Designation: E266 – 23

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 two days (for longer irradiations, or when there are significant variations in reactor power during the irradiation, 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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.6 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

E170 Terminology Relating to Radiation Measurements and Dosimetry
E177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods
E181 Guide for Detector Calibration and Analysis of Radionuclides in Radiation Metrology for Reactor Dosimetry
E261 Practice for Determining Neutron Fluence, Fluence Rate, and Spectra by Radioactivation Techniques
E456 Terminology Relating to Quality and Statistics
E844 Guide for Sensor Set Design and Irradiation for Reactor Surveillance
E944 Guide for Application of Neutron Spectrum Adjustment Methods in Reactor Surveillance
E1005 Test Method for Application and Analysis of Radiometric Monitors for Reactor Vessel Surveillance
E1018 Guide for Application of ASTM Evaluated Cross Section Data File

3. Terminology

3.1 *Definitions:*

3.1.1 Refer to Terminologies E170 and E456.

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 Guide 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]

[1] This test method is under the jurisdiction of ASTM Committee E10 on Nuclear Technology and Applications and 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.

5.4 ^{24}Na has a half-life of 14.958 (2)[4] h (**2**) and emits gamma rays with energies of 1.368630 (5) and 2.754049 (13) MeV (**2**).

5.5 Fig. 1 shows a plot of the International Reactor Dosimetry and Fusion File (IRDFF-II) cross section (**3, 4**) versus neutron energy for the fast-neutron reaction ^{27}Al(n,α)^{24}Na (**3**) along with a comparison to the current experimental database (**5, 6**). While the RRDF-2008 and IRDFF-1.05 cross sections extend from threshold up to 60 MeV, due to considerations of the available validation data, the energy region over which this standard recommends use of this cross section for reactor dosimetry applications only extends from threshold at ~4.25 MeV up to 20 MeV. This figure is for illustrative purposes and is used to indicate the range of response of the ^{27}Al(n,α) reaction. Refer to Guide E1018 for recommended sources for the tabulated dosimetry cross sections.

5.6 Two competing activities, ^{28}Al (2.25 (2) minute half-life) and ^{27}Mg (9.458 (12) minute half-life), 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*—Due to its high resolution, the germanium detector is useful when contaminant activities are present (see Guide E181 and Test Method 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 2.754049 MeV gamma ray, the probability of interference from contaminant gamma rays is much less than if the 1.368630 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).

[4] The value of uncertainty, in parenthesis, refers to the corresponding last digits, thus 14.958 (2) corresponds to 14.958 ± 0.002.

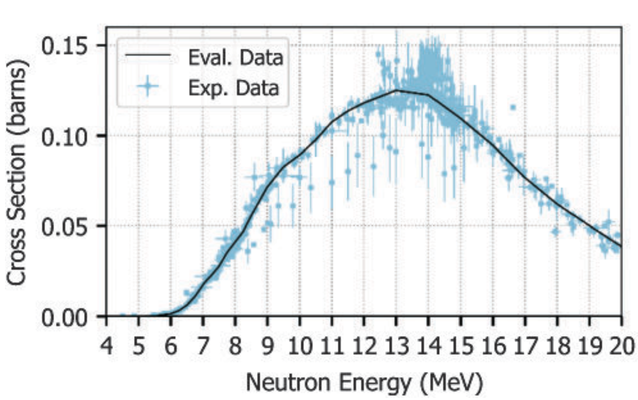

FIG. 1 ^{27}Al(n,α)^{24}Na Cross Section, from IRDFF-II Library, with EXFOR Experimental Data

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 14.958 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 (1.5 h will usually suffice, approximately ten half-lives of ^{27}Mg) or until the contaminant activities, if any, have decayed (see Guide E181 and Test Method E1005).

8.8 Disintegration of ^{24}Na nuclei produces 1.368630-MeV and 2.754049-MeV gamma rays with probabilities per decay of 0.999934 (5) and 0.99862 (3), 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 Guide 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 14.958 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 = 1.287210×10^{-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:

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

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 (**7, 8**). 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 Precision and bias in this standard are treated in accordance with the definitions in Practice E177. 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,α)^{24}Na cross section is shown in Fig. 2 (**3**).

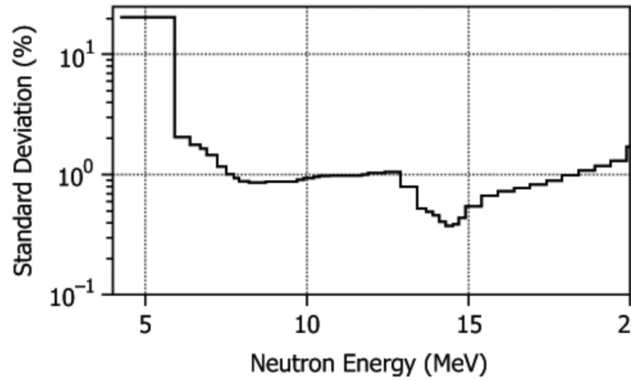

FIG. 2 Energy-Dependent Uncertainty (%) for the IRDFF-II ^{27}Al(n,α)^{24}Na Cross Section

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 mb ± 1.47 % (**9**) and the calculated cross section using the IRDFF-II cross section is 1.0184 mb with a spectrum integrated cross section uncertainty of 0.7158 % (**3**) and a spectrum characterization uncertainty of 1.609 % (**10**). This results in a calculated-to-experimental (C/E) ratio of 1.00236 ± 1.761 %.

11.3.2 In the ^{235}U thermal neutron field, as characterized in the JENDL 4.0 nuclear data file, the measured cross section is 0.7007 mb ± 1.28 % (**9**) and the calculated cross section using the IRDFF-II cross section is 0.7000346 mb with a spectrum integrated cross section uncertainty of 0.37504957 % (**4**) and a spectrum characterization uncertainty of 13.59351 % (**10**). This results in a calculated-to-experimental (C/E) ratio of 0.99905 ± 13.65364 %.

12. Keywords

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

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