

ISNR Terminology – 1st edition

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1. Preface

A broadly shared, agreed and well-defined terminology is of outstanding importance for efficient communication within and outside an organization as well as for every related scientific and applied context in a specific field of activity. The ISNR as a scientific society concerned with neutron radiography/imaging and its applications considers itself responsible to provide and update a concise and complete set of terms describing corresponding activities and methodology.

The ISNR is a scientific interest group/organisation without legal binding framework and reliabilities. Hence, the ISNR might publish recommendations for their members as well as for the general public but has not and does not aim for the authority to implement rules. The ISNR might expect “officials” of the ISNR, i.e. voted members like the board etc. to follow recommendations, but cannot and does not want to enforce such conduct on others. An ISNR task group is working on a guideline of recommended terminology in order to enable stringent and concise use of terms in publications and communications for obvious merits. The task group is however aware and acknowledges that terminology, like language in general, changes with time and progress, and that hence definitions of terminology require reassessment and adaptation on a regular basis in order to be meaningful in a longterm perspective. The first edition shall be accomplished within a single term of presidency of the ISNR (2014-2018). Broad agreement on recommendations published by the ISNR is achieved by a staged (2 step) implementation of definitions of terminology: 1) the task group elaborates definitions and decides upon proposals by majority vote (if consensus cannot be reached with respect to the timeline) and 2) the proposed definitions and terminology recommendations are approved and implemented by the board through a majority vote.

2. Introduction – Scope and Aim

This first edition of ISNR terminology is the first attempt by the society to establish a terminology on its own, for its very own framework and concerns. This is undertaken in the light of growing dissents on terminology, which before has been lent from strongly related fields such as X-ray radiology (medical and scientific), non-destructive testing and neutron science communities. As fast progress in all these fields and in particular also related to more scientific impact

has led to inconsistent use of terminology within and among the related communities, this has led to ambiguity, contradicting use of terms and lack of conciseness also in the field represented by ISNR.

An outstanding example for this issue is the name of the society, characterizing the field with the term RADIOLOGY. Radiology as defined in general, apart from its medical definition, is extremely broad and includes all science related to radiation, in this case neutron radiation. Although historically it might have been more limited and taking radiographic images being a more dominating and early application, this has changed tremendously, and while the name of our society has been sustained, in contrast to its meaning the society does not serve and represent major fields within such definition like fundamental neutron science, neutron scattering etc. The diversification might be a reason why the term is hardly applied with respect to neutrons at all anymore, leaving it as an artifact to the limited scope of this society with distorted or invalid definition.

Against this background it has become necessary for our community to develop an own scheme of terminology that clarifies the use of high level terminology as much as it defines an extensive set of terms to concisely describe and reflect the diversity of established methodology and applications and to enable extensions in developing and evolving fields.

It is essential for such terminology to be as much as possible consistent with definitions in related fields but also with the general public use of terms in order to enable best possible interdisciplinary communications as well as broad public impact. Indeed in the light of established inconsistencies such endeavor poses some challenges and will not always allow for full equivalence of terms and definitions.

3. High Level Terms and Context: Neutron Radiology, Neutron Radiography and Neutron Imaging.

First this section will investigate and discuss terms which are broader and of higher level and thus including but not defining the subject of this document. Such terms are in general defined elsewhere and are beyond the scope of this document, however, they provide the context of the terminology developed here. Subsequently this section will define the highest level terms of the field that is subject to the activities of the ISNR. The structure is such that first a term is defined, while the lead number will refer to the basic hierarchy of terms and hence its specific position and relation to the matters of ISNR. The definitions will be followed by discussions of the context in relation to other fields of science and applications including such not subject to the ISNR objectives.

3.1. General umbrella terms

The highest level terms are naturally such, describing a general field of which the subject of the ISNR and hence the here defined terminology is a sub-category of. Such terms can be expected to be defined already elsewhere and that such definitions leave room for the specific field in the focus here to be part of these. These terms are listed here and available definitions or the general use of these terms are discussed with respect to how they serve or include and provide a context for the subject in the focus of this document and ISNR.

