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IUPAC Recommendations

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Vocabulary of radioanalytical methods (IUPAC Recommendations 2020)

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Abstract: These recommendations are a vocabulary of basic radioanalytical terms which are relevant to radioanalysis, nuclear analysis and related techniques. Radioanalytical methods consider all nuclear-related techniques for the characterization of materials where 'characterization' refers to compositional (in terms of the identity and quantity of specified elements, nuclides, and their chemical species) and structural (in terms of location, dislocation, *etc.* of specified elements, nuclides, and their species) analyses, involving nuclear processes (nuclear reactions, nuclear radiations, *etc.*), nuclear techniques (reactors, accelerators, radiation detectors, *etc.*), and nuclear effects (hyperfine interactions, *etc.*). In the present compilation, basic radioanalytical terms are included which are relevant to radioanalysis, nuclear analysis and related techniques.

Keywords: nuclear effects; nuclear processes; nuclides; radioanalytical chemistry; terminology.

1 INTRODUCTION

These Recommendations contain terms found in the corresponding chapter of the IUPAC Orange Book, third edition of the Compendium of Analytical Nomenclature (definitive rules 1997) [1], which was based on the Glossary of Terms used in Nuclear Analytical Chemistry published in 1982 [2] and the Nomenclature for Radioanalytical Chemistry, published in 1994 [3]. In addition to terms of analytical interest, terms from nuclear technology, nuclear physics and radioactivity measurements are included. The IUPAC Technical Report on the use of X-ray-based techniques for analysis of trace elements in environmental samples provided a useful overview [4] of techniques using high-energy photons. This Recommendation will furnish terms on radioanalytical chemistry for the new chapter 8 in the next edition of the Orange Book [5].

The available terms in the field of radioanalytical methods were first compiled 20–30 years ago. With the development of modern science and technology, some of the terms are outdated. In the meantime, more and more new terms in the field of radioanalytical methods have appeared or are emerging. In particular, sophisticated nuclear facilities and detectors, like advanced nuclear reactors, dedicated particle accelerators, and various new types of radiation detectors with excellent performance are changing the outlook of radioanalytical methods. For example, many advanced nuclear analytical laboratories across the world have access

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to synchrotron radiation devices and spallation neutron sources. Related new nuclear analytical methods have been established or are being developed for scientific and applied purposes. Various new radioanalytical methods, like neutron scattering, accelerator mass spectrometry, X-ray absorption, and fluorescence methods based on synchrotron radiation have become more and more popular analytical tools.

Following the International Vocabulary of Metrology (VIM) [6] and the present IUPAC format, the concept entries of these Recommendations provide terms, definitions, and explanations through examples and notes. Additionally, the main document the information is taken from (not necessarily verbatim) is stated as "Source" using the respective reference number (*e.g.* [1] for the third edition of the Orange Book). Where there have been changes to wording, the sources are referenced as "Source: Adapted from …". For Recommendations, this change will replace the existing entry. Where a completely rewritten entry is intended to replace an existing Recommendation, this is noted as "Replaces:".

Within a given entry, terms referring to other concepts termed and defined in these Recommendations appear in italics on first use. The same holds for VIM terms, however these are marked with the VIM entry number, *e.g. measurement principle* [VIM 2.4], because the definition is not reproduced here.

2 Terms in radioanalytical chemistry

1 absolute activation analysis

Measurement method [VIM 2.5] of *activation analysis* in which the amounts of elements in a material are measured using a measurement model with known nuclear constants and *irradiation* and *radiation* measurement parameters without the use of a *calibrator* with known property values.

Reference: [7] p 1575. See also: [8]. Replaces: [3] p 2515.

2 absolute activity

See: *activity of a radioactive substance*.

3 absolute counting

Measurement method [VIM 2.5] in which the *counting rate*, observed under well-defined conditions, is used to measure the *activity* of a *radionuclide* without the use of a *calibrator* with known property values.

Replaces: [3] p 2517.

4 absolute counting efficiency

Number of particles or photons counted by a *radiation detector* divided by the number emitted by a *radiation source*.

Source: Adapted from [3] 'counting efficiency'. See: *counting efficiency*.

5 absorption cross section

See: *capture cross section*.

6 absorption edge

See: *X-ray absorption edge*.

7 accelerator mass spectrometry, (AMS)

Mass spectrometry technique in which atoms and molecules from a sample are ionized, accelerated to mega-electron volt (1 MeV = 1.602 176 634 × 10^{-13} J) energies, and separated according to their momentum, charge, and energy, allowing high discrimination for the measurement of *nuclide* abundances.

Note: AMS is typically used for (but not limited to) the measurement of radionuclides with long half-lives, such as ^{10}Be, ^{14}C, ^{26}Al, ^{36}Cl, ^{53}Mn, and ^{129}I.

Source: [9]. See also: [10].

8 activation (in radiation chemistry)

Induction of *radioactivity* by *irradiation*.

Note: In general, the type of incident *radiation* (*e.g.* nuclei, neutron, photon, charged particles) and/or the *energy* of this radiation (*e.g.* cold neutron, *thermal neutron*, *epithermal neutron*, fast neutron. See: *neutron energy*) is specified.

Source: Adapted from [3] p 2515. See also: [7] p 1555, *instrumental activation analysis*.

9 activation analysis

Measurement principle [VIM 2.4] for measuring elemental or isotopic contents in a specified amount of a material, in which the *activity* of *radionuclides* formed directly or indirectly by nuclear reactions of elementary particles, or the absorption of electromagnetic radiation by stable *nuclides*, is measured.

Note: Users should specify the type of incident particle/radiation (*e.g. neutron activation analysis*, photon *activation analysis*, charged particle activation analysis) and its energy (*e.g.* cold neutron activation analysis, (epi)thermal neutron activation analysis, fast neutron activation analysis. (See: *neutron energy*)).

Source: Adapted from [3] p 2515. See also: [7] p 1555.

10 activation cross section

Microscopic cross section for a nuclear reaction resulting in the formation of a *radionuclide* under specified conditions.

Source: [11]. Replaces: [3] p 2517.

11 activity growth curve

Graph of the *activity* of a *radioactive nuclide* as a function of time and showing the increase of activity through the decay of the precursor or as a result of *activation*.

Source: Adapted from [3] p 2515.

12 activity of a radioactive material, *A*

activity
absolute activity
decay rate

Number of nuclear decays occurring in a given quantity of material in a small-time interval, divided by that time interval.

Source: [3] p 2515.

Note 1: For a specified substance B, $A = -\mathrm{d}N_\mathrm{B}/\mathrm{d}t$, where N_B is the number of decaying entities B. (Source: [12] p 24).

Note 2: The SI unit of activity is the *becquerel* (Bq), which is equal to one decay per second (s^{-1}). The Curie (Ci) is a former unit of activity equal to exactly 3.7×10^{10} Bq.

Note 3: The synonym 'disintegration rate' is no longer recommended.

13 analytical radiochemistry

See: *radioanalytical chemistry*.

14 autoradiograph

Radiograph of an object containing a *radioactive* substance, produced by placing the object adjacent to a photographic plate or film or to a fluorescent screen.

Source: [13].

15 autoradiolysis

Radiolysis of a *radioactive* material resulting directly or indirectly from its *radioactive decay*.

Source: [3] p 2516.

16 background radiation

Radiation from any *radioactive source* other than the one it is desired to measure.

Source: [3] p 2516.

17 backscattering analysis

Measurement principle [VIM 2.4] in which the backscattering of *nuclear radiation* impinging on a sample is applied to measure the structure and composition of materials.

18 barn, b

Non-SI unit of area used in expressing nuclear *cross section*. $1\ \mathrm{b} = 1 \times 10^{-28}\ \mathrm{m}^2 = 100\ \mathrm{fm}^2$.

Note: One barn is approximately the area of a nucleus of radius 5.6×10^{-15} m.

19 branching ratio

decay fraction
decay probability

Number of nuclei of a given *radionuclide* divided by the total number of nuclei of that radionuclide that, in *nuclear decay* by two or more different transitions, decays by a specified transition.

Source: [14].

20 calibration, k_0 method

Calibration [VIM 2.39] method of *neutron activation analysis* in which the k_0 proportionality factors, together with a value of the *neutron flux* (as a function of the neutron energy) and with a value of the *radiation detector's* response for gamma radiation (as a function of the gamma-ray energy) are used for establishing a relationship between the number of *counts* measured and the corresponding amounts of elements in a material.

