Designation: E266 – 11

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

This standard is issued under the fixed designation E266; 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 measuring reaction rates by the activation reaction $^{27}Al(n,\alpha)^{24}$ Na.

1.2 This activation reaction is useful for measuring neutrons with energies above approximately 6.5 MeV and for irradiation times up to about 2 days (for longer irradiations, see Practice E261).

1.3 With suitable techniques, fission-neutron fluence rates above 10^6 $cm^{-2}\cdot s^{-1}$ can be determined.

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

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:*[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 aluminum is irradiated in a neutron field, thereby producing radioactive ^{24}Na from the $^{27}Al(n,\alpha)^{24}$Na activation reaction.

4.2 The gamma rays emitted by the radioactive decay of ^{24}Na are counted (see 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 6.5 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 aluminum in the form of foil or wire is readily available and easily handled. ^{27}Al has an abundance of 100 % (**1**)[3].

5.4 ^{24}Na has a half-life of 14.9574 h (**2**) and emits gamma rays with energies of 1.368626 and 2.754007 MeV(**2**).

5.5 Fig. 1 shows a plot of cross section versus neutron energy for the fast-neutron reaction $^{27}Al(n,\alpha)^{24}$Na (**3**) along with a comparison to the current experimental database (**4**). This figure is for illustrative purposes only to indicate the range of response of the $^{27}Al(n,\alpha)$ reaction. Refer to Guide E1018 for descriptions of recommended tabulated dosimetry cross sections.

[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.

[3] The boldface numbers in parentheses refer to a list of References at the end of this standard.

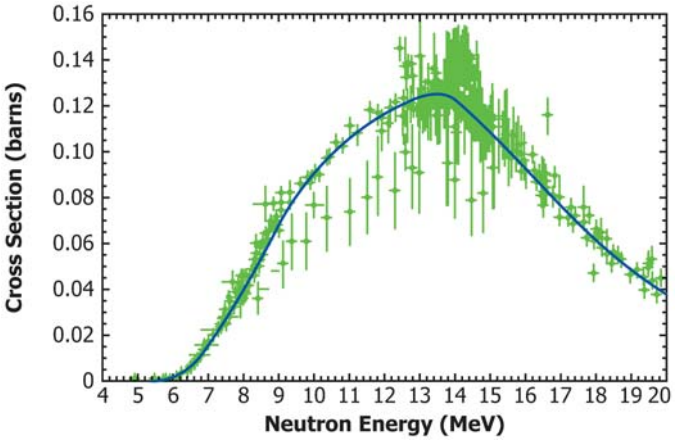

FIG. 1 ^{27}Al(n,α)^{24}Na Cross Section with EXFOR Experimental Data

5.6 Two competing activities, ^{28}Al and ^{27}Mg, are formed in the reactions ^{27}Al(n,γ) ^{28}Al and ^{27}Al(n,p) ^{27}Mg, respectively, but these can be eliminated by waiting 2 h before counting.

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.

7. Materials

7.1 The purity of the aluminum is important. No impurities should be present that produce long-lived gamma-ray-emitting radionuclides having gamma-ray energies that interfere with the ^{24}Na determination. Discard aluminum that contains such impurities or that contains quantities of ^{23}Na sufficient to interfere, through thermal-neutron capture, with ^{24}Na determination. The presence of these impurities should be determined by activation analysis since spectrographically pure aluminum may contain a contaminant not detectable by the emission spectrograph. If the ^{24}Na content of the irradiated samples is determined from the emission rate of the 2.754007 MeV gamma ray, the probability of interference from contaminant gamma rays is much less than if the 1.368626 MeV gamma ray is used.

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 aluminum sample to be irradiated. This is influenced by the irradiation space and the expected production of ^{24}Na. Calculate the expected production rate of ^{24}Na from the activation equation described in Section 9, and adjust sample size and irradiation time so that the ^{24}Na may be accurately counted. A trial irradiation is recommended.

8.2 Determine a suitable irradiation time (see 8.1). Since ^{24}Na has a 14.9574 h half-life, the ^{24}Na activity will approach equilibrium after a day of irradiation.

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

8.5 After irradiation, the sample should be thoroughly rinsed in warm water. This will remove any ^{24}Na surface contamination produced during irradiation.

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 ^{24}Na content in disintegrations per second using the gamma-ray spectrometer after the ^{28}Al and ^{27}Mg have decayed (1 to 2 h will usually suffice) or until the contaminant activities, if any, have decayed (see Test Methods E181 and E1005).

8.8 Disintegration of ^{24}Na nuclei produces 1.368626-MeV and 2.754007-MeV gamma rays with probabilities per decay of 0.999935 and 0.99872, respectively(**2**). When analyzing either gamma-ray peak, 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).

