


**Vocabulary of radioanalytical methods**

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Complete List of Authors:	Chai, Zhifang; Institute of High Energy Physics Chinese Academy of Sciences, Lab. Nuclear Analytical Techniques ; Chatt, Amares; Dalhousie University, Department of Chemistry Bode, Peter; Delft University of Technology Faculty Applied Sciences, Department Radiation Science and Technology Kucera, Jan; Nuclear Physics Institute Czech Academy of Sciences Greenberg, Robert; NIST Hibbert, David; University of New South Wales, School of Chemistry
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# Vocabulary of radioanalytical methods (IUPAC Recommendations 201x)

Zhifang Chai<sup>1</sup>, Amares Chatt<sup>2</sup>, Peter Bode<sup>3</sup>, Jan Kucera<sup>4</sup>, Robert Greenberg<sup>5</sup>, D. Brynn Hibbert<sup>6‡</sup>

<sup>1</sup>Lab. Nuclear Analytical Techniques Institute of High Energy Physics Chinese Academy of Sciences, P.O.Box 918, Beijing 100049,

<sup>2</sup>Trace Analysis Research Centre, Department of Chemistry, Dalhousie University, Halifax, Nova Scotia B3H 4J3 Canada

<sup>3</sup>Delft University of Technology, Reactor Institute Delft, Mekelweg 15, NL-2629 JB Delft, The Netherlands

<sup>4</sup>Nuclear Physics Institute CZ-25068, Rez near Prague, Czech Republic

<sup>5</sup>National Institute of Standards and Technology, 100 Bureau Drive, 8395 Building 235, Rm B176, Gaithersburg,

<sup>6</sup> School of Chemistry, UNSW Sydney, NSW 2052, Australia

‡ Corresponding author: School of Chemistry, UNSW Sydney, NSW 2052, Australia. [b.hibbert@unsw.edu.au](mailto:b.hibbert@unsw.edu.au)

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

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[https://iupac.org/projects/project-details/?project\\_nr=2010-030-1-500](https://iupac.org/projects/project-details/?project_nr=2010-030-1-500)).

## 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 are included from nuclear technology, nuclear physics and radioactivity measurements. 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 twenty to thirty 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. Particularly, sophisticated nuclear facilities and detectors, like advanced nuclear reactors, dedicated particle accelerators, and various new types of radiation detectors with excellent performances are changing the outlook of radioanalytical methods. For example, many advanced nuclear analytical laboratories in the world have access 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 present IUPAC format, the concept entries of these Recommendations provide term, definition and explanations by 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). Changes to wording are referenced as "Source: Adapted from ...", and for Recommendations this change will replace the existing entry. Where a completely rewritten entry is 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.

## 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, *irradiation* and *radiation* measurement parameters without the use of a *calibrator* with known property values.

Reference: [7] p1575. See also: [8]. Replaces: [3] p 2515.

1           **2. absolute activity**  
2  
3

4           See: *activity of a radioactive substance*.

5  
6           **3. absolute counting**  
7

8           *Measurement method* [VIM 2.5] in which the observed *counting rate* under well-  
9 defined conditions is used to measure the *activity* of a *radionuclide* without the use  
10 of a *calibrator* with known property values.  
11

12           Replaces: [3] p 2517.

13  
14  
15           **4. absolute counting efficiency**  
16

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

19           Source: Adapted from [3] ‘counting efficiency’. See: *counting efficiency*.

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23           **5. absorption cross section**  
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25           See: *capture cross section*.

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27  
28           **6. absorption edge**  
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30           See: *X-ray absorption edge*.

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33           **7. accelerator mass spectrometry, (AMS)**  
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35           Mass spectrometry technique in which atoms and molecules from a sample are  
36 ionized, accelerated to mega-electron volt ( $1 \text{ MeV} = 1.602\,176\,634 \times 10^{-13} \text{ J}$ )  
37 energies and separated according to their momentum, charge, and energy, allowing  
38 high discrimination for measurement of *nuclide* abundances.  
39

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

42                       Source: [9]. See also: [10].  
43

44  
45  
46           **8. activation (in radiation chemistry)**  
47

48           Induction of *radioactivity* by *irradiation*.

49           Note:       In general, a specification is added of the type of incident *radiation* (e.g.  
50                       nuclei, neutron, photon, charged particles) and/or the *energy* of this  
51                       radiation (e.g. cold neutron, *thermal neutron*, *epithermal neutron*, fast  
52                       neutron. See: *neutron energy*).  
53

54                       Source: Adapted from [3] p 2515. See also: [7] p1555, *instrumental activation*  
55                       *analysis*.  
56

## 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 absorption of electromagnetic radiation by stable *nuclides*, is measured.

Note: A specification is added of the type of the 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] p1555.

## 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 *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,  $A = -dN_B/dt$  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 ( $s^{-1}$ ). Curie (Ci) is a former unit of activity equal to exactly  $3.7 \times 10^{10}$  Bq.

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

## 13. analytical radiochemistry

See: *radioanalytical chemistry*.

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**14. autoradiograph**

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

Source: [13].

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**15. autoradiolysis**

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

Source: [3] p 2516.

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**16. background radiation**

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

Source: [3] p 2516.

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**17. backscattering analysis**

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

**18. barn, b**

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

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

**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 relation 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 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 this term 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 which, 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

1 collimated particle beam impinges on a crystal along its principal axis or principal  
2 plane.  
3

4 Source: [17].  
5  
6

### 7 **27. channels ratio method**

8  
9 *Measurement method* [VIM 2.5] to obtain a *quenching correction* by counting the  
10 spectrum in two separate channels, the ratio of which gives the degree of  
11 quenching.  
12

13 Source: [18].  
14  
15

### 16 **28. characteristic X-radiation**

17 X-radiation consisting of discrete energies which are characteristic for the emitting  
18 element.  
19

20 Note: X-rays are electromagnetic radiation with wavelength between  $10^{-11}$   
21 and  $10^{-8}$  m, corresponding to energies between 100 keV and 100 eV.  
22

23 Source: Adapted from [3] p 2526.  
24  
25

### 26 **29. Compton scattering analysis**

27  
28 *Measurement principle* [VIM 2.4] in which wavelengths and angular distribution  
29 of Compton scattered electrons is applied for reconstruction of X-ray and gamma-  
30 ray spectra.  
31

32 Note: Compton scattering analysis is applied e.g. in mammography.  
33

34 Source:[19] p 54-66.  
35  
36

### 37 **30. count**

38 Single event recorded by a *radiation counter*.  
39

40 Replaces: [3] p 2516.  
41  
42

### 43 **31. count rate**

44 See: *counting rate*.  
45  
46

### 47 **32. counting efficiency**

48 intrinsic counting efficiency  
49

50 Number of particles or photons counted divided by the number that has struck the  
51 envelope.  
52

53 Note: This ratio limits the sensitive volume of a *radiation detector*.  
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Replaces: [3] p 2517. See also: *absolute counting*, *absolute counting efficiency*.

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4 **33. counting geometry**

5  
6 Arrangement in space of the various components of an experiment, particularly the  
7 *source* and the *radiation detector* in *radiation* measurements.  
8

9 Replaces: [3] p 2520.

10  
11  
12 **34. counting loss**

13  
14 Reduction of the *counting rate* resulting from phenomena such as the *dead time of*  
15 *a radiation counter*.  
16

17 Source: Adapted from [3] p 2517.

18  
19 Note: Counting loss is corrected for by a *dead time correction* or a *resolving*  
20 *time correction*.  
21

22  
23 **35. counting rate**

24 count rate

25  
26 Number of *counts* occurring in unit time.  
27

28 Source: [3] p 2517.

29  
30  
31 **36. cross reactivity**

32  
33 Ability of substances other than the analyte to bind to the binding reagent and  
34 ability of substances other than the binding reagent to bind the analyte in  
35 *competitive binding assays*.  
36

37 Note: Binding described here is known as cross reaction.

38 Source: [3] p 2517, 'cross reaction'.  
39

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42  
43 **37. cross section (in radiation chemistry),  $\sigma$**   
44 microscopic cross section

45  
46 Characteristic area related to the probability of a specified interaction or reaction  
47 between an incident nuclear *radiation* and a target particle or system of particles.  
48

49 Note 1: Cross section is the reaction rate per target particle for a specified  
50 process divided by the flux density of the incident radiation.  
51

52 Note 2: In general, a specification is added of the type of nuclear radiation (e.g.  
53 neutron, photon), the energy of the incident radiation (e.g. thermal,  
54 epithermal, fast (See: *neutron energy*)) and the type of interaction of  
55 reaction (e.g. activation, fission, scattering).  
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1 Example: The capture cross section of  $^{10}\text{B}$  for slow neutrons is 200 barn.

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

5  
6 **38. daughter product**

7  
8 *Nuclide* which follows a specified *radionuclide* in a *decay chain*.

9  
10 Source:[3] p 2517.

11  
12  
13 **39. dead time correction of a radiation counter**

14 dead time correction

15 resolving time correction

16  
17 Correction to be applied to the observed number of *counts* in order to take into  
18 account the number of counts lost during the resolving or *dead time of a radiation*  
19 *counter*.

20  
21 Note: If the measured number of counts is  $N_m$  and the true number of counts is  
22  $N_{\text{true}}$  then for measurements at time  $t$  with dead time  $t_d$ ,  
23  $N_{\text{true}} = N_m / (1 - t_d/t)$ .

24  
25  
26 Source: Adapted from [3] p 2518.

27  
28  
29 **40. dead time of a radiation counter,  $t_d$**

30 down time

31  
32 Time taken for charged particles to reach an electrode in a *radiation counter*,  
33 during which time particles are not counted.

34  
35 Example: The dead time of a *Geiger-Müller counter* is 100 to 400  $\mu\text{s}$ .

36  
37 Source: [21]. Replaces: [3] p 2517.

38  
39  
40 **41. decay chain**

41 radioactive chain

42 radioactive series

43  
44 Series of *radionuclides* in which each radionuclide transforms into the next through  
45 *nuclear decay* until a stable *nuclide* has been formed.

46  
47 Source: Adapted from [3] p 2518.

48  
49  
50 **42. decay constant of a radionuclide,  $\lambda$ ,  $k$**

51 decay rate constant of a radionuclide

52  
53 Proportionality constant between the *activity* ( $A$ ) of a specified *radionuclide* and  
54 the number of decaying entities ( $N_B$ ).  $A = \lambda N_B$ .

1 Note 1: The decay constant is related to the *half life of a radionuclide* ( $t_{1/2}$ ) by  $t_{1/2}$   
2 =  $(\ln 2)/\lambda \approx 0.693/\lambda$ .  
3

4 Note 2: Synonyms ‘disintegration constant of a radionuclide’ and  
5 ‘disintegration rate constant of a radionuclide’ are not  
6 recommended.  
7  
8

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

10  
11 **43. decay curve**

12 Graph of the *activity of a radionuclide* against time after a specified reference time.  
13

14 Replaces: [3] p 2518.  
15

16 **44. decay fraction**

17 See: *branching ratio*.  
18

19 **45. decay probability**

20 See: *branching ratio*.  
21

22 **46. decay rate**

23 See: *activity of a radioactive substance*.  
24

25 **47. decay rate constant of a radionuclide**

26 See: *decay constant of a radionuclide*.  
27

28 **48. delayed-neutron activation analysis, (DNAA)**

29 delayed-neutron analysis, (DNA)

30 delayed-neutron counting, (DNC)

31 *Neutron activation analysis* where neutrons are counted after a delay to allow  
32 interfering species to decay.  
33

34 **49. delayed-neutron analysis, (DNA)**

35 See: *delayed-neutron activation analysis*.  
36

37 **50. delayed-neutron counting, (DNC)**

38 See: *delayed-neutron activation analysis*.  
39

40 **51. destructive activation analysis**

41 See: *radiochemical activation analysis*.  
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1           **52. direct isotope dilution analysis**  
2

3           See: *isotope dilution analysis*.  
4

5           **53. directly-ionizing radiation**  
6

7           Beam of particles capable of removing one or more orbital electrons in a single  
8 quantum event from a specified atom resulting in an ion.  
9

10           Note 1:     To have sufficient energy for direct ionization most ionizing particles  
11                    are electrically charged, for example, alpha particles, beta particles,  
12                    electrons, positrons, protons. Photons can ionize atoms directly through  
13                    the photoelectric effect or the Compton effect.  
14

15           Note 2:     When considering health effects of radiation, the distinction may be made  
16                    between multiple ionizations by charged particles as they move through  
17                    a material (called 'direct ionization'), and a single event of ionization  
18                    caused by a photon.  
19

20           See also: *indirectly-ionizing radiation*.  
21

22           Reference: [22] p 11.  
23

24           **54. disintegration constant of a radionuclide**  
25

26           See: *decay constant of a radionuclide*.  
27

28           **55. disintegration rate constant of a radionuclide**  
29

30           See: *decay constant of a radionuclide*.  
31

32           **56. down time**  
33

34           See: *dead time of a radiation counter*.  
35

36           **57. effective cadmium cut-off energy**  
37

38           In a given experimental configuration, the *energy* value determined by the  
39                    condition that the *radiation detector* response would be unchanged if the cadmium  
40                    cover surrounding the detector was replaced by a cover opaque to neutrons with  
41                    *energy* below this value and transparent to neutrons with *energy* above this value.  
42

43           Note:       Typically, the thickness of this cadmium cover is taken to be 1 mm.  
44

45           Source: [2] p 1540.  
46

47           **58. effective thermal cross section**  
48

49           Westcott cross section  
50

1 A calculated cross-section for a specified reaction, which, when multiplied by the  
2 2200-metre-per-second particle (or photon) flux density, gives the correct reaction  
3 rate for *thermal neutrons*.  
4

5  
6 Source: Adapted from [3] p 2517.  
7

8 **59. energy flux density,  $J_E$**   
9

10 *Energy of radiation* traversing unit area perpendicular to the direction of the  
11 energy flow per unit time.  
12

13  
14 Note: The SI unit of energy flux density is  $J s^{-1} m^{-2} = W m^{-2}$   
15

16 Source: Adapted from [3] p 2519.  
17

18 **60. energy resolution**  
19

20 For a given energy, the smallest difference between the energies of two particles or  
21 photons capable of being distinguished by a *radiation counter*.  
22

23  
24 Note: The energy resolution is often expressed as the Full Width at Half  
25 Maximum (FWHM) of the counter's *indication* [VIM 4.1] at a given  
26 energy of *radiation*.  
27

28  
29 Source: Adapted from [3] p 2519. Also See: [23] p 117-118.  
30

31 **61. energy threshold**  
32

33 Limiting kinetic energy of an incident particle or energy of an incident photon  
34 below which a specified *nuclear reaction* is not detectable.  
35

36 Source: [2] p 1541.  
37

38  
39 **62. energy-dispersive X-ray analysis, (EDXA)**  
40

41 See: *energy-dispersive X-ray fluorescence analysis*.  
42

43  
44 **63. energy-dispersive X-ray fluorescence analysis, (EDX)**  
45

46 energy-dispersive X-ray analysis, (EDXA)  
47 energy-dispersive X-ray spectroscopy, (EDS, EDXS)  
48

49 *Measurement method* [VIM 2.5] of *X-ray fluorescence analysis* in which the  
50 energies and intensities of *characteristic X-radiation* are used to measure amounts  
51 of elements.  
52

53 Note: EDX is often coupled with scanning electron microscopy, or *proton-*  
54 *induced X-ray emission*.  
55

56 Source: [24].  
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**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 which contains information characterizing the arrangement of atoms, including 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* by use of a gamma-radiation source to generate a spectrum of Compton electrons within the sample vial.