Note: The k_0 proportionality factor is a ratio of the experimentally measured nuclear parameters of the (radio)*nuclides* and those parameters of the respective (radio)*isotopes* of a *calibrator* (often based on Au).

Source: [15].

21 calibrator (in activation analysis)

obsolete: comparator

Measured amount of an element with stated *measurement uncertainty* [VIM 2.26] that is simultaneously irradiated with the sample during *activation analysis*.

Note 1: The term ‘calibrator’ is preferred over ‘comparator’.
Note 2: If one calibrator is used (single calibrator method, which is preferred over “single comparator method”), it is essentially identical to a *flux monitor* (except that the latter is not necessarily linked to activation analysis).

22 capture

See: *nuclear capture*.

23 capture cross section

absorption cross section

Cross section for *nuclear capture*.

Note: Absorption cross section is not recommended because it implies absorption of electromagnetic radiation.

Source: Adapted from [3] p 2516.

24 carrier (in radiation chemistry)

Substance in appreciable concentration that, when associated with an *isotopic tracer* of a specified substance, will carry the tracer with it through a chemical or physical process, or prevent the tracer from undergoing nonspecific processes, due to its low mass fraction or concentration.

Source: [16].

25 carrier-free

See: *no carrier added*.

26 channeling effect

Range- (traveling distance) increasing effect caused by the decrease in interaction cross sections of the incident particles with atoms in a single crystal when a highly collimated particle beam impinges on a crystal along its principal axis or principal plane.

Source: [17].

27 channels ratio method

Measurement method [VIM 2.5] to obtain a *quenching correction* by counting the spectrum in two separate channels, the ratio of which gives the degree of quenching.

Source: [18].

28 characteristic X-radiation

X-radiation consisting of discrete energies that are characteristic for the emitting element.

Note: X-rays are electromagnetic radiation with a wavelength between 10^{-11} and 10^{-8} m, corresponding to energies between 100 keV and 100 eV.

Source: Adapted from [3] p 2526.

29 compton scattering analysis

Measurement principle [VIM 2.4] in which wavelengths and angular distribution of Compton scattered electrons is applied in order to reconstruct X-ray and gamma-ray spectra.

Note: Compton scattering analysis is applied, for example, in mammography.

Source: [19] p 54–66.

30 count

Single event recorded by a *radiation counter*.

Replaces: [3] p 2516.

31 count rate

See: *counting rate*.

32 counting efficiency

intrinsic counting efficiency

Number of particles or photons counted divided by the number that has struck the envelope.

Note: This ratio limits the sensitive volume of a *radiation detector*.

Replaces: [3] p 2517. See also: *absolute counting*, *absolute counting efficiency*.

33 counting geometry

Arrangement in space of the various components of an experiment, particularly the *source* and the *radiation detector* in *radiation* measurements.

Replaces: [3] p 2520.

34 counting loss

Reduction of the *counting rate* resulting from phenomena such as the *dead time of a radiation counter*.
Source: Adapted from [3] p 2517.

Note: Counting loss is corrected for by a *dead time correction* or a *resolving time correction*.

35 counting rate

count rate

Number of *counts* occurring in unit time.

Source: [3] p 2517.

36 cross reactivity

Ability of substances other than the analyte to bind to the binding reagent and ability of substances other than the binding reagent to bind the analyte in *competitive binding assays*.

Note: The binding described here is known as cross reaction.

Source: [3] p 2517, ‘cross reaction’.

37 cross section (in radiation chemistry), *σ*

microscopic cross section

Characteristic area related to the probability of a specified interaction or reaction between an incident nuclear *radiation* and a target particle or system of particles.

Note 1: Cross section is the reaction rate per target particle for a specified process divided by the flux density of the incident radiation.

Note 2: In general, the type of nuclear radiation (*e.g.* neutron, photon), the energy of the incident radiation (*e.g.* thermal, epithermal, fast (See: *neutron energy*)) and the type of interaction of reaction (*e.g.* activation, fission, scattering) are specified.

Example: The capture cross section of ^{10}B for slow neutrons is 200 barn.

Source: [20] p 769. Replaces: [3] p 2517.

38 daughter product

Nuclide which follows a specified *radionuclide* in a *decay chain*.

Source: [3] p 2517.

39 dead time correction of a radiation counter

dead time correction
resolving time correction

Correction to be applied to the observed number of *counts* in order to take into account the number of counts lost during the resolving or *dead time of a radiation counter*.

Note: If the measured number of counts is N_{m} and the true number of counts is N_{true} then for measurements at time t with dead time t_{d},$N_{\mathrm{true}} = N_{\mathrm{m}}/(1 - t_{\mathrm{d}}/t)$.

Source: Adapted from [3] p 2518.

40 dead time of a radiation counter, t_{d}

down time

Time taken for charged particles to reach an electrode in a *radiation counter*, during which time particles are not counted.

Example: The dead time of a *Geiger-Müller counter* is 100–400 μs.

Source: [21]. Replaces: [3] p 2517.

41 decay chain

radioactive chain
radioactive series

Series of *radionuclides* in which each radionuclide transforms into the next through *nuclear decay* until a stable *nuclide* has been formed.

Source: Adapted from [3] p 2518.

42 decay constant of a radionuclide, λ, k

decay rate constant of a radionuclide

Proportionality constant between the *activity* (A) of a specified *radionuclide* and the number of decaying entities (N_{B}), $A = \lambda\, N_{\mathrm{B}}$.

Note 1: The decay constant is related to the *half life of a radionuclide* ($t_{1/2}$) by $t_{1/2} = (\ln 2)/\lambda \approx 0.693/\lambda$.
Note 2: The synonyms ‘disintegration constant of a radionuclide’ and ‘disintegration rate constant of a radionuclide’ are not recommended.

Source: [12] p 24. See also: *mean life of a radionuclide*.

43 decay curve

Graph of the *activity of a radionuclide* against time after a specified reference time.

Replaces: [3] p 2518.

44 decay fraction

See: *branching ratio*.

45 decay probability

See: *branching ratio*.

46 decay rate

See: *activity of a radioactive substance*.

47 decay rate constant of a radionuclide

See: *decay constant of a radionuclide*.

48 delayed-neutron activation analysis, (DNAA)

delayed-neutron analysis, (DNA)
delayed-neutron counting, (DNC)

Neutron activation analysis where neutrons are counted after a delay to allow interfering species to decay.

49 delayed-neutron analysis, (DNA)

See: *delayed-neutron activation analysis*.

50 delayed-neutron counting, (DNC)

See: *delayed-neutron activation analysis*.

51 destructive activation analysis

See: *radiochemical activation analysis*.

52 direct isotope dilution analysis

See: *isotope dilution analysis*.

53 directly-ionizing radiation

Beam of particles capable of removing one or more orbital electrons in a single quantum event from a specified atom resulting in an ion.

Note 1: To have sufficient energy for direct ionization, most ionizing particles are electrically charged, for example, alpha particles, beta particles, electrons, positrons, protons. Photons can ionize atoms directly through the photoelectric effect or the Compton effect.

Note 2: When considering the health effects of radiation, the distinction may be made between multiple ionizations by charged particles as they move through a material (called 'direct ionization') and a single event of ionization caused by a photon.

See also: *indirectly-ionizing radiation*.

Reference: [22] p 11.

54 disintegration constant of a radionuclide

See: *decay constant of a radionuclide*.

55 disintegration rate constant of a radionuclide

See: *decay constant of a radionuclide*.

56 down time

See: *dead time of a radiation counter*.

57 effective cadmium cut-off energy

In a given experimental configuration, the *energy* value determined by the condition that the *radiation detector* response would be unchanged if the cadmium cover surrounding the detector was replaced by a cover opaque to neutrons with *energy* below this value and transparent to neutrons with *energy* above this value.

Note: Typically, the thickness of this cadmium cover is taken to be 1 mm.

Source: [2] p 1540.

58 effective thermal cross section

Westcott cross section

A calculated cross-section for a specified reaction, which, when multiplied by the 2200-m-per-second particle (or photon) flux density, gives the correct reaction rate for *thermal neutrons*.
Source: Adapted from [3] p 2517.

59 energy flux density, J_E

Energy of *radiation* traversing unit area perpendicular to the direction of the energy flow per unit time.

Note: The SI unit of energy flux density is $J\ s^{-1}\ m^{-2} = W\ m^{-2}$

Source: Adapted from [3] p 2519.

