Designation: ~~E526 – 08 (Reapproved 2013)~~ E526 – 17

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

This standard is issued under the fixed designation E526; 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 reactions ^{46}Ti(n,p) ^{46}Sc + ^{47}Ti(n, np)^{46}Sc + ^{47}Ti(n,d)^{46}Sc.

NOTE 1—~~Since the~~ The cross section for the ^{47}~~(n,np)~~Ti(n,np+d) reaction is relatively small for energies less than 12 MeV and is not easily distinguished from that of the ^{46}~~(n,p) reaction, this~~Ti(n,p) reaction. This test method will ~~refer~~apply to the ~~(n,p)~~composite ^{nat}Ti(n,X) ^{46}~~reaction only.~~ Sc reaction that is typically used for dosimetry purposes.

1.2 The reaction is useful for measuring neutrons with energies above approximately 4.4 MeV and for irradiation ~~times~~ times, under uniform power, up to about 250 days (for longer irradiations, or for varying power levels, see Practice E261).

1.3 With suitable techniques, fission-neutron fluence rates above 10^9 $cm^{-2}{\cdot}s^{-1}$ can be determined. However, in the presence of a high thermal-neutron fluence rate, ^{46}Sc depletion should be investigated.

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~~ safety, health, and ~~health~~environmental practices and determine the applicability of regulatory limitations prior to use.*

1.7 *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 Test Methods for Detector Calibration and Analysis of Radionuclides
E261 Practice for Determining Neutron Fluence, Fluence Rate, and Spectra by Radioactivation Techniques
~~E262~~E456 ~~Test Method for Determining Thermal Neutron Reaction Rates and Thermal Neutron Fluence Rates by Radioactivation Techniques~~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 ~~Terminology~~Terminologies E170 and E456.

[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.

4. Summary of Test Method

4.1 High-purity titanium is irradiated in a fast-neutron field, thereby producing radioactive ^{46}Sc from the ^{46}Ti(n,p)^{46}Sc activation reaction.

4.2 The gamma rays emitted by the radioactive decay of ^{46}Sc are counted in accordance with Methods E181 and the reaction rate, as defined by Test Method E261, is calculated from the decay rate and the irradiation conditions.

4.3 The neutron fluence rate above about 4.4 MeV can then be calculated from the spectral-weighted neutron activation cross section as defined by Test Method 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 Test Method E261 for a general discussion of the determination of fast-neutron fluence rate with threshold detectors.

5.3 Titanium has good physical strength, is easily fabricated, has excellent corrosion resistance, has a melting temperature of ~~1675°C,~~1668°C, and can be obtained with satisfactory purity.

5.4 ^{46}Sc has a half-life of ~~83.79 days.~~83.787 (16)[3] ~~The~~ days(~~^{46}1Sc).decay~~[4] The ^{46}Sc decay emits a ~~0.8893~~ 0.889271 (2) MeV gamma ~~99.984 %~~ 99.98374 (35) % of the time and a second gamma with an energy of ~~1.1205 MeV 99.987 %~~ 1.120537 (3) MeV 99.97 (2) % of the time.

5.5 The isotopic content of natural titanium recommended for ^{46}Ti is 8.25 %. **(2)**

5.6 The radioactive products of the neutron reactions ^{47}Ti(n,p)^{47}Sc ($\tau_{1/2}$ = ~~3.3492~~ 3.3485 (9) d) **(1)** and ^{48}Ti(n,p)^{48}Sc ($\tau_{1/2}$ = 43.67 h), **(2)** might interfere with the analysis of ^{46}Sc.

5.7 Contaminant activities (for example, ^{65}Zn and ^{182}Ta) might interfere with the analysis of ^{46}Sc. See ~~Sections~~ 7.1.2 and 7.1.3 for more details on the ^{182}Ta and ^{65}Zn interference.

