A COMPARATIVE STUDY OF INTERNATIONALLY USED CONSTANCY TESTING PROTOCOLS FOR MEDICAL IMAGING DEVICES

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Dedication

I would like to dedicate this dissertation to the staff at the Medical Imaging Department who are always in the background but very vital for the patient's care.

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Abstract

Background: One of the difficulties confronted by medical physicists is the variability in constancy testing protocols and acceptable tolerances promoted by different international standard setting and Medical Physics professional organizations around the world.

Objectives: This project compared protocols and tolerances from different organizations focussing on their similarities, differences, and relative strengths and weaknesses.

Methodology: The methodology that was used in this study is a comparative qualitative documentary thematic analysis of constancy testing protocols published by the IEC, EU Commission, IAEA, IPEM, AAPM and ACR. The thematic categories and labels that were analysed were: Document Metadata (Document Number, Recency, Price of Document), Equipment used in the constancy testing (Equipment required, Expense of the Equipment, Ease of Availability), Measurement protocol for constancy testing (Professional Performing the Test, Level of Complexity), Test Frequency and Tolerance Limits.

Results: The results from the data collection were presented in four comparative thematic template tables, one for each modality considered in the study (Digital Radiography, Mammography, Fluoroscopy, Computed Tomography).

Conclusions and Recommendations: From this study, the main conclusion that was drawn was that there isn't one specific organization that publishes suitable constancy testing protocols for all the selected imaging modalities and that one often needs to take good practice elements from more than one organization when setting up own protocols. Recommendations for specific imaging modalities were put forward.

Keywords: Medical Imaging Devices, Constancy Testing, Comparative Document Analysis, Thematic Analysis

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List of Definitions

Quality Assurance (QA): "all those planned and systematic actions necessary to provide adequate assurance that a structure, system, component or procedure will perform satisfactorily in compliance with agreed standard" (2013/59/EURATOM Ch. II, Art 4(70)).

Quality Control (QC): "the set of operations (programming, coordinating, implementing) intended to maintain or to improve quality. It includes monitoring, evaluation and maintenance at required levels of all characteristics of performance of equipment that can be defined, measured, and controlled" (2013/59/EURATOM Ch. II, Art 4(71).

Constancy Testing: includes "those tests that are undertaken either regularly or after maintenance or repairs, to detect whether any change in the performance of the equipment has occurred that would require corrective action" (Dance, Christofides, Maidment, McLean, & Ng, 2014, p. 485).

Baseline Values: these are values "established during commissioning against which performance will be compared in the future as part of the ongoing quality control program" (Human Health IAEA, n.d.).

Acceptable: Acceptable indicates that performance must be within these tolerances; if it is not, the equipment should not be used (IAEA Human Health Series No. 17, 2011, p. 37).

Achievable: Achievable indicates the level of performance that should be attained under favourable circumstances; this is the level at which a facility should work if it is feasible (IAEA Human Health Series No. 17, 2011, p. 37).

Remedial Level: A level of performance at which remedial action is required, but the unit may continue to be used in the meantime (IPEM 91, 2005).

Suspension Level: A level of performance at which it is recommended the equipment is removed from clinical use immediately (IPEM 91, 2005).

List of Abbreviations

IEC	International Electrotechnical Commission
MPE	Medical Physics Expert
EU	European Union
IAEA	International Atomic Energy Agency
IPEM	Institute of Physics and Engineering in Medicine
AAPM	American Association of Physicists in Medicine
ACR	American College of Radiology
CT	Computed Tomography
MRI	Magnetic Resonance Imaging
AEC	Automatic Exposure Control
FOV	Field of View
3D	Three-Dimensional
QA	Quality Assurance
QC	Quality Control
NA	Not Available
SID	Source to Image Receptor Distance
SOP	Standard Operating Procedure
HVL	Half-Value Layer
kV	Kilo Voltage
EUREF	European Reference Organisation for Quality Assured Breast Screening and Diagnostic Services.

Chapter 1: Introduction

1.1 Introduction

This chapter presents the problem statement, background and context, objectives, scope, summary of the research methodology, ethical considerations and relevance of the study.

1.2 Problem Statement

One of the difficulties confronted by medical physicists is the variability in constancy testing protocols and acceptable tolerances promoted by different international standard setting and Medical Physics professional organizations around the world. This project will therefore compare protocols and tolerances from such organizations focussing on their similarities, differences, and relative strengths and weaknesses with a view to develop a comparative document which would inform the debate among local Medical Physics professionals regarding the further development of existing local constancy testing protocols.

1.3 Background and Context

Constancy tests are tests done on a regular basis after maintenance and to investigate any changes in the performance of the equipment following reparative work. According to IEC

61223-3-5:2019 standard, constancy testing makes sure that the equipment's performance satisfies the established criteria and permits early detection of any variations in the performance indicators of the device which could lead to significant loss in image quality or unnecessary patient doses (IEC, 2019).

The constancy testing programme may involve different professionals; however, they are usually managed by and require the guidance and oversee of Medical Physics Experts (MPE) (Dance, Christofides, Maidment, McLean, & Ng, 2014). As stated in EU Directive 2013/59/EURATOM an MPE must "contribute in particular to the definition and performance of quality assurance of the medical radiological equipment". Constancy testing is a subset of quality control which is itself a subset of the overarching quality assurance program.

The diagnostic Medical Physics team in Malta consists of a group of understaffed and young Medical Physicists that are working hard to work in accordance with internationally used standards and protocols for the benefit of patients. This project will help them to achieve their vision.

1.4 Objectives of the Study

The following are the main objectives of this project;

1. To compare internationally used constancy testing protocols for selected medical imaging devices.

2. To identify the similarities and differences between them in both protocols and tolerances
3. To identify the strengths and weaknesses of each.
4. To provide a set of recommendations for improved protocols for the selected imaging devices.

1.5 Scope of the Study

Owing to time constraints the scope of the study was delimited to Digital Radiography, Fluoroscopy, Mammography and Computed Tomography devices.

1.6 Relevance of the Study

The study is relevant because it would help imaging physics staff improve its constancy testing programme, hence contributing to the patient's health and safety.

This study is important because if medical imaging devices deteriorate without radiology and radiography staff noticing as a result of insufficiently effective constancy testing protocols, misdiagnosis and possibly unnecessary radiation patient doses would result. Therefore, it is of the utmost importance that the Medical Physics and the Radiography staff make use of the most updated constancy testing protocols. Therefore, the importance of the study is that it provides a structured evaluation study to determine which constancy testing protocols are best to be used and which tolerances one should use.

Ionising radiation is carcinogenic and if not used wisely, the damage to the genetic pool of the population would increase leading to increased incidence of carcinogenesis and mutagenesis. If the equipment is well maintained using the correct constancy testing protocols, small lesions will be detected at a very early stage (Dance, Christofides, Maidment, McLean, & Ng, 2014).

1.7 Ethical Considerations

Since the sources of the data collected for this study are publicly available documents, there are no ethical issues. The research ethics application was nevertheless submitted together with a one-page research proposal. Since there are no ethical issues in this study, the ethics form was submitted 'for records' only as per faculty ethics committee procedures.

This study has been approved by the University Research Ethics Committee of the University of Malta.

1.8 Brief Overview of the Research Methodology

In this study, a comparative documentary thematic analysis was carried out in which constancy testing protocols published by the IEC, EU Commission, IAEA, IPEM, AAPM and ACR were compared with respect to the following themes:

- Document Metadata
- Equipment required to carry out the constancy test
- Measurement protocol of the constancy test
- Test Frequency
- Tolerance Limits.

1.9 Conclusion

This chapter provided a brief overview of the study. In chapter two, one will read a critical review of the literature that has been found related to this project. Chapter three describes the research methodology utilized in this study. Chapter four presents the results and Chapter five a discussion of the results. Finally, Chapter six summarises the most significant conclusions from this study, and any recommendations arising from this study for professional practice and future research.

Chapter 2: Literature Review

2.1 Introduction

Chapter two provides a detailed, comprehensive review of the literature related to the study. First, the various imaging devices within the scope of the study are briefly described; then quality assurance programmes with particular focus on constancy testing are discussed. The different international organizations and their respective standards are then presented. Finally, comparative studies of these standards found in the literature are described and discussed.

2.2 Medical Imaging Devices within the Scope of the Study

2.2.1 Introduction

There are different imaging modalities used on a daily basis to image the human body for both diagnostic as well as for the purpose of the planning and monitoring of treatment (Dance, Christofides, Maidment, McLean, & Ng, 2014). It is very important that continuous constancy testing of these devices is done, since they have a direct impact on the health of patients and in the case of screening programmes the general public.

Medical imaging devices are also used in interventional procedures such as in cardiovascular procedures (WHO, n.d.).

As a result of enhanced health care policy, the number of global imaging-based procedures is increasing rapidly. Thus, effective and safe imaging devices and protocols are vital for medical decision-making and reduction of any unnecessary procedures. For instance, some surgical interventions can be avoided if diagnostic imaging equipment such as ultrasound are readily available (WHO, n.d.).

The following are some of the main medical imaging modalities which are commonly used in hospitals and clinics:

- Projection Radiography: used for first-line investigation as it imparts a low radiation dose compared to other modalities such as Computed Tomography.
- Mammography: breast imaging with very low dose of radiation to screen patients or for diagnosis.
- Computed Tomography (CT): a sequence of X-ray images taken from different angles around the body and uses computer processing to generate cross-sectional images.
- Fluoroscopy: the use of X-rays for real time moving images.
- Magnetic Resonance Imaging (MRI): use of strong magnetic fields, magnetic field gradients, and radio waves to produce images.
- Ultrasound: also known as sonography, the production of images with the use of high-frequency soundwaves.

In diagnostic processes, the medical imaging devices are used to obtain an image of the body to be able to diagnose and determine correct patient care. Medical imaging devices

are divided into two categories the ionizing modalities and the non-ionizing modalities. Ionizing modalities includes projection radiography, fluoroscopy, computed tomography and mammography whilst non-ionizing modalities include magnetic resonance imaging (MRI) and ultrasound. This thesis will focus on the common ionizing imaging modalities.

2.2.2 Overview of the X-Ray Generation and Image Production Process

Generally, X-ray systems are made up of three basic components:

- X-ray tube and generator
- X-ray detector and image construction and processing unit
- Geometrical arrangement of the tube, patient table and detector.

X-ray imaging devices include a radiation source which emits X-ray photons and photon sensors that produces an image from the X-ray photons traversing the patient. In the case of indirect detectors, a scintillator is used to convert X-ray photons into light which will be detected by a light sensor. The attenuation of the X-ray photons varies according to material traversed. For instance, attenuation by dense high atomic number materials such as bones will be higher than that in softer tissues and hence a contrast can be seen on the image (Mikla & Mikla, 2014, pp. 65-87).