60 energy resolution

For a given energy, the smallest difference between the energies of two particles or photons capable of being distinguished by a *radiation counter*.

Note: The energy resolution is often expressed as the Full Width at Half Maximum (FWHM) of the counter's *indication* [VIM 4.1] at a given energy of *radiation*.

Source: Adapted from [3] p 2519. Also See: [23] p 117–118.

61 energy threshold

Limiting kinetic energy of an incident particle or energy of an incident photon below which a specified *nuclear reaction* is not detectable.

Source: [2] p 1541.

62 energy-dispersive X-ray analysis, (EDXA)

See: *energy-dispersive X-ray fluorescence analysis*.

63 energy-dispersive X-ray fluorescence analysis, (EDX)

energy-dispersive X-ray analysis, (EDXA)
energy-dispersive X-ray spectroscopy, (EDS, EDXS)

Measurement method [VIM 2.5] of *X-ray fluorescence analysis* in which the energies and intensities of *characteristic X-radiation* are used to measure amounts of elements.

Note: EDX is often coupled with scanning electron microscopy or *proton-induced X-ray emission*.

Source: [24].

64 energy-dispersive X-ray spectroscopy, (EDS, EDXS)

See: *energy-dispersive X-ray fluorescence analysis*.

65 epicadmium neutron

Neutron of kinetic energy greater than the *effective cadmium cut-off energy*.

Source: Adapted from [3] p 2522.

66 epithermal neutron

Neutron of kinetic energy greater than that of thermal agitation.

Note 1: The term 'epithermal' is often restricted to energies just above thermal. See also: *neutron energy*.

Source: [3] p 2522.

Note 2: Epithermal neutron' is often used interchangeably with *epicadmium neutron*.

67 extended X-ray absorption fine structure, (EXAFS)

Measurement method [VIM 2.5] of *X-ray absorption analysis* in which the fine structure of the adsorption spectrum in the range 30 eV to 1 keV above the adsorption edge is used to measure the number and species of neighbouring atoms, their distance from the selected atom, and the thermal or structural disorder of their positions.

Note 1: In the EXAFS region, interference between the wave functions of the core and neighbouring atoms gives a periodic pattern that contains information characterizing the arrangement of atoms, including the number and type of neighbouring atoms and their distance to the absorbing atom.
Note 2: The method uses synchrotron radiation.

Source: [25, 26]. See also: *X-ray absorption near edge structure*.

68 external standardization for quenching correction

Measurement method [VIM 2.5] to obtain a *quenching correction* through the use of a gamma-radiation source to generate a spectrum of Compton electrons within the sample vial.

Source: [27]. See also: Compton scattering analysis.

69 fluence, *F*, *H*

Energy per area delivered in a given time interval. $F = \int I \ \mathrm{d}t = \int (\mathrm{d}P/\mathrm{d}A)\mathrm{d}t$, where I is intensity, P is power, and A is area.

Note 1: The SI unit of fluence is J m^{-2}.

Source: Adapted from [12] p 35.

70 fluorescence

Prompt (within about 10^{-8} s) emission of electromagnetic radiation caused by the de-excitation of atoms in a material following the initial excitation of these atoms by absorption of energy from incident *radiation* or particles.

Note 1: Fluorescence is often specified by the type of incident radiation, such as *X-ray fluorescence*.

Replaces: [3] p 2519. See also: *prompt gamma radiation*.

71 fluorescence yield

For a given transition from an excited state of a specified atom, the number of excited atoms that emit a photon divided by the total number of excited atoms.

Source: Adapted from [3] p 2526. See also: [28].

72 flux depression

Reduction of particle (or photon) flux density in the neighbourhood of an object due to absorption and/or scattering of these particles (or photons) in the object.

Source: Adapted from [3] p 2519. See also: [29].

73 flux monitor

Radiation detector to measure energy flux density.

Note: A flux monitor may be a known amount of material irradiated together with a sample; the induced *radioactivity* is used to measure the flux density during the irradiation.

Replaces: [3] p 2519.

74 flux perturbation

Change of *energy flux density* or energy distribution of particles or photons in an object as a result of effects such as *flux depression* and/or *self-shielding*.

Source: Adapted from [3] p 2519. See also: [30].

75 gamma-ray spectrometry

obsolete: gamma-ray spectroscopy

Measurement principle [VIM 2.4] of the quantitative study of the energy spectra of gamma-ray sources.

Source: [31].

76 geiger-Müller counter

Gas-filled X-ray detector in which gas amplification reaches saturation and proportionality no longer exists. The output signal does not depend on the incident energy.

Note 1: Radiation detected includes alpha particles, beta particles, and gamma rays using the ionization effect produced in a Geiger–Müller tube, which gives its name to the instrument [32].
Note 2: Geiger-Müller counters are in wide use as a hand-held radiation survey instrument.
Note 3: The time taken for the counter to recover from saturation is called *dead time*.

Adapted from [33] p 1754.

77 geometry factor

Average solid angle in steradians at a *source* subtended by the aperture or sensitive volume of the *radiation detector*, divided by 4π.

Source: [3] p 2520.

78 half life of a radionuclide, $t_{1/2}$, $T_{1/2}$

Time for a number of decaying entities (N_B) to be reduced to one half of that value. $N_B(t_{1/2}) = N_B(0)/2$.

Note: *Half life* is related to the *decay constant of a radionuclide* λ by $t_{1/2} = (\ln 2)/\lambda$.

Source: Adapted from [12] p 24. Replaces: [3] p 2520. See also: [34] p 63, *average life of a radionuclide*.

79 half thickness

See: *half -value thickness*.

80 half-value thickness

half thickness
half-value layer thickness

Thickness of a specified material that, when introduced into the path of a given beam of *radiation*, reduces the intensity of a specified radiation by one half.

Source: [3] p 2520. See also: [35].

81 hot atom

Atom in an excited energy state or having kinetic energy above the ambient thermal level, usually as a result of nuclear processes.

Source: [3] p 2520. See also: [36].

82 hot cell

Heavily shielded enclosure for highly *radioactive* materials.

Note: A hot cell may be used for handling or processing highly radioactive materials by remote means or for their storage.

Source: Adapted from [3] p 2520.

83 indirectly-ionizing radiation

Beam of electrically neutral particles that cause *ionization* by interacting with atoms in a material, producing electrically-charged particles that subsequently cause direct ionization (See: *directly-ionizing radiation*) in the material.

Examples: Gamma-rays and X-rays, which produce electrons, and neutrons, which produce alpha and beta particles.

Reference: [22] p 11.

84 instrumental activation analysis

non-destructive activation analysis

Measurement method [VIM 2.5] of *activation analysis* in which the amounts of elements in a material are measured using a *measurement model* [VIM 2.48] with known nuclear constants and *irradiation* and *radiation* measurement parameters, as well as a *calibrator* with known property values, without chemical processing after the *irradiation*.

Source: [7] p 1569. See also: [37].

85 intrinsic counting efficiency

See: *counting efficiency*.

86 *in-vivo* neutron activation analysis

Measurement method [VIM 2.5] of *neutron activation analysis* in which a living organism is exposed to neutrons to measure the concentrations of elements in that living organism.

Note 1: The neutrons are typically provided by a neutron beam.
Note 2: Often *prompt gamma-ray analysis* is used to measure half-value thickness, rather than the *activity* of neutrons produced.

Source: [7] p 1567. See also: [38].

87 ion beam analysis, (IBA)

Measurement principle [VIM 2.4] in which elementary particles resulting from *nuclear reactions* of charged particles with nuclei in a material are applied in order to measure the amount and depth distribution of elements in materials.

Source: [39] p 632.

88 ionizing radiation

Radiation with sufficient *energy* to liberate electrons from atoms or molecules, thereby ionizing them.

Note: Radiation may be termed directly-ionizing radiation or indirectly-ionizing radiation.

Source: Adapted from [3] p 2520.

89 irradiation

Exposure to *radiation*.

Source: Adapted from [3] p 2520.

90 isotope dilution

Mixing of a given *nuclide* with one or more of its *isotopes*.

Source: [3] p 2521.

91 isotope dilution analysis, (IDA)

direct isotope dilution analysis
radioisotope dilution analysis

Measurement principle [VIM 2.4] in which the amount of an element in a substance is measured by adding to that substance a known amount of a *radionuclide* of that element and mixing it with a stable *isotope* of this element in the substance; a measurement is subsequently made of the *activity* of that *radionuclide* in a subsample taken from the mixture.