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

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**69. fluence,  $F$ ,  $H$** 

Energy per area delivered in a given time interval.  $F = \int I dt = \int (dP/dA)dt$ , where  $I$  is intensity,  $P$  is power and  $A$  is area.

Note: 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 de-excitation of atoms in a material following the initial excitation of these atoms by absorption of energy from incident *radiation* or particles.

Note: 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 which 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].

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**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].

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**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.

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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].

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Note 2: Geiger-Müller counters are in wide use as a hand-held radiation survey instrument.

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Note 3: The time taken for the counter to recover from saturation is called *dead time*.

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Adapted from [33] p 1754.

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**77. geometry factor**

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

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Source: [3] p 2520.

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

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

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

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

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**79. half thickness**

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See: *half-value thickness*.

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**80. half-value thickness**

half thickness  
half-value layer thickness

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1 Thickness of a specified material which, when introduced into the path of a given  
2 beam of *radiation*, reduces the intensity of a specified radiation by one half.  
3

4 Source: [3] p 2520. See also: [35].  
5  
6

7 **81. hot atom**

8 Atom in an excited energy state or having kinetic energy above the ambient  
9 thermal level, usually as a result of nuclear processes.  
10  
11

12 Source: [3] p 2520. See also: [36].  
13  
14

15 **82. hot cell**

16 Heavily shielded enclosure for highly *radioactive* materials.  
17

18 Note: A hot cell may be used for handling or processing highly radioactive  
19 materials by remote means or for their storage.  
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22 Source: Adapted from [3] p 2520.  
23  
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25 **83. indirectly-ionizing radiation**

26 Beam of electrically neutral particles that cause *ionization* by interaction with  
27 atoms in a material producing electrically-charged particles that subsequently cause  
28 direct ionization (See: *directly-ionizing radiation*) in the material.  
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31 Examples: Gamma-rays and X-rays which produce electrons, and neutrons which  
32 produce alpha and beta particles.  
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34

35 Reference: [22] p 11.  
36  
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38 **84. instrumental activation analysis**  
39 non-destructive activation analysis  
40

41 *Measurement method* [VIM 2.5] of *activation analysis* in which the amounts of  
42 elements in a material are measured using a *measurement model* [VIM 2.48] with  
43 known nuclear constants, *irradiation* and *radiation* measurement parameters and  
44 the use of a *calibrator* with known property values, without the use of chemical  
45 processing after the *irradiation*.  
46  
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48 Source: [7] p 1569. See also: [37].  
49  
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51 **85. intrinsic counting efficiency**

52 See: *counting efficiency*.  
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**86. *in-vivo* neutron activation analysis**

*Measurement method* [VIM 2.5] of *neutron activation analysis* in which a living organism is exposed to neutrons for measuring 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 for the measurement of 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

1 the substance, and subsequent measurement of the *activity* of that *radionuclide* in a  
2 subsample taken from the mixture.  
3

4  
5 Note: IDA may be classified in terms of (i) the manner of introducing  
6 radioactivity into the system; (ii) the method of measuring the activity;  
7 (iii) number of dilution steps; (iv) relative masses of sample and  
8 diluent.  
9

10 Source: [40] p 1-16. See also: [41] p 122-124. Replaces: [3] p 2521.  
11

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13 **92. isotope effect**  
14 isotopic effect  
15

16 Effect on the rate constant or equilibrium constant of two reactions that differ only  
17 in the isotopic composition of one or more of their otherwise chemically identical  
18 components is referred to as a kinetic isotope effect or a thermodynamic (or  
19 equilibrium) isotope effect, respectively. (See: *isotopes*).  
20

21  
22 Note: Reference [42] pp 1130 – 1131 defines heavy atom isotope effect,  
23 intramolecular isotope effect, inverse isotope effect, kinetic isotope  
24 effect, primary isotope effect, secondary isotope effect, solvent isotope  
25 effect, steric isotope effect, and thermodynamic (equilibrium) isotope  
26 effect.  
27

28  
29 Source: Adapted with minor change from [42] p 1130. See also: [43, 44].  
30

31 **93. isotope exchange**  
32

33 See: *isotopic exchange*.  
34

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36 **94. isotopes**  
37 isotopic nuclides  
38

39 *Nuclides* having the same atomic number but different mass numbers.  
40

41 Examples:  $^{12}\text{C}$  and  $^{13}\text{C}$ ;  $^1\text{H}$ ,  $^2\text{H}$  and  $^3\text{H}$ .  
42

43  
44 Note 1: If no left superscript is added denoting the mass number an element  
45 symbol is read as including all isotopes in natural abundance.  
46

47 Source: Adapted from [12] p 49.  
48

49  
50 Note 2: The use of the singular term '*isotope*' should always relate to a  
51 particular element (e.g. deuterium is an isotope of hydrogen). When  
52 used in a general sense, the term *nuclide* is preferred (e.g. *radionuclides*  
53 are used in the treatment of cancer).  
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55 See also: *radioisotope*.  
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**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'.

1 Note 2: In general usage 'label' and 'tracer' are used synonymously. See: [46]  
2 4.1.12.  
3

4 Source: Adapted from [3] p 2521.  
5

### 6 **101. isotopic nuclides**

7 See: *isotopes*.

### 8 **102. isotopic tracer**

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

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

12 Example: Deuterium ('isotopic label') that is substituted for protium in the illegal  
13 drug methylamphetamine, for use in analysis by mass spectrometry.  
14 Methylamphetamine incorporating deuterium is the 'isotopic tracer'.  
15

16 Note: In general usage label and tracer are often used synonymously. See: [46]  
17 4.1.12.  
18

### 19 **103. lifetime of a radionuclide**

20 See: *mean life of a radionuclide*.

### 21 **104. liquid scintillation detector**

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

23 Source: Adapted from [3] p 2522.  
24

### 25 **105. live time**

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

27 Note 1: Live time equals the clock time minus the integrated resolving or *dead*  
28 *time*.

29 Note 2: Live time should not be confused with 'lifetime' of a radioactive  
30 species.  
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32 Source: Adapted from [3] p 2522 and [47].  
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### 34 **106. macroscopic cross section**

35 *Cross section* per unit volume of a given material for a specified process.  
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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,  $\tau$**

average life of a radionuclide  
lifetime of a radionuclide

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

Note: The mean life is greater than the *half life of a radionuclide* by the factor  $1/\ln 2$  ( $\approx 1.44$ ); 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,  $A_m(\text{R})$**

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  $\text{Bq mol}^{-1}$ . Also used is  $\text{Ci mmol}^{-1}$ . (Curie, symbol Ci, is a former unit of activity equal to exactly  $3.7 \times 10^{10}$  Bq.)

Note 2: If the term “molar activity” is used without qualification it should be made clear whether it is of a material or of 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,  $A_m(\text{R},\text{M})$**

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<sup>-1</sup>, but molar activity is often expressed in unit Ci mmol<sup>-1</sup>. (Curie, symbol Ci, is a former unit of activity equal to exactly  $3.7 \times 10^{10}$  Bq.)

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

Example: The certificate of analysis of adenosine 5'-triphosphate containing the *isotopic label* <sup>33</sup>P (called <sup>33</sup>P-gamma-ATP) quotes the activity as 3000 Ci mmol<sup>-1</sup> [48].

Using the recommended symbol,  $A_m(^{33}\text{P},\text{ATP}) = 3000 \text{ Ci mmol}^{-1}$ .

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: : <sup>9</sup>Be, <sup>19</sup>F, <sup>23</sup>Na, <sup>27</sup>Al, <sup>31</sup>P, <sup>45</sup>Sc, <sup>51</sup>V, <sup>55</sup>Mn, <sup>59</sup>Co, <sup>75</sup>As, <sup>85</sup>Rb, <sup>89</sup>Y, <sup>93</sup>Nb, <sup>103</sup>Rh, <sup>113</sup>In, <sup>127</sup>I, <sup>133</sup>Cs, <sup>139</sup>La, <sup>141</sup>Pr, <sup>153</sup>Eu, <sup>159</sup>Tb, <sup>165</sup>Ho, <sup>169</sup>Tm, <sup>175</sup>Lu, <sup>185</sup>Re, <sup>197</sup>Au.

Note 2: General usage of the term "monoisotopic" refers to the 21 elements with one isotope determining their relative atomic masses, i.e. <sup>9</sup>Be, <sup>19</sup>F, <sup>23</sup>Na, <sup>27</sup>Al, <sup>31</sup>P, <sup>45</sup>Sc, <sup>55</sup>Mn, <sup>59</sup>Co, <sup>75</sup>As, <sup>89</sup>Y, <sup>93</sup>Nb, <sup>103</sup>Rh, <sup>127</sup>I, <sup>133</sup>Cs, <sup>141</sup>Pr, <sup>159</sup>Tb, <sup>165</sup>Ho, <sup>169</sup>Tm, <sup>197</sup>Au, <sup>209</sup>Bi, <sup>231</sup>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 to 0.025	cold neutron



0.025 (corresponding to 295 K)	<i>thermal neutron</i>
0.025 to 0.4	<i>epithermal neutron</i>
0.4 to 0.6	cadmium neutron
0.6 to 1	<i>epicadmium neutron</i>
1 to 10*	slow neutron
10 to 300	<i>resonance neutron</i>
300 to $1 \times 10^6$	intermediate neutron
$(1 \text{ to } 20) \times 10^6$	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] p1547.

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 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:  
 $^{197}\text{Au} + \text{n} \rightarrow ^{198}\text{Au} + \gamma$ , or in short form  $^{197}\text{Au}(\text{n},\gamma)^{198}\text{Au}$ .

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

**127. nuclear chemistry**

Scientific discipline which 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  $^{14}\text{C}$  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 suffix '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  $\text{m}^{-2} \text{s}^{-1}$ .
- 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  $\text{n cm}^{-2} \text{s}^{-1}$ . As 'n' is not a unit, it is metrologically unacceptable and therefore not recommended.

Replaces: [3] p 2519. See also: [12] at Note (26) at p 44 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 ( $\mu$ -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 applied for measurement of 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 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 is performed both in a time-differential (TDPAC) or 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 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 ( $0.511 \text{ MeV} = 8.187\,122\,6 \times 10^{-14} \text{ J}$ ).

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 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)

1 *Measurement principle* [VIM 2.4] in which gamma radiation emitted during the  
2 de-excitation of the compound nucleus formed by neutron capture is applied to  
3 measure the amounts of elements in a material.  
4

5  
6 Note: The measurement method is often denoted as prompt gamma-ray  
7 neutron activation analysis (PGNAA) or prompt gamma-ray activation  
8 analysis (PGAA) though the measurement method is not in agreement  
9 with the definition of *activation analysis*. The term prompt gamma-ray  
10 analysis (PGA) is therefore to be preferred.  
11

12  
13 Source: [38, 68].  
14

#### 15 **144. pulse pile-up**

16  
17 Processing by a *radiation counter* of pulses resulting from the simultaneous  
18 absorption of independent particles or photons in a *radiation detector* resulting in  
19 the counting as one single particle or photon with energy between the individual  
20 energies and the sum of these energies.  
21

22  
23 Source: [69] p 655.  
24

#### 25 **145. quenching correction**

26  
27 Correction for errors due to different *quenching in radiation detectors* for  
28 standards and samples.  
29

30  
31 Note: When using *liquid scintillation detectors*, these corrections can be based  
32 e.g. on the standard addition or sample *channels ratio method* or the use  
33 of automated *external standardization*.  
34

35  
36 Source: Adapted from [3] p 2523.  
37

#### 38 **146. quenching in radiation detectors**

39  
40 Process of inhibiting continuous or multiple discharges following a single ionizing  
41 event in certain types of radiation detectors, particularly in *Geiger-Müller counters*.  
42

43  
44 Source: [70]. See: *quenching correction*.  
45

#### 46 **147. radiation**

47  
48 Emission of energy as electromagnetic waves or as fast-moving subatomic  
49 particles.  
50

51  
52 Note: In *radioanalytical chemistry*, the term usually refers to radiation used  
53 and emitted during nuclear processes (e.g., *radioactive decay*, *nuclear*  
54 *decay*, *nuclear fission*).  
55

56  
57 Source: Adapted from [3] p 2523. See also: *ionizing radiation*.  
58  
59  
60

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### 148. radiation chemistry

Sub-discipline of chemistry which 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 *radiation* 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 *radionuclide*.

Note 2: 'Radioactive' is also used to describe a material that includes a radionuclide.

1 **153. radioactive chain**

2  
3  
4 See: *decay chain*.

5  
6 **154. radioactive decay**

7  
8 *Nuclear decay* in which particles or electromagnetic *radiation* are emitted or the  
9 nucleus undergoes spontaneous fission or electron capture.