The structure of the X-ray source is generally similar in almost all X-ray devices. This contains an evacuated vessel which includes a negatively charged cathode and a positively charged anode. Across the space between the anode and the cathode there is a potential difference (kVp). The cathode, which is made up of spiralled coiled wires, is heated to a

temperature above 2000^{O}C. At high temperatures, the electrons drift away from the nuclei and are accelerated towards the anode due to the high potential difference (Mikla & Mikla, 2014).

On hitting the anode, a small amount of the kinetic energy is transformed into x-rays, which is a result of two processes. The most probable process by far leads to the bremsstrahlung continuous radiation spectrum and is a result of the interaction between the accelerated electron and the nuclei of the target. The other process is the characteristic radiation which is a result of the interaction between the electrons and the orbital electrons of the atoms of the anode. The X-rays produced from the anode are emitted in all directions however, all X-rays excluding those which are emitted in the direction of the X-ray tube window are absorbed by the tube's shielding (Mikla & Mikla, 2014).

Other components utilized in X-ray devices are the automatic exposure control (AEC) and filters. AECs are essential to achieve consistent image quality. Its function is to limit an exposure when the image receptor has received a specific pre-set amount of radiation energy fluence. Since low energy photons do not contribute to the image formation, filters are added to limit as much as possible these low energy photons since they would give an unnecessary radiation dose to the patient. These filters are added between the x-ray tube window and the collimator (Christofides, Dance, Maidment, McLean, & Ng, 2014, pp. 106,111).

2.2.3 Digital Radiography

Digital radiography is the procedure of generating two-dimensional images by exposing the specific part of the body with X-rays and obtaining an image using a flat-panel digital X-ray sensor. This is the most common medical imaging device that is used in clinics and hospitals around the world.

The most important requirement for a chest x-ray unit is a very large FOV, a high spatial resolution and a large dynamic range to adjust to the different penetration levels for the lungs and mediastinum. Image processing can be used in order to equalize the image and hence lower X-ray doses (Mikla & Mikla, 2014). Equalizing an image is an image processing technique which provides a contrast enhancement (Jordanski, Arsic, & Tuba, 2016).

Another application of digital radiography is the examination of fractures and abnormalities in the skeletal system. Since bones have a much higher attenuation coefficient than the surrounding tissues, this will result in having a suitable contrast. In addition to detecting fractures, digital radiography is also used to detect changes in bone density for instance when the patient has osteoporosis or bone cancer (Maier, Steidl, Christlein, & Hornegger , 2018).

Figure 1: Digital Radiography (Philips, n.d.)

2.2.4 Digital Mammography

Mammography is an X-ray imaging modality that uses low dose to image the breast. A mammography image (known as a mammogram) helps in the early detection of breast abnormalities and diseases in both men and women. A mammogram enables one to see soft tissues (EurekAlert, 2018). Breast compression is also required so that the breast is of uniform thickness. Mammograms are carried out for screening asymptomatic patients of predefined age groups and for diagnostic imaging of symptomatic patients. In screening, two projections for each breast are taken in bilateral Craniocaudal (CC) and Mediolateral Oblique (MLO) views. Mammography is also used for guidance in biopsies (Mikla & Mikla, 2014).

The spatial resolution has to be high in order to be able to visualize abnormalities and microcalcifications which are very small (Yaffe, 2006, pp. 363-371).

Figure 2: Digital Mammography (MedWrench, n.d.)

2.2.5 Fluoroscopy

Another demanding application of flat-panel imaging device is fluoroscopy. Modern X-ray fluoroscopy is carried out with a small area flat digital detector. Older systems used Image Intensifiers. Fluoroscopic procedures are lengthy and hence patient doses are also higher.

Fluoroscopy is a sequence of radiographic images that are obtained at a specific periodic frame rate. The maximum frame rate is mostly dependent on the acquisition speed of the detection system. Generally, the frame rate can reach up to 30 frames per second but it is

typically kept at a lower rate to keep the radiation dose low too (Maier, Steidl, Christlein, & Hornegger , 2018). However, the frame rate must be carefully set so that the image quality is still satisfactory (Mikla & Mikla, 2014). Fluoroscopy is used to investigate several body systems some of which are the digestive, urinary, cardiovascular and respiratory systems.

Figure 3: Fluoroscopy (Kumar, 2021)

2.2.6 Computed Tomography

Computed Tomography (CT) is commonly utilized to be able to produce 3D attenuation datasets and see the cross-section of a body region of interest. In Computed Tomography, X-Ray radiographic projections from many positions around the patient, are by utilizing mathematical algorithms used to form a slice image of the region of interest that is being scanned. Then, the tomograms can be put together to form a three-dimensional representation of the scanned region of interest (Mikla & Mikla, 2014, pp. 65-87).

Figure 4: Computed Tomography (itn, n.d.)

In the past, the scan had to be performed by a series of rotate-tube-stop-move –patient table sequence. However, nowadays helical CT is utilized where the x-ray source in the gantry and patient table move continuously. Projections from all angles resulting from the helical rotation, will then be interpolated and reconstruction methods will be utilized to obtain a 3D image of the region of interest (Maier, Steidl, Christlein, & Hornegger , 2018).

2.3 Constancy testing

2.3.1 Quality assurance and Quality control

EU Directive 2013/59/Euratom defines Quality Assurance (QA) as "all those planned and systematic actions necessary to provide adequate assurance that a structure, system, component or procedure will perform satisfactorily in compliance with agreed standard". (2013/59/EURATOM Ch. II, Art 4(70)). Quality Control (QC) in turn is defined as "the set of operations (programming, coordinating, implementing) intended to maintain or to improve quality. It includes monitoring, evaluation and maintenance at required levels of all characteristics of performance of equipment that can be defined, measured, and controlled" (2013/59/EURATOM Ch. II, Art 4(71)).

Quality Assurance programs help staff to manage the utilized radiation in an optimised manner and to minimize the radiation dose as much as possible for the safety and protection of the patient, radiation staff and the general public from harmful effects of radiation whilst ensuring diagnostic accuracy. (Ręba, 2019). A high excess cancer occurrence is a global burden which must be controlled using all the possible ways (Muhammad Kabir Abdulkadir, 2020, pp. 238-244).

In 1982, the World Health Organization stated that a Quality Assurance program is an important component when it comes to the diagnostic imaging services (Ręba, 2019). There are mainly three goals from a QA program, which are: controlling expenses,

decreasing of unnecessary exposures and radiation dose, and maintenance of image quality. The Quality Assurance program includes several Quality Control (QC) tests on the medical imaging devices that ensure detection of any deviation from the ideal performance happens as early as possible (Ręba, 2019).

Quality Assurance ensures that the right devices are purchased and that the performance and safety of the devices remain up to standard and sufficient throughout all their life cycle. The QA will ensure that any malfunctions are detected before they become critical and resolved in the shortest time possible for minimum device downtime. The QA programme is not made up of a single procedure; it includes different procedures performed in an ongoing manner to prevent any instances of low performance. (Dance, Christofides, Maidment, McLean, & Ng, 2014, pp. 477-479).

In order to have a QA programme that is effective, one also requires to have a maintenance programme at hand. This will ensure that any flaw or malfunction of the equipment, disclosed by a QC test, is corrected. Tests are also required to be done after the maintenance or repairs that may affect the devices' imaging and radiation properties (Dance, Christofides, Maidment, McLean, & Ng, 2014, pp. 477-479).

The QA programme requires active participation of different professionals; medical physicists, radiologists and radiographers. Furthermore, these professionals need to take into account standards set by international and professional organizations. l (Speer, 2020).

In summary the QA processes focus mainly on a proactive prevention of potential defects by having appropriate composition of QA committees, qualified people and setting of Standard Operating Procedures (SOP). On the other hand, the QC focuses on the detection of any eventual defects. Constancy Testing is part of the QC programme.

2.3.2 Acceptance Testing and Commissioning

When it comes to new medical imaging equipment, the acceptance testing and commissioning testing are two very important stages which are essential before the equipment is put into use in the hospital or clinic. Acceptance testing ensures that the department that bought the equipment is receiving the correct equipment with the correct specifications as per tender and agreed upon in the purchase agreement. This is extremely important since these devices are extremely expensive. As soon as the equipment's specifications and performance have been verified, then commissioning is required in which the medical physicists provide the essential presets and protocol information for clinical use. *Baseline values are also established during the commissioning which are necessary when it comes to quality control tests (including constancy testing)* in the future so that the equipment performance indicators can be compared to these baseline values (IAEA Human Health, n.d.).

2.3.3 Constancy Testing

Constancy testing also known as routine performance testing is an essential process during the lifetime of the medical imaging device. As its name implies constancy testing requires one to monitor the constancy of the essential performance indicators of the device following acceptance testing and commissioning. Constancy testing is a subset of the Quality Control (QC) program. Quality control refers to the maintenance and improvement of quality however, constancy testing refers only to the maintenance and not the improvement process. Constancy tests are performed at regular intervals and after a preventive or reparative maintenance to check whether the performance indicators of the medical imaging device have changed. From these tests, it is easier to pinpoint if any corrective action is required.

Constancy testing involves personnel with different levels of knowledge. Those tests that need to be done frequently (particularly daily and perhaps weekly) and rather quickly, should be carried out by the operators of the radiological equipment (often the radiographers). Medical Physics Experts in charge of QC programs should insist on the importance of constancy checks and that healthcare professionals check any medical device before use on patients. Tests that are more complex and mathematical are carried out by the Medical Physicists with the use of special instrumentation, software and calculations. The results of the constancy tests are evaluated and compared to the baseline values that were established during the commissioning testing. Two important elements that are required in routine performance are a good collaboration between different

categories of staff and a multidisciplinary approach (Dance, Christofides, Maidment, McLean, & Ng, 2014, pp. 487-488).

Constancy testing can also be considered as a measure of the long-term stability of the imaging system.

The main characteristics of constancy tests are the following:

- Frequency: the suggested frequency of the constancy test ranges from one to three times annually to daily. The frequency of the tests depends on certain characteristics of the equipment such as how old the equipment is and the workload. Generally simple imaging devices that are not used regularly require low frequency of constancy tests.
- Priority: this indicates if a constancy test is high in priority or not. When a test is essential that means that it is critical to ensure minimum standards. On the other hand, when a test is known to be desirable but not essential the tests are considered as good practice. Nonetheless, the carrying out of some tests may be limited due to costs, availability of personnel, workload and other factors.
- Tolerances: tolerance limits refer to the upper and lower limit values of each performance indicator to make sure that the test results are not outside the manufacturer's or desired specifications. Tolerance limits are described as either Remedial Level or Suspension level. Remedial level refers to when a test result requires some actions to return it to acceptable values. On the other hand, suspension level means that the device can no longer be used until the corrective action is carried out.