The terms identified are:

- A. Radiology
- B. Imaging
- C. Radiography
- D. Neutron Radiology
- E. Neutron Science

3.1.1. Definitions of general umbrella terms

Although these highest level terms are used very frequently in the context and environment of ISNR it was found that not all of them seem to be properly defined. Therefore either a collection of definitions that could be found as well as their sources or self-formulated definitions as close as possible to the known utilization of terms are provided here and discussed below.

A. Radiology

Etymology

1900, "medical use of X-rays," later extended to "scientific study of radiation," from *radio-*, comb. form of *radiation*, + Greek-based scientific suffix *-(o)logy*, *branch of knowledge, science* (1500, since app. 1800 in nonce formations)

rad, radio-: from *radius*, Latin, originally: *shaft, rod, spoke of wheel, beam of light; radius of circle* (1600); potentially related to *radix: root*

-logy, -ology: from *lego/logia/ logos* Greek (later Latin), originally: *speak, word, speech, account, story*

Definition(s)

Encyclopedia Britannica:

A branch of medicine that uses some forms of radiation (such as X-rays) to diagnose and treat diseases

Oxford Dictionary:

The science dealing with X-rays and other high-energy radiation, especially the use of such radiation for the diagnosis and treatment of disease.

Marriam Webster Dictionary:

1: a branch of medicine concerned with the use of radiant energy (as X-rays) or radioactive material in the diagnosis and treatment of disease

2: the science of radioactive substances and high-energy radiations

ASTM/E1316:

The science and application of X rays, gamma rays, neutrons, and other penetrating radiations



Figure 1 Covers of the journal Radiology underlining the dominance of imaging in medical context.

Discussion

Extended research of definitions for the term Radiology underlined the dominance of medicine for the usage of the term. Hence, without providing a specific other context, most definitions found refer to the medical dimension of Radiology. Only in a limited number of cases other dimensions of Radiology and therefore more general definitions, mostly put behind the medical one, are available. In this context the definitions provided by Oxford Dictionary and ASTM are the most general and seemingly least biased by the dominance of a specific field of the highest public relevance. While the Oxford definition points such out, the ASTM definition remains most neutral.

However, already in the Etymology the origin of the term is traced to the discovery and (medical) application of X-rays, while an extension of the meaning has obviously been implied by the discovery of other forms of (penetrating) radiation, which already provides the correct historic context for the term.

Attention has to be paid to the repeatedly used term of “high-energy radiation”, for which, however, hardly a definition can be found. It can be concluded, that this term is with high probability mainly used to describe the penetrating nature of the radiation referred to, but does not so much refer to the ionizing or non-ionizing nature or a specific energy limit. (Also Sonography is part of Medical Radiology for example.) This is important because the neutron spectra used cannot in general be characterized as “high- energy” spectra and neutrons are only indirectly ionizing.

It has to be further noted that general definitions of the term Radiology do not refer to a nature of the term related specifically to the production of images, although again, within the medical field radiography, tomography and other forms of imaging are clearly dominant (Fig. 1).

Adopted Definition and Conclusion

In conclusion the topical focus of ISNR as concerned with the science and application of neutron radiation lies within the field of Radiology defined as

3.1.1.A. Radiology: The science and application of penetrating radiation.