Note: IDA may be classified in terms of (i) the manner of introducing radioactivity into the system; (ii) the method of measuring the activity; (iii) number of dilution steps; (iv) the relative masses of sample and diluent.

Source: [40] p 1–16. See also: [41] p 122–124. Replaces: [3] p 2521.

92 isotope effect

isotopic effect

Effect on the rate constant or equilibrium constant of two reactions that differ only in the isotopic composition of one or more of their otherwise chemically identical components, which is then referred to as a kinetic isotope effect or a thermodynamic (or equilibrium) isotope effect, respectively. (See: *isotopes*).

Note: Reference [42] pp 1130–1131 defines heavy atom isotope effect, intramolecular isotope effect, inverse isotope effect, kinetic isotope effect, primary isotope effect, secondary isotope effect, solvent isotope effect, steric isotope effect, and thermodynamic (equilibrium) isotope effect.

Source: Adapted with minor change from [42] p 1130. See also: [43, 44].

93 isotope exchange

See: *isotopic exchange*.

94 isotopes

isotopic nuclides

Nuclides having the same atomic number but different mass numbers.

Examples: ^{12}C and ^{13}C; ^{1}H, ^{2}H and ^{3}H.

Note 1: If no left superscript is added denoting the mass number, an element symbol is read as including all isotopes in natural abundance.

Source: Adapted from [12] p 49.

Note 2: The use of the singular term '*isotope*' should always relate to a particular element (*e.g.* deuterium is an isotope of hydrogen). When used in a general sense, the term *nuclide* is preferred (*e.g.* *radionuclides* are used in the treatment of cancer).

See also: *radioisotope*.

95 isotopic carrier

Excess of a substance, differing only in isotopic composition from an *isotopic tracer*, which will carry the tracer through a chemical or physical process, preventing the tracer from undergoing non-specific processes due to its low concentration.

Source: Adapted from [3] p 2516.

96 isotopic effect

See: *isotope effect*.

97 isotopic enrichment

Any process by which the isotopic abundance of a specified isotope in a mixture of *isotopes* of an element is increased.

Source: [2] p 1541.

Note: When the specified isotope is stable, the process is termed 'stable isotopic enrichment'.

98 isotopic exchange

isotope exchange

Exchange of places between *isotopes* of atoms in different chemical or physical states or positions.

Source: [3] p 2521.

99 isotopic exchange analysis

Measurement principle [VIM 2.4] based on *isotopic exchange* to measure the amount of the corresponding element.

Source: Adapted from [3] p 2521 and [45] p 52.

100 isotopic label

Radioactive or stable *isotope* of a specified element distinguishable by the observer but not by the system used to identify an *isotopic tracer*.

Note 1: 'Isotopic labelling' is the incorporation of an isotopic label in a substance. It may be qualified by the manner of introduction of the label, *e.g.* exchange labelling, conjugation labelling, recoil labelling.

Example: Deuterium ('isotopic label') that is substituted for protium in the illegal drug methylamphetamine, for use in analysis by mass spectrometry. Methylamphetamine incorporating deuterium is the 'isotopic tracer'.

Note 2: In general usage, 'label' and 'tracer' are used synonymously. See: [46] 4.1.12.

Source: Adapted from [3] p 2521.

101 isotopic nuclides

See: *isotopes*.

102 isotopic tracer

Isotopically labelled molecule (See: *isotopic label*) used to measure certain properties of a system.

Source: Adapted from [3] p 2526. See also: *isotopic enrichment*.

Example: Deuterium (‘isotopic label’) that is substituted for protium in the illegal drug methylamphetamine, for use in analysis by mass spectrometry. Methylamphetamine incorporating deuterium is the ‘isotopic tracer’.

Note: In general usage, label and tracer are often used synonymously. See: [46] 4.1.12.

103 lifetime of a radionuclide

See: *mean life of a radionuclide*.

104 liquid scintillation detector

Scintillation detector in which the sample is mixed with a liquid *scintillator*.

Source: Adapted from [3] p 2522.

105 live time

Time interval during which a *radiation detector* is capable of processing events.

Note 1: Live time equals the clock time minus the integrated resolving or *dead time*.
Note 2: Live time should not be confused with the ‘lifetime’ of a radioactive species.

Source: Adapted from [3] p 2522 and [47].

106 macroscopic cross section

Cross section per unit volume of a given material for a specified process.

Note: For a pure *nuclide*, it is the product of the *microscopic cross section* and the number of target nuclei per unit volume; for a mixture of *radionuclides*, it is the sum of such products.

Source: Adapted from [3] p 2517 and [21].

107 mean life of a radionuclide, τ

average life of a radionuclide
lifetime of a radionuclide

Reciprocal of the *decay constant of a radionuclide* (λ). $\tau = 1/\lambda$.

Note: The mean life is greater than the *half life of a radionuclide* by the factor $1/\ln 2$ (≈ 1.44); the difference arises because of the weight given in the averaging process to the fraction of atoms that by chance survives for a long time.

Source: Adapted from [12] p 24.

108 microscopic cross section

See: *cross section (in radiation chemistry)*.

109 moderator

Material used to reduce the *energy* of a neutron by scattering without appreciable *capture*.

Source: [3] p 2522.

110 molar activity of a radionuclide, A_m(R)

molar activity

Activity of a specified *radionuclide* (R) per unit amount of substance of the specified radionuclide.

Note 1: The SI unit of molar activity is Bq mol^{-1}. Also used is Ci $mmol^{-1}$. (Curie, symbol Ci, is a former unit of activity equal to exactly 3.7×10^{10} Bq.)

Note 2: If the term "molar activity" is used without qualification, it should be made clear whether it refers to a material or a radionuclide. See: *molar activity of a radionuclide in a material*.

Replaces: [3] p 2515. See also *specific activity of a radionuclide*.

111 molar activity of a radionuclide in a material, A_m(R, M)

molar activity

Activity of a specified *radionuclide* (R) in a material (M) divided by amount of substance of that material.

Note 1: The SI unit of molar activity is Bq mol^{-1}, but molar activity is often expressed in unit Ci $mmol^{-1}$. (Curie, symbol Ci, is a former unit of activity equal to exactly 3.7×10^{10} Bq.)

Note 2: If the term "molar activity" is used without qualification, it should be made clear whether it refers to a material or a radionuclide. See: *molar activity of a radionuclide*.

Example: The certificate of analysis of adenosine 5′-triphosphate containing the *isotopic label* ^{33}P (called ^{33}P-gamma-ATP) quotes the activity as 3000 Ci $mmol^{-1}$ [48]. Using the recommended symbol, $A_m(^{33}\text{P,ATP}) = 3000$ Ci $mmol^{-1}$.

Replaces: [3] p 2515. See also: *specific activity of a radionuclide in a material*.

112 monoisotopic element

Chemical element having only one stable *nuclide*.

Note 1: There are 26 elements that follow the definition: ^{9}Be, ^{19}F, ^{23}Na, ^{27}Al, ^{31}P, ^{45}Sc, ^{51}V, ^{55}Mn, ^{59}Co, ^{75}As, ^{85}Rb, ^{89}Y, ^{93}Nb, ^{103}Rh, ^{113}In, ^{127}I, ^{133}Cs, ^{139}La, ^{141}Pr, ^{153}Eu, ^{159}Tb, ^{165}Ho, ^{169}Tm, ^{175}Lu, ^{185}Re, ^{197}Au.

Note 2: General usage of the term "monoisotopic" refers to the 21 elements with one isotope determining their relative atomic masses, *i.e.* ^{9}Be, ^{19}F, ^{23}Na, ^{27}Al, ^{31}P, ^{45}Sc, ^{55}Mn, ^{59}Co, ^{75}As, ^{89}Y, ^{93}Nb, ^{103}Rh, ^{127}I, ^{133}Cs, ^{141}Pr, ^{159}Tb, ^{165}Ho, ^{169}Tm, ^{197}Au, ^{209}Bi, ^{231}Pa.

Reference: [49].

113 mössbauer spectrometry

Measurement method [VIM 2.5] in which recoil-less resonance gamma ray *scattering* and absorption in solids is applied to measure the nuclear environment of atoms of elements in a material.

Source: [50]. See also: [51].