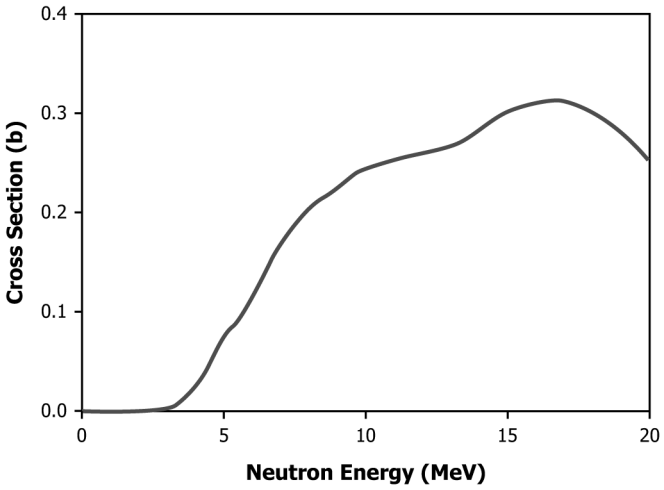
5.8 ^{46}Ti and ^{46}Sc have cross sections for thermal neutrons of 0.59 ~~and 8~~ ± 0.18 and 8.0 ± 1.0 barns, respectively **(3)**; therefore, when an irradiation exceeds a thermal-neutron fluence greater than about 2×10^{21} cm^{-2}, provisions should be made to either use a thermal-neutron shield to prevent burn-up of ^{46}Sc or measure the thermal-neutron fluence rate and calculate the burn-up.

5.9 Fig. 1 shows a plot of the Russian Reactor Dosimetry File (RRDF-2002) cross section **(4)** versus neutron energy for the

[3] ~~Nuclear Wallet Cards, National Nuclear Data Center, prepared by Jagdish K. Tuli, April 2005.~~The value of uncertainty, in parentheses, refers to the corresponding last digits, thus 14.958(2) corresponds to 14.958 ± 0.002.

[4] ~~Evaluated Nuclear Structure Data File (ENSDF), maintained by the National Nuclear Data Center (NNDC), Brookhaven National Laboratory, on behalf of the International Network for Nuclear Structure Data Evaluation.~~

[4] ~~Nuclear Data retrieval program NUDAT, 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/nudat2/indx_sigma.jsp.~~ The boldface numbers in parentheses refer to a list of references at the end of this standard.



[7] ~~Zolotarev, K. I., Ignatyuk, A. V., Mahokhin, V. N., Pashchenko, A. B., RRDF-98, Russian Reactor Dosimetry File, Rep. IAEA-NDS-193, Rev. 1, IAEA, Vienna, 2005. URL is http://www-nds.ipen.br/ndspub/libraries2/rrdf98/~~

FIG. 1 ^{Nat}Ti(n,X)^{46}Sc Cross Section (Normalized per Ti-46 Atom Using Natural Abundance Data)

fast-neutron reactions of titanium which ~~produce~~ produce ^{46}Sc [that is, ^{Nat}Ti(n,X)^{46}Sc]. This cross section is identical, for energies up to 20 MeV, to what is found in the latest International Atomic Energy Agency (IAEA) International Reactor Dosimetry and Fusion File, IRDFF-1.05 (**5**). Included in the plot is the ^{46}Ti(n,p) reaction and the ^{47}Ti(n,np) contribution to the ^{46}Sc production, normalized ~~(at 14.7 MeV)~~per ^{46}Ti ~~atom.~~ atom using the natural abundances (**2**). This figure is for illustrative purposes only to indicate the range of response of the ^{nat}Ti(n,p) ^{46}~~Ti(n,p)~~Sc reaction. Refer to Guide E1018 for descriptions of recommended tabulated dosimetry cross sections. Fig. 2 compares the cross section for the ^{46}Ti(N,p)^{47}Sc reaction to the current experimental database (**6, 7**).Fig. 3 compares the cross section for the ^{47}Ti(N, np+d) reaction to the current experimental database (**6, 7**).