10  
11 Source: [3] p 2518.

12  
13  
14 **155. radioactive equilibrium**

15  
16 See: *radioactive steady state*.

17  
18  
19 **156. radioactive purity**

20  
21 See: *radionuclide purity*.

22  
23  
24 **157. radioactive series**

25  
26 See: *decay chain*.

27  
28 **158. radioactive source**

29  
30 *Radioactive* material which is intended for use as a source of *ionizing radiation*.

31  
32 Source: Adapted from [3] p 2526.

33  
34  
35 **159. radioactive steady state**

36 radioactive equilibrium  
37 secular equilibrium

38  
39 Among the *radionuclides* of a *decay chain*, the state which prevails when the ratios  
40 between the *activities* of successive radionuclides remain constant.

41  
42 Note: This is not equilibrium in the strict sense since *radioactive decay* is an  
43 irreversible process.

44  
45 Source: Adapted from [3] p 2519, [72] p 185.

46  
47  
48 **160. radioactivity**

49  
50 Phenomenon of *nuclides* undergoing *radioactive decay*.

51  
52 Source: Adapted from [3] p 2513.

53  
54  
55 **161. radioanalytical chemistry**

56 analytical radiochemistry



1 That part of analytical chemistry in which the application of *radioactivity* is an  
2 essential step in the analytical procedures.  
3

4  
5 Source: [2] p 1535.  
6

7 Note 1: Use is made of nuclear processes (e.g., *nuclear decay*, *nuclear fission*),  
8 nuclear effects, *radiation*, and nuclear facilities, and of radiochemical  
9 and nuclear measurement techniques.  
10

11 Note 2: Radioanalytical chemistry is part of *radiochemistry*.  
12  
13

## 14 **162. radiochemical activation analysis**

15 destructive activation analysis  
16

17 *Measurement method* [VIM 2.5] of *activation analysis*, in which concentrations or  
18 mass contents of elements in a material are measured using a *measurement model*  
19 [VIM 2.48] with known nuclear constants, *irradiation* and *radiation* measurement  
20 parameters and the use of a *calibrator* with known property values and in which  
21 chemical separation is applied after the irradiation.  
22  
23

24 Source: [7] p 1583. See also: [73].  
25

## 26 **163. radiochemical purity**

27 For a material, the fraction of the stated *radionuclide* present in the stated chemical  
28 form.  
29

30 Source: [3] p 2523.  
31  
32

33 Note 1: The unit of radiochemical purity is mol/mol = 1.  
34  
35

36 Note 2: The medical literature often defines radiochemical purity as the fraction  
37 of the radioactivity of a material in a stated chemical form. (See: [74]  
38 p347, and *radionuclide purity*.)  
39  
40

## 41 **164. radiochemical recoil effect**

42 See: *Szilard-Chalmers effect*.  
43  
44

## 45 **165. radiochemical separation**

46 Separation by a chemical means of *radionuclide(s)* of a specific element from a  
47 mixture of radionuclides of other chemical elements.  
48  
49

50 Source: [3] p 2526.  
51  
52

## 53 **166. radiochemical yield**

54 *Activity* of a specified *radionuclide* of a specified element after its *radiochemical*  
55 *separation* divided by its activity originally present in the substance undergoing  
56 *radiochemical separation*.  
57  
58  
59

60 32

1 Source: Adapted from [3] p 2526.  
2  
3

4 **167. radiochemistry**  
5

6 Part of chemistry which deals with *radioactive* materials.  
7

8 Note: Radiochemistry includes the production of *radionuclides* and their  
9 compounds by processing irradiated materials or naturally occurring  
10 radioactive materials, the application of chemical techniques to nuclear  
11 studies, and the application of *radioactivity* to the investigation of  
12 chemical, biochemical or any other problems.  
13  
14

15 Source: Adapted from [3] p 2524 and [75] p 1423.  
16

17 **168. radioenzymatic assay**  
18

19 *Measurement principle* [VIM 2.4] in which a *radioactive* substrate is applied to  
20 measure the catalytic activity of an enzyme.  
21  
22

23 Source: Adapted from [3] p 2524 and [76] p 259.  
24  
25

26 **169. radiograph**  
27

28 Visual representation of an object produced by placing the object between a source  
29 of *ionizing radiation* and a photographic plate, film or detector.  
30  
31

32 Source: Adapted from [3] p 2524.  
33

34 Note: Radiographs are used in medicine and dentistry.  
35

36 **170. radiogravimetric analysis**  
37

38 *Measurement principle* [VIM 2.4] in which the *activity* of a precipitate is applied to  
39 measure its mass.  
40  
41

42 Source: Adapted from [3] p 2524.  
43  
44

45 **171. radioiodination**  
46

47 Incorporation of a *radionuclide* of iodine into substance, or of covalently linking a  
48 radioiodinated substance to a substance.  
49

50 Note: Commonly used radionuclides of iodine are  $^{129}\text{I}$ ,  $^{131}\text{I}$  and  $^{123}\text{I}$ .  
51

52 Source: Adapted from [3] p 2524.  
53  
54

55 **172. radioisotope**  
56

57 A *radioactive* isotope (See: *isotopes*) of a specified element.  
58  
59

60 Source: [3] p 2524.

1 **173. radioisotope dilution analysis**

2  
3  
4 See: *isotope dilution analysis*.

5  
6 **174. radioisotope induced X-ray emission analysis**

7  
8 *Measurement method* [VIM 2.5] of *X-ray analysis* in which a *radioactive source* is  
9 used for irradiation of the sample.

10  
11 Source: [19].

12  
13  
14 **175. radiolysis**

15  
16 Chemical decomposition of materials by *ionizing radiation*.

17  
18 Source: [3] p 2524.

19  
20  
21 **176. radiometric analysis**

22  
23 *Measurement principle* [VIM 2.4] in which the *activity* of a *radioactive* component  
24 with known specific activity is applied for measurement of the amount of an  
25 element in a material.

26  
27 Source: [77] p 564. Replaces: [3] p 2524.

28  
29  
30 **177. radiometric titration**

31  
32 Titration in which a *radioactive* indicator is used to monitor the end-point of the  
33 titration.

34  
35 Source: [3] p 2524. See also: [78] p 168.

36  
37  
38 **178. radionuclide**

39  
40 *Nuclide* that is *radioactive*.

41  
42 Source: [3] p 2524.

43  
44 Note: When an element is specified the radionuclide is termed a *radioisotope*.

45  
46  
47 **179. radionuclide purity**

48 radionuclidic purity  
49 radioactive purity

50  
51  
52 *Activity* of a stated *radionuclide*, including *daughter products*, in a material divided  
53 by the total activity of the material.

54  
55 Source: Adapted from [3] p 2523.

56  
57 Note 1: The SI unit of radionuclide purity is  $\text{Bq/Bq} = 1$ .

Note 2: Radionuclide purity is important for calibrators, *isotopic tracers*, and in pharmaceutical uses.

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

### 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 a 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,  $\tau$**

Smallest time interval which elapses between the occurrence of two consecutive ionizing events, in order that the *radiation counter* can be 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 is the nature of the radiation ( $X \equiv n$  denotes neutron,  $X \equiv fis$  denotes neutron induced fission),  $\sigma_X$  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  $^{238}\text{U}$ .

1 **192. reversed isotope dilution analysis**

2  
3  
4 *Isotope dilution analysis* in which the amount of an *isotopic carrier* in a solution of  
5 a *radionuclide* is measured by addition of one of its stable isotopes.

6  
7 Source: [41] p 122-124.

8  
9 **193. saturation (in radiation chemistry)**

10  
11 Of an irradiated element for a specified *nuclide*, the steady state reached when the  
12 *decay rate* of the *nuclide* formed is equal to its production rate.

13  
14  
15 Source: Adapted from [3] p 2525.

16  
17 **194. saturation activity,  $A_s$**

18  
19 For a specified *radionuclide*, the maximum *activity* at *saturation*.  $A_s = \sigma \times \Phi$  where  
20  $\sigma$  is the *cross section* and  $\Phi$  the *particle flux density*.

21  
22  
23 Replaces: [3] p 2525.

24  
25 **195. scanning proton microscopy, (SPM)**

26  
27  
28 *Measurement method* [VIM 2.5] of *X-ray fluorescence analysis* in which protons  
29 are focused and collimated to form a micro beam to obtain an image of a surface.

30  
31 **196. scavenging of radionuclides**

32 scavenging

33  
34  
35 In *radiochemistry*, the use of a precipitate to remove from solution by absorption or  
36 co- precipitation, a large fraction of one or more *radionuclides*.

37  
38 Note: In *radiation chemistry* the term scavenging is used to denote binding of  
39 radicals or free electrons with a receptive (or reactive) material.

40  
41  
42 Source: Adapted from [3] p 2525.

43  
44 **197. scintillation**

45  
46 Burst of luminescence caused by an individual energetic particle.

47  
48  
49 Source: Adapted from [3] p 2525.

50  
51 **198. scintillation detector**

52  
53 Kind of *radiation detector* having a *scintillator* to measure *ionizing radiation*.

54  
55  
56 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 as 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 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

1 combination with a high voltage and electrodes for collection of these charge  
2 carriers.  
3

4 Source: [3] p 2526.  
5  
6

7 **206. sensitive volume of a radiation detector**  
8

9 That volume of a *radiation detector* where an incident radiant power produces a  
10 measurable output.  
11

12 Source: [33] p 1751.  
13  
14

15 **207. solid phase antibody radioimmunoassay**  
16

17 *Measurement method* [VIM 2.5] of *radioimmunoassay* employing an antibody,  
18 made into an *isotopic tracer* by labelling with a *radionuclide*, bound to a solid  
19 phase.  
20

21 Source: Adapted from [3] p 2524. See also: [46] 4.1.12.  
22  
23

24 **208. source efficiency**  
25

26 See: *self-absorption factor*.  
27  
28

29 **209. specific activity of a radionuclide,  $A_S(R)$**   
30

31 specific activity  
32

33 *Activity* of a specified *radionuclide* (R) per unit mass of that nuclide.  
34

35 Note: If the term “specific activity” is used without qualification it should be  
36 made clear whether it is of a material or of a radionuclide. See: *specific*  
37 *activity of a radionuclide in a material*.  
38

39 Example: Specific activity of tritium ( $^3\text{H}$ ) is  $3.57 \times 10^{17}$  Bq kg<sup>-1</sup> (9.65 Ci mg<sup>-1</sup>)  
40 [85].  
41

42 Source: [86] p 206. Replaces: [3] p 2515. See also: [16].  
43  
44

45 **210. specific activity of a radionuclide in a material,  $A_S(R,M)$**   
46

47 specific activity  
48

49 *Activity* of a specified *radionuclide* (R) in a material (M) divided by the mass of  
50 that material.  
51

52 Note 1: It is implicitly assumed that the various isotopes (stable and *radioactive*  
53 ones) are present in the same chemical and physical form, and thus will  
54 behave fully identically in radiochemical processing and a radionuclide  
55 application, i.e. nuclidic exchange with other chemical forms is  
56 prohibited or at least very slow compared to the duration of the  
57 experiment.  
58  
59



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

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

Note 4: 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  $[\gamma\text{-}^{33}\text{P}]$  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:  $\text{H}[\text{}^{36}\text{Cl}]$ , hydrogen  $[\text{}^{36}\text{Cl}]$ chloride.  $\text{Ge}[\text{}^2\text{H}_2]\text{F}_2$ , difluoro $[\text{}^2\text{H}_2]$ germane,  $[\text{}^{15}\text{N}]\text{H}_2[\text{}^2\text{H}]$ ,  $[\text{}^2\text{H}_1, \text{}^{15}\text{N}]$ 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.

1 Source: [41] p 122-124.  
2  
3

4 **214. synchrotron radiation induced X ray fluorescence analysis**  
5

6 *Measurement method* [VIM 2.5] of *X-ray fluorescence analysis* in which  
7 synchrotron X- radiation is used to irradiate the substance.  
8

9 Source: [87].  
10

11 **215. Szilard-Chalmers effect**  
12 radiochemical recoil effect  
13 recoil effect  
14

15  
16 Rupture of the chemical bond between an atom and the molecule of which the  
17 atom is a part, as a result of *nuclear reaction* of that atom.  
18

19 Source: Adapted from [3] p 2525. See also: [88] p 240.  
20

21 **216. thermal neutron**  
22

23 Neutron in thermal equilibrium with the medium in which it exists.  
24

25 Note: Thermal neutrons have an average energy of approximately 0.025 eV  
26 and an average speed of 2200 m s<sup>-1</sup>.  
27

28 Source: Adapted from [3] p 2522.  
29

30 **217. total reflection X- ray fluorescence analysis, (TXRF)**  
31

32 *Measurement method* [VIM 2.5] of *X-ray fluorescence analysis* in which a  
33 collimated X-ray flux impinges on a smooth surface under a grazing angle  
34 rendering total reflection is used to excite atoms in the top layers of the material for  
35 measurement of the amounts of elements.  
36

37 Note: The method is highly sensitive because interfering X-rays of higher  
38 energies are refracted or adsorbed. Mass fractions of 10<sup>-12</sup> (ng kg<sup>-1</sup>)  
39 may be measured.  
40

41 Source: [89].  
42

43 **218. two-site immunoradiometric assay**  
44

45 See: *two-site radioimmunoassay*.  
46

47 **219. two-site radioimmunoassay**  
48 two-site immunoradiometric assay  
49

50 *Radioimmunoassay* in which two sets of antibodies, one of which is isotopically  
51 labelled (See: *isotopic label*), combine with different immunoreactive sites of an  
52 antigen molecule.  
53  
54  
55

56  
57  
58  
59  
60 41

1 Source: [90]. See also: See also: [46] 4.1.12.  
2

3  
4 **220. uniformly-labelled isotopic tracer**

5  
6 *Isotopic tracer* in which the *isotopic label* is uniformly distributed over its possible  
7 positions in a molecule.  
8

9 Source: [3] p 2526.  
10

11  
12 **221. wavelength-dispersive X-ray fluorescence analysis**

13  
14 *Measurement method* [VIM 2.5] of *X-ray fluorescence analysis* in which the  
15 wavelength spectrum of the emitted *radiation* is used to measure the amounts of  
16 elements.  
17