114 muon induced X-ray emission analysis

Measurement method [VIM 2.5] of *X-ray analysis* in which *characteristic X-radiation* emitted upon *irradiation* of a material with a beam of muons of certain energy is used to measure the chemical composition and chemical state of an element.

115 near edge X-ray absorption fine structure, (NEXAFS)

Measurement method [VIM 2.5] of *X-ray absorption analysis* similar to *X-ray absorption near edge structure*, but usually reserved for soft X-rays with photon energy less than 1 keV.

Note: NEXAFS is generally used in surface and molecular science.

116 neutron activation analysis, (NAA)

Activation analysis using neutrons as the incident particles.

117 neutron density

Number of free neutrons divided by their containing volume.

Note: Partial densities may be defined for neutrons characterized by such parameters as *neutron energy* and direction.

Source: [52].

118 neutron depth profiling, (NDP)

Measurement method [VIM 2.5] of *activation analysis* for near-surface-depth light elements in which a *thermal* neutron or cold neutron (see: neutron energy) beam passes through a material with target nuclei that emit monoenergetic charged particles upon neutron absorption. The reduction of the energy of an emitted charged particle measures the depth of the target nuclei in a material.

Source: [53].

119 neutron diffraction analysis

Measurement method [VIM 2.5] in which the *diffraction* of neutrons is applied to measure parameters of the atomic and/or magnetic structure of a material.

Source: [54, 55].

120 neutron energy

Kinetic *energy* of a free neutron.

Note 1: Neutron energy is usually given with unit electronvolt (eV). 1 eV = $1.602\,176\,634 \times 10^{-19}$ J.

Note 2: Neutrons are classified according to their energies as follows:

Neutron energy range (in eV)	Name
0.0–0.025	cold neutron
0.025 (corresponding to 295 K)	*thermal neutron*
0.025–0.4	*epithermal neutron*
0.4–0.6	cadmium neutron
0.6–1	*epicadmium neutron*
1–10*	slow neutron
10–300	*resonance neutron*
$300–1 \times 10^6$	intermediate neutron
$(1–20) \times 10^6$	fast neutron
$>20 \times 10^6$	ultrafast neutron

*Slow neutron also may be defined as any neutron below a threshold which may vary over a wide range and depends on the application. In reactor physics, the threshold value is frequently chosen to be 1 eV; in dosimetry, the effective cadmium cut-off is used. See: [2] p 1547.

Note 3: *Neutron temperature* has unit kelvin, and the term should not be used for the neutron energy.

Source: [56, 57].

121 neutron scattering analysis

Measurement method [VIM 2.5] in which the elastic or inelastic *scattering* of neutrons by the target nuclei is applied to study the composition and structure of a material.

Source: [58, 59].

122 neutron temperature

Temperature assigned to a population of neutrons when this population is approximated by a Maxwellian distribution.

Source: [2] p 1547.

Note: Neutron temperature (T) is related to the *neutron energy* (E) $T = 2E/3k$, where k is the Boltzmann constant.

Source: Adapted from [60].

123 no carrier added, (NCA)

carrier-free

Preparation of a *radioactive isotope* which is essentially free from *stable isotopes* of the element in question.

Source: [3] p 2522. See also: *isotopic carrier*.

124 non-destructive activation analysis

See: *instrumental activation analysis*.

125 non-radiative quenching

Deactivation of an electronically-excited state by interaction with the external environment through a non-radiative process.

Note 1: Non-radiative quenching may lead to spectral shift or *counting losses*.
Note 2: The effects of quenching may be taken into account by a *quenching correction*.

Source: Adapted from [3] p 2523. See also: [61] p 26.

126 nuclear capture
capture

Process in which an atomic nucleus acquires an additional particle.

Note 1: The captured particle may be an elementary particle (See: [2] p 1547) and may be charged or neutral.
Note 2: In general, a specification is added of the type of the captured particle or its energy.

Example: Gold-197 captures a neutron and emits a gamma ray:
^{197}Au + n → ^{198}Au + γ, or in short form ^{197}Au(n, γ)^{198}Au.

Source: Adapted from [3] p 2513. See also: *capture cross section*.

127 nuclear chemistry

Scientific discipline that deals with the study of nuclei, *nuclear decay*, nuclear reactions, and nuclear processes using chemical methods.

Source: Adapted from [3] p 2516 and [2] p 1537.

128 nuclear decay

Spontaneous nuclear transformation.

Source: [3] p 2518.

129 nuclear fission

Exoergic division of a nucleus into two or more parts with masses of approximate equal order of magnitude, usually accompanied by the emission of neutrons, gamma radiation, and, rarely, small charged nuclear fragments.

Source: Adapted from [3] p 2519.

130 nuclide

Atom of specified atomic number (proton number) and mass number (nucleon number).

Note 1: A nuclide may be specified by attaching the mass number as a left superscript to the symbol for the element, as in ^{14}C, or added with a hyphen after the name of the element, as in carbon-14.
Note 2: Nuclide is the general term used when referring to all elements. The term '*isotopes*' should only be used to describe nuclides of a particular element (*i.e.* same atomic number *Z*).

Note 3: The prefix 'radio' may be added to denote that the nuclide is *radioactive*. See: *radionuclide*, *radioisotope*.

Source: Adapted from [12] p 49. Replaces: [3] p 2522.

131 nuclide precursor

Radionuclide which precedes a *nuclide* in a *decay chain*.

Source: Adapted from [3] p 2523.

132 particle (or photon) flux density, *j*

obsolete: fluence rate

Number of particles (or photons) incident on a plane perpendicular to the incident radiation per unit time per unit area.

Note 1: Particle flux density is identical with the product of the particle density and the average speed of the particles.
Note 2: The SI unit of flux density is $m^{-2}\ s^{-1}$.
Note 3: Often an indication of the type of incident particles is wrongly added to the unit of flux density, *e.g.*, the neutron flux density is sometimes indicated as $n\ cm^{-2}\ s^{-1}$. As 'n' is not a unit, it is metrologically unacceptable and therefore not recommended.

Replaces: [3] p 2519. See also: [12] p 44, Note (26) to the definition of diffusion coefficient on p 43.

133 particle induced X-ray emission analysis, (PIXE)

Measurement method [VIM 2.5] of *X-ray analysis* in which *energies* and intensities of *characteristic X-radiation* emitted by a test portion during *irradiation* with charged particles other than electrons are used to measure the amounts of elements in a material.

Note 1: The particle inducing the X-radiation is sometimes explicitly mentioned, *e.g.* proton-induced X-ray emission analysis.
Note 2: Micro PIXE (μ-PIXE) uses highly collimated beams to analyse very small areas.

Source: [62].

134 particle-induced gamma-ray-emission analysis, (PIGE)

Measurement principle [VIM 2.4] in which the *energies* and intensities of characteristic *prompt gamma-radiation* emitted during *nuclear reactions* with charged particles other than electrons is used to measure the amounts of elements in a material.

Note: The particle that induces gamma-rays may be explicitly mentioned, *e.g.* 'proton-induced gamma-ray-emission analysis'.

Source: [63] p 546.

135 perturbed angular correlation spectrometry, (PAC)

perturbed directional correlation spectrometry

Measurement method [VIM 2.5] of *gamma-ray spectrometry* in which coincidence counting is used for the measurement of parameters describing hyperfine interactions, with internal or external electrical or magnetic field gradients, of the spin of an intermediate level between two gamma-ray transitions in cascade emitted in the decay of a *radionuclide*.

Note 1: Perturbed angular correlation spectrometry can be performed both in a time-differential (TDPAC) and in a time-integrated (TIPAC) mode of measurement.

Note 2: The parameters describing hyperfine interactions provide information on the chemical atomic environment of the decaying nucleus.

Source: [64] p 997.

136 perturbed directional correlation spectrometry

See: *perturbed angular correlation spectrometry*.

137 positron annihilation analysis, (PAA)

positron annihilation spectroscopy for chemical analysis, (PASCA)

Measurement principle [VIM 2.4] in which the annihilation of positrons is applied to study the microscopic structure of materials.

Note 1: Annihilation lifetime (See: *positron lifetime spectrometry*), Doppler broadening, and the angular correlation of annihilation radiation are measured in this technique.

Note 2: In the most common case of positron annihilation, two photons are created, each with energy equal to the rest energy of the electron or positron (0.511 MeV = $8.187\,122\,600 \times 10^{-14}$ J).