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. See 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

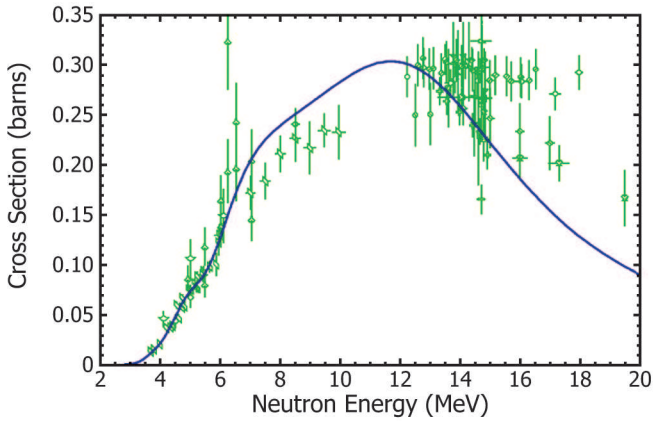
7.1 *Titanium Metal*—High-purity titanium metal in the form of wire or foil is available.

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, scandium impurity must be low because of the reaction, ^{45}Sc(n,γ)^{46}Sc. To reduce this interference, the use of a thermal-neutron shield during irradiation would be advisable if scandium impurity is suspected. As an example, when a titanium sample containing 6 ppm scandium has been irradiated in a neutron field with equal thermal and fast-neutron fluence rates about 1 % of the ^{46}Sc in the sample is due to the reaction ^{45}Sc(n,γ)^{46}Sc.

7.1.2 Tantalum impurities can also cause a problem. The low-energy response of the ^{181}Ta(n,γ)^{182}Ta reaction produces gamma activity that interferes with the measurement of ^{46}Sc radioactivity produced from the ^{46}Ti(n,p)^{46}Sc high-energy threshold reaction. The radioactive ^{182}Ta isotope has a half-life of $\tau_{1/2}$ = ~~114.43~~ 114.61 (13) d and emits a ~~1121.302~~ 1121.290 (3) keV photon ~~34.7 %~~ 35.17 (33) % of the ~~time.~~time (**1**). This photon is very close in energy to one of the two photons emitted by ^{46}Sc ~~(889.3~~ (889.271 (2) keV and ~~1120.5~~ 1120.537 (3) keV). Moreover, during the ^{46}Sc decay, the ~~1120.5~~1120.537 keV and ~~889.3~~889.271 keV photons are emitted in true coincidence and the random coincidence between the ~~1121.302~~1121.395 keV photons from ^{182}Ta and the ~~889.3~~889.271 keV photons from ^{46}Sc can affect the application of summing corrections when the counting is done in a close geometry and the ^{46}Sc activity is being monitoring with ~~889.3~~889.271 keV photon.

7.1.3 Zinc contamination can lead to the production of ^{65}Zn via the ^{64}Zn(n,γ)^{65}Zn reaction. The radioactive ^{65}Zn isotope has a half-life of $\tau_{1/2}$ = ~~243.66~~ 244.01 (9) d and emits a ~~1115.518~~1115.539 keV photon ~~50.75 %~~ 50.22 (11) % of the time. These ~~1115.518~~1115.539 keV photons can interfere with the 1120.5 keV line from ^{46}Sc and require a multi-peak resolution. For a small contaminant level the ^{65}Zn line may be hidden in the background of the larger ^{46}Sc peak. There is no other high probability ^{65}Zn decay gamma with which to monitor or correct for the presence of zinc in the titanium sample.

7.1.4 Impurity problems in titanium are a particular concern for applications to reactor pressure vessel surveillance dosimetry because the ^{46}Ti(n,p)^{46}Sc, along with the ^{63}Cu(n,α)^{60}Co reaction, are the two highest-energy dosimetry reactions used to detect spectrum differences in reactor neutron environments. Incorrect radioactivity measurements of these two reactions can alter the high-energy end of the derived spectrum, and result in the incorrect prediction of neutron irradiation damage.



[9] 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, Gaithersburg, MD, 1994.

FIG. 2 ^{46}Ti(n,p)^{46}Sc Cross Section, from RRDF-2002/IRDFF-1.05, with EXFOR Experimental Data