18 Note: A diffraction grating, or crystal is used to obtain the spectrum.  
19

20 Source: [91].  
21

22  
23 **222. Westcott cross section**

24 See: *effective thermal cross section*.  
25

26  
27 **223. Wilzbach labelling**

28 Isotopic labelling (See: *isotopic label*) of a substance by exposing it to tritium gas.  
29

30  
31 **224. X-ray absorption analysis, (XAA)**  
32 X-ray absorption spectroscopy, (XAS)

33  
34 *Measurement principle* [VIM 2.4] of *X-ray analysis* in which the absorption  
35 spectrum is used to measure the number of atoms, species and other parameters of  
36 chemical elements.  
37

38 Note 1: XAS measures changes in the linear absorption coefficient of an  
39 element in a sample as a function of incident photon energy.  
40

41 Note 2: XAS requires a highly monochromatic (with  $\Delta E/E \approx 10^{-4}$  to  $10^{-5}$ ), high  
42 flux X-ray beam.  
43

44 Source: [25, 26]. See also: *X-ray absorption near edge structure*,  
45

46  
47 **225. X-ray absorption edge**  
48 absorption edge  
49

50 Increase in X-ray absorption observed at the energy at which a strongly bound  
51 electron is released.  
52

53 Source: [92].  
54  
55  
56  
57  
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1           **226. X-ray absorption near edge fine structure**  
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3           See: *X-ray absorption near edge structure*.  
4

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

7           X-ray absorption near edge fine structure  
8

9           *Measurement method* [VIM 2.5] of *X-ray absorption analysis* in which the fine  
10          structure of the adsorption spectrum in the range 30 below to 50 eV above the  
11          *adsorption edge* is used to measure parameters describing the chemical state,  
12          coordination environment, and local geometry distortion for the X-ray absorbing  
13          atom.  
14

15  
16          Note 1:       The method uses synchrotron radiation.  
17

18          Note 2:       The *wavelength* of the emitted photoelectrons is longer than the  
19          interatomic distances between the absorbing atom and its nearest  
20          neighbours.  
21

22  
23          Source: [25, 92]. See also: *near edge X-ray absorption fine structure, extended X-*  
24          *ray absorption fine structure*.  
25

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27           **228. X-ray absorption spectroscopy, (XAS)**

28           See: *X-ray absorption analysis*.  
29

30  
31           **229. X-ray analysis**

32           *Measurement principle* [VIM 2.4] in which *characteristic X-radiation*, produced  
33          upon *irradiation* of a material with elementary particles or photons, is applied to  
34          measure amounts of elements in a material.  
35  
36

37           Source: [62, 93].  
38

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40           **230. X-ray computed micro-tomography, (XCMT)**

41           X-ray micro-tomography, (XMT)  
42

43           *Measurement method* [VIM 2.5] based on the transmission of X-rays to obtain  
44          three-dimensional images of a sample.  
45  
46

47          Note:        Spatial resolution is in the range 100 nm to 10  $\mu\text{m}$ .  
48

49          Source: [4].  
50

51  
52           **231. X-ray diffraction analysis**

53           X-ray diffraction, (XRD)  
54

55           *Measurement method* [VIM 2.5] using diffraction of X-radiation to obtain the  
56          spatial arrangement of atoms in a crystalline sample.  
57  
58

Note 1: Bragg reflection follows  $n\lambda = 2d \sin \theta$  where  $\lambda$  is the X-ray wavelength,  $d$  is the spacing between atomic planes and  $\theta$  is the angle of diffraction.

Note 2: Copper K- $\alpha$  radiation ( $\lambda = 0.15406$  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 ( $\mu$ -XRF) analysis uses highly brilliant X-ray sources (synchrotron source and spot size 100 nm to 2  $\mu$ m) 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 of elements in a sample.

Note 1: X-ray beam energies of 5 to 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  $\mu$ m, but using specialised probes at synchrotron facilities the lower limit can be reduced 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 photoemission of inner-shell electrons and 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].

1 **237. X-ray micro-tomography, (XMT)**  
 2  
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4 See: *X-ray computed micro-tomography*.  
 5

6 **LIST OF SYMBOLS AND ABBREVIATIONS**  
 7

8	$\lambda$	decay constant of a radionuclide	42
9	$\sigma$	cross section (in radiation chemistry)	37
10	$\tau$	mean life of a radionuclide	107
11	$\tau$	resolving time of a radiation counter	188
12			
13			
14	$A$	activity of a radioactive substance	12
15	$A_m(\text{R})$	molar activity of a radionuclide	110
16	$A_m(\text{R},\text{M})$	molar activity of a radionuclide in a material	111
17	$A_s$	saturation activity	194
18	$A_s(\text{R})$	specific activity of a radionuclide	209
19	$A_s(\text{R},\text{M})$	specific activity of a radionuclide in a material	210
20	$b$	barn	18
21	$F$	fluence	69
22	$H$	fluence	69
23	$I_x$	resonance integral	190
24	$j$	particle (or photon) flux density	132
25	$J_E$	energy flux density	59
26	$k$	decay constant of a radionuclide	42
27	$t_{1/2}$	half life of a radionuclide	78
28	$T_{1/2}$	half life of a radionuclide	78
29	$t_d$	dead time of a radiation counter	40
30			
31			
32			
33			
34	AMS	accelerator mass spectrometry	7
35	DNAA	delayed-neutron activation analysis	48
36	DNA	delayed-neutron analysis	48
37	DNC	delayed-neutron counting	48
38	EDS	energy-dispersive X-ray spectroscopy	63
39	EDX	energy-dispersive X-ray fluorescence analysis	63
40	EDXA	energy-dispersive X-ray analysis	63
41	EDXS	energy-dispersive X-ray spectroscopy	63
42	EXAFS	extended X-ray absorption fine structure	67
43	IBA	ion beam analysis	87
44	IDA	isotope dilution analysis	91
45	NAA	neutron activation analysis	116
46	NCA	no carrier added	123
47	NDP	neutron depth profiling	118
48	NEXAFS	near edge X-ray absorption fine structure	115
49	PAA	positron annihilation analysis	137
50	PAC	perturbed angular correlation spectrometry	135
51	PALS	positron annihilation lifetime spectrometry	141
52	PASCA	positron annihilation spectroscopy for chemical analysis	137
53	PET	positron emission tomography	140
54	PIGE	particle-induced gamma-ray-emission analysis	134
55	PIXE	particle induced X-ray emission analysis	133
56	PGA	prompt gamma-ray analysis	143
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1	PLS	positron lifetime spectrometry	141
2	SPM	scanning proton microscopy	195
3	TDPAC	time-differential perturbed angular correlation spectrometry	135
4	TIPAC	time-integrated perturbed angular correlation spectrometry	135
5	XAA	X-ray absorption analysis	224
6	XANES	X-ray absorption near edge structure	227
7	XCMT	X-ray computed micro-tomography	230
8	XAS	X-ray absorption spectroscopy	224
9	XMT	X-ray micro-tomography	230
10	XRD	X-ray diffraction	231
11	XRF	X-ray fluorescence	236
12	XRM	X-ray fluorescence microscopy	234

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# Vocabulary of radioanalytical methods (IUPAC Recommendations 20xx)

Zhifang Chai, Amares Chatt, Peter Bode, Jan Kucera, Robert Greenberg, D. Brynn Hibbert

Responses to reviewers' comments. Note there is a track changes document following these specific points..

Comment	Response	Changes to MS
<p><b>Reviewer 6</b></p> <p>I didn't receive a version of the MS with tracked changes or a point-by-point response to the reviewers' comments. These documents may have been submitted, but didn't make it through the manuscript handling system. Therefore, I've just looked for changes relating to my previous comments/suggestions. The changes made are all completely adequate and alleviate my previous concerns.</p>	<p>Apologies but these files were included in the resubmission. We may have uploaded them in the wrong place.</p>	
<p>The new note 1 for term 207 ("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.") should be moved to term 208 (specific activity of a radionuclide in a material) because term 207 only refers to a single radionuclide. The explanation about "various isotopes" does not make sense in the context of term 207.</p>	<p>Accepted</p> <p>Also the Example in 208 moved to 207 and a new example added. (See response to last reviewer below)</p>	<p>Note 1 of 207 moved to become Note 1 of 208.</p> <p>Other notes re-numbered.</p> <p>(these are now 209 and 210 because of addition of new entries 201 and 206)</p>
<p><b>Reviewer 8</b></p> <p>The revised definition of counting efficiency is not grammatically correct.</p>	<p>Accepted. The second sentence is adopted as suggested as a Note.</p>	<p>32. counting efficiency</p>

Comment	Response	Changes to MS
<p>Number of particles or photons counted divided by the number that has struck the envelope. This ratio limits the sensitive volume of a radiation detector.</p>		<p>intrinsic counting efficiency</p> <p>Number of particles or photons counted divided by the number that has struck the envelope.</p> <p>Note: This ratio limits the sensitive volume of a <i>radiation detector</i>.</p>
<p>'sensitive volume' should be defined</p>	<p>done – we take the definition in the present Gold Book from PAC, 1995, 67, 1745. (Nomenclature, symbols, units and their usage in spectrochemical analysis-XI. Detection of radiation (IUPAC Recommendations 1995)) on page 1751</p>	<p>205. sensitive volume of a radiation detector</p> <p>That volume of a radiation detector where an incident radiant power produces a measurable output.</p> <p>Source: [33] p 1751.</p>
<p><b>Reviewer: RadioanalR2rev.pdf</b></p> <p>Neither of the two cover letters accompanying the two revisions of the document present any discussion of the reviews submitted. This seems highly unusual. The latest cover letter states that adjustments have been made in accord with the reviewers' comments. However, quite a few problems remain, as will be seen below, and now we do not know whether this is because the authors (or the editor) after all did not agree in every suggestion made.</p>	<p>See answer to Reviewer 6. We can only apologise that the uploaded files did not get through to the reviewer. Our response document was 11 pages, and we certainly answered each point raised by each reviewer.</p>	
<p>An overall purpose of recommending vocabularies like this one is to amend definitions in the Gold Book where needed and supply new ones as needed. I would expect to be able to see whether any given entry in the document is new, is copied from the Gold Book without change or is changed (in which case the change should, in general be motivated). The Gold Book, in principle, picks up definitions from the Orange Book, so reference to what is in the latest Orange Book would be as good. But the entire vocabulary here has no</p>	<p>No. At present the Gold Book picks up PAC Recommendations (although with almost no activity since 2007). The definitive version is PAC (or some colour books, e.g. Green Book). So the ultimate authority is still a PAC Recommendation, and this is what is cited even though it might also appear in the Gold Book.</p>	

Comment	Response	Changes to MS
<p>references to the 1997 Orange Book [1] or the Gold Book in any of its entries.</p>	<p>The 1997 Orange Book is being completely re-written and the way agreed with ICTNS (Ron Weir) was to submit each chapter as a PAC Rec before compiling into the OB. In the 12 years (!) since the start of the OB project this approach has been modified to one in which terms that are appropriately defined by Division V of IUPAC are submitted to PAC in Recommendations. These will appear without change in the OB. As the OB is a general work of reference other material may be included along with terms taken from different sources (ISO, VIM etc). It is intended that the final manuscript of the OB will be reviewed by ICTNS.</p>	
<p>Some entries just disappeared since the last version (<i>e.g.</i>, average life of a radionuclide, competitive binding assay, radioimmunoassay, stable isotope enrichment). I would expect to see an explanation for that, if not in the document, then at least to the reviewers.</p>	<p>Once again we provided a commentary against the reviewers suggestions.</p> <p>Could the reviewer be given the Response submitted with the last revision? (We are loath to add here for fear of confusing the situation more).</p>	
<p>The definition of 'isotopes' (now Def. 94) was reworded to emphasise how one should go about using the singular and plural of the word. In the following definitions, the singular 'isotope' and/or the plural 'isotopes' is used at variance with the prescription in Def. 94, note 2 (list not pretending to be exhaustive):</p> <p>7. accelerator mass spectrometry 9. activation analysis 100. isotopic label 140. position emission tomography, Note 1 163. radiochemical purity</p>	<p>The definition of Isotopes was not changed from R1 to R2 (but from the original manuscript to R1).</p> <p>We have reviewed the occurrences of 'isotope' and 'isotopes' and have made changes as indicated.</p>	<p>7 AMS <i>isotope</i> abundances -&gt; <i>nuclide</i> abundances</p> <p>9 AA by stable <i>isotopes</i> -&gt; by stable <i>nuclides</i></p> <p>140 PET Note 1: A commonly used <i>nuclide</i> is fluorine-</p>

Comment	Response	Changes to MS
		18.  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.  163 radiochemical purity  See response below
<p><b>12. activity of radioactive material</b>            From the point of view of strict terminology, this definition is in bad shape.            The definition involves 'a radioactive material', 'a radioactive entity' and 'the number of decaying entities B'. This makes it completely unclear what situation the definition relates to. The term 'radioactive' is italicised, and if one looks up the definition (Def. 152), it is the defining characteristic of a radionuclide, not a material or an entity. Thus, for Def. 12 to work as it stands, the definition of 'radioactive' will have to be extended to include material. On the other hand, the subscript 'B' maybe indicates that there was a desire to single out a particular kind of radionuclides. This will also have to be made clear, since a material could include several kinds of radionuclides.            Later definitions of molar and specific activities of specified radionuclides cover intensive properties, so here it was probably desired to express a extensive quantity, in which case the definition should speak about an <i>amount of material</i>.            In any case the definition is basically 'number of decays per unit of time'. The number of entities present does not matter for that definition and it does not make sense to designate <math>N_B</math> as the number of decaying entities – most of them are <i>not</i> decaying at time <math>t</math>. In the integrated form with exponential function there will of course be an initial population at <math>t = 0</math>. Finally, 'disintegration rate' is deprecated</p>	<p>This comment shows nicely the problems faced by writers of Recommendations.             The entry is taken from the PAC Rec PAC, 1994, 66, 2513. (Nomenclature for radioanalytical chemistry (IUPAC Recommendations 1994)) on page 2515, and the Green Book (p 24) and is abstracted in the Gold Book. The term is “activity of a radioactive material” and we see in the Green Book on p24             activity (of a radioactive substance)            and             (18) <math>N_B</math> is the number of decaying entities B.             So we have ‘material’, ‘substance’ and ‘entities’.             We accept that ‘radioactive’ would be improved with a note saying the term is used to describe a material that includes a radionuclide.</p>	<p>152 radioactive             Note 2: ‘Radioactive’ is also used to describe a material that includes a radionuclide.             12. activity of a radioactive material, A             activity             absolute activity             decay rate             deprecated:            disintegration 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, <math>A = -</math></p>