2.4 Organizations Publishing Constancy Testing Protocols

There are several organizations around the world which develop constancy testing protocols for imaging equipment. The main ones that publish in the English language are described below.

2.4.1 International Electrotechnical Commission

The International Electrotechnical Commission (IEC, www.iec.ch) is the largest organization in the world that is responsible to prepare and publish international standards that are related to electrical, electronic and other associated technologies. IEC was founded in 1906, and is made up of around 20,000 experts from around the world and from 173 countries. This organization provides access and verification standards for the safety and performance of electric and electronic devices or systems, which can range from a small device such as a mobile phone up to refrigerators, electricity generation and medical equipment (IEC, n.d.).

2.4.2 International Atomic Energy Agency

Another organization that publishes constancy testing standards for medical imaging devices is the International Atomic Energy Agency (IAEA, www.iaea.org). This organization was founded in 1957 and is the world's central intergovernmental forum which is responsible for scientific and technological elements that are found in the nuclear/ionizing radiation field. This organization's main goal is to ensure safety, and peaceful utilization of

nuclear/ionizing radiation science and technology which eventually contributes to international peace and security taking also into consideration the United Nation's Sustainable Development Goals (IAEA, n.d.). The Dosimetry and Medical Physics section of the IAEA Human Health Campus produces much documentation of relevance to constancy testing.

2.4.3 The European Commission

The EU Commission is the executive wing of the EU (www.ec,europa.eu). The Commission is structured into several individual departments which are responsible for specific policies areas. These departments are known as the Directorates-General (DGs). DGs are required to create, implement and manage the EU policy, law and the funding programmes. Among other things the Directorate General for Energy is responsible for the use of radiation in medicine and radiation protection (European Commission, n.d.). Constancy testing protocols for medical imaging devices fall under the Radiation Protection Department of the DG for Energy.

2.4.4 The Institute of Physics and Engineering in Medicine (UK)

The Institute of Physics and Engineering in Medicine, (IPEM, www.ipem.ac.uk) is based in the United Kingdom with more than 4,600 members from healthcare, academia and industry sectors. IPEM publishes international journals to continue to develop knowledge and expertise in the use of medical devices and protection from physical agents. IPEM has

an active role in the advancements and evaluation of standards, regulations and guidance at the UK level but which are used also at an international level by English speaking countries.

2.4.5 The American Association of Physicists in Medicine

The American Association of Physicists in Medicine (AAPM, www.aapm.org) consists of more than 9231 members in 94 countries. The mission of the AAPM organization is to continue to develop medicine with the help of science, education and the involvement of the medical physics profession, and the main goal is to apply physics principles to medical applications. AAPM provides Medical Physics guidelines and support to continue to improve patient care, through research and development of professional standards.

2.4.6 The American College of Radiology

The American College of Radiology (ACR, https://www.acr.org) was founded in 1923 and is made up of approximately 40,000 members. These members are radiologists, radiation oncologists, nuclear medicine physicians and medical physicists. The main goal of this organization is to improve the work, science and professional competences of the radiology departments for the benefit of the patients and society. The ACR is a fundamental voice in legislation and regulations matters in the US.

2.5 Comparative Studies of Constancy Testing Protocols in the Literature

A literature search was carried out to see if there are any published studies similar to this project, that is a comparative study of constancy testing protocols. The keywords used to for the literature review were “comparative study”, “constancy testing” and “medical imaging”. Only one study was found which compares a German protocol with an IEC protocol for Dental Cone-beam Computed Tomography. This study is entitled: “Comparison of methods for acceptance and constancy testing in dental cone-beam computed tomography” (Steiding, Kolditz, & Kalender, 2014) .

Apart from the fact that it deals with a modality which is not being considered in this project, the study was found to compare only the procedure and not other elements such as the tolerances, equipment availability etc. Another aspect that was noted in this study is that not all tests were considered. Only four basic tests were analysed which are the following; uniformity, image contrast, spatial resolution and image noise. The tests were performed and the numerical results obtained compared.

2.6 Conclusion

This chapter presented a detailed analysis and evaluation of the literature related to this study.

The next chapter discusses the research methodology that was used to carry out the comparative analysis of the different constancy testing standards from the various international organizations.

Chapter 3: Research Methodology

3.1 Introduction

This chapter describes the research methodology that was used for this study. The methodology of the dissertation project is a vital stage and should be designed well in order to achieve the objectives of the study. This chapter includes the research approach, research strategy, the data collection technique utilized and how the data was analysed.

3.2 Research Approach

There are mainly three different research approaches which are qualitative, quantitative and mixed methods which is a combination of both qualitative and quantitative (The Selection of a Research Approach, n.d.). Since in this study we will be comparing published documents (document analysis) the research approach utilized was a qualitative one.

3.3 Research Strategy

A research strategy is an overall plan of how the study is going to be carried out. The research strategy is very important as it helps and guides the researchers in the development, accomplishing and checking of the whole process of the study (Johannesson & Perjons, 2014, pp. 39-73).

In this study a qualitative comparative document analysis research strategy was used. Different constancy testing protocols from the six different international organizations mentioned in the literature review were collected. These protocols were then compared using thematic analysis and evaluated with respect to the relative differences and similarities and strengths and weaknesses of each. Karl Deutsch 1912-1992) claims that document analysis as a strategy for research has been used for more than 2,000 years (Bukhari, 2011).

Document analysis has both its advantages as well as its limitations. Some advantages of document analysis as a data collection technique are that:

- It is an efficient method: it is less time-consuming than other methods this is because it includes data selection rather than data collection. In this technique, the data has already been collected so the task is to select the data appropriate to the objectives and evaluate it.
- Availability: several documents are freely available on the internet and there is no need for the authors' permission to gain access.
- It is a cost-effective method: most of the time document analysis is less expensive than other research methods and generally it is the method used when collecting new data is not possible.
- Unobtrusive and non-reactive: this means that the documents are not affected in any way by confounding factors unlike other qualitative techniques such as interviews.
- Stable: documents are stable objects and hence appropriate for repeated reviews.

- Details and Precision: generally, data which is published in documents is detailed, is referenced and more accurate
- Coverage: documents usually offer a broad coverage on the whole topic, event or situation (Yin, 1994).
- Documents can suggest questions that need to be tackled and issues that need to be observed in more detail.
- Document analysis is a technique in which one will be able to track any changes or developments. The researcher may also have access to drafts of a specific document and hence one will be able to compare the changes that have been made. The researcher may study for instance how constancy testing protocols have evolved with time.
- Documents can be examined in such a way as to confirm or otherwise any evidence that has been found from other sources. (Bowen, 2009).

On the other hand, document analysis also has its disadvantages or limitations. The following are some disadvantages:

- Limited Data and lack of detail: The data can be sometimes limited. It may be that some documents do not give the full details required. In fact, this was noticed in this research where one of the organizations produced protocol documents with lack of detail of how to perform the test for constancy testing.
- Inaccurate: documents may also be inaccurate or outdated. This was eliminated in this project by using the most updated constancy testing protocols from each organization.

- Data out of context: The data available in the documents may be out of context and thus will not be relevant to the study. (QuestionPro, n.d.).
- Some documents especially scientific papers, sometimes are not freely accessible or it may be that documents are blocked purposely.
- Certain documents are difficult to locate and find, this especially refers to technical documents since they are not very commonly found and very specific in nature.

3.4 Data Collection Technique

At first, the most recent constancy testing protocols from the various organizations and for the four imaging modalities (Digital Radiography, Mammography, CT and Fluoroscopy) were selected. In this case, most of the documents were freely available online or borrowed from the Medical Physics Department of the national public hospital.

Then the required thematic data related to this project was selected from the documents. In this case, the thematic data collected was based on the following themes (thematic analysis):

- Document metadata
- The equipment used for the constancy testing
- Measurement protocol used for constancy testing
- The test frequency
- Tolerance Limits

The steps of thematic data collection as denoted by Braun and Clarke (2006) are as follows:

- Data familiarization: the data is transcribed when necessary, read and re-read. In this case no transcription was necessary since the source of the data were documents.
- Generating initial code: important features are coded into small phrases or keywords.
- Searching for the themes: the data is re-read several times and categorized into the different selected themes.
- Reviewing: the themes are reviewed to ensure that all the data and the correct data is included.
- Report: finally, the report writing and visual data representation (Braun & Clarke, 2008)

3.5 Data Collection Tool

A thematic template was designed specifically for the study as can be seen in table 3.1. The template was used to guide how the qualitative data would be collected and analysed (in the research literature this is known as 'Template Analysis'). The template followed the themes selected by the researcher and helped ensure that the data is organized in a meaningful and useful way (University of Huddersfield, n.d.).

Table 3. 1: Template Used for this Study

System	Sub-system	Thematic Category	Thematic Labels	Organization Name	Organization Name	Organization Name	Organization Name
		Document Metadata	Document Number				
			Recency				
			Price of Document				
		Equipment	Equipment required				
			Expense of Equipment / €				
			Ease of availability				
		Measurement Protocol	Professional performing the test				
			Level of Complexity				
		Test Frequency	Test Frequency				
		Tolerance Limits	Tolerance Limits				

3.6 Data Analysis Technique

The data analysis technique used was thematic analysis. Thematic analysis has several advantages that makes it the ideal technique for this study, however it also has its limitations.

In this research, a comparison of 5 different organizations that publish the constancy testing protocols was carried out with a particular attention to five specific thematic

categories. The five thematic categories with their respective thematic labels are the following:

[1] **Document Metadata** is a summary of basic information about the document which can result in searching and working with the specific documents much easier. Document metadata generally includes the organization which published the document, the date of when it was created and the title/reference number of the document (Wigmore, 2014). In this study, the Document Metadata that were considered are the document reference number, the recency and the price of the document.

Document Number

Generally, this is made up of a mixture of letters and numbers. These letters and numbers are given by the organization. This document number is very important so that one will be able to find the document much faster compared to searching by title (Kent, 2021).

Recency

Recency refers to the year of publication and indicates how recent the document is. Due to advancements in constancy testing technology and the equipment itself, having an updated and recent document is very important.