B. Imaging

Etymology

20th century, from verb ***image***: *make a visual/mental representation, make a copy*, from Latin ***imago***, (related to English *imitate*); root: from Proto-Indo-European *aim-*, *aiem-*, *iem-* : *similarity, resemblance*; cognate with Sanskrit *yamá*: *pair, twin*, Old English *emn*, *efn*: *equal, level, even*;



Figure 2 Use of term "Imaging"

Definition(s)

Cambridge dictionary:

The process of producing an exact picture of something, especially on a computer screen;

Encyclopaedia Britannica:

The action or process of producing an image especially of a part of the body by radiographic techniques

Imaging in multimedia:

Imaging is the capture, storage, manipulation, and display of images

(image: the optical counterpart of an object produced by an optical device (as a lens or mirror) or an electronic device)

Oxford Learner's dictionary:

The process of capturing, storing and showing an image on a computer screen

(Oxford Dictionary

Image: A visible impression obtained by a camera, telescope, microscope, or other device, or displayed on a computer or video screen

Medical imaging: The use of electromagnetic or ultrasonic radiation to produce images of organs and tissues within the body for diagnostic or screening purposes.)

Medical Dictionary:

The use of computerized axial tomography, sonography, or other specialized techniques and instruments to obtain pictures of the interior of the body, especially those including soft tissues

American Heritage dictionary:

Visual representation of an object, such as a body part or celestial body, for the purpose of medical diagnosis or data collection, using any of a variety of techniques, such as ultrasonography or spectroscopy

(medical: (medicine) obtaining pictures of the interior of the body)

Discussion

Imaging appears to be a very young term (compare Fig. 2). While it is as such not available yet in the standard Oxford dictionary (but only in a form entitled Oxford Learner's Dictionary), on the one hand again strong reference to the Medical field (Oxford Dictionary has imaging only in the combination "Medical Imaging") is found in definitions and on the other hand definitions sometimes imply the involvement of computers to be a characterizing feature.

The late establishment of the term might be explained by the corresponding progress of technologies for a broad production and availability of images, first by photography and medical x-ray imaging entering and finally through digital technology becoming an integrated part of our daily life.

It may be concluded, that only the definitions taken together provide a clear picture of what the term Imaging refers to in the most general usage of the word.

Adopted Definition and Conclusion

In conclusion the topical focus of ISNR as concerned with the production of images of the interior of objects lies within a field properly described by the relatively young term of Imaging defined as

3.1.1.B Imaging: The process, science and application of producing images (physically or in the form of data) of objects and phenomena.

Where the term Image is defined as

3.1.1.b Image: A real space representation of an object or phenomenon in 1, 2 or 3 dimensions.

C. Radiography (Radiograph)

Etymology

1896, from **radiograph** (1880), originally *a device to measure sunshine*; from *radio-*, comb. form of *radiation*, + *-graph*. As a type of *image-making device*; **rad, radio-**: from *radius*, Latin, originally: *shaft, rod, spoke of wheel, beam of light; radius of circle* (1600); potentially related to *radix: root*

-graphy: via Latin from Greek *graphos, graphein: something written, to write, to draw*, indicating (i) a form or process of writing, representing, etc (calligraphy, photography) or (ii) an art or descriptive science (choreography, oceanography)