Comment	Response	Changes to MS
<p>here, but it is nevertheless used later (<i>e.g.</i>, in Def. 42). See also comments for Def. 42.</p>	<p>Having said all of the above, we accept the point with thanks and revert to the 1994 PAC Rec definition, with a note to bring in the Green Book equation.</p> <p>The awkwardness of the Green Book ‘decaying entities’ remains.</p> <p>We remove ‘deprecate’ against disintegration, but suggest it is no longer recommended.</p>	<p><math>dNB/dt</math> where NB is the number of decaying entities B. (Source: [12] p 24).</p> <p>Note 2: The SI unit of activity is the becquerel (Bq) which is equal to one decay per second (s<sup>-1</sup>). Curie (Ci) is a former unit of activity equal to exactly <math>3.7 \times 10^{10}</math> Bq.</p> <p>Note 3: The synonym ‘disintegration rate’ is no longer recommended.</p>
<p><b>42. decay constant of a radionuclide</b> The comments for this definition are to be seen together with the comments for Def. 12. Def. 42 presupposes a definition of the activity of a radionuclide. Presumably, here, the subscript B is intended to specify a particular radionuclide. The definition of activity of a radionuclide must relate to a population of that particular radionuclide to make sense. Here, 'disintegration rate' does not seem to be deprecated (as opposed to Def. 12) ??</p>	<p>Yes – this is for a radionuclide not a material.</p> <p>We insert ‘specified’ before ‘radionuclide’ and expect the reader to understand this is the Green Book definition.</p> <p>We hope that in the next edition of the Green Book the advice that “Synonyms ‘disintegration constant of a radionuclide’ and ‘disintegration rate constant of a radionuclide’ are not recommended” might be heeded.</p>	<p>decay constant of a radionuclide, <math>\lambda</math>, k</p> <p>decay rate constant of a radionuclide</p> <p>Proportionality constant between the activity (A) of a specified radionuclide and the number of decaying entities (NB). <math>A = \lambda NB</math>.</p> <p>Note 1: The decay constant is related to the half life of a radionuclide (<math>t_{1/2}</math>) by <math>t_{1/2} = (\ln 2)/\lambda \approx 0.693/\lambda</math>.</p> <p>Note 2: Synonyms ‘disintegration constant of a radionuclide’ and ‘disintegration rate constant of a radionuclide’ are not recommended.</p> <p>Source: [12] p 24. See also: mean life of a radionuclide.</p>
<p><b>78. half life of a radionuclide</b> The definition has the two incongruent</p>	<p>Noted.</p>	

Comment	Response	Changes to MS
<p>1 constructions 'half life of a radionuclide' 2 and ' number of decaying 3 entities', one referring to a single atomic 4 entity, the other one to an ensemble. 5 I maintain that the number <math>N_B</math> is not the 6 number of decaying entities, and it is not 7 necessary to use that 8 construction. One could, for example, 9 write: 'the half life of a radionuclide is the 10 time for a number of that 11 radionuclide to be reduced to one half 12 through its radioactive decay'. 13 The definition refers to 'average life' in 14 italics, but that is not an entry any longer. 15 See also comment for Def. 16 107.</p>	<p>However given that the Green Book espouses 'decaying entities' meaning 'entities capable of decay' we keep these words without too much concern that the reader will be misled.</p>	
<p><b>91. isotope dilution analysis</b> I wonder why the notes 1 and 2 present in the former version are not there any more. And does the term now not replace the earlier defintion?</p>	<p>There was lengthy debate about 'specific activity' and we realised Notes 2 and 3 were no longer correct.</p> <p>Yes – it does replace [3] p 2521 (see reference line)</p>	no change
<p><b>93. isotopic exchange</b> The definition is not worded properly. It should not involve both 'places' and 'positions'. It must be something like 'Exchange of isotopes of atoms between different chemical or physical states or positions (or perhaps better, '...isotopes of a particular kind of atom...').</p>	<p>This is the wording of the existing Recommendation (other than to make the main term 'isotopic exchange' which is more exact grammar).</p> <p>The point about 'isotopes' is that they must be of a given element. We cannot see sufficient reason to change.</p>	no change
<p><b>100. isotopic label</b> Definition uses 'isotope' where I believe it should be 'nuclide' due to the strict definition of the use of isotope. But that strictness does get one into trouble with a term like this, where nobody speaks about 'nuclidic label'. The part 'used to identify an isotopic tracer' does not make sense to me. Maybe elaboration of the deuterium example would help (what is the label, the system, and the tracer).</p>	<p>Again there was much discussion after comments on the previous revision. 'Isotope' is used throughout even when, as the reviewer points out, 'nuclide' is more exact.</p> <p>However again the definition is from the Recommendation, particularly "used to identify a tracer"</p>	<p>The example is amplified:</p> <p>Example: Deuterium ( 'isotopic label' ) that is substituted for protium in a the illegal drug molecule methylamphetamine, for use in analysis by mass spectrometry. Methylamphetamine incorporating deuterium</p>

Comment	Response	Changes to MS
		<p>is the 'isotopic tracer'.</p> <p>This note is also added to 'isotopic tracer'.</p>
<p><b>107. mean life of a radionuclide</b> The note suddenly uses 'average life' which is not defined. I assume it should have been mentioned together with lifetime as an alternative to mean life.</p>	<p>Thank you.</p> <p>average life added as alternative term and average changed to mean in Note.</p>	<p>107 mean life of a radionuclide, <math>\tau</math></p> <p>average life of a radionuclide</p> <p>lifetime of a radionuclide</p> <p>Reciprocal of the decay constant of a radionuclide (<math>\lambda</math>). <math>\tau = 1/\lambda</math>.</p> <p>Note: The average mean life is greater than the half life of a radionuclide by the factor <math>1/\ln 2</math> (<math>\approx 1.44</math>); 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.</p> <p>Source: Adapted from [12] p 24.</p>
<p><b>110. molar activity of a radionuclide</b> Why does the definition include 'in a material' ? The distinction from Def. 111 would seem to me to dictate that 'material' not be involved here.</p>	<p>Thank you – you are completely correct.</p> <p>'in a material' deleted</p>	<p>110. molar activity of a radionuclide, <math>A_m(R)</math></p> <p>molar activity</p> <p>Activity of a specified radionuclide (R) per unit amount of substance of the specified radionuclide.</p>
<p><b>126. nuclear capture</b> The term 'elementary particle' is not defined within this document. The wording 'elementary or charged particle' is unclear. Certainly some particles normally considered to be elementary particles are charged. On</p>	<p>'Elementary particle' is not defined here, but already exists in the Gold Book (from a 1982 Rec).</p> <p>However 'elementary or</p>	<p>126. nuclear capture</p> <p>capture</p> <p>Process in which an atomic nucleus acquires</p>

Comment	Response	Changes to MS
<p>the other hand, alpha particles are not elementary. Are they, or even charged molecules, included?</p> <p>The term 'gamma ray' was also used in the previous version. It does not seem appropriate in a context where a reaction on the atomic scale is described. It should be, <i>e.g.</i>, a 'gamma quantum'. A ray is understood to be a beam, <i>i.e.</i>, a stream of particles or quanta.</p>	<p>charged' is not in the Recommendation which uses 'additional'. We wanted to be more specific, but this doesn't work. We revert to the original but add a note.</p>	<p>an additional particle.</p> <p>Note 1: The captured particle may be an elementary particle (See: [2] p 1547) and may be charged or neutral.</p> <p>...</p>
<p><b>163. radiochemical purity</b></p> <p>The definition first uses 'isotope' in the singular. See general comment on that above.</p> <p>Should it not have been 'Amount of a particular radionuclide...'? It then speaks about 'the total amount of isotopes'. It is not clear at all what that means: isotopes of what?</p> <p>Any relation of the term defined here to other terms used in practice in connection with labelled compounds, <i>e.g.</i>, degree of substitution, should be explained. Some examples would be in place here.</p>	<p>Thank you. We have reverted to the original PAC Rec definition, but using your suggestion of 'radionuclide' and clarifying 'fraction' by adding 'amount'</p> <p>In reading more on this entry we note the large medical literature that defines this in terms of activity fraction.</p>	<p>163. radiochemical purity</p> <p>For a material, the fraction of the stated radionuclide present in the stated chemical form.</p> <p>Source: [3] p 2523.</p> <p>Note 1: The unit of radiochemical purity is mol/mol = 1.</p> <p>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.)</p>
<p><b>179. radionuclide purity</b></p> <p>I note that the introduction of daughter products is new to this revision. A comment on that should be made.</p> <p>The <math>^{99m}\text{Tc}</math> example should be elaborated. What is the material there, the daughter products if any (if there are none, provide an additional example where there are some), and what do the other nuclides mentioned mean in terms of the total activity.</p>	<p>The definition is from the PAC REC and had included 'daughter products' before.</p> <p>We add to the example "<math>^{99}\text{Tc}</math> is generated as a daughter product from <math>^{99}\text{Mo}</math>, directly or via <math>^{99m}\text{Tc}</math>."</p>	
<p><b>190. resonance integral</b></p> <p>The designations 'n' and 'fis' explained in the parenthesis are not present in the equation.</p> <p>As for the note, a matter of language: an integral cannot coincide with a definition of an energy range!</p>	<p>See definition where X in the equation is replaced by 'n' or 'fis'. We clarify.</p> <p>cAlso the word 'range' was missing from the Note.</p>	<p>where X is the nature of the radiation (<math>X \equiv \text{'n'}</math> denotes neutron, <math>X \equiv \text{'fis'}</math> denotes neutron induced fission),</p> <p>Note: In radioanalytical</p>

Comment	Response	Changes to MS
		chemistry, the resonance integral <b>range</b> coincides with the definition of the epithermal neutron energy range.
<p><b>193. saturation (in radiation chemistry)</b> The definition now omitted the wording about the irradiation. This makes it unclear what situations the definition is intended to cover. In cases with irradiation of a particular element, the nuclide being irradiated is not necessarily a radionuclide?</p>	Accepted. We use the original wording 'Of an irradiated element' and write 'nuclide' instead of 'radionuclide' (or 'isotope' in the original)	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.
<p><b>194. saturation activity</b> What cross-section of what? the density of which particles? This must be explained for the definition to make sense.</p>	If the cross references are followed we believe the definition is sufficient.	<i>particle flux density</i> is now cross referenced
<p><b>201. self-absorption factor</b> With the definition given, a factor of 1 corresponds to no self-absorption and a factor of 0 corresponds to 100 % self-absorption. The factor defined corresponds better to the term 'source efficiency' which runs oppositely to self-absorption.</p>	True, but both the Gold Book (PAC Rec) and the new reference define it thus. See <a href="http://goldbook.iupac.org/terms/view/S05581">http://goldbook.iupac.org/terms/view/S05581</a>	no change
<p><b>207. specific activity of a radionuclide</b> Note 1 seems completely out of place here. The definition has nothing to do with 'radiochemical processing' or any experiment. Maybe copied from somewhere else?</p>	This note is out of place and has been moved. (See response to reviewer 6).	
<p><b>208. specific activity of a radionuclide in a material</b> Note 2: do we really want to call activity specified in Ci mmol<sup>-1</sup> 'molar activity'? Perhaps millimolar activity? It would be good to have a relevant example. The example given would seem to rather relate to definition 207.</p>	<p>molar activity is correct. See Green Book 1.4 USE OF THE WORDS "EXTENSIVE", "INTENSIVE", "SPECIFIC", AND "MOLAR".</p> <p>Thank you. Example moved to 207, and new example provided.</p>	Example: Certificate of analysis of adenosine 5'-triphosphate solution isotopically-labelled with [ <sup>33</sup> P] gives "Specific activity 370 MBq/g"
<p><b>209. specifically-labelled isotopic tracer</b> Change 'a molecule' to 'the molecule'. A particular molecule is implicitly understood.</p>	<p>done.</p> <p>Yes – thank you, selectively-labelled now</p>	<p>a molecule -&gt; the molecule</p> <p>See new entry 201</p>

<b>Comment</b>	<b>Response</b>	<b>Changes to MS</b>
Should there also be a definition of 'selectively-labelled'?	defined.  We also add a useful note on Nomenclature from ref [86]	selectively-labelled isotopic tracer  Also see new Note and example to specifically-labelled isotopic tracer

For Peer Review Only

# Vocabulary of radioanalytical methods (IUPAC Recommendations 201x)

Zhifang Chai<sup>1</sup>, Amares Chatt<sup>2</sup>, Peter Bode<sup>3</sup>, Jan Kucera<sup>4</sup>, Robert Greenberg<sup>5</sup>, D. Brynn Hibbert<sup>6‡</sup>

<sup>1</sup>Lab. Nuclear Analytical Techniques Institute of High Energy Physics Chinese Academy of Sciences, P.O.Box 918, Beijing 100049,

<sup>2</sup>Trace Analysis Research Centre, Department of Chemistry, Dalhousie University, Halifax, Nova Scotia B3H 4J3 Canada

<sup>3</sup>Delft University of Technology, Reactor Institute Delft, Mekelweg 15, NL-2629 JB Delft, The Netherlands

<sup>4</sup>Nuclear Physics Institute CZ-25068, Rez near Prague, Czech Republic

<sup>5</sup>National Institute of Standards and Technology, 100 Bureau Drive, 8395 Building 235, Rm B176, Gaithersburg,

<sup>6</sup> School of Chemistry, UNSW Sydney, NSW 2052, Australia

‡ Corresponding author: School of Chemistry, UNSW Sydney, NSW 2052, Australia. [b.hibbert@unsw.edu.au](mailto:b.hibbert@unsw.edu.au)

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

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[https://iupac.org/projects/project-details/?project\\_nr=2010-030-1-500](https://iupac.org/projects/project-details/?project_nr=2010-030-1-500)).