Note 3: Techniques based on PAA have been used particularly for the study of free volume in polymers.

Source: [65].

138 positron annihilation lifetime spectrometry, (PALS)

See: *positron lifetime spectrometry*.

139 positron annihilation spectroscopy for chemical analysis, (PASCA)

See: *positron annihilation analysis*.

140 positron emission tomography, (PET)

Imaging method based on the detection of pairs of gamma rays emitted indirectly by a positron-emitting *isotopic tracer*.

Note 1: A commonly used *nuclide* is fluorine-18.

Note 2: Three-dimensional imaging is obtained using computed tomography.

Source: [66].

141 positron lifetime spectrometry, (PLS)

positron annihilation lifetime spectrometry, (PALS)

Measurement method [VIM 2.5] of *positron annihilation analysis* in which the time interval between the emission of positrons from a *radioactive source* and the detection of gamma rays due to the annihilation of these positrons with electrons from the surrounding matter is the lifetime of the positron or positronium.

Source: [67] p 500.

142 prompt gamma radiation

Gamma *radiation* emitted during the de-excitation of a compound nucleus formed in a nuclear capture reaction.

143 prompt gamma-ray analysis, (PGA)

deprecated: prompt gamma activation analysis**,** (PGAA)
deprecated: prompt gamma neutron activation analysis, (PGNAA)

Measurement principle [VIM 2.4] in which gamma radiation emitted during the de-excitation of the compound nucleus formed by neutron capture is applied to measure the amounts of elements in a material.

Note: The measurement method is often denoted as prompt gamma-ray neutron activation analysis (PGNAA) or prompt gamma-ray activation analysis (PGAA), though the measurement method is not in agreement with the definition of *activation analysis*. The term prompt gamma-ray analysis (PGA) is therefore preferred.

Source: [38, 68].

144 pulse pile-up

Processing by a *radiation counter* of pulses resulting from the simultaneous absorption of independent particles or photons in a *radiation detector*, resulting in them being counted as one single particle or photon with energy between the individual energies and the sum of these energies.

Source: [69] p 655.

145 quenching correction

Correction for errors due to different *quenching in radiation detectors* for standards and samples.

Note: For example, when using *liquid scintillation detectors*, these corrections can be based on the standard addition or sample *channels ratio method* or the use of automated *external standardization*.

Source: Adapted from [3] p 2523.

146 quenching in radiation detectors

Process of inhibiting continuous or multiple discharges following a single ionizing event in certain types of radiation detectors, particularly in *Geiger-Müller counters*.

Source: [70]. See: *quenching correction*.

147 radiation

Emission of energy as electromagnetic waves or as fast-moving subatomic particles.

Note: In *radioanalytical chemistry*, the term usually refers to radiation used and emitted during nuclear processes (*e.g.*, *radioactive decay*, *nuclear decay*, *nuclear fission*).

Source: Adapted from [3] p 2523. See also: *ionizing radiation*.

148 radiation chemistry

Sub-discipline of chemistry that deals with the chemical effects of *ionizing radiation*.

Note: Radiation chemistry is distinguished from photochemistry, which is associated with visible and ultraviolet electromagnetic *radiation*.

Source: Adapted from [3] p 2523 and [71] p1.

149 radiation counter

counter

Measuring system [VIM 3.2] for measuring r*adiation*, comprising a *radiation detector*, in which events caused by interaction of the *radiation* with the radiation detector result in electrical pulses, and the associated equipment for processing and counting the pulses.

Note: Often an expression is added indicating the type of radiation detector (*e.g*. ionization, *scintillation*, semiconductor).

Source: Adapted from [3] p 2516.

150 radiation detector

Measuring system [VIM 3.2] or material for the conversion of *radiation energy* to a kind of energy which is suitable for indication and/or measurement.

Note: Detectors are usually named by the principle of detection or kind of material, *e.g. scintillation detector*, *semiconductor detector*

Source: Adapted from [2] p 1540.

151 radiation filter

Material interposed in the path of *radiation* to modify the energy distribution of the radiation.

Source: Adapted from [2] p 1542.

152 radioactive

Property of a *nuclide* undergoing spontaneous nuclear transformations with the emission of *radiation*.

Source: [3] p 2523.

Note 1: Such a nuclide may be termed a *radionuclide*.
Note 2: ‘Radioactive’ is also used to describe a material that includes a radionuclide.

153 radioactive chain

See: *decay chain*.

154 radioactive decay

Nuclear decay in which particles or electromagnetic *radiation* are emitted or the nucleus undergoes spontaneous fission or electron capture.

Source: [3] p 2518.

155 radioactive equilibrium

See: *radioactive steady state*.

156 radioactive purity

See: *radionuclide purity*.

157 radioactive series

See: *decay chain*.

158 radioactive source

Radioactive material that is intended for use as a source of *ionizing radiation*.

Source: Adapted from [3] p 2526.

159 radioactive steady state

radioactive equilibrium
secular equilibrium

Among the *radionuclides* of a *decay chain,* the state that prevails when the ratios between the *activities* of successive radionuclides remain constant.

Note: This is not equilibrium in the strict sense, since *radioactive decay* is an irreversible process.

Source: Adapted from [3] p 2519, [72] p 185.

160 radioactivity

Phenomenon of *nuclides* undergoing *radioactive decay*.

Source: Adapted from [3] p 2513.

161 radioanalytical chemistry

analytical radiochemistry

That part of analytical chemistry in which the application of *radioactivity* is an essential step in the analytical procedures.

Source: [2] p 1535.

Note 1: Use is made of nuclear processes (*e.g.*, *nuclear decay*, *nuclear fission*), nuclear effects, *radiation*, and nuclear facilities, as well as of radiochemical and nuclear measurement techniques.
Note 2: Radioanalytical chemistry is part of *radiochemistry*.

162 radiochemical activation analysis

destructive activation analysis

Measurement method [VIM 2.5] of *activation analysis* in which concentrations or mass contents of elements in a material are measured using a *measurement model* [VIM 2.48] with known nuclear constants, *irradiation* and *radiation* measurement parameters, and the use of a *calibrator* with known property values and in which chemical separation is applied after the irradiation.

Source: [7] p 1583. See also: [73].

163 radiochemical purity

For a material, the fraction of the stated *radionuclide* present in the stated chemical form.

Source: [3] p 2523.

Note 1: The unit of radiochemical purity is mol/mol = 1.

Note 2: The medical literature often defines radiochemical purity as the fraction of the radioactivity of a material in a stated chemical form. (See: [74] p347, and *radionuclide purity*.).

164 radiochemical recoil effect

See: *Szilard-Chalmers effect*.

165 radiochemical separation

Separation, by a chemical means, of *radionuclide*(s) of a specific element from a mixture of radionuclides of other chemical elements.

Source: [3] p 2526.

166 radiochemical yield

Activity of a specified *radionuclide* of a specified element after its *radiochemical separation* divided by its activity originally present in the substance undergoing *radiochemical separation*.

Source: Adapted from [3] p 2526.

167 radiochemistry

Part of chemistry which deals with *radioactive* materials.

Note: Radiochemistry includes the production of *radionuclides* and their compounds by processing irradiated materials or naturally occurring radioactive materials, the application of chemical techniques to nuclear studies, and the application of *radioactivity* to the investigation of chemical, biochemical, or any other problems.

Source: Adapted from [3] p 2524 and [75] p 1423.

168 radioenzymatic assay

Measurement principle [VIM 2.4] in which a *radioactive* substrate is applied to measure the catalytic activity of an enzyme.

Source: Adapted from [3] p 2524 and [76] p 259.

169 radiograph

Visual representation of an object produced by placing the object between a source of *ionizing radiation* and a photographic plate, film, or detector.

Source: Adapted from [3] p 2524.

Note: Radiographs are used in medicine and dentistry.

170 radiogravimetric analysis

Measurement principle [VIM 2.4] in which the *activity* of a precipitate is applied to measure its mass.

Source: Adapted from [3] p 2524.

171 radioiodination

Incorporation of a *radionuclide* of iodine into a substance, or of covalently linking a radioiodinated substance to a substance.

Note: Commonly used radionuclides of iodine are ^{129}I, ^{131}I, and ^{123}I.

Source: Adapted from [3] p 2524.

172 radioisotope

A *radioactive* isotope (See: *isotopes*) of a specified element.

Source: [3] p 2524.

173 radioisotope dilution analysis

See: *isotope dilution analysis*.