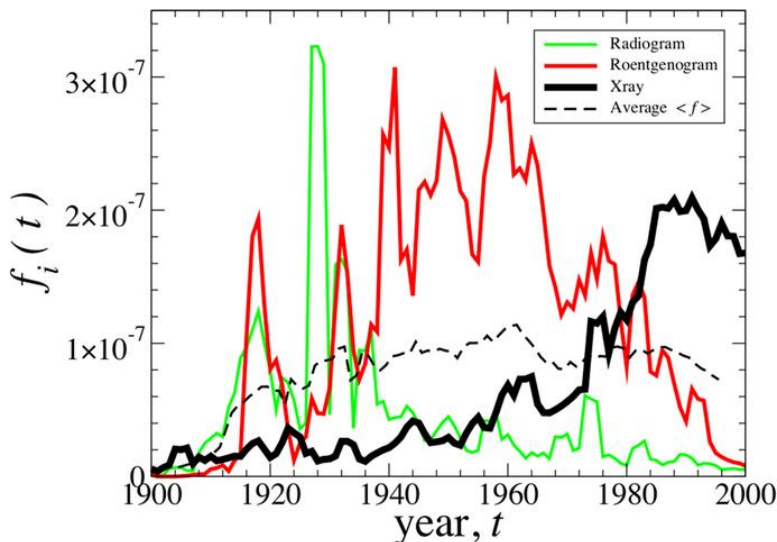


Figure 3 from A.M. Petersen et al., “Statistical Laws Governing Fluctuations in Word Use from Word Birth to Word Death” *Scientific Reports* **2**, 313 (2012), doi:10.1038/srep00313: The English word “Roentgenogram” derives from the Nobel prize

winning scientist and discoverer of the X-ray, Wilhelm Röntgen (1845–1923). The prevalence of this word was quickly challenged by two main competitors, “X-ray” (recorded as “Xray” in the database) and “Radiogram.” The arithmetic mean frequency of these three time series is relatively constant over the 80-year period 1920–2000, $\langle f \rangle \approx 10^{-7}$, illustrating the limited linguistic “market share” that can be achieved by any competitor. We conjecture that the main reason “Xray” has a higher frequency is due to the “fitness gain” from its efficient short word length and also due to the fact that English has become the base language for scientific publication.

The definition of the term Radiography is investigated in combination with terms like Radiograph and where needed a few other related terms, as such are used in definitions and hence required for the readability of the first. It has to be noted, that also in correspondence with Etymology the different endings –graph, -graphy and –gram have the same origin. While they all originate in the same Greek term graphos, the ending –graph generally refers to a device or product of the device (Telegraph, Photograph, Monograph), -graphy refers to the process, the product or a field of knowledge (Photography, Telegraphy, Oceanography) and –gram finally mainly to a product (Telegram, Photogram, Radiogram, Monogram).

Definition(s)

Oxford Dictionary:

The process or occupation of taking radiographs to assist in medical examinations
Radiograph: an image produced on a sensitive plate or film by X-rays, gamma rays, or similar radiation, and typically used in medical examination

Thesaurus dictionary:

A photographic image produced by the action of x-rays or nuclear radiation. Also called shadowgraph.

Radiogram - a photographic image produced on a radiosensitive surface by radiation other than visible light (especially by X-rays or gamma rays)

Medical Dictionaries :

The making of film records (radiographs) of internal structures of the body by exposure of film specially sensitized to x-rays or gamma rays

The production of shadow images on photographic emulsion through the action of ionizing radiation; the image is the result of the differential attenuation of the radiation in its passage through the object being radiographed.

The art, act, or process of making radiographs

The recording of an image of a region placed in a beam of radiation; also: Roentgenography, Radiographic Imaging, Imaging

Radiogram: another name for radiograph

ASTM/E1316 definitions:

The art, act, or process of making radiographs;

Radiograph: a permanent, visible image on a recording medium produced by penetrating radiation passing through the material being tested.

Discussion

It becomes obvious, that most definitions originate from times before the availability of digital image recording and hence clearly refer to film and permanent images. The addition of the terms computerized or digital to refer to modern digital techniques seems to be required.

On the other hand the focus is not necessarily on medical imaging, but many definitions are more general concerning the radiation used and objects exposed. The context of Imaging appears regularly.

Several terms seem to be in use alternatively to Radiography and Radiograph. (The study represented in Fig. 3 suggests that in general language use the term Xray for an X-ray radiograph is dominating nowadays. This is similar to many other cases of unprecisely customized language use in the medical context, like e.g. "Ultrasound is a type of imaging". Or: "neutron radiography: that in which a narrow beam of neutrons from a nuclear reactor is passed through tissues; especially useful in visualizing bony tissue.")

In general no hints are found that the term Radiography would contain also tomography as a technique producing three dimensional or cross sectional images in contrast to e.g. the medical definitions for Imaging. Definitions that assume all kinds of (medical) imaging techniques included in the term (digital/computerized) Radiography are absolute exceptions.