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## 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 are included from nuclear technology, nuclear physics and radioactivity measurements. 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 twenty to thirty 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. Particularly, sophisticated nuclear facilities and detectors, like advanced nuclear reactors, dedicated particle accelerators, and various new types of radiation detectors with excellent performances are changing the outlook of radioanalytical methods. For example, many advanced nuclear analytical laboratories in the world have access 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 present IUPAC format, the concept entries of these Recommendations provide term, definition and explanations by 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). Changes to wording are referenced as "Source: Adapted from ...", and for Recommendations this change will replace the existing entry. Where a completely rewritten entry is 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.

## 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, *irradiation* and *radiation* measurement parameters without the use of a *calibrator* with known property values.

Reference: [7] p1575. See also: [8]. Replaces: [3] p 2515.



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2. **absolute activity**

See: *activity of a radioactive substance*.

3. **absolute counting**

*Measurement method* [VIM 2.5] in which the observed *counting rate* 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 ( $1 \text{ MeV} = 1.602\,176\,634 \times 10^{-13} \text{ J}$ ) energies and separated according to their momentum, charge, and energy, allowing high discrimination for measurement of *isotope-nuclide* abundances.

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

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

8. **activation (in radiation chemistry)**

Induction of *radioactivity* by *irradiation*.

Note: In general, a specification is added of 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*).

Source: Adapted from [3] p 2515. See also: [7] p1555, *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 absorption of electromagnetic radiation by stable *isotopesnuclides*, is measured.

Note: A specification is added of the type of the 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] p1555.

## 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 *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

~~deprecated: disintegration rate~~

~~Number of nuclear decays occurring in a given quantity of material in a small time interval, divided by that time interval. Rate at which a *radioactive* entity decays.  $A = -dN_B/dt$  where  $N_B$  is the number of decaying entities B.~~

~~Source: Adapted from [3] p 2515 and [12] p 24.~~

Note 1: For a specified substance B,  $A = -dN_B/dt$  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 ( $s^{-1}$ ). Curie (Ci) is a former unit of activity equal to exactly  $3.7 \times 10^{10}$  Bq.

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

~~Source: Adapted from [3] p 2515 and [12] p 24.~~

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**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 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 for measurement of the structure and composition of materials.

**18. barn, b**

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

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

**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 relation 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 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 this term 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 which, 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].

1       **25. carrier-free**  
2

3                See: *no carrier added*.  
4

5  
6       **26. channeling effect**  
7

8                Range (traveling distance) increasing effect caused by the decrease in interaction  
9                cross sections of the incident particles with atoms in a single crystal when a highly  
10               collimated particle beam impinges on a crystal along its principal axis or principal  
11               plane.  
12

13                Source: [17].  
14

15  
16       **27. channels ratio method**  
17

18                *Measurement method* [VIM 2.5] to obtain a *quenching correction* by counting the  
19               spectrum in two separate channels, the ratio of which gives the degree of  
20               quenching.  
21

22                Source: [18].  
23

24  
25       **28. characteristic X-radiation**  
26

27                X-radiation consisting of discrete energies which are characteristic for the emitting  
28               element.  
29

30                Note:        X-rays are electromagnetic radiation with wavelength between  $10^{-11}$   
31                and  $10^{-8}$  m, corresponding to energies between 100 keV and 100 eV.  
32

33                Source: Adapted from [3] p 2526.  
34

35  
36       **29. Compton scattering analysis**  
37

38                *Measurement principle* [VIM 2.4] in which wavelengths and angular distribution  
39               of Compton scattered electrons is applied for reconstruction of X-ray and gamma-  
40               ray spectra.  
41

42                Note:        Compton scattering analysis is applied e.g. in mammography.  
43

44                Source:[19] p 54-66.  
45

46  
47       **30. count**  
48

49                Single event recorded by a *radiation counter*.  
50

51                Replaces: [3] p 2516.  
52

53  
54       **31. count rate**  
55

56                See: *counting rate*.  
57

1       **32. counting efficiency**  
2       intrinsic counting efficiency  
3

4  
5       Number of particles or photons counted divided by the number that has struck the  
6       envelope.

7  
8       Note: ~~limiting~~ This ratio limits the sensitive volume of a *radiation detector*.  
9

10       Replaces: [3] p 2517. See also: *absolute counting*, *absolute counting efficiency*.  
11

12  
13       **33. counting geometry**  
14

15       Arrangement in space of the various components of an experiment, particularly the  
16       *source* and the *radiation detector* in *radiation* measurements.  
17

18       Replaces: [3] p 2520.  
19

20  
21       **34. counting loss**  
22

23       Reduction of the *counting rate* resulting from phenomena such as the *dead time of*  
24       *a radiation counter*.  
25

26       Source: Adapted from [3] p 2517.  
27

28  
29       Note:       Counting loss is corrected for by a *dead time correction* or a *resolving*  
30       *time correction*.  
31

32  
33       **35. counting rate**  
34       count rate  
35

36       Number of *counts* occurring in unit time.  
37

38       Source: [3] p 2517.  
39

40  
41       **36. cross reactivity**  
42

43       Ability of substances other than the analyte to bind to the binding reagent and  
44       ability of substances other than the binding reagent to bind the analyte in  
45       *competitive binding assays*.  
46

47       Note:       Binding described here is known as cross reaction.  
48

49       Source: [3] p 2517, 'cross reaction'.  
50

51  
52       **37. cross section (in radiation chemistry),  $\sigma$**   
53       microscopic cross section  
54

55       Characteristic area related to the probability of a specified interaction or reaction  
56       between an incident nuclear *radiation* and a target particle or system of particles.  
57  
58  
59

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, a specification is added of 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).

Example: The capture cross section of  $^{10}\text{B}$  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  $N_{\text{true}}$  then for measurements at time  $t$  with dead time  $t_d$ ,  

$$N_{\text{true}} = N_m / (1 - t_d/t).$$

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 to 400  $\mu\text{s}$ .

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,  $\lambda$ ,  $k$** 

decay rate constant of a radionuclide

~~disintegration constant of a radionuclide~~

~~disintegration rate constant of a radionuclide~~

Proportionality constant between the *activity* ( $A$ ) of a specified radionuclide and the number of decaying entities ( $N_B$ ).  $A = \lambda N_B$ .

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: 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*.



1 **50. delayed-neutron counting, (DNC)**  
2

3 See: *delayed-neutron activation analysis*.  
4

5 **51. destructive activation analysis**  
6

7 See: *radiochemical activation analysis*.  
8  
9

10 **52. direct isotope dilution analysis**  
11

12 See: *isotope dilution analysis*.  
13  
14

15 **53. directly-ionizing radiation**  
16

17 Beam of particles capable of removing one or more orbital electrons in a single  
18 quantum event from a specified atom resulting in an ion.  
19

20  
21 Note 1: To have sufficient energy for direct ionization most ionizing particles  
22 are electrically charged, for example, alpha particles, beta particles,  
23 electrons, positrons, protons. Photons can ionize atoms directly through  
24 the photoelectric effect or the Compton effect.  
25

26  
27 Note 2: When considering health effects of radiation, the distinction may be made  
28 between multiple ionizations by charged particles as they move through  
29 a material (called 'direct ionization'), and a single event of ionization  
30 caused by a photon.  
31

32 See also: *indirectly-ionizing radiation*.  
33

34 Reference: [22] p 11.  
35

36 **54. disintegration constant of a radionuclide**  
37

38 See: *decay constant of a radionuclide*.  
39

40 **55. disintegration rate constant of a radionuclide**  
41

42 See: *decay constant of a radionuclide*.  
43  
44

45 **56. down time**  
46

47 See: *dead time of a radiation counter*.  
48  
49

50 **57. effective cadmium cut-off energy**  
51

52 In a given experimental configuration, the *energy* value determined by the  
53 condition that the *radiation detector* response would be unchanged if the cadmium  
54 cover surrounding the detector was replaced by a cover opaque to neutrons with  
55 *energy* below this value and transparent to neutrons with *energy* above this value.  
56  
57

58 Note: Typically, the thickness of this cadmium cover is taken to be 1 mm.  
59  
60

61

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-metre-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  $\text{J s}^{-1} \text{m}^{-2} = \text{W m}^{-2}$

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.

1 Note: EDX is often coupled with scanning electron microscopy, or *proton-*  
2 *induced X-ray emission*.  
3

4 Source: [24].  
5  
6

7 **64. energy-dispersive X-ray spectroscopy, (EDS, EDXS)**  
8

9 See: *energy-dispersive X-ray fluorescence analysis*.  
10

11 **65. epicadmium neutron**  
12

13 Neutron of kinetic energy greater than the *effective cadmium cut-off energy*.  
14  
15

16 Source: Adapted from [3] p 2522.  
17

18 **66. epithermal neutron**  
19

20 Neutron of kinetic energy greater than that of thermal agitation.  
21  
22

23 Note 1: The term ‘epithermal’ is often restricted to energies just above thermal.  
24 See also: *neutron energy*.  
25

26 Source: [3] p 2522.  
27

28 Note 2: ‘Epithermal neutron’ is often used interchangeably with *epicadmium*  
29 *neutron*.  
30  
31

32 **67. extended X-ray absorption fine structure, (EXAFS)**  
33

34 *Measurement method* [VIM 2.5] of *X-ray absorption analysis* in which the fine  
35 structure of the adsorption spectrum in the range 30 eV to 1 keV above the  
36 adsorption edge is used to measure the number and species of neighbouring atoms,  
37 their distance from the selected atom, and the thermal or structural disorder of their  
38 positions.  
39  
40

41 Note 1: In the EXAFS region interference between the wave functions of the  
42 core and neighbouring atoms gives a periodic pattern which contains  
43 information characterizing the arrangement of atoms, including number  
44 and type of neighbouring atoms and their distance to the absorbing  
45 atom.  
46  
47

48 Note 2: The method uses synchrotron radiation.  
49  
50

51 Source: [25, 26]. See also: *X-ray absorption near edge structure*.  
52

53 **68. external standardization for quenching correction**  
54

55 *Measurement method* [VIM 2.5] to obtain a *quenching correction* by use of a  
56 gamma-radiation source to generate a spectrum of Compton electrons within the  
57 sample vial.  
58  
59

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

69. **fluence**,  $F$ ,  $H$

Energy per area delivered in a given time interval.  $F = \int I dt = \int (dP/dA)dt$ , where  $I$  is intensity,  $P$  is power and  $A$  is area.

Note: 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 de-excitation of atoms in a material following the initial excitation of these atoms by absorption of energy from incident *radiation* or particles.

Note: 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 which 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  $4\pi$ .

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*  $\lambda$  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*.

- 1  
2  
3  
4  
5
- 80. half-value thickness**  
half thickness  
half-value layer thickness

6  
7  
8  
9

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

10  
11

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

- 12  
13
- 81. hot atom**

14  
15  
16

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

17  
18  
19

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

- 20  
21
- 82. hot cell**

22  
23

Heavily shielded enclosure for highly *radioactive* materials.

24  
25  
26

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

27  
28  
29

Source: Adapted from [3] p 2520.

- 30  
31
- 83. indirectly-ionizing radiation**

32  
33  
34  
35  
36

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

37  
38  
39

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

40  
41  
42

Reference: [22] p 11.

- 43  
44  
45
- 84. instrumental activation analysis**  
non-destructive activation analysis

46  
47  
48  
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50  
51  
52

*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, *irradiation* and *radiation* measurement parameters and the use of a *calibrator* with known property values, without the use of chemical processing after the *irradiation*.

53  
54  
55

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

- 56  
57
- 85. intrinsic counting efficiency**

58  
59  
60

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 for measuring 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 for the measurement of 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

1 the substance, and subsequent measurement of the *activity* of that *radionuclide* in a  
2 subsample taken from the mixture.  
3

4  
5 Note: IDA may be classified in terms of (i) the manner of introducing  
6 radioactivity into the system; (ii) the method of measuring the activity;  
7 (iii) number of dilution steps; (iv) relative masses of sample and  
8 diluent.  
9

10 Source: [40] p 1-16. See also: [41] p 122-124. Replaces: [3] p 2521.  
11

12  
13 **92. isotope effect**  
14 isotopic effect  
15

16 Effect on the rate constant or equilibrium constant of two reactions that differ only  
17 in the isotopic composition of one or more of their otherwise chemically identical  
18 components is referred to as a kinetic isotope effect or a thermodynamic (or  
19 equilibrium) isotope effect, respectively. (See: *isotopes*).  
20

21  
22 Note: Reference [42] pp 1130 – 1131 defines heavy atom isotope effect,  
23 intramolecular isotope effect, inverse isotope effect, kinetic isotope  
24 effect, primary isotope effect, secondary isotope effect, solvent isotope  
25 effect, steric isotope effect, and thermodynamic (equilibrium) isotope  
26 effect.  
27

28  
29 Source: Adapted with minor change from [42] p 1130. See also: [43, 44].  
30

31 **93. isotope exchange**  
32

33 See: *isotopic exchange*.  
34

35  
36 **94. isotopes**  
37 isotopic nuclides  
38

39 *Nuclides* having the same atomic number but different mass numbers.  
40

41 Examples:  $^{12}\text{C}$  and  $^{13}\text{C}$ ;  $^1\text{H}$ ,  $^2\text{H}$  and  $^3\text{H}$ .  
42

43  
44 Note 1: If no left superscript is added denoting the mass number an element  
45 symbol is read as including all isotopes in natural abundance.  
46

47 Source: Adapted from [12] p 49.  
48

49  
50 Note 2: The use of the singular term '*isotope*' should always relate to a  
51 particular element (e.g. deuterium is an isotope of hydrogen). When  
52 used in a general sense, the term *nuclide* is preferred (e.g. *radionuclides*  
53 are used in the treatment of cancer).  
54

55 See also: *radioisotope*.  
56  
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**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 ~~a~~**the illegal drug molecule-methylamphetamine**, for use in analysis by mass spectrometry. **Methylamphetamine incorporating deuterium is the 'isotopic tracer'**.

