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AMERICAN SOCIETY FOR TESTING AND MATERIALS
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Standard Test Method for Atom Percent Fission in Uranium and Plutonium Fuel (Mass Spectrometric Method)[1]

This standard is issued under the fixed designation E 244; 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 the determination of the heavy element atom percent fission in irradiated uranium (U) fuel with initial plutonium (Pu) content from 0 to 50 % from isotopic analyses of the fuel before and after irradiation **(1,2).**[2]

1.2 The test method specifies the computational procedures for handling mass spectrometric analyses. Chemical separation procedures and mass spectrometer operation procedures are specified in Test Method E 267.

1.3 The test method is applicable to thermal-reactor U and Pu fuels but does not apply to fuels containing thorium or ^{233}U before irradiation.

1.4 The determination of burnup from changes in isotopic composition has several requirements that limit its usefulness and accuracy. The most obvious requirement is the availability of a pre-irradiation specimen which truly represents the sample to be analyzed. A second limiting requirement is the availability of correct neutron-spectrum-dependent reactor parameters, especially capture-to-fission ratios for ^{235}U, ^{239}Pu, and ^{241}Pu. Finally, many additional factors implicitly assumed to be negligible in this treatment become significant at high exposures.

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 267 Test Method for Uranium and Plutonium Concentrations and Isotopic Abundances[3]

3. Terminology

3.1 *Definitions:*

3.1.1 *gigawatt days per metric ton*—the gigawatt days of heat produced per metric ton of U plus Pu initially present in a nuclear fuel.

3.1.2 *heavy element atom percent fission*—the number of fissions per 100 U plus Pu atoms initially present in a nuclear fuel.

3.2 *Symbols:Symbols*—Symbols used in the procedural equations are defined as follows:

F_5, F_9, F_1, F_8 = heavy element atom percent fission from fission of ^{235}U, ^{239}Pu, ^{241}Pu, and ^{238}U.

F_T = total heavy element atom percent fission.

N_8^0, N_5^0 = heavy element atom percent ^{238}U and ^{235}U, in the pre-irradiated fuel.

$R_{5/8}^0$, $R_{6/8}^0$, $R_{6/5}^0$ = atoms ratios of ^{235}U to ^{238}U, ^{236}U to ^{238}U, and ^{236}U to ^{235}U in the pre-irradiated fuel.

$R_{5/8}$, $R_{6/8}$, $R_{6/5}$ = atom ratios of ^{235}U to ^{238}U, ^{236}U to ^{238}U, and ^{236}U to ^{235}U in the final irradiated sample.

$R_{9/8}$, $R_{0/8}$, $R_{1/8}$, $R_{2/8}$ = atom ratios of ^{239}Pu, ^{240}Pu, ^{241}Pu, and ^{242}Pu to ^{238}U in the final irradiated sample.

$R'_{1/8}$ = atom ratio of ^{241}Pu to ^{238}U in the final irradiated sample corrected for neutron capture, fission, and decay during and after irradiation.

ν_8 = 2.67 ± 0.30 neutrons per fission of ^{238}U **(3).**

ν_5 = 2.426 ± 0.006 neutrons per fission of ^{235}U **(4).**

ν_9/ν_5 = ratio of number of neutrons per fission of ^{239}Pu to ^{235}U = 1.192 ± 0.005 **(4).**

ν_1/ν_5 = ratio of number of neutrons per fission of ^{241}Pu to ^{235}U = 1.237 ± 0.017 **(4).**

t' = elapsed time from the end of irradiation to measurement.

[1] This test method is under the jurisdiction of ASTM Committee C-26 on Nuclear Fuel Cycle.

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[2] The boldface numbers in parentheses refer to the list of references appended to this method.

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

t = irradiation time, s.
λ_1 = decay constant of $^{241}Pu = 1.53 \times 10^{-9}\ s^{-1}$.
c = ratio of the ^{238}U fission rate to the fission rate from all other sources expressed as equivalent ^{235}U fission rate.
ϵ = fast fission factor [defined in Ref **(5)**] which is 1.00 for fully enriched reactors. Typically, ϵ ranges from 1.03 to 1.07 for low enrichment systems.
α_5 = effective ratio of ^{235}U (n, γ) capture-to-fission cross sections obtained from reactor designer, experiment, or machine calculation. If not otherwise available, it may be estimated from Fig. 1 for well-moderated thermal reactors.
α_9 = effective ratio of ^{239}Pu (n, γ) capture-to-fission cross sections obtained from reactor designer, experiment, or machine calculation. If not otherwise available, it may be estimated from Fig. 2 for well-moderated thermal reactors.
α_1 = effective ratio of ^{241}Pu (n, γ) capture-to-fission cross sections = 0.40 ± 0.15 for thermal reactors **(6).** Its neutron spectrum dependence has not been measured.
α_8 = effective ratio of ^{238}U (n, γ) capture-to-fission cross sections averaged over a fission spectrum = 0.58 ± 0.45 **(3).**
r = epithermal index which is a measure of the proportion of epithermal neutrons in a reactor spectrum. In Ref **(7),** r is defined and related mathematically to the cadmium ratio. Note that for $r = 0$ the spectrum is pure Maxwellian.
ϕ = neutron flux, neutrons/cm^2-s.
$\sigma_1, \sigma_5, \sigma_6$ = total neutron absorption cross sections of ^{241}Pu, ^{235}U, and ^{236}U. For boiling water reactors, typical core average values are 188, 64.6, and 5×10^{-23} cm^2, respectively. For pressurized water reactors, typical core average values are 155, 55.6, and 8.4×10^{-23} cm^2, respectively.
P = total ^{239}Pu neutron captures per initial ^{238}U atom.

4. Summary of Test Method

4.1 Atomic ratios of the isotopes ^{235}U, ^{236}U, ^{239}Pu, ^{240}Pu, ^{241}Pu, and ^{242}Pu to ^{238}U are measured by mass spectrometry. The atom percent fission attributed to fission of ^{235}U, ^{238}U, ^{239}Pu, and ^{241}Pu are separately calculated and then summed to obtain the total heavy element atom percent fission **(6, 8).**

5. Significance and Use

5.1 This test method provides a measure of heavy element atom percent fission from which the output of heat during irradiation can be estimated.

5.2 The test method is restricted in use to samples where accurate pre-irradiation isotopic analysis can be obtained. It is recommended that this analysis be obtained on the same instrument, under similar conditions, and at the same time as

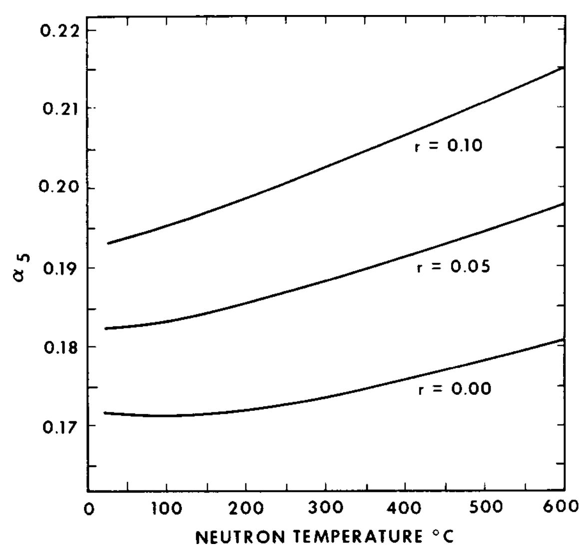

FIG. 1 Calculated Dependence of α_5 on Neutron Temperature and Epithermal Index, *r*, for Well-Moderated Thermal Reactors