Adopted Definition and Conclusion

In conclusion the topical focus of ISNR as concerned with the production of images of the interior of objects utilizing neutron radiation, i.e. Radiographs/Radiograms has a strong overlap and is at least partly contained in the field described by the term Radiography defined as

3.1.1.C Radiography: The process, science and application of producing a projection image (Radiographs, Radiograms) by means of penetrating radiation.

Where Radiograph/Radiogram shall be defined as

3.1.1.c Radiograph/Radiogram: A one- or two-dimensional projection image recorded by means of penetrating radiation.

D. Neutron Radiology

Definition

As compared to (A) Radiology, here just the word Neutron is added, which commonly means nothing else but that the meaning of the word is here further specified and the frame of reference limited to a specific kind of Radiology, namely the one concerned with Neutron radiation. Consequently Neutron Radiology is a sub-field of Radiology defined as:

3.1.1.D Neutron Radiology: The Radiology concerned with neutron radiation

or

The science and application of neutron radiation

This, however, implies, that Neutron Radiology is not only concerned with the production of images utilizing neutron radiation or with Radiography using neutrons, but also with the study of the neutron itself or its application in many fields of material science, like neutron diffraction and spectroscopy. It has to be further noted, that the term Neutron Radiology is not very much in use in the context of Neutron Science and Physics in general. One reason might be that the term Radiology is very much publicly occupied by the specific medical meaning. Another reason might be that it does not refer to science in particular. It seems to be nowadays to be mainly used in the context of real space investigations with neutrons in particular in the context of ISNR. Therefore the term Neutron Science shall be discussed below in addition.

E. Neutron Science

Etymology Science

Science: from Latin *scire, to know* to Latin *scientia* via old French to English:
science

Definition Science

Oxford Dictionaries:

The intellectual and practical activity encompassing the systematic study of the structure and behaviour of the physical and natural world through observation and experiment

Definition and conclusion

Again the word Neutron acts to classify a specific sub-field. Hence, though there is no specific definition of Neutron Science to be found elsewhere it can be defined as:

3.1.1.E Neutron Science: The science involving neutrons/neutron radiation (as a subject or a probe)

It can be concluded that the subject matters of the ISNR are strongly overlapping with the field of Neutron Science, but only to the degree that Science as Science is concerned, not when well established or even standardized techniques are simply applied for non-destructive testing or other industrial/commercial applications. The pure application of neutron radiation without any added scientific value, which is included in Neutron Radiology but not in Neutron Science distinguishes these two fields and terms and makes Neutron Science a sub-category of Neutron Radiology (Fig. 4).

3.1.2. Discussion and Conclusion

The above discussed and defined high level umbrella terms provide the framework for the terminology developed here for the requirements of the ISNR and its subject that include on a high level terms like Neutron Radiography, Neutron Tomography and Neutron Imaging. A schematic of this context and framework corresponding to the above is sketched in Figure 4.

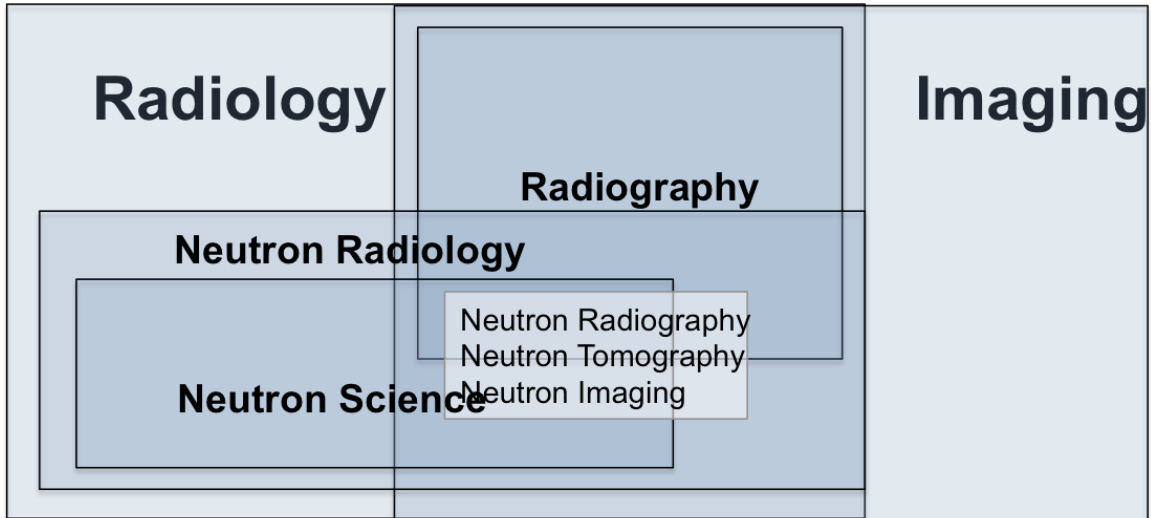


Figure 4 Context of Terminology for ISNR with respect to higher-level general umbrella terms like Radiology, Imaging, Radiography etc.

According to the definitions derived the terminology, which is the main subject of this document, is to be located in the context and as a part of the overlap of the lead terms Radiology and Imaging but also Neutron Radiology, which it self is a sub-category of Radiology. Furthermore there is a strong overlap with the big fields of Radiography and Neutron Science. While Neutron Science does not include non-scientific areas of the subject matter, whether Radiography is suited to fully host the subject requires more detailed considerations and discussions of the definitions.

Radiography is largely still defined as producing physical images and terms acting to extend these definitions towards digital or electronic data collection are applied. In any case the nature of the hitherto defined images seems to be 2-dimensional projection images. No definition of Radiography is e.g. to be found which would include Tomography, as the production of cross sectional or 3D images. In contrast to the term Imaging, which implies physical, electronic (Radioscopy, comp. ASTM (STSM) E1314) and digital image data and also hosts tomographic techniques. In addition this seems to be particular also the case for any earlier approaches to characterize the terminology with respect to neutron techniques. However, it has to be also stressed that the term Imaging in contrast to Radiography does not seem to refer to penetrating radiation only, and can hence also host conventional Photography or Microscopy.

It is therefore concluded for this terminology, that the term Radiography relates to any form of up to 2D imaging with penetrating radiation, but is different from Tomography and imaging with visible light. Consequently the term Radiography does not fully convey the subject of the ISNR and its terminology but is strongly

overlapping with it. However, it has to be also noted, that the process of producing e.g. Tomograms might still be considered a Radiographic process, because recording plain images is to some extent essentially the basis of producing Tomographic data sets and images.

The term Neutron Radiology on the other hand must appear to wide to specify the content in the remit of ISNR and its members sufficiently as it defines a much wider field of techniques and expertise not represented in the ISNR. However, ISNR carries the term Neutron Radiology in its name. Hence, if the name shall be kept there appear only two possibilities, either (i) to deviate from the general definition of Radiology for Neutron Radiology and create an own one only relating to the own matters, or (ii) to significantly increase the scope of ISNR and try to collect all Neutron Science and Application in this framework. The latter does neither seem promising, as the field has grown very large and has its own societies for specific technologies and applications, which the current members of ISNR would loose in this case. The first would be a measure hard to justify in a scientific environment. It is therefore proposed to replace the term Radiology in name of ISNR. Potential alternatives shall be discussed after lying down the high level terms of the subject matter of ISNR below.

3.2. The high level terms

3.2.1. Definitions and high level breakdown

1. Neutron Imaging

Definition

Based on the above derived definition of Imaging the term Neutron Imaging is defined as

1. Neutron Imaging: The process, science and application of producing real space images (physically or in the form of data) of objects and phenomena by the means of neutron radiation.

Image is defined above as

3.1.1.b Image: A real space representation of an object or phenomenon in 1, 2 or 3 dimensions.

Hence image refers to having established a direct relation in real space between the points in the object and points in the image (pixel, voxel).

Consequently all methods and activities satisfying this definition are sub-categories of the term Neutron Imaging and the field defined by it. Consequently a high level break down into sub-fields can be found and defined to be:

1.I. Neutron Radiography

Defintion:

1.I. Radiography: The process, science and application of producing a projection image (Radiographs, Radiograms) by means of neutron radiation.

Discussion

1.II. Neutron Tomography

Definition:

1.II. Neutron Tomography: The process, science and application of producing a digital real space image of the cross section of an object with 2 or 3 dimensional real space resolution by the means of neutron radiation (from 1 or 2 dimensional Neutron Radiographs, respectively).

Etymology Tomography

Tomo-: from *tomos*, Greek: *slice, section*; since 1930ies *Tomo+graphy* (-graphy: see above)

Discussion

Like already the case for Radiography and Radiology most “general” definitions of the term tomography to be found refer to x-rays and medical applications. However, common to most definitions is the reference to the creation of an image of a cross section of an investigated object.

1.III. Neutron Gauging

Definition:

I.III. Neutron Gauging: The process, science and application of producing a digital real space image by point by point sampling in 1, 2 or 3 dimensions, where a point is defined by a 3-dimensional gauge volume.

Discussion

While scanning techniques to achieve radiographic images, i.e. projections along the beam axis as well as gaining 2D or 3D images of the interior in terms of cross sections follow the same principles as radiographic and tomographic techniques acquiring radiographic projection images in one shot, gauging describes the ability to probe limited volumes of the interior separately and hence not as projections integrating over the beam direction. Therefore such techniques are able to acquire 1D, 2d and 3D images with corresponding scanning, but cannot subsumed by the terms radiography and tomography and hence require a separate category of the same level next to radiography and tomography.

3.2.2 Discussion

Based on the definitions of the terms Imaging and Radiography and their general use it has to be concluded, that Neutron Imaging is the more general term conveying all kinds of methods of producing images as real space representations of objects. Radiography in contrast is commonly understood but also in general defined as restricted to plane projection images produced with penetrating radiation such as neutrons in Neutron Radiography. The term Radiography does in conclusion not convey techniques such as Tomography (or other 3D techniques). However, the restriction of the term to permanent images on film seems to be a historic artifact, and nowadays an addition of the terms *digital* or *electronic* should not be required for inclusion of such detection techniques, which are state-of-the-art. Therefore the addition of terms such as *digital* or *analogue* should be used to define a sub-field of Radiography, which conveys such techniques with regards to the terminology defined here. These specification terms will hence be found in the structured modular classification scheme and terms defined in Section 6.

Consequently Neutron Imaging is broken down to the high level specifications Neutron Radiography, Tomography and Gauging, which can be distinct clearly in their nature. While Neutron Radiography refers to up to 2-dimensional projection imaging with neutrons, Neutron Tomography refers to the production of cross

section images in 2 and 3 dimensions from Radiographs, i.e. to adding 1 dimension through computing of a number of projections. In contrast Gauging is a scanning technique that can produce cross section images in 1, 2 or 3 dimensions by probing selected gauge volumes, one after the other and hence does not require tomographic reconstruction. However, a defined gauge volume can only be achieved in the case of measuring deflected beams, which is a significant restriction of this technique, being a scanning topography approach practically. An alternative distinction and classification could be thought in distinguishing and defining Neutron Radiography as relating to direct beam techniques only, in which case besides Neutron Tomography the third class would be defined Neutron Topography, subsuming neutron imaging methods based on diffraction and recording projection images out of the direct beam. However, such solution has been excluded and a topographic image is regarded a projection image in the sense of Neutron Radiography as well.