174 radioisotope induced X-ray emission analysis

Measurement method [VIM 2.5] of *X-ray analysis* in which a *radioactive source* is used for irradiation of the sample.

Source: [19].

175 radiolysis

Chemical decomposition of materials by *ionizing radiation*.

Source: [3] p 2524.

176 radiometric analysis

Measurement principle [VIM 2.4] in which the *activity* of a *radioactive* component with known specific activity is applied in order to measure the amount of an element in a material.

Source: [77] p 564. Replaces: [3] p 2524.

177 radiometric titration

Titration in which a *radioactive* indicator is used to monitor the end-point of the titration.

Source: [3] p 2524. See also: [78] p 168.

178 radionuclide

Nuclide that is *radioactive*.

Source: [3] p 2524.

Note: When an element is specified, the radionuclide is termed a *radioisotope*.

179 radionuclide purity

radionuclidic purity
radioactive purity

Activity of a stated *radionuclide*, including *daughter products*, in a material divided by the total activity of the material.

Source: Adapted from [3] p 2523.

Note 1: The SI unit of radionuclide purity is Bq/Bq = 1.
Note 2: Radionuclide purity is important for calibrators, *isotopic tracers*, and in pharmaceutical uses.

Example: Activity of ^{99m}Tc from a Mo generator with impurities ^{99}Mo, ^{95}Nb, ^{188}Re, ^{198}Au, *etc*. (Note that ^{99}Tc is generated as a daughter product from ^{99}Mo, directly or *via* ^{99m}Tc.)

180 radionuclidic purity

See: *radionuclide purity*.

181 radioreceptor assay

Measurement principle [VIM 2.4] in which labelled (See: *isotopic label*) and unlabelled molecules, assumed to bind to a receptor at random, are applied to measure the amount of an analyte by exposing a mixture of the sample and a known amount of the radiolabelled substance to a measured amount of receptors for the analyte.

Note: The analyte is typically a hormone.

Source: [79].

182 recoil

Nuclear phenomenon in which an atom or a particle undergoes movement through a collision with, or the emission of, another particle or electromagnetic *radiation*.

Source: Adapted from [3] p 2524.

183 recoil effect

See: *Szilard-Chalmers effect*.

184 recovery time of a radiation counter

Period of time after the *dead time of a radiation counter* during which the output pulses are smaller than the original.

Note: Depending on the sensitivity of the *counter*, some pulses in this period will not be counted.

Source: [21].

185 relative counting

Measurement method [VIM 2.5] in which the *activity* of a sample is measured from the *counting rate* of the sample divided by the counting rate of a *radioactive source* of known activity.

Source: Adapted from [3] p 2525.

186 relative counting efficiency

Absolute counting efficiency of a given *radiation counter* divided by the absolute counting efficiency of a reference radiation counter.

187 resolving time correction

See: *dead time correction of a radiation counter*.

188 resolving time of a radiation counter, τ

Smallest time interval which can elapse between the occurrence of two consecutive ionizing events, in order that the *radiation counter* is capable of fulfilling its function for each of the two occurrences separately.

Source: [2] p 1551.

189 resonance energy

Minimum *energy* of a particle entering a *nuclear reaction*, required to form reaction products in one of their excited states.

Source: Adapted from [3] p 2525.

190 resonance integral, I_X

Integral, over all or some specified portion of the *resonance energy* range, of the *cross section* divided by the energy of a *radiation*.

$$I_X = \int_{E_c}^{\infty} \sigma_X(E) \frac{dE}{E}$$

where X denotes the nature of the radiation (n for neutron, fis for neutron induced fission), σ_X the cross section, and E_C the lower limit of energy (*e.g. effective cadmium cut-off energy*)

Note: In *radioanalytical chemistry*, the resonance integral range coincides with the definition of the *epithermal neutron* energy range.

Source: [80] p 199. See also: [81]. Replaces: [3] p 2525.

191 resonance neutron

Neutron, the energy of which corresponds to the *resonance energy* of a specified *nuclide* or element.

Note: If the nuclide is not specified, the term refers to a resonance neutron of ^{238}U.

192 reversed isotope dilution analysis

Isotope dilution analysis in which the amount of an *isotopic carrier* in a solution of a *radionuclide* is measured by addition of one of its stable isotopes.

Source: [41] p 122–124.

193 saturation (in radiation chemistry)

Of an irradiated element for a specified *nuclide*, the steady state reached when the *decay rate* of the *nuclide* formed is equal to its production rate.

Source: Adapted from [3] p 2525.

194 saturation activity, A_s

For a specified *radionuclide*, the maximum *activity* at *saturation*.

$A_s = \sigma \times \Phi$, where σ is the *cross section* and Φ the *particle flux density*.

Replaces: [3] p 2525.

195 scanning proton microscopy, (SPM)

Measurement method [VIM 2.5] of *X-ray fluorescence analysis* in which protons are focused and collimated to form a micro beam to obtain an image of a surface.

196 scavenging of radionuclides

scavenging

In *radiochemistry*, the use of a precipitate to remove from solution a large fraction of one or more *radionuclides* by absorption or co- precipitation.

Note: In *radiation chemistry*, the term scavenging is used to denote the binding of radicals or free electrons with a receptive (or reactive) material.

Source: Adapted from [3] p 2525.

197 scintillation

Burst of luminescence caused by an individual energetic particle.

Source: Adapted from [3] p 2525.

198 scintillation detector

Kind of *radiation detector* having a *scintillator* to measure *ionizing radiation*.

Replaces: [3] p 2525.

199 scintillator

Material in which *scintillation* occurs.

Note: A scintillator may be a solid or a liquid (See: *liquid scintillation detector*). See: *scintillation detector*.

Replaces: [3] p 2525.

200 secular equilibrium

See: *radioactive steady state*.

201 selectively-labelled isotopic tracer

An isotopically labelled compound is designated as selectively labelled when a mixture of isotopically substituted compounds is formally added to the analogous isotopically unmodified compound in such a way that the position(s), but not necessarily the number, of each labelling *nuclide* is defined.

Note: A selectively labelled compound may be considered a mixture of *specifically-labelled isotopic tracers*.

Source: [82] p 1893.

202 self-absorption factor

source efficiency

Intensity of *radiation* emitted by a *source* divided by the intensity of radiation produced by *radionuclides* present in the source.

Source: [83]. Replaces: [3] p 2525.

203 self-absorption of radiation

Absorption of *radiation* by the emitting source.

Source: [3] p 2525. See also: [84] p 7.

204 self-shielding

Decrease of particle flux density in the inner part of an object due to interactions in its outer layers.

Source: Adapted from [3] p 2525.

205 semiconductor detector

Kind of *radiation detector* using a semiconductor material, in which free electric charge carriers are produced along the path of incident *ionizing radiation*, in combination with a high voltage and electrodes for the collection of these charge carriers.

Source: [3] p 2526.

206 sensitive volume of a radiation detector

That volume of a *radiation detector* where an incident radiant power produces a measurable output.

Source: [33] p 1751.

207 solid phase antibody radioimmunoassay

Measurement method [VIM 2.5] of *radioimmunoassay* employing an antibody, made into an *isotopic tracer* by labelling with a *radionuclide*, bound to a solid phase.

Source: Adapted from [3] p 2524. See also: [46] 4.1.12.

208 source efficiency

See: *self-absorption factor*.

209 specific activity of a radionuclide, A_S(R)

specific activity

Activity of a specified *radionuclide* (R) per unit mass of that nuclide.

Note: If the term "specific activity" is used without qualification, it should be made clear whether it is of a material or of a radionuclide. See: *specific activity of a radionuclide in a material*.

Example: Specific activity of tritium (^{3}H) is 3.57×10^{17} Bq kg^{-1} (9.65 Ci mg^{-1}) [85].

Source: [86] p 206. Replaces: [3] p 2515. See also: [16].

210 specific activity of a radionuclide in a material, A_S(R, M)

specific activity

Activity of a specified *radionuclide* (R) in a material (M) divided by the mass of that material.

Note 1: It is implicitly assumed that the various isotopes (stable and *radioactive* ones) are present in the same chemical and physical form, and thus will behave fully identically in radiochemical processing and a radionuclide application, *i.e.* nuclidic exchange with other chemical forms is prohibited or at least very slow compared to the duration of the experiment.