Every International Standard that is published either by ISO or by the IEC, undergoes Systematic Review (SR) so that it can be decided if the standard is confirmed, revised/

modified, transformed to another form of output or even withdrawn. When a standard has not been approved with or without any changes or is not being utilized in at least five countries, the standard must be withdrawn. This is because it becomes no longer internationally used. Some other reason which may result in a standard being withdrawn are the following:

- The standard is not reflecting the present practice or research
- The standard is not appropriate for new and existing applications
- The standard is not appropriate with current observations and expectations with regards to quality, safety and environment (ISO, 2019).

Price of the Document

Since it is very important that the Medical Physics Department have the correct and latest versions of the constancy testing protocols, the price of the document also has a significant importance.

Equipment: this refers to what equipment is required to carry out the test, the approximate cost of the equipment and if the equipment is easily available or otherwise

Equipment Required

The Equipment Required is very important to analyse to see if a given test requires specific and complex equipment to carry out a particular test. For practicality and a cost-effective approach, a test which uses less instruments or equipment and which is not that

sophisticated is preferred to the use of more complicated instruments (ElectronicsNotes, 2021). One of the reasons why simpler and more commonly found instruments are preferred is because time is very important time shouldn't be wasted on understanding how to use the instrument especially when the department is understaffed.

Expense of the Equipment

When choosing the equipment for testing, the expense of the equipment has a significant importance as well. This is because with such important tests, the equipment does not only need to be bought but has to be maintained and calibrated regularly to minimize measurement uncertainty or inaccuracy.

The expense of the equipment in Appendix A is an estimate. The ranges that were used are the following: <€500, €500-€1000, €1000-€2000, €2000-€5000 and <€5000.

Ease of availability

Ease of availability of the equipment refers to whether the equipment is normally available in the Medical Physics Department or if it has to be specially purchased.

[2] **Measurement Protocol**: is divided into two thematic labels, the first one being the Professional performing the test. This refers to whether the test is done by the Medical Imaging Device user for instance a radiographer or if it has to be done by a Medical Physicists or under the guidance of a Medical Physicist. The second

thematic label describes the level of complexity. Usually if the test is simple and straightforward it is done by a radiographer, if not a medical physicist will carry out the test.

Professional Performing the Test

Whether the test should be carried out by a Medical Physicist or the device user, depends on several factors. Some of these factors are if the test requires complex equipment or simple equipment, the duration of the test, the simplicity or complexity of the test procedure. If a test can be done by the device user then the Medical Physicists will benefit and have more time to conduct other tests or tasks.

Level of Complexity

The Level of Complexity is divided into two elements, either Simple or Complex. Simple means that it can be carried out by the user of the medical imaging device and Complex means that it can be carried out by a Medical Physicist or a Medical Physics trainee with the presence of a senior Medical Physicist. If a test is said to be simple, then the test can be carried out without the supervision of a senior Medical Physicist. This was also chosen based on what test is being carried out, what equipment is being used and what mathematics is being used.

[3] **Test frequency**: this refers to how often the test should be carried out. This varies a lot from one test to another, some tests are done more frequently than others.

For example, some tests are done on a daily basis and some tests are done every 3 months or annually. Generally, the ones that are done on a daily basis are done by a radiographer whilst the ones that are done less frequently, are lengthier and more complex tests are done by medical physicists.

[4] **Tolerance Limits**: this refers to what should be tolerable deviations from acceptable values of performance indicators and what actions and further investigations should be carried out when these are not.

Tolerance limits include an upper and a lower limit which allows a certain device to pass or fail a test. There are two sets of terms which are used for tolerance limits which are Remedial-Suspension (used mostly by the IPEM and the IEC) and Achievable-Acceptable (used mostly by the IAEA and the EU Commission) explained as follows:

- ***Remedial Level***: when the performance level lies within the tolerance limits, the equipment requires some action, however the device can still be used (IPEM 91, 2005).
- ***Suspension Level***: when the performance level lies within this limit this means that the equipment should not be used. (IPEM 91, 2005)
- ***Achievable***: when the performance reaches these tolerances, it is working in a satisfactory manner and thus the department can continue working with the devices normally (IAEA Human Health Series No. 17, 2011, p. 37).
- ***Acceptable***: when the performance is outside these tolerance limits, the medical image device should not be used (IAEA Human Health Series No. 17, 2011, p. 37).

3.7 Ethical Considerations

Since in this study, the data is secondary publicly available data which has already been published by the international organizations, there are no ethical issues involved. This study was approved by the University Research Ethics Committee of the University of Malta.

3.8 Limitations of the Methodology

Not all protocols are readily available in the English language, for instance the German Medical Association (GMA) has the protocols published in German only. Machine translation applications were considered for such documents but were not considered satisfactory as meaning may be altered from the original language. Consequently, the standards that were used were those in the English language only

Moreover, because of time constraint and the complexity of the constancy testing, this project did not consider all medical imaging devices but only selected devices with the main focus being on ionizing radiation devices. The four medical imaging devices selected were Digital Radiography, Mammography, Fluoroscopy and Computed Tomography (CT).

Another limitation that was met during the data collection stage was that certain organizations did not publish protocols for all the four devices that were investigated up to the date that data was collected. For instance, the IAEA have protocols for Mammography and Computed Tomography (CT), however, it does not have protocols for Fluoroscopy and Digital Radiography.

3.9 Conclusion

This chapter presented the research methodology utilized in this project so that the aims of the study are accomplished. The next chapter will include the presentation of the results.

Chapter 4: Results

4.1 Introduction

This chapter presents the results extracted from the documents regarding the constancy testing of the four different imaging modalities. Results were categorised using thematic template analysis and placed in the appropriate thematic categories and respective thematic labels. An analysis of the results follows.

4.2 Results and Analysis

The results are presented in four separate tables one for each modality (Digital Radiography, Mammography, Fluoroscopy and CT).
Five thematic categories were analysed in this study. These are the Document Metadata, Equipment, Measurement protocol, Frequency of the Test and the Tolerance Limits.

For the first category, Document Metadata, the thematic labels that fall under Document Metadata were the following: the cost of the document (therefore this indicates if it is freely available online or if it has to be bought and its approximate cost) and its recency (that is whether it is still valid or possibly outdated).

In the second thematic category, the Equipment section, there were three thematic labels: equipment required, the range of expense of the equipment and how easily the equipment is available. For the equipment required label, all the equipment that is used for that

particular test is listed. The cost ranges used for the equipment were: <€500, €500-€1000, €1000-€2000, €2000-€5000 and >€5000. The ease of availability specifies whether the equipment is normally found in the Medical Physics department or if it has to be specially purchased for that particular constancy test.

For the Measurement Protocol thematic category, there were two thematic labels: who is going to perform the test (i.e., whether it is the User or the Medical Physicist and the level of complexity. This indicates whether complex equipment, complex methods and mathematics are required. Therefore, it is then recommended that this is done by a Medical Physicists or a Medical Physics Trainee supervised by a qualified Medical Physicist. The fourth thematic category is the Frequency. As the name implies, the thematic label indicates how long the interval between test repeats should be.

Finally, the last thematic category that is analysed is the Tolerance Limit. Tests may have two tolerances designated as either 'Remedial - Suspension' or 'Achievable-Acceptable'. Some organizations have double columns since the tests are done both by the equipment user and by the medical physicists as well.

Table 4.1 shows sample results that were collected for Digital Radiography. Table 4.2 shows sample results collected for Mammography. Table 4.3 shows sample results for Fluoroscopy and table 4.4 shows sample results collected for CT. The complete tables can be found in Appendix A.

Table 4. 1: Sample of Comparative Results Extracted from Constancy Testing Documents for Digital Radiography

System	Subsystem	Thematic Category	Thematic Labels	IEC	EU COMMISSION	IPEM	AAPM
X-ray Tube and Generator		**Document Metadata**	Document Number	IEC 61223-2-11	RP 162	IPEM 91	AAPM 74
			Recency	1999	2012	2005	2002
			Price of Document	€190	€0	€30	€0
	Light Beam/X-ray Alignment	Equipment	Equipment required	Tape measure, two cassettes with screens, radiographic film, ruler, spirit level, test device for alignment	NA	Collimation test tool /radio-opaque markers	NA
			Expense of Equipment/ €	<500	NA	<500	NA
			Ease of availability	Cassettes and film less available now	NA	Normally available	NA
		Measurement Protocol	Professional performing the test	User	NA	User	Performed by or under guidance of Medical Physicist

			Level of Complexity	Simple	Simple	Simple	Simple
		Test frequency	Test Frequency	Manufacturer's instructions or at least every 3 months	NA	Every 1 or 2 months	Annually but more frequently as the system ages
		Tolerance Limits	Tolerance Limits	Remedial: > 10mm, Suspension: >20 mm at 1 m SID	Misalignment in any direction > 3 % of focus- image receptor distance	Remedial: ±1cm misalignment at 1m SID, Suspension: > 3 cm misalignment at 1m SID	±2% of the SID
	Field Size Indicator Accuracy	Equipment	Equipment required	Tape measure, spirit level	NA	NA	NA
			Expense of Equipment/ €	<500	NA	NA	NA
			Ease of availability	Normally available	NA	NA	NA
		Measurement Protocol	Professional performing the test	User	NA	User	Performed by or under guidance of Medical Physicist
			Level of Complexity	Simple	NA	Simple	Simple
		Test frequency	Test frequency	At least every 3 months	NA	Every 1 or 2 months	Annually / often as necessary

		Tolerance Limits	Tolerance Limits	±2% of the Focal spot to image receptor distance	NA	±1cm at 1m	±2% of the SID

Table 4.2: Sample of Comparative Results Extracted from Constancy Testing Documents for Mammography

System	Sub-system	Thematic Category	Thematic Labels	IEC	EU COMMISSION	IAEA	IPEM	AAPM	ACR	
Mammography		**Document Metadata**	Document Number	IEC 61223-2-10	EUREF 4th Edition	IAEA Human Health Series No. 17	IPEM 89	AAPM 74	ACR 2018 Digital Mammography Quality Control Manual	
			Recency	1999	2013	2011	2005	2002	2018	
			Price of Document	€190	€0	€0	€35	€0	€0	
									User	MPE
X-ray tubes and Generator	**X-ray/light field alignment**	Equipment	Equipment required	Test device with steel balls	Tape measure	NA	Screen-film cassette, markers (e.g. stiff wire/coins), steel ruler	No Mammography QC recommendations in the document	NA	5 coins or flat opaque objects, collimation test tool
			Expense of Equipment/ €	<500	<500	NA	<500		NA	<500
			Ease of availability	Specially purchased	Normally available	NA	Normally available		NA	Normally available