8.9 If any question exists as to the purity of the gamma ray being counted, the sample should be counted periodically to determine if the decay follows the 14.9574-h half-life of ^{24}Na(**2**).

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 = ^{24}Na disintegrations per second measured by counting,
λ = decay constant for ^{24}Na = 1.287262×10^{-5} s^{-1},
t_i = irradiation duration, s, and
t_w = elapsed time between the end of irradiation and counting, s.

NOTE 1—The equation 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 ^{27}Al 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 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 (**5,6**). 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 bias of ± 3 % (1S %) and with a precision of ± 1 % (1S %).

11.2 The energy-dependent uncertainty, expressed as a percentage of the baseline cross section, for the $^{27}Al(n,\alpha)^{24}Na$ cross section is shown in Fig. 2.(**3**)

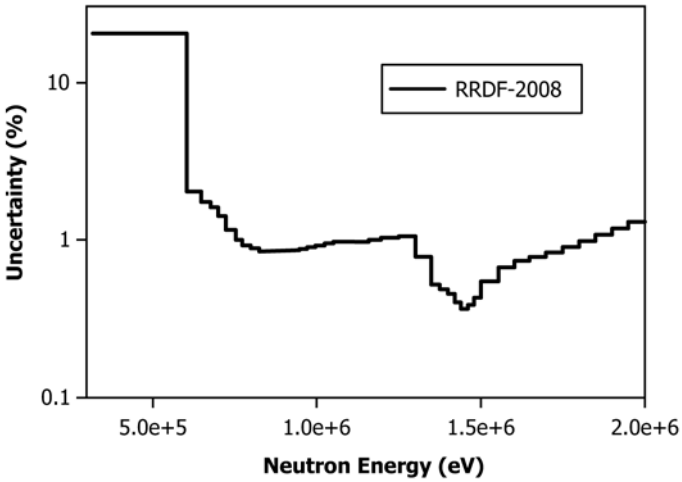

FIG. 2 Energy-dependent undertainty (%) for the $^{27}Al(N,\alpha)$ ^{24}Na Cross Section

11.3 Test results have been reported in neutron benchmark fields.

11.3.1 In the ^{252}Cf spontaneous fission reference neutron field, the measured cross section is 1.016 b ± 1.47 % (**7**) and the calculated cross section using the RRDF-2008 cross section is 1.0182 b with a spectrum integrated cross section undertainty of 0.336 % (**3**) and a spectrum characterization uncertainty of 1.609 %. This results in a calculated-to-experimental (C/E) ratio of 1.0022 ± 2.21 %.

11.3.2 In the ^{235}U thermal neutron field, the measured cross section is 0.7007 b ± 1.28 % (**7**) and the calculated cross section using the RRDF-2008 cross section is 0.7173 b with a spectrum integrated cross section uncertainty of 0.287 % (**3**) and a spectrum characterization uncertainty of 6.951 %. This results in a calculated-to-experimental (C/E) ratio of 1.024 ± 7.08 %.

12. Keywords

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

REFERENCES

(**1**) *Nuclear Wallet Cards*, compiled by J. K. Tuli, National Nuclear Data Center, April 2005 .

(**2**) Update of X-ray and Gamma Ray Decay Data Standards for Detector Calibration and Other Applications: Vol 1: Reommended Decay Data, High Energy Gamma Ray Standards and Anular Correlation Coefficients, International Atomic Energy Agency, Vienna, report STI/PUB/1287, 2007.

(**3**) Zolotarev, K. I., Ignatyuk, A. V., Mahokhin, V. N., Pashchenco, A. B., *"RRDF-98 Russian Reactor Dosimetry File"*, report IAEA-NDS-193, March 1999. The last full release was in 1998. Updated versions referenced here corresponding to the RRDF-2008 library.

(**4**) *"EXFOR Formats Description for Users (EXFOR Basics)"*, report IAEA-NDS-206, International Atomic Energy Agency, Vienna, Austria, June 2008. On-line database available at URL: http://www-nds.iaea.org/indg_nexp.html. Data here as present on January 3, 2011.

(**5**) *Guide to the Expression of Uncertainty in Measurement*, International Organization for Standardization, 1995, ISBN 92-67-10188-9.

(**6**) Taylor, B. N., Kuyatt, C. E., *Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results*, NIST Technical Note 1297, National Institute of Standards and Technology, Gaithersbrug, MD, 1994.

(**7**) Mannhart, W., Validation of Differential Cross Sections with Integral Data, Report INDC(NDS)-435, pp. 59-64, IAEA, Vienna, September 2002.