1 Note 2: In general usage 'label' and 'tracer' are used synonymously. See: [46]  
2 4.1.12.  
3

4 Source: Adapted from [3] p 2521.  
5

### 6 **101. isotopic nuclides**

7 See: *isotopes*.

### 8 **102. isotopic tracer**

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

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

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

15 Note: In general usage label and tracer are often used synonymously. See: [46]  
16 4.1.12.

### 17 **103. lifetime of a radionuclide**

18 See: *mean life of a radionuclide*.

### 19 **104. liquid scintillation detector**

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

21 Source: Adapted from [3] p 2522.

### 22 **105. live time**

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

24 Note 1: Live time equals the clock time minus the integrated resolving or *dead*  
25 *time*.

26 Note 2: Live time should not be confused with 'lifetime' of a radioactive  
27 species.

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

### 29 **106. macroscopic cross section**

30 *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,  $\tau$**

average life of a radionuclide

lifetime of a radionuclide

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

Note: The average-mean life is greater than the *half life of a radionuclide* by the factor  $1/\ln 2$  ( $\approx 1.44$ ); 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,  $A_m(\text{R})$**

molar activity

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

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

Note 2: If the term “molar activity” is used without qualification it should be made clear whether it is of a material or of 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,  $A_m(\text{R},\text{M})$**

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<sup>-1</sup>, but molar activity is often expressed in unit Ci mmol<sup>-1</sup>. (Curie, symbol Ci, is a former unit of activity equal to exactly  $3.7 \times 10^{10}$  Bq.)

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

Example: The certificate of analysis of adenosine 5'-triphosphate containing the *isotopic label* <sup>33</sup>P (called <sup>33</sup>P-gamma-ATP) quotes the activity as 3000 Ci mmol<sup>-1</sup> [48].

Using the recommended symbol,  $A_m(^{33}\text{P},\text{ATP}) = 3000 \text{ Ci mmol}^{-1}$ .

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: : <sup>9</sup>Be, <sup>19</sup>F, <sup>23</sup>Na, <sup>27</sup>Al, <sup>31</sup>P, <sup>45</sup>Sc, <sup>51</sup>V, <sup>55</sup>Mn, <sup>59</sup>Co, <sup>75</sup>As, <sup>85</sup>Rb, <sup>89</sup>Y, <sup>93</sup>Nb, <sup>103</sup>Rh, <sup>113</sup>In, <sup>127</sup>I, <sup>133</sup>Cs, <sup>139</sup>La, <sup>141</sup>Pr, <sup>153</sup>Eu, <sup>159</sup>Tb, <sup>165</sup>Ho, <sup>169</sup>Tm, <sup>175</sup>Lu, <sup>185</sup>Re, <sup>197</sup>Au.

Note 2: General usage of the term "monoisotopic" refers to the 21 elements with one isotope determining their relative atomic masses, i.e. <sup>9</sup>Be, <sup>19</sup>F, <sup>23</sup>Na, <sup>27</sup>Al, <sup>31</sup>P, <sup>45</sup>Sc, <sup>55</sup>Mn, <sup>59</sup>Co, <sup>75</sup>As, <sup>89</sup>Y, <sup>93</sup>Nb, <sup>103</sup>Rh, <sup>127</sup>I, <sup>133</sup>Cs, <sup>141</sup>Pr, <sup>159</sup>Tb, <sup>165</sup>Ho, <sup>169</sup>Tm, <sup>197</sup>Au, <sup>209</sup>Bi, <sup>231</sup>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 to 0.025	cold neutron

0.025 (corresponding to 295 K)	<i>thermal neutron</i>
0.025 to 0.4	<i>epithermal neutron</i>
0.4 to 0.6	cadmium neutron
0.6 to 1	<i>epicadmium neutron</i>
1 to 10*	slow neutron
10 to 300	<i>resonance neutron</i>
300 to $1 \times 10^6$	intermediate neutron
$(1 \text{ to } 20) \times 10^6$	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] p1547.

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 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*.

1 **124. non-destructive activation analysis**  
2

3 See: *instrumental activation analysis*.  
4

5 **125. non-radiative quenching**  
6

7  
8 Deactivation of an electronically-excited state by interaction with the external  
9 environment through a non-radiative process.  
10

11 Note 1: Non-radiative quenching may lead to spectral shift or *counting losses*.  
12

13 Note 2: The effects of quenching may be taken into account by a *quenching*  
14 *correction*.  
15

16 Source: Adapted from [3] p 2523. See also: [61] p 26.  
17

18 **126. nuclear capture**  
19 capture  
20

21 Process in which an atomic nucleus acquires an ~~elementary or charged~~ additional  
22 particle.  
23

24 Note 1: The captured particle may be an elementary particle (See: [2] p 1547)  
25 and may be charged or neutral.  
26

27 Note 2: In general, a specification is added of the type of the captured particle or  
28 its energy.  
29

30 Example: Gold-197 captures a neutron and emits a gamma ray:  
31  $^{197}\text{Au} + \text{n} \rightarrow ^{198}\text{Au} + \gamma$ , or in short form  $^{197}\text{Au}(\text{n},\gamma)^{198}\text{Au}$ .  
32

33 Source: Adapted from [3] p 2513. See also: *capture cross section*.  
34

35 **127. nuclear chemistry**  
36

37 Scientific discipline which deals with the study of nuclei, *nuclear decay*, nuclear  
38 reactions and nuclear processes using chemical methods.  
39

40 Source: Adapted from [3] p 2516 and [2] p 1537.  
41

42 **128. nuclear decay**  
43

44 Spontaneous nuclear transformation.  
45

46 Source: [3] p 2518.  
47

48 **129. nuclear fission**  
49

50 Exoergic division of a nucleus into two or more parts with masses of approximate  
51 equal order of magnitude, usually accompanied by the emission of neutrons,  
52 gamma radiation and, rarely, small charged nuclear fragments.  
53

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  $^{14}\text{C}$  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 suffix '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  $\text{m}^{-2} \text{s}^{-1}$ .
- 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  $\text{n cm}^{-2} \text{s}^{-1}$ . As 'n' is not a unit, it is metrologically unacceptable and therefore not recommended.

Replaces: [3] p 2519. See also: [12] at Note (26) at p 44 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 ( $\mu$ -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 applied for measurement of 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 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 is performed both in a time-differential (TDPAC) or 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.

- 1 Note 1: Annihilation lifetime (See: *positron lifetime spectrometry*), Doppler  
2 broadening and angular correlation of annihilation radiation are  
3 measured in this technique.  
4  
5  
6 Note 2: In the most common case of positron annihilation, two photons are  
7 created, each with energy equal to the rest energy of the electron or  
8 positron ( $0.511 \text{ MeV} = 8.187\,122\,6 \times 10^{-14} \text{ J}$ ).  
9  
10 Note 3: Techniques based on PAA have been used particularly for the study of  
11 free volume in polymers.  
12

13  
14 Source: [65].  
15

16 **138. positron annihilation lifetime spectrometry, (PALS)**

17  
18 See: *positron lifetime spectrometry*.  
19

20 **139. positron annihilation spectroscopy for chemical analysis, (PASCA)**

21  
22 See: *positron annihilation analysis*.  
23

24 **140. positron emission tomography, (PET)**

25  
26 Imaging method based on the detection of pairs of gamma rays emitted indirectly  
27 by a positron-emitting *isotopic tracer*.  
28

29 Note 1: A commonly used *isotope-nuclide* is fluorine-18.  
30

31 Note 2: Three-dimensional imaging is obtained using computed tomography.  
32

33  
34 Source: [66].  
35

36 **141. positron lifetime spectrometry, (PLS)**  
37 positron annihilation lifetime spectrometry, (PALS)

38  
39 *Measurement method* [VIM 2.5] of *positron annihilation analysis* in which the  
40 time interval between the emission of positrons from a *radioactive source* and the  
41 detection of gamma rays due to annihilation of these positrons with electrons from  
42 the surrounding matter is the lifetime of the positron or positronium.  
43  
44  
45  
46

47 Source: [67] p 500.  
48

49 **142. prompt gamma radiation**

50  
51 Gamma *radiation* emitted during the de-excitation of a compound nucleus formed  
52 in a nuclear capture reaction.  
53  
54

55 **143. prompt gamma-ray analysis, (PGA)**  
56 deprecated: prompt gamma activation analysis, (PGAA)  
57 deprecated: prompt gamma neutron activation analysis, (PGNAA)  
58  
59

1 *Measurement principle* [VIM 2.4] in which gamma radiation emitted during the  
2 de-excitation of the compound nucleus formed by neutron capture is applied to  
3 measure the amounts of elements in a material.  
4

5  
6 Note: The measurement method is often denoted as prompt gamma-ray  
7 neutron activation analysis (PGNAA) or prompt gamma-ray activation  
8 analysis (PGAA) though the measurement method is not in agreement  
9 with the definition of *activation analysis*. The term prompt gamma-ray  
10 analysis (PGA) is therefore to be preferred.  
11

12  
13 Source: [38, 68].  
14

#### 15 **144. pulse pile-up**

16  
17 Processing by a *radiation counter* of pulses resulting from the simultaneous  
18 absorption of independent particles or photons in a *radiation detector* resulting in  
19 the counting as one single particle or photon with energy between the individual  
20 energies and the sum of these energies.  
21

22  
23 Source: [69] p 655.  
24

#### 25 **145. quenching correction**

26  
27 Correction for errors due to different *quenching in radiation detectors* for  
28 standards and samples.  
29

30  
31 Note: When using *liquid scintillation detectors*, these corrections can be based  
32 e.g. on the standard addition or sample *channels ratio method* or the use  
33 of automated *external standardization*.  
34

35  
36 Source: Adapted from [3] p 2523.  
37

#### 38 **146. quenching in radiation detectors**

39  
40 Process of inhibiting continuous or multiple discharges following a single ionizing  
41 event in certain types of radiation detectors, particularly in *Geiger-Müller counters*.  
42

43  
44 Source: [70]. See: *quenching correction*.  
45

#### 46 **147. radiation**

47  
48 Emission of energy as electromagnetic waves or as fast-moving subatomic  
49 particles.  
50

51  
52 Note: In *radioanalytical chemistry*, the term usually refers to radiation used  
53 and emitted during nuclear processes (e.g., *radioactive decay*, *nuclear*  
54 *decay*, *nuclear fission*).  
55

56  
57 Source: Adapted from [3] p 2523. See also: *ionizing radiation*.  
58  
59  
60

**148. radiation chemistry**

Sub-discipline of chemistry which 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 *radiation* 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 *radionuclide*.

Note 2: 'Radioactive' is also used to describe a material that includes a radionuclide.

1 **153. radioactive chain**

2  
3 See: *decay chain*.

4  
5  
6 **154. radioactive decay**

7  
8 *Nuclear decay* in which particles or electromagnetic *radiation* are emitted or the  
9 nucleus undergoes spontaneous fission or electron capture.

10  
11 Source: [3] p 2518.

12  
13  
14 **155. radioactive equilibrium**

15  
16 See: *radioactive steady state*.

17  
18  
19 **156. radioactive purity**

20  
21 See: *radionuclide purity*.

22  
23  
24 **157. radioactive series**

25  
26 See: *decay chain*.

27  
28 **158. radioactive source**

29  
30 *Radioactive* material which is intended for use as a source of *ionizing radiation*.

31  
32 Source: Adapted from [3] p 2526.

33  
34  
35 **159. radioactive steady state**

36 radioactive equilibrium  
37 secular equilibrium

38  
39 Among the *radionuclides* of a *decay chain*, the state which prevails when the ratios  
40 between the *activities* of successive radionuclides remain constant.

41  
42 Note: This is not equilibrium in the strict sense since *radioactive decay* is an  
43 irreversible process.

44  
45 Source: Adapted from [3] p 2519, [72] p 185.

46  
47  
48 **160. radioactivity**

49  
50 Phenomenon of *nuclides* undergoing *radioactive decay*.

51  
52 Source: Adapted from [3] p 2513.

53  
54  
55 **161. radioanalytical chemistry**

56 analytical radiochemistry

1 That part of analytical chemistry in which the application of *radioactivity* is an  
2 essential step in the analytical procedures.  
3

4 Source: [2] p 1535.  
5

6  
7 Note 1: Use is made of nuclear processes (e.g., *nuclear decay*, *nuclear fission*),  
8 nuclear effects, *radiation*, and nuclear facilities, and of radiochemical  
9 and nuclear measurement techniques.  
10

11 Note 2: Radioanalytical chemistry is part of *radiochemistry*.  
12  
13

## 14 **162. radiochemical activation analysis**

15 destructive activation analysis  
16

17 *Measurement method* [VIM 2.5] of *activation analysis*, in which concentrations or  
18 mass contents of elements in a material are measured using a *measurement model*  
19 [VIM 2.48] with known nuclear constants, *irradiation* and *radiation* measurement  
20 parameters and the use of a *calibrator* with known property values and in which  
21 chemical separation is applied after the irradiation.  
22  
23

24 Source: [7] p 1583. See also: [73].  
25

## 26 **163. radiochemical purity**

27  
28 For a material, the fraction of the stated *radionuclide* present in the stated chemical  
29 form.  
30

31  
32 Amount of an *isotope* in a stated chemical form in a material divided by the total  
33 amount of isotopes in that stated chemical form.  
34

35 Source: [3] p 2523.  
36

37  
38 Note 1: The unit of radiochemical purity is mol/mol = 1.  
39

40 Note 2: The medical literature often defines radiochemical purity as the fraction  
41 of the radioactivity of a material in a stated chemical form. (See: [74].  
42 p347, and *radionuclide purity*.)  
43  
44

45 Source: Adapted from [3] p 2523.  
46

## 47 **164. radiochemical recoil effect**

48 See: *Szilard-Chalmers effect*.  
49

## 50 **165. radiochemical separation**

51  
52 Separation by a chemical means of *radionuclide(s)* of a specific element from a  
53 mixture of radionuclides of other chemical elements.  
54  
55

56 Source: [3] p 2526.  
57  
58  
59  
60

**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 substance, or of covalently linking a radioiodinated substance to a substance.

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

Source: Adapted from [3] p 2524.