Note 2: The SI unit of specific activity is Bq kg^{-1}, but specific activity is often expressed in unit s^{-1} g^{-1} or Ci mg^{-1}. (Curie, symbol Ci, is a former unit of activity equal to exactly 3.7×10^{10} Bq.)

Note 3: Commercial preparations of isotopically-labelled molecules often quote 'specific activity' in Ci mmol^{-1}. The correct term is *molar activity of a radionuclide in a material*.

Note: If the term "specific activity" is used without qualification it should be made clear whether it is of a material or of a *radionuclide*. See: *specific activity of a radionuclide*.

Example: Certificate of analysis of adenosine 5′-triphosphate solution isotopically-labelled with [γ^{-33}P] gives "Specific activity 370 MBq/g"

Source: [86] p 206. Replaces: [3] p 2515.

211 specifically-labelled isotopic tracer

Isotopic tracer in which the *isotopic label* is present in a specified position in the molecule.

Source: Adapted from [3] p 2526. See also: *selectively-labelled isotopic tracer*.

Note: The name of a specifically labelled compound is formed by inserting in square brackets the nuclide symbol(s), preceded by any necessary locant(s) (letters and/or numerals), before the name or preferably before the name for that part of the compound that is isotopically modified. Immediately after the brackets there is neither space nor hyphen, except that when the name, or a part of the name, requires a preceding locant, a hyphen is inserted.

Example: H[^{36}Cl], hydrogen [^{36}Cl]chloride. Ge[$^2H_2$]F_2, difluoro[$^2H_2$]germane, [^{15}N]H_2[^{2}H], [$^2H_1$, ^{15}N]ammonia.
Source: [82] p 1892.

212 stereospecifically-labelled isotopic tracer

Isotopic tracer in which the *isotopic label* is present in a stereo-specific position in the molecule.

Source: Adapted from [3] p 2526.

213 substoichiometric isotope dilution analysis

Isotope dilution analysis in which a substoichiometric amount of a *radionuclide* of the element to be measured is added to both a sample and to a *calibrator* and subsequently, after mixing, the specific activities of that *radionuclide* are measured in equal amounts of the sample and calibrator.

Source: [41] p 122–124.

214 synchrotron radiation induced X-ray fluorescence analysis

Measurement method [VIM 2.5] of *X-ray fluorescence analysis* in which synchrotron X- radiation is used to irradiate the substance.

Source: [87].

215 szilard-Chalmers effect

Radiochemical recoil effect
Recoil effect

Rupture of the chemical bond between an atom and the molecule of which the atom is a part as a result of *nuclear reaction* of that atom.

Source: Adapted from [3] p 2525. See also: [88] p 240.

216 thermal neutron

Neutron in thermal equilibrium with the medium in which it exists.

Note: Thermal neutrons have an average energy of approximately 0.025 eV and an average speed of 2200 m s^{-1}.

Source: Adapted from [3] p 2522.

217 total reflection X- ray fluorescence analysis, (TXRF)

Measurement method [VIM 2.5] of *X-ray fluorescence analysis* in which a collimated X-ray flux impinges on a smooth surface under a grazing angle; rendering total reflection is used to excite atoms in the top layers of the material for measurement of the amounts of elements.

Note: The method is highly sensitive because interfering X-rays of higher energies are refracted or adsorbed. Mass fractions of 10^{-12} (ng kg^{-1}) may be measured.

Source: [89].

218 two-site immunoradiometric assay

See: *two-site radioimmunoassay*.

219 two-site radioimmunoassay

two-site immunoradiometric assay

Radioimmunoassay in which two sets of antibodies, one of which is isotopically labelled (See: *isotopic label*), combine with different immunoreactive sites of an antigen molecule.

Source: [90]. See also: See also: [46] 4.1.12.

220 uniformly-labelled isotopic tracer

Isotopic tracer in which the *isotopic label* is uniformly distributed over its possible positions in a molecule.

Source: [3] p 2526.

221 wavelength-dispersive X-ray fluorescence analysis

Measurement method [VIM 2.5] of *X-ray fluorescence analysis* in which the wavelength spectrum of the emitted *radiation* is used to measure the amounts of elements.

Note: A diffraction grating or crystal is used to obtain the spectrum.

Source: [91].

222 Westcott cross section

See: *effective thermal cross section*.

223 Wilzbach labelling

Isotopic labelling (See: *isotopic label*) of a substance by exposing it to tritium gas.

224 X-ray absorption analysis, (XAA)

X-ray absorption spectroscopy, (XAS)

Measurement principle [VIM 2.4] of *X-ray analysis* in which the absorption spectrum is used to measure the number of atoms, species, and other parameters of chemical elements.

Note: XAS measures changes in the linear absorption coefficient of an element in a sample as a function of incident photon energy.

Note: XAS requires a highly monochromatic (with $\Delta E/E \approx 10^{-4}$ to 10^{-5}), high flux X-ray beam.

Source: [25, 26]. See also: X-ray absorption near edge structure,

225 X-ray absorption edge

Absorption edge

Increase in X-ray absorption observed at the energy at which a strongly bound electron is released.

Source: [92].

226 X-ray absorption near edge fine structure

See: *X-ray absorption near edge structure*.

227 X-ray absorption near edge structure, (XANES)

X-ray absorption near edge fine structure

Measurement method [VIM 2.5] of *X-ray absorption analysis* in which the fine structure of the adsorption spectrum in the range 30 eV below to 50 eV above the *adsorption edge* is used to measure parameters describing the chemical state, coordination environment, and local geometry distortion for the X-ray absorbing atom.

Note: The method uses synchrotron radiation.
Note: The *wavelength* of the emitted photoelectrons is longer than the interatomic distances between the absorbing atom and its nearest neighbours.

Source: [25, 92]. See also: *near edge X-ray absorption fine structure*, *extended X-ray absorption fine structure*.

228 X-ray absorption spectroscopy, (XAS)

See: *X-ray absorption analysis*.

229 X-ray analysis

Measurement principle [VIM 2.4] in which *characteristic X-radiation*, produced upon *irradiation* of a material with elementary particles or photons, is applied to measure amounts of elements in a material.

Source: [62, 93].

230 X-ray computed micro-tomography, (XCMT)

X-ray micro-tomography, (XMT)

Measurement method [VIM 2.5] based on the transmission of X-rays to obtain three-dimensional images of a sample.

Note: Spatial resolution is in the range 100 nm to 10 μm.

Source: [4].

231 X-ray diffraction analysis

X-ray diffraction, (XRD)

Measurement method [VIM 2.5] using diffraction of X-radiation to obtain the spatial arrangement of atoms in a crystalline sample.

Note: Bragg reflection follows $n\lambda = 2\,d \sin\theta$, where λ is the X-ray wavelength, d is the spacing between atomic planes, and θ is the angle of diffraction.
Note: Copper K–α radiation (λ = 0.15406 nm, E = 8.04 keV) is typically used for routine XRD.

232 X-ray diffraction, (XRD)

See: *X-ray diffraction analysis*.

233 X-ray fluorescence analysis

X-ray fluorescence spectroscopy

Measurement method [VIM 2.5] of *X-ray fluorescence* used to measure amounts of elements in a material.

Note: Micro-XRF (μ-XRF) analysis uses highly brilliant X-ray sources (synchrotron source and spot size 100 nm to 2 μm) and microfocussing X-ray optics to give fg to ag detection limits [4].

Source: [94].

234 X-ray fluorescence microscopy, (XRM)

Measurement method [VIM 2.5] of *X-ray fluorescence* to obtain quantitative and spatial information about elements in a sample.

Note 1: X-ray beam energies of 5–25 keV excite core level vacancies and promote hard X-ray emission, for which the fluorescence yield is high.

Note 2: Spatial resolution is typically in the range from 200 nm to 10 μm, but, using specialised probes at synchrotron facilities, the lower limit can be decreased to tens of nm [95].

Source: [4].

235 X-ray fluorescence spectroscopy

See: *X-ray fluorescence analysis*.

236 X-ray fluorescence, (XRF)

Emission of *characteristic X-radiation* by an atom after the photoemission of inner-shell electrons and the refilling of the vacated energy level by outer-shell electrons.

Note: X-ray fluorescence is the measurement principle [VIM 2.4] of X-ray fluorescence analysis and X-ray fluorescence microscopy.

Source: [96, 97].

237 X-ray micro-tomography, (XMT)

See: *X-ray computed micro-tomography*.

LIST OF SYMBOLS and ABBREVIATIONS

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