counting,
λ = decay constant for ^{58}Co = 1.1332×10^{-7} s^{-1},
t_i = irradiation duration, s, and
t_w = elapsed time between the end of irradiation and counting, s.

NOTE 1—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 E 261 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 E 261 and Guide E 944 for a discussion of fast-neutron fluence rate and fluence.

10. Report

10.1 Practice E 261 describes how data should be reported.

11. Precision and Bias

NOTE 2—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.[7,7] 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.

[6] J. K. Tulti, "Nuclear Wallet Cards," National Nuclear Data Center, Brookhaven National Laboratory, Upton, New York, January 2000.

[7] 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.

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