1 **172. radioisotope**

2  
3 A *radioactive* isotope (See: *isotopes*) of a specified element.

4  
5  
6 Source: [3] p 2524.

7  
8 **173. radioisotope dilution analysis**

9  
10 See: *isotope dilution analysis*.

11  
12 **174. radioisotope induced X-ray emission analysis**

13  
14  
15 *Measurement method* [VIM 2.5] of *X-ray analysis* in which a *radioactive source* is  
16 used for irradiation of the sample.

17  
18 Source: [19].

19  
20 **175. radiolysis**

21  
22 Chemical decomposition of materials by *ionizing radiation*.

23  
24 Source: [3] p 2524.

25  
26 **176. radiometric analysis**

27  
28  
29 *Measurement principle* [VIM 2.4] in which the *activity* of a *radioactive* component  
30 with known specific activity is applied for measurement of the amount of an  
31 element in a material.

32  
33 Source: [77] p 564. Replaces: [3] p 2524.

34  
35 **177. radiometric titration**

36  
37  
38 Titration in which a *radioactive* indicator is used to monitor the end-point of the  
39 titration.

40  
41 Source: [3] p 2524. See also: [78] p 168.

42  
43 **178. radionuclide**

44  
45  
46 *Nuclide* that is *radioactive*.

47  
48 Source: [3] p 2524.

49  
50 Note: When an element is specified the radionuclide is termed a *radioisotope*.

51  
52 **179. radionuclide purity**

53  
54 radionuclidic purity

55  
56 radioactive purity



1 *Activity of a stated radionuclide, including daughter products, in a material divided*  
2 *by the total activity of the material.*  
3

4  
5 Source: Adapted from [3] p 2523.  
6

7 Note 1: The SI unit of radionuclide purity is Bq/Bq = 1.  
8

9 Note 2: Radionuclide purity is important for calibrators, *isotopic tracers*, and in  
10 pharmaceutical uses.  
11

12  
13 Example: Activity of  $^{99m}\text{Tc}$  from a Mo generator with impurities  $^{99}\text{Mo}$ ,  $^{95}\text{Nb}$ ,  
14  $^{188}\text{Re}$ ,  $^{198}\text{Au}$ , etc. (Note that  $^{99}\text{Tc}$  is generated as a daughter product  
15 from  $^{99}\text{Mo}$ , directly or via  $^{99m}\text{Tc}$ .)  
16  
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## 20 **180. radionuclidic purity**

21 See: *radionuclide purity*.  
22

## 23 **181. radioreceptor assay**

24 *Measurement principle* [VIM 2.4] in which labelled (See: *isotopic label*) and  
25 unlabelled molecules, assumed to bind to a receptor at random, are applied to  
26 measure the amount of an analyte by exposing a mixture of the sample and a  
27 known amount of the radiolabelled substance to a measured amount of receptors  
28 for the analyte.  
29  
30  
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32

33 Note: The analyte is typically a hormone.  
34

35 Source: [79].  
36  
37

## 38 **182. recoil**

39 Nuclear phenomenon in which an atom or a particle undergoes a movement  
40 through a collision with, or the emission of, another particle or electromagnetic  
41 radiation.  
42  
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45 Source: Adapted from [3] p 2524.  
46  
47

## 48 **183. recoil effect**

49 See: *Szilard-Chalmers effect*.  
50  
51

## 52 **184. recovery time of a radiation counter**

53 Period of time after the *dead time of a radiation counter* during which the output  
54 pulses are smaller than the original.  
55  
56

57 Note: Depending on the sensitivity of the *counter* some pulses in this period  
58 will not be counted.  
59  
60

45

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,  $\tau$**

Smallest time interval which elapses between the occurrence of two consecutive ionizing events, in order that the *radiation counter* can be 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 is the nature of the radiation ( $X \equiv n^2$  denotes neutron,  $X \equiv \text{fis}^2$  denotes neutron induced fission),  $\sigma_X$  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.

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**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  $^{238}\text{U}$ .

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**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 for~~ a specified *radionuclide*, 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  $\sigma$  is the *cross section* and  $\Phi$  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 by absorption or co-precipitation, a large fraction of one or more *radionuclides*.

Note: In *radiation chemistry* the term scavenging is used to denote 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 as a mixture of specifically-labelled isotopic tracers.

Source: [82] p 1893.

**201:202. self-absorption factor**

source efficiency

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

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

**202:203. self-absorption of radiation**

Absorption of *radiation* by the emitting source.

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

**203:204. 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.

48

**204.205. \_\_\_\_\_ 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 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.

**205.207. \_\_\_\_\_ 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.

**206.208. \_\_\_\_\_ source efficiency**

See: *self-absorption factor*.

**207.209. \_\_\_\_\_ specific activity of a radionuclide,  $A_S(R)$   
specific activity**

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

~~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: 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 ( $^3\text{H}$ ) is  $3.57 \times 10^{17}$  Bq kg<sup>-1</sup> (9.65 Ci mg<sup>-1</sup>) [85].-

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

**208:210. 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 12: The SI unit of specific activity is  $\text{Bq kg}^{-1}$ , but specific activity is often expressed in unit  $\text{s}^{-1} \text{g}^{-1}$  or  $\text{Ci mg}^{-1}$ . (Curie, symbol Ci, is a former unit of activity equal to exactly  $3.7 \times 10^{10} \text{ Bq}$ .)

Note 23: Commercial preparations of isotopically-labelled molecules often quote ‘specific activity’ in  $\text{Ci mmol}^{-1}$ . The correct term is *molar activity of a radionuclide in a material*.

Note 34: 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: Specific activity of tritium ( $^3\text{H}$ ) is  $3.57 \times 10^{17} \text{ Bq kg}^{-1}$  ( $9.65 \text{ Ci mg}^{-1}$ )~~  
~~[85]~~

Example: Certificate of analysis of adenosine 5'-triphosphate solution isotopically-labelled with  $[\gamma\text{-}^{33}\text{P}]$  gives “Specific activity 370 MBq/g”

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

**209:211. specifically-labelled isotopic tracer**

*Isotopic tracer* in which the *isotopic label* is present in a specified position in a-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:  $\text{H}^{[36]\text{Cl}}$ , hydrogen  $^{[36]\text{Cl}}$ chloride.  $\text{Ge}^{[2\text{H}_2]\text{F}_2}$ , difluoro $^{[2\text{H}_2]}$ germane,  
 $^{[15\text{N}]\text{H}_2[2\text{H}]}$ ,  $^{[2\text{H}_1, 15\text{N}]}$ ammonia.

Source: [82] p 1892.

#### **210,212. stereospecifically-labelled isotopic tracer**

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

Source: Adapted from [3] p 2526.

#### **211,213. 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.

#### **212,214. 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].

#### **213,215. 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.

#### **214,216. 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<sup>-1</sup>.

Source: Adapted from [3] p 2522.

1 **215.217. total reflection X-ray fluorescence analysis, (TXRF)**

2  
3  
4 *Measurement method* [VIM 2.5] of *X-ray fluorescence analysis* in which a  
5 collimated X-ray flux impinges on a smooth surface under a grazing angle  
6 rendering total reflection is used to excite atoms in the top layers of the material for  
7 measurement of the amounts of elements.  
8

9  
10 Note: The method is highly sensitive because interfering X-rays of higher  
11 energies are refracted or adsorbed. Mass fractions of  $10^{-12}$  (ng kg<sup>-1</sup>)  
12 may be measured.  
13

14 Source: [89].  
15

16 **216.218. two-site immunoradiometric assay**

17  
18 See: *two-site radioimmunoassay*.  
19

20  
21 **217.219. two-site radioimmunoassay**

22 two-site immunoradiometric assay  
23

24 *Radioimmunoassay* in which two sets of antibodies, one of which is isotopically  
25 labelled (See: *isotopic label*), combine with different immunoreactive sites of an  
26 antigen molecule.  
27

28  
29 Source: [90]. See also: See also: [46] 4.1.12.  
30

31 **218.220. uniformly-labelled isotopic tracer**

32  
33 *Isotopic tracer* in which the *isotopic label* is uniformly distributed over its possible  
34 positions in a molecule.  
35

36  
37 Source: [3] p 2526.  
38

39  
40 **219.221. wavelength-dispersive X-ray fluorescence analysis**

41  
42 *Measurement method* [VIM 2.5] of *X-ray fluorescence analysis* in which the  
43 wavelength spectrum of the emitted *radiation* is used to measure the amounts of  
44 elements.  
45

46 Note: A diffraction grating, or crystal is used to obtain the spectrum.  
47

48 Source: [91].  
49

50  
51 **220.222. Westcott cross section**

52  
53 See: *effective thermal cross section*.  
54

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56 **221.223. Wilzbach labelling**

57  
58 Isotopic labelling (See: *isotopic label*) of a substance by exposing it to tritium gas.  
59

60



**222:224. 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 1: XAS measures changes in the linear absorption coefficient of an element in a sample as a function of incident photon energy.

Note 2: 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*,

**223:225. 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].

**224:226. X-ray absorption near edge fine structure**

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

**225:227. 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 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 1: The method uses synchrotron radiation.

Note 2: 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*.

**226:228. X-ray absorption spectroscopy, (XAS)**

See: *X-ray absorption analysis*.

**227:229. 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].

**228:230. 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  $\mu\text{m}$ .

Source: [4].

**229:231. 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 1: Bragg reflection follows  $n\lambda = 2d \sin \theta$  where  $\lambda$  is the X-ray wavelength,  $d$  is the spacing between atomic planes and  $\theta$  is the angle of diffraction.

Note 2: Copper K- $\alpha$  radiation ( $\lambda = 0.15406 \text{ nm}$ ,  $E = 8.04 \text{ keV}$ ) is typically used for routine XRD.

**230:232. X-ray diffraction, (XRD)**

See: *X-ray diffraction analysis*.

**231:233. 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 ( $\mu\text{-XRF}$ ) analysis uses highly brilliant X-ray sources (synchrotron source and spot size 100 nm to 2  $\mu\text{m}$ ) and microfocussing X-ray optics to give fg to ag detection limits [4].

Source: [94].

**232-234. X-ray fluorescence microscopy, (XRM)**

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

Note 1: X-ray beam energies of 5 to 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  $\mu\text{m}$ , but using specialised probes at synchrotron facilities the lower limit can be reduced to tens of nm [95].

Source: [4].

**233-235. X-ray fluorescence spectroscopy**

See: *X-ray fluorescence analysis*.

**234-236. X-ray fluorescence, (XRF)**

Emission of *characteristic X-radiation* by an atom after photoemission of inner-shell electrons and 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].

**235-237. X-ray micro-tomography, (XMT)**

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

**LIST OF SYMBOLS AND ABBREVIATIONS**

$\lambda$	decay constant of a radionuclide	42
$\sigma$	cross section (in radiation chemistry)	37
$\tau$	mean life of a radionuclide	107
$\tau$	resolving time of a radiation counter	188
$A$	activity of a radioactive substance	12
$A_m(\text{R})$	molar activity of a radionuclide	110
$A_m(\text{R},\text{M})$	molar activity of a radionuclide in a material	111
$A_s$	saturation activity	194
$A_s(\text{R})$	specific activity of a radionuclide	207
$A_s(\text{R},\text{M})$	specific activity of a radionuclide in a material	208
$\text{b}$	barn	18
$F$	fluence	69
$H$	fluence	69
$I_X$	resonance integral	190
$j$	particle (or photon) flux density	132

1	$J_E$	energy flux density	59
2	$k$	decay constant of a radionuclide	42
3			
4	$t_{1/2}$	half life of a radionuclide	78
5	$T_{1/2}$	half life of a radionuclide	78
6	$t_d$	dead time of a radiation counter	40
7			
8	AMS	accelerator mass spectrometry	7
9	DNAA	delayed-neutron activation analysis	48
10	DNA	delayed-neutron analysis	48
11	DNC	delayed-neutron counting	48
12	EDS	energy-dispersive X-ray spectroscopy	63
13	EDX	energy-dispersive X-ray fluorescence analysis	63
14	EDXA	energy-dispersive X-ray analysis	63
15	EDXS	energy-dispersive X-ray spectroscopy	63
16	EXAFS	extended X-ray absorption fine structure	67
17	IBA	ion beam analysis	87
18	IDA	isotope dilution analysis	91
19	NAA	neutron activation analysis	116
20	NCA	no carrier added	123
21	NDP	neutron depth profiling	118
22	NEXAFS	near edge X-ray absorption fine structure	115
23	PAA	positron annihilation analysis	137
24	PAC	perturbed angular correlation spectrometry	135
25	PALS	positron annihilation lifetime spectrometry	141
26	PASCA	positron annihilation spectroscopy for chemical analysis	137
27	PET	positron emission tomography	140
28	PIGE	particle-induced gamma-ray-emission analysis	134
29	PIXE	particle induced X-ray emission analysis	133
30	PGA	prompt gamma-ray analysis	143
31	PLS	positron lifetime spectrometry	141
32	SPM	scanning proton microscopy	195
33	TDPAC	time-differential perturbed angular correlation spectrometry	135
34	TIPAC	time-integrated perturbed angular correlation spectrometry	135
35	XAA	X-ray absorption analysis	222
36	XANES	X-ray absorption near edge structure	225
37	XCMT	X-ray computed micro-tomography	228
38	XAS	X-ray absorption spectroscopy	222
39	XMT	X-ray micro-tomography	228
40	XRD	X-ray diffraction	229
41	XRF	X-ray fluorescence	234
42	XRM	X-ray fluorescence microscopy	232
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Em Professor D Brynn Hibbert  
School of Chemistry

6 October 2019

Dear Jürgen

On behalf of my co-authors I have the pleasure in submitting Revision 3 of “Vocabulary of radioanalytical methods (IUPAC Recommendations 201x)”.

I apologise for the mix-up in the submission of R2 over the reply to reviewers and version with track changes which were submitted but apparently did not make it to them.

Our rebuttal and track change version are together in one manuscript submitted as "Author's Response to Reviewers" as instructed.

Yours sincerely

Emeritus Professor D Brynn Hibbert,  
School of Chemistry  
[b.hibbert@unsw.edu.au](mailto:b.hibbert@unsw.edu.au)  
+61 23856774