		Measurement Protocol	Professional performing the test	Performed by or under guidance of Medical Physicist	Performed by or under guidance of Medical Physicist	NA	Performed by or under guidance of Medical Physicist		NA	Performed by or under guidance of Medical Physicist
			Level of Complexity	Simple	Simple	NA	Simple		NA	Simple
		Test frequency	Test frequency	After maintenance or service	Annually	NA	Every 6 months		NA	Annually and after relevant service
		Tolerance Limits	Tolerance Limits	At least five balls at each side of the high-contrast test device are totally visible	X-ray field extending beyond the image receptor >5mm on any side, Chest wall side: distance between	NA	Misalignment >5mm along any edge		NA	< ±2% of SID

					image receptor and edge> 5mm					
	Alignment of x-ray field to film/digital detector	Equipment	Equipment required	NA	NA	2 rulers, opaque material, 5 phosphorescent pieces and PMMA slabs	Screen-film cassette, markers (e.g. stiff wire/coins), steel ruler		NA	5 coins or flat opaque objects, collimation test tool
			Expense of Equipment/ €	NA	NA	500-1000	<500		NA	<500
			Ease of availability	NA	NA	Normally available	Normally available but less available now.		NA	Normally available
		Measurement Protocol	Professional performing the test	NA	NA	Performed by or under guidance of Medical Physicist	Performed by or under guidance of Medical Physicist		NA	Performed by or under guidance of Medical Physicist

			Level of Complexity	NA	NA	Simple	Simple		NA	Simple
		Test frequency	Test frequency	NA	NA	Annually and after x-ray tube service/replacement	Every 6 months		NA	Annually and after relevant service
		Tolerance Limits	Tolerance Limits	NA	NA	Achievable: ≤5mm, Acceptable: ≤7mm,	Remedial: >5mm or <0mm overlap along all sides, Suspension: >10mm overlap or >2mm unexposed border or >19mm overlap along left or tight edge		NA	< ±2% of SID

Table 4.3: Sample of Comparative Results Extracted from Constancy Testing Documents for Fluoroscopy

Subsystem	Thematic Category	Thematic Labels	IEC	EU Commission	IPEM		AAPM
	Document Metadata	Document Number	IEC 61223-2-9 (Image Intensifier)	RP 162 (Image Intensifier)	IPEM 91 (Image Intensifier)		AAPM 74 (Flat Panel Detectors/ Image Intensifier)
		Recency	1999	2012	2005		2002
		Price of Document	€135	€0	€30		€0
					User	MPE	
Radiation/image field size and virtual collimation	Equipment	Equipment required	NA	NA	Film or CR plate, collimation test tool/collimators visible on monitor	NA	Collimation test tool
		Expense of Equipment/ €	NA	NA	500-1000	NA	500-1000
		Ease of availability	NA	NA	Normally available	NA	Normally available

	Measurement Protocol	Professional performing the test	NA	User	User	NA	Performed by or under guidance of Medical Physicist
		Level of Complexity	NA	Simple	Simple	NA	Simple
	Test frequency	Test frequency	NA	NA	Annually	NA	Annually
	Tolerance Limits	Tolerance Limits	NA	Radiation/field size: Radiation area>1.25 image area; Collimation limits: Deviation>3% of SID in either direction or >4% for the sum of two directions	Remedial level: Ratio of areas >1.15, Suspension level: X-ray field outside image receptor housing	NA	±2% of the SID in all edges
Limiting spatial resolution	Equipment	Equipment required	High-contrast test device, correction test filter device	NA	Resolution Test pattern	Lead grating resolution bar pattern	Line pair phantom, copper plate
		Expense of Equipment/ €	<500	NA	<500	500-1000	<500

		Ease of availability	Normally available	NA	Normally available	Normally available	Normally available
	Measurement Protocol	Professional performing the test	Performed by or under guidance of Medical Physicist	Performed by or under guidance of Medical Physicist	User	Performed by or under guidance of Medical Physicist	Medical Physicist (Same individual should do this test from time to time)
		Level of Complexity	Simple	Simple	Simple	Simple	
	Test frequency	Test frequency	At least every 3 months	NA	At least every 1-3 months	Annually	Annually
	Tolerance Limits	Tolerance Limits	+2/-3 visible patterns	<0.8 lp/mm for field sizes > 25 cm, <1 lp/mm for field sizes ≤25	Baseline reduced by 2 groups	Baseline reduced by 2 groups or 36-40cm: ≤ 0.7-line pairs mm-1, 30-35 cm: ≤ 0.8-line pairs mm-1,25-29 cm: ≤ 0.9-line pairs mm-1, 20-24 cm: ≤ 1.0-line	Highest spatial frequency should be visible

	pairs mm-1, 15-18 cm: ≤ 1.25-line pairs mm-1,					

Table 4.4:Sample of Comparative Results Extracted from Constancy Testing Documents for Computed Tomography

Sub-system	Thematic Category	Thematic Labels	IEC	EU COMMISSION	IAEA		IPEM		AAPM	ACR	
	Document Metadata	Document Number	61223-2-11	RP 162	IAEA Human Health Series No. 19		IPEM 91		AAPM 74/ AAPM 66	ACR CT Quality Control Manual	
		Recency	1999	2012	2012		2005		2002/2003	2017	
		Price of Document	€135	€0	€0		€30		€0	€0	
					User	MPE	User	MPE		User	MPE
Image noise	Equipment	Equipment required	Cylindrical test device of specified size containing a uniform medium	Water-filled phantom	Manufacturer's phantom/ commercial phantom/ simple phantom	Manufacturer's phantom/ commercial phantom/ simple phantom	System manufacturer's quality control phantom	Head and body sized water or equivalent phantoms	Water-filled phantom	Water phantom	NA
		Expense of Equipment / €	2000-5000	2000-5000	2000-5000	2000-5000	2000-5000	2000-5000	2000-5000	2000-5000	NA

		Ease of availability	Normally available	Normally available	Specially purchased	Specially purchased	Specially purchased	Normally available	Normally available	Normally available	NA
	Measurement Protocol	Professional performing the test	Performed by or under guidance of Medical Physicist	Performed by or under guidance of Medical Physicist	User	Performed by or under guidance of Medical Physicist	User	Performed by or under guidance of Medical Physicist	Performed by or under guidance of Medical Physicist	User	NA
		Level of Complexity	Simple	Simple	Simple	Simple	Simple	Simple	Simple	Simple	NA
	Test frequency	Test frequency	At least monthly	Daily	Monthly	Annually	Daily to weekly	Annually	Daily	Daily	NA
	Tolerance Limits	Tolerance Limits	Baseline values ± 10% or ±0.2HU	Deviation of noise from specified values >15%	Acceptable ±25% baseline value, Achievable ±10% baseline value	Acceptable ±25% of baseline, Achievable ±10% of baseline	Remedial level: Baseline ± 10%, Suspension level: Baseline ± 25%	Remedial level: Water: Baseline ± 10% Inter slice variation mean ± 10%, Suspension level:	Manufacturer specifications	0 ± 5 HU	NA

								Baseline ± 25%			
Scan plane localization from alignment lights	Equipment	Equipment Required	Test device thin absorber:1 mm diameter wire	Markers	CT phantom	CT phantom, test device including a thin absorber ex. a 1mm diameter wire	Film or radio-opaque markers	NA	Markers	NA	A phantom that has radiopaque markers
		Expense of Equipment / €	<500	<500	2000-5000	2000-5000	<500	NA	<500	NA	2000-5000
		Ease of availability	Normally available	Normally available	Normally available	Normally available	Normally available	NA	Normally available	NA	Normally available
	Measurement Protocol	Professional performing the test	Performed by or under guidance of Medical Physicist	Performed by or under guidance of Medical Physicist	User	Performed by or under guidance of Medical Physicist	User	NA	Performed by or under guidance of Medical Physicist	NA	Performed by or under guidance of Medical Physicist

		Level of Complexity	Simple	Simple	Simple	Simple	Simple	NA	Simple	NA	Simple
	Test frequency	Test frequency	At least every 3 months	Annually	Monthly	Annually	Every 1-3 months	NA	Annually	NA	Annually or after relevant service
	Tolerance Limits	Tolerance Limits	± 2mm	>± 5mm	Acceptable ± 5mm, Achievable ± 1mm	Acceptable ± 5mm, Achievable ± 1mm	>± 2mm	NA	± 1mm over the scan range	NA	> ± 2mm

4.3 Conclusion

This chapter presented the results that were collected in the study together with a brief summary of how the data was analysed. The data from the thematic categories and labels together with other thematic aspects which were discovered during the data collection process will be discussed in Chapter 5.

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Chapter 5: Discussion

5.1 Introduction

This chapter presents a discussion of the results of the project. The discussion is presented in sections by modality. In this chapter the different standards from the different organizations for each modality will be compared to each other with respect to the thematic categories and thematic labels and discussed.

5.2 Comparative Analysis of Constancy Testing Protocols for Digital Radiography

For Digital Radiography, the international organizations that have Constancy Testing Protocols are: IEC, EU Commission, IPEM and AAPM.

5.2.1 Digital Radiography: Document Metadata

Document Number

In this project, for Digital Radiography all documents that were used from four different international organizations which are the IEC, EU Commission, the IPEM and the ACR, had

its own document number. It was noted that the IAEA and AAPM do not have protocols for Digital Radiography when this study was carried out.

Recency

For Digital Radiography, it was noted that the EU Commission document, RP 162, is the most recent document which was published in 2012. On the other hand, the IEC 61223-2-11 standard is the least recent as it was created in 1999 and has now been withdrawn. The AAPM 74 is also a bit old and close to the IEC published year approximately 3 years later.

Then research was carried out to see if there are any updated IEC standards for Digital Radiography. However, there aren't any updated versions available to date when this study was carried out.

Price of Document

The prices of the documents vary a lot from one organization to another. There are organizations that have their guidelines freely available online. The EU Commission and the AAPM have their documents freely available online for Digital Radiography.

On the other hand, the IPEM documents are not freely available but they are rather reasonably priced since the document for Digital Radiography is €30 and includes constancy testing protocols for all the x-ray imaging modalities. From all the four

organizations, the most expensive documents that were used for this modality is the one of the IEC organization which costs around €190.

5.2.2 Digital Radiography: Equipment

Equipment Required

From the data that was collected, found in Appendix A, Table A.1, one can notice that the AAPM 74 does not give details on which equipment should be used. This may be a disadvantage because it is left to the Medical Physicist to decide on which equipment to use. The EU Commission document, RP 162 also does not state which equipment should be used. However, the IEC 61223-2-11 and IPEM 91 give the full details on what equipment to use and even the full procedure with all the details.

Expense of the Equipment

In table A.1, it can be seen the expense of the equipment for the IEC organization and the IPEM are very similar. For the EU Commission and AAPM since the equipment required was not available, the estimate of the equipment couldn't be carried out.

Ease of availability

In Table A.1, it was noted that for all the equipment that was stated from the four organizations they are all normally available in a Medical Physics Department.

5.2.3 Digital Radiography: Measurement Protocol

Professional Performing the Test

For digital radiography, in table A.1 in the IPEM 91 there are some tests which are specifically done by the user as indicated in the document and others which should be done or performed under the guidance of Medical Physicists. On the other hand, the other three documents do not state who should carry out the test so assumptions were made based on the equipment, procedure or the test itself.

Level of Complexity

For digital radiography as can be seen from table A.1, all four documents have a combination of both Simple and Complex tests mainly being Simple. This means that several tests can be done by the users or even Medical Physics trainees which would free up more time for the senior Medical Physicists provided there are enough testing instruments in the department.

5.2.4 Digital Radiography: Test Frequency

From table A.1 for Digital Radiography, it can be clearly seen than in terms of frequency, IEC 61223-2-11, RP 162, IPEM 91 have similar testing frequencies. On the other hand, in AAPM 74, the tests are carried out less frequently. This may be a disadvantage, because if

there is a fault it may not be detected early enough. Therefore, more frequent tests should be preferred so that any faults and errors will be solved at the earliest.

5.2.5 Digital Radiography: Tolerance Limits

When taking a look at the tolerance limits from the four documents for digital radiography in table A.1, it can be seen that some are very similar such as the for Light Beam/ X-ray Alignment the tolerances are quite close to each other. However, when it comes to the Tube Potential as can be clearly seen in table 5.1 there is quite a difference. AAPM having the smallest tolerance limit (±4 kVp) and the EU Commission having the highest tolerance limit (±10 kVp). The IPEM 91 gives the full detail of the Remedial and the Suspension tolerance limits, therefore when the equipment can still be used and when the equipment should not be used. See table 5.1.

Table 5. 1:Tube Potential Tolerance Limits for Digital Radiography

Thematic Label	**IEC**	**EU COMMISSION**	**IPEM**	**AAPM**
Tolerance Limits	NA	> ±10 % or ±10 kVp whichever is the greater	Remedial: ±5 kVp or ±5 %, Suspension: ±10kVp or ±10 %	±4 kVp

5.3 Comparative Analysis of Constancy Testing Protocols for Mammography

For Mammography, the international organizations that have Constancy Testing Protocols are: IEC, EU Commission, IAEA, IPEM and ACR.

5.3.1 Mammography: Document Metadata

Document Number

For Mammography as can be seen in table in Table A.2, the IEC, IAEA and IPEM have a document reference number. On the other hand, the EU Commission document and the ACR document have a document title only.

Recency

The most recent standard document is the EUREF 4th Edition which was published in 2013 and the least recent being the IEC 61223-2-10 which was published in 1999. IEC 61223-2-10 is a withdrawn document.

Research was carried out if there are other updated IEC documents which are not withdrawn and related to the Constancy Testing of a Mammography unit. The following documents were found:

- *IEC 61223-3-6:2020; Evaluation and routine testing in medical imaging departments - Part 3-6: Acceptance and constancy tests - Imaging performance of mammographic X-ray equipment used in a mammographic tomosynthesis mode of operation.*

- *IEC 61223-3-2:2007; Evaluation and routine testing in medical imaging departments - Part 3-2: Acceptance tests - Imaging performance of mammographic X-ray equipment.*

However, both of these documents are not suitable for this study. This is because *IEC 61223-3-6:2020* considers the mammography unit when operating in tomosyntheses mode. On the other hand, the *IEC 61223-3-2:2007,* gives guidelines on the acceptance testing only and not the constancy testing protocols.

Specifically, for Mammography, recency is very important, since nowadays most if not all Mammography equipment is Digital Mammography which requires a difference type of constancy testing. Unfortunately, the IEC unlike the EU, IAEA and IPEM does not consider digital mammography. Another aspect why recency and up to date documents are vital in mammography is because most of the patients that are being screened are healthy people. Therefore, it is very important that radiation be kept as low as possible.

Price of the Document

The EU Commission, the IAEA and ACR organizations have documents which are related to the constancy testing freely available online for mammography. The same stands for Digital Radiography, IPEM 89 is not very expensive since it is approximately, €35. From all the five organizations, the most expensive documents that were used for this modality was the IEC 61223-2-10 which costs around €190.

5.3.2 Mammography: Equipment

Equipment Required

From the data that was collected, found in Appendix A, Table A.2, it can be seen that all of the five documents give the full details including the equipment that is required to carry out the tests. Apart from the equipment that is required, the procedure on how the test is carried out is also provided from the five documents.

Expense of the Equipment

Since the equipment that is used from the different organizations is quite similar, then the expense is also very similar as can be seen in table A.2.

Ease of availability

For Mammography, most of the equipment is normally available in the Medical Physics Department such as an ionization chamber, mammography phantoms and an electrometer.

5.3.3 Mammography: Measurement Protocol

Professional Performing the Test

For Mammography, IPEM 89 and the ACR document state clearly who should perform the test, if it is either done by the equipment's user or if it is done or under the guidance of a Medical Physicist. For the IEC 61223-2-10, EU Commission and the IAEA, if the equipment and procedure was rather simple, it was decided that the test may be carried out by the user, otherwise by or under the guidance of a Medical Physicist.

Level of Complexity

The Level of Complexity goes hand in hand with to who is performing the test. Apart from the equipment, if software is required or some calculations are necessary then the test must be performed by a Medical Physicist or under his guidance, to avoid any errors. For the levels of complexity, the documents are equal.

5.3.4 Mammography: Test Frequency

From Table A.2 in Appendix A it was noted that most of the tests are done every 6 months. The more frequent the tests are, then the faults or any changes are detected earlier compared to those having less frequent checking.

However, for the Sensitivity Variations and Plate Uniformity test as seen in table 5.2 below, there was some variability in the test frequency from the four organizations. The EU Commission document states that is should be carried out monthly whilst the others state that it should be performed annually. If there is lack of uniformity, then very small lesions might not be detected. Detecting small lesions at the earliest is a very crucial requirement especially in breast screening, therefore, having it checked more frequently than once a year is more reasonable.

Table 5. 2: Test Frequency for Uniformity Constancy Testing for Mammography

Sub-system	**Thematic Category**	**Thematic Labels**	**IEC**	**EU COMMISSION**	**IAEA**	**IPEM**	**ACR**	
Sensitivity variations and plate uniformity	Test frequency	Test frequency	At least annually	Monthly	Annually / after updates or any changes	Annually	NA	NA
	Tolerance Limits	Tolerance Limits	Optical density from mean value ±0.20	No artefacts should be present	No artefacts should be present	Remedial: at the centre: > 0.2 and at the left or right point: > 0.15, any significant artefacts should be investigated	NA	NA

5.3.5 Mammography: Tolerance Limits

The tolerance limits are also very close to each other from one document to another. However, in the test illustrated in table 5.2, the EU Commission and the IAEA state that there shouldn't be any artefacts whatsoever whilst for the IEC and IPEM there is a tolerance limit which may be accepted.

5.4 Comparative Analysis of Constancy Testing Protocols for Fluoroscopy

For Fluoroscopy, the international organizations that have Constancy Testing Protocols are: IEC, EU Commission, IPEM and AAPM.

5.4.1 Fluoroscopy: Document Metadata

Document Number

As can be seen in table in Table A.3, all documents used for constancy testing for Fluoroscopy that is the IEC, EU Commission, the IPEM and the AAPM documents have a document number. Hence, all of them can be easily found and distinguished straightaway

from other documents. The IEC, EU Commission, IPEM and AAPM cater for Image Intensifier systems but the IPEM also provides data for flat panel detectors.

Recency

Similarly, for the already mentioned medical imaging devices, in Fluoroscopy, the most recent standard that was considered in this study is the RP 162 from the EU Commission and the least recent standard was the IEC 61223-2-9. The IEC document is also a withdrawn document.

Price of the Document

The EU Commission and the AAPM organizations have documents which are related to the constancy testing freely available online for fluoroscopy. For the IPEM, the same document as for digital radiography is used that is the IPEM 91, which is not very expensive approximately €30. From all the four organizations that provided constancy testing protocols for fluoroscopy, the most expensive document was the IEC 61223-2-9 which costs around €135. Keeping in mind that the year in which was published was 1999, and the cost can be indications that it might not be worth pursuing.

5.4.2 Fluoroscopy: Equipment

Equipment Required

All the equipment that is used for the constancy testing of fluoroscopy is general equipment such as dosimeter and phantoms. However, one of the weaknesses that was noted in Table A.3 is that RP 162 does not provide what equipment is required to carry out the tests. This may lead to variability from one person to another.

Expense of the Equipment

For the RP 162, since the equipment was not provided then the expense of the equipment couldn't be estimated. The phantoms and the oscilloscope are normally quite pricey.

Ease of availability

All equipment from all the different documents are normally found in a Medical Physics Department.

5.4.3 Fluoroscopy: Measurement Protocol

Professional Performing the Test

Similarly to Digital Radiography, the IPEM 91 document gives direct guidelines on who should perform the test. Since most of the tests require commonly used equipment and are simple they can be performed by the equipment's user.

Level of Complexity

Moving on to the Level of Complexity of the tests, some tests which are a bit complex are for instance the video voltage the IPEM 91 makes use of an oscilloscope whilst the AAPM just uses a non-invasive kV meter. Overall, the level of complexity, is quite low however use of the oscilloscopic method may be beyond the capability of many users.

5.4.4 Fluoroscopy: Test Frequency

Most of the tests are stated to be done "At least annually" in all four documents. This means that is should be checked at least once a year without the obligation to perform the test more frequently. However, in table A.3 it can be clearly seen that IPEM 91, have tests which are done more frequently such as the Threshold Contrast and the Limiting Spatial Resolution.

5.4.5 Fluoroscopy: Tolerance Limits

The tolerance limits for Fluoroscopy are also very close to each other from one document to another. However, there is a specific test that the AAPM suggests to use the Manufacturer's Specifications for the HVL test. This means that for the AAPM there isn't a

specific tolerance limit for every fluoroscopy unit but the medical physicists should take into consideration the limits from the manufacturer.

5.5 Comparative Analysis of Constancy Testing Protocols for Computed Tomography

For Computed Tomography, the international organizations that have constancy testing protocols are: IEC, EU Commission, IAEA, IPEM, AAPM and ACR.

5.5.1 Computed Tomography: Document Metadata

Document Number

From table A.3, it was noted that almost all the Constancy Testing documents have their own document number. However, the ACR document only has a worded title.

Recency

For Computed Tomography the least recent are the AAPM documents published in 2002 and 2003, whilst the most recent document is the IEC 61223-3-5:2019 which was published in 2019.

Price of Document

Most of the Constancy Testing documents for Computed Tomography are freely available online, specifically the EU Commission, the IAEA, the AAPM and the ACR documents. On the other hand, the IPEM 91 is the same document which is also used for Digital Radiography and Fluoroscopy that costs approximately €30. The IEC document is more on the expensive side and costs around €300.

5.5.2 Computed Tomography: Equipment

Equipment Required

In table A.4 in Appendix A, it was noted that some of the tests from the IAEA and the AAPM they state that the manufacturer's specifications and provided equipment should be used. However, for the rest of the tests the equipment that should be used is provided.

Expense of the Equipment

For the expense of the equipment used for the constancy testing of Computed Tomography, the most expensive equipment are the head and body phantoms which are required by all the organizations that were used in this study. Therefore, there isn't a specific organization that makes the Constancy Testing of a CT at a much lower equipment cost.

Ease of Availability

An example when the equipment has to be specially purchased is in the CT number test where the IPEM 91 requires a specific phantom with different ranges of density materials. On the other hand, the other documents require a water-filled or water equivalent phantom. However, other than this the equipment is all usually found in the Medical Physics department for the constancy testing of a CT.

5.5.3 Computed Tomography: Measurement Protocol

Professional Performing the Test

The IAEA document, IPEM 91 and the ACR document provide direct indication on who should perform the test. Since, accuracy and precision are critical most of the tests are done by or performed under the guidance of a Medical Physicist.

Level of Complexity

The Level of Complexity of the tests varies on what test is being performed, some tests are a bit complex but others less so. When it comes to CT number and CTDI they are slightly more complicated than the other tests, hence these should be carried out by Medical Physicists.

5.5.4 Computed Tomography: Test Frequency

In the table A.2 in Appendix A it can be seen that there is quite a variation in the test frequency from one document to another. Specifically, for the image noise the variation is from daily (EU Commission, AAPM, ACR) up to annually (IAEA, IPEM). However, this situation is not for image noise test only but for several other tests. There isn't a pattern in which one organization does the tests more frequently than the others.

5.5.5 Computed Tomography: Tolerance Limits

Similarly, to the Test Frequency for Computed Tomography, for the Tolerance Limits there is also a variation from one organization to another and no pattern is identified. However, there are some of the tests where the tolerance limits are very close to each other or even identical when comparing them with other documents from the different organizations.

5.6 General Discussion

From the above, it can be clearly noticed that the IEC organization has the least updated standards document for the different imaging modalities. Whilst the most recent constancy testing protocols documents are from the ACR. Moreover, another point that was noticed during data collection is that three IEC standards were marked as withdrawn and there aren't updated versions up to when this study was carried out.

The AAPM 74 is also a retired document, however, there isn't an updated version up to when this study was carried out.

Another aspect which was noted during the data collection is that the ACR documents provide the time duration of a test, meaning how long it would take to carry out the test. This is helpful when it comes to the planning of a particular Constancy Testing regime especially when there are heavily used imaging devices that cannot be taken out of clinical use for long. However, the ACR does not provide constancy testing protocols for all imaging modalities. Therefore, one shouldn't stick to a specific organization for the Constancy Testing for all imaging modalities.

5.7 Conclusion

From this chapter, it can be concluded that there isn't a specific organization which is suitable to cater for constancy testing protocols for all imaging modalities. Some documents are better in giving the full details of the tests and whilst others focus mainly on the tolerances. It is important to take the best features of multiple constancy testing protocols when deciding on one's own protocol.

Chapter six will discuss the conclusions that were drawn from this study and any recommendations for the professional practice and for the future research.

Chapter 6: Conclusions and Recommendations

6.1 Introduction

This chapter presents the main conclusions that were drawn from the results that were acquired. This chapter also includes recommendations both for the Medical Physics profession as well as for future research studies.

6.2 Summary of Conclusions from the Study

The main conclusions that were drawn from this study are:

a) There isn't one particular organization that caters for the most suitable Constancy Testing protocols across all imaging modalities.
b) There are some documents which are withdrawn or retired without being replaced.
c) Some Constancy Testing protocols focus mainly on the tolerance limits whilst others provide the full details such as procedure, equipment required and much more.
d) There are some variations from one organization to another for a given modality and some incorporate more tests than others.
e) The best protocol to use is often a combination of elements of best practice from protocols from different organizations.

6.3 Recommendations for Professional Practice

The following are recommendations for professional medical physics practice:

a) Medical Physicists and the equipment users should be aware of which constancy testing protocols are recommended by their own department.

b) Clear instructions must be created to indicate clearly which tests should be carried out by the equipment users and which tests should be performed by the medical physicists or under the guidance of the medical physicists.

c) Since technology and devices are continuously evolving, then the constancy testing protocols used must be revised and updated frequently.

d) Protocols suggested for the medical imaging devices which were considered in this study are as follows:

   i. Digital Radiography: A combination of IPEM 91 and RP 162 are suggested to be used.

   ii. Mammography: A combination of EUREF 4th Edition and ACR 2018 Digital Mammography Quality Control Manual are suggested to be used.

   iii. Fluoroscopy: A combination of IPEM 91 and AAPM 74 are suggested to be used. Care must be taken when combining the two since IPEM 91 also caters for flat panel detectors.

   iv. Computed Tomography: A combination of IEC 61223-3-5:2019 and the ACR CT Quality Control Manual are suggested to be used.

6.4 Recommendations for Future Research

Suggestions for further research are:

a) A similar comparative study should be carried out on the rest of the medical imaging equipment that is usually found in hospitals such as for the Dental Cone Beam CT, Intra-Oral, Ultrasound and Magnetic Resonance Imaging (MRI). Although, non-ionizing radiation is not carcinogenic, constancy testing is important so that the image quality does not degrade and hence very small abnormalities can be detected.

6.5 Conclusion

It is very important that the correct constancy tests are carried out for both the patient's safety and for a better diagnosis. The study showed, that there are different organizations with different strengths and weaknesses, that have suitable constancy testing protocols according to which medical image device is being tested. It is hoped that this study will help Medical Physicists to decide on which constancy testing protocols they should choose for their own constancy testing programme.

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Appendix A: Tables of Results

Table A.1 shows all the data that was collected for Digital Radiography. Table A.2 shows the data collected for Mammography. Table A.3 shows the data for Fluoroscopy and table A.4 shows all the data collected for CT.

A.1 Digital Radiography Results Table

Table A. 1: Comparative Results Extracted from Constancy Testing Documents for Digital Radiography

System	Sub-system	Thematic Category	Thematic Labels	IEC	EU COMMISSION	IPEM	AAPM
X-ray tubes and Generator		**Document Metadata**	Document Number	IEC 61223-2-11	RP 162	IPEM 91	AAPM 74
			Recency	1999	2012	2005	2002
			Price of Document	€190	€0	€30	€0
	Radiation Output	Equipment	Equipment required	Radiation meter. Anti-scatter grid, radiographic cassette, attenuation phantom	NA	NA	NA
			Expense of Equipment/ €	2000-5000	NA	NA	NA
			Ease of availability	Cassettes and film less available now	NA	NA	NA
		Measurement Protocol	Professional performing the test	Performed by or under guidance of Medical Physicist	NA	NA	Performed by or under guidance of Medical Physicist

			Level of Complexity	Simple	NA	NA	Simple
		Test frequency	Test frequency	Daily for the first week, then two-week cycle for 6 months, then at least every 3 months	NA	NA	Annually/ replacement/ service
		Tolerance Limits	Tolerance Limits	Manual control: Baseline ±30%, AEC: Baseline ±15%	NA	NA	NA
	Light Beam/X-ray Alignment	Equipment	Equipment required	Tape measure, two cassettes with screens, radiographic film, ruler, spirit level, test device for alignment	NA	Collimation test tool /radio-opaque markers	NA
			Expense of Equipment/ €	<500	NA	<500	NA
			Ease of availability	Cassettes and film less available now	NA	Normally available	NA
		Measurement Protocol	Professional performing the test	User	NA	User	Performed by or under guidance of Medical Physicist
			Level of Complexity	Simple	Simple	Simple	Simple
		Test frequency	Test frequency	Manufacturer's instructions or at	NA	Every 1 or 2 months	Annually but more frequency as the system ages

				least every 3 months			
		Tolerance Limits	Tolerance Limits	Remedial: < 10mm, Suspension: >20 mm at 1 m SID	Misalignment in any direction > 3 % of focus- image receptor distance	Remedial: ±1cm misalignment at 1m SID, Suspension: > 3 cm misalignment at 1m SID	±2% of the SID
	Field Size Indicator Accuracy	Equipment	Equipment required	Tape measure, spirit level	NA	NA	NA
			Expense of Equipment/ €	<500	NA	NA	NA
			Ease of availability	Normally available	NA	NA	NA
		Measurement Protocol	Professional performing the test	User	NA	User	Performed by or under guidance of Medical Physicist
			Level of Complexity	Simple	NA	Simple	Simple
		Test frequency	Test frequency	At least every 3 months	NA	Every 1 or 2 months	Annually / often as necessary
		Tolerance Limits	Tolerance Limits	±2% of the Focal spot to image receptor distance	NA	±1cm at 1m	±2% of the SID
	Positive Beam Limitation System (PBL)	Equipment	Equipment required	NA	NA	NA	NA
			Expense of Equipment/ €	NA	NA	NA	NA

			Ease of availability	NA	NA	NA	NA
		Measurement Protocol	Professional performing the test	NA	NA	NA	Performed by or under guidance of Medical Physicist
			Level of Complexity	NA	NA	NA	Simple
		Test frequency	Test frequency	NA	NA	NA	Annually/ often as necessary
		Tolerance Limits	Tolerance Limits	NA	NA	NA	±2% of the SID
	X-ray Beam-Bucky Alignment	Equipment	Equipment required	Tape measure, two cassettes with screens, radiographic film, ruler, spirit level, test device for alignment	NA	Alignment test tool /radio-opaque markers	NA
			Expense of Equipment/ €	<500	NA	<500	NA
			Ease of availability	Cassettes and film less available now.	NA	Normally available	NA
		Measurement Protocol	Professional performing the test	User	NA	User	Performed by or under guidance of Medical Physicist
			Level of Complexity	Simple	NA	Simple	Simple
		Test frequency	Test frequency	Manufacturer's instructions or at least every 3 months	NA	Every 1 or 2 months	Annually/ often as necessary/ older systems more frequent

		Tolerance Limits	Tolerance Limits	Remedial: < 10mm, Suspension: <20 mm at 1 m SID	Alignment of crosswire with centre of Bucky > 1% of focus-image receptor distance	±1cm at 1m	±2% of the SID
	Focal Spot Size	Equipment	Equipment required	Tape measure, two cassettes with screens, radiographic film, ruler, spirit level, test device for alignment	Test to be performed with 20 cm of PMMA between test object and receptor.	NA	NA
			Expense of Equipment/ €	<500	<500	NA	NA
			Ease of availability	Normally available	Normally available	NA	NA
		Measurement Protocol	Professional performing the test	User	Performed by or under guidance of Medical Physicist	NA	Performed by or under guidance of Medical Physicist
			Level of Complexity	Simple	Simple	NA	Simple
		Test frequency	Test frequency	Manufacturer's instructions or at least every 3 months	NA	NA	At acceptance/ replacement/ annually
		Tolerance Limits	Tolerance Limits	≈ 1.2 mm	< 1.6 lp/mm	NA	Approximately 0.1% of SID
	Tube Potential	Equipment	Equipment required	NA	Digital kV meter	Digital kV meter	kVp meter

			Expense of Equipment/ €	NA	<500	<500	<500
			Ease of availability	NA	Normally available	Normally available	Normally available
		Measurement Protocol	Professional performing the test	NA	Performed by or under guidance of Medical Physicist	Performed by or under guidance of Medical Physicist	Performed by or under guidance of Medical Physicist
			Level of Complexity	NA	Simple	Simple	Simple
		Test frequency	Test frequency	NA	1-2 yearly	1-2 yearly	At acceptance/ annually
		Tolerance Limits	Tolerance Limits	NA	> 10 % or 10 kVp whichever is the greater	Remedial: ±5 kVp or ±5 %, Suspension: ±10kVp or ±10 %	±4 kVp
	Exposure Time	Equipment	Equipment required	NA	NA	Digital timer meter	mAs indicator and generator specifications
			Expense of Equipment/ €	NA	NA	<500	<500
			Ease of availability	NA	NA	Normally available	Normally available
		Measurement Protocol	Professional performing the test	NA	Performed by or under guidance of Medical Physicist	Performed by or under guidance of Medical Physicist	Performed by or under guidance of Medical Physicist
			Level of Complexity	NA	NA	Simple	Simple
		Test frequency	Test frequency	NA	NA	1-2 yearly	At acceptance and annually

		Tolerance Limits	Tolerance Limits	NA	(t≥ 0.1s): ± 20 %, (t<0.1s): ± 30 %	NA	±5% for times > 10 msec, ±10% for times < 10 msec.
	Beam Quantity	Equipment	Equipment required	NA	Dosimeter, oscilloscope	NA	Radiation detector, oscilloscope or digital capture device
			Expense of Equipment/ €	NA	2000-5000	NA	2000-5000
			Ease of availability	NA	Normally available	NA	Normally available
		Measurement Protocol	Professional performing the test	NA	Performed by or under guidance of Medical Physicist	NA	Performed by or under guidance of Medical Physicist
			Level of Complexity	NA	Complex	NA	Complex
		Test frequency	Test frequency	NA	Annually	NA	At acceptance/ annually
		Tolerance Limits	Tolerance Limits	NA	Y outside range of 25 to 80 µGy/mAs at 80kVp and total filtration of 2.5mmAl	NA	±20%
	Light Beam/X-ray Centering	Equipment	Equipment required	Tape measure, two cassettes with screens, radiographic film, ruler, spirit level, test device for alignment	NA	Alignment test tool/radio-opaque markers	NA

			Expense of Equipment/ €	<500	NA	<500	NA
			Ease of availability	Normally available	NA	Normally available	NA
		Measurement Protocol	Professional performing the test	User	NA	User	NA
			Level of Complexity	Simple	NA	Simple	NA
		Test frequency	Test frequency	Manufacturer's instructions or at least every 3 months	NA	Every 1 or 2 months	NA
		Tolerance Limits	Tolerance Limits	<1.5 ° perpendicular to the axis of the image reception area	NA	± 1 cm at1m	NA
	Dose Area Product (DAP)	Equipment	Equipment required	NA	NA	NA	NA
			Expense of Equipment/ €	NA	NA	NA	NA
			Ease of availability	NA	NA	NA	NA
		Measurement Protocol	Professional performing the test	NA	Performed by or under guidance of Medical Physicist	NA	NA
			Level of Complexity	NA	NA	NA	NA
		Test frequency	Test frequency	NA	NA	NA	NA

		Tolerance Limits	Tolerance Limits	NA	Overall uncertainty > ± 25 %	NA	NA
	Light beam diaphragm (LBD) field size calibration	Equipment	Equipment required	NA	NA	Collimation test tool/radio-opaque markers	NA
			Expense of Equipment/ €	NA	NA	<500	NA
			Ease of availability	NA	NA	Normally available	NA
		Measurement Protocol	Professional performing the test	NA	NA	User	NA
			Level of Complexity	NA	NA	Simple	NA
		Test frequency	Test frequency	NA	NA	Every 1 or 2 months	NA
		Tolerance Limits	Tolerance Limits	NA	NA	± 1 cm at1m	NA
	Distances and scales	Equipment	Equipment required	NA	NA	Steel rule, tape measure	NA
			Expense of Equipment/ €	NA	NA	<500	NA
			Ease of availability	NA	NA	Normally available	NA
		Measurement Protocol	Professional performing the test	NA	NA	User	NA
			Level of Complexity	NA	NA	Simple	NA

		Test frequency	Test frequency	NA	NA	1-2 yearly	NA
		Tolerance Limits	Tolerance Limits	NA	NA	± 1.5% of set distance	NA
	Film changer alignment and collimation	Equipment	Equipment required	NA	Alignment test tool, markers	Collimation test tool/radio-opaque markers	NA
			Expense of Equipment/ €	NA	<500	<500	NA
			Ease of availability	NA	Normally available	Normally available	NA
		Measurement Protocol	Professional performing the test	NA	User	User	NA
			Level of Complexity	NA	Simple	Simple	NA
		Test frequency	Test frequency	NA	NA	Every 3-6 months	NA
		Tolerance Limits	Tolerance Limits	NA	Automatic collimation: X-ray beam outside the active area of the image receptor > 2% of the focus-image receptor distance	Remedial level: Any one side ±1cm at1m, Suspension level: Any one side ± 3cm at1m	NA

	Radiation output: repeatability	Equipment	Equipment required	NA	Radiation dosimeter/dose-area product (DAP) meter	Radiation dosimeter/dose-area product (DAP) meter	NA
			Expense of Equipment/ €	NA	<500	<500	NA
			Ease of availability	NA	Normally available	Normally available	NA
		Measurement Protocol	Professional performing the test	NA	User	User	NA
			Level of Complexity	NA	Simple	Simple	NA
		Test frequency	Test frequency	NA	Every 1-2 months	Every 1-2 months	NA
		Tolerance Limits	Tolerance Limits	NA	Deviation from mean value of measurements > 20%	Remedial level: ±Mean 10%, Suspension level: ± Mean 20%	NA
	Radiation output: reproducibility	Equipment	Equipment required	Radiation dosimeter	NA	Radiation dosimeter/DAP meter	Radiation detector, oscilloscope or digital capture device
			Expense of Equipment/ €	NA	NA	<500	500-1000
			Ease of availability	Normally available	NA	Normally available	Normally available
		Measurement Protocol	Professional performing the test	User	NA	User	Performed by or under guidance of Medical Physicist

			Level of Complexity	Simple	NA	Simple	Complex
		Test frequency	Test frequency	Daily for the first week, then two-week cycle for 6 months, then at least every 3 months	NA	Every 1 or 2 months	At acceptance/ annually
		Tolerance Limits	Tolerance Limits	Manual control: ±20%, AEC ±25% (copper/lead), +25%: -20% (PMMA)	NA	Remedial level: Baseline ±20%, Suspension level: Baseline ± 50%	variation < 0.1
	Radiation output: repeatability	Equipment	Equipment required	NA	NA	Radiation dosimeter	NA
			Expense of Equipment/ €	NA	NA	<500	NA
			Ease of availability	NA	NA	Normally available	NA
		Measurement Protocol	Professional performing the test	NA	NA	Performed by or under guidance of Medical Physicist	NA
			Level of Complexity	NA	NA	Simple	NA
		Test frequency	Test frequency	NA	NA	1-2 yearly	NA
		Tolerance Limits	Tolerance Limits	NA	NA	Remedial level: ±Mean 10%,	NA

						Suspension level: ± Mean 20%	
	Radiation output: reproducibility	Equipment	Equipment required	NA	NA	Radiation dosimeter	NA
			Expense of Equipment/ €	NA	NA	<500	NA
			Ease of availability	NA	NA	Normally available	NA
		Measurement Protocol	Professional performing the test	NA	NA	Performed by or under guidance of Medical Physicist	NA
			Level of Complexity	NA	NA	Simple	NA
		Test frequency	Test frequency	NA	NA	1-2 yearly	NA
		Tolerance Limits	Tolerance Limits	NA	NA	Remedial level: Baseline ±20%, Suspension level: Baseline ± 50%	NA
	High-contrast detail Resolution	Equipment	Equipment required	Magnifying glass, high-contrast test device, radiographic cassette and screen-film	NA	NA	NA
			Expense of Equipment/ €	<500	NA	NA	NA
			Ease of availability	Normally available	NA	NA	NA

		Measurement Protocol	Professional performing the test	User	NA	NA	NA
			Level of Complexity	Simple	NA	NA	NA
		Test frequency	Test frequency	Manufacturer's instructions or at least every 3 months	NA	NA	NA
		Tolerance Limits	Tolerance Limits	<20% variation in resolution patterns or one-line pair group	NA	NA	NA
	Grid artefacts	Equipment	Equipment required	NA	NA	NA	NA
			Expense of Equipment/ €	NA	NA	NA	NA
			Ease of availability	NA	NA	NA	NA
		Measurement Protocol	Professional performing the test	NA	NA	NA	Performed by or under guidance of Medical Physicist
			Level of Complexity	NA	NA	NA	Simple

		Test frequency	Test frequency	NA	Annually	NA	Annually for auxiliary grids, every 3 months for portable operations, at acceptance and annually for grids that are permanently installed in Bucky devices
		Tolerance Limits	Tolerance Limits	NA	If significant grid artefacts are visible investigation should be carried out	NA	If grid artefacts are revealed investigation should be carried out
	Moving grid	Equipment	Equipment required	NA	NA	NA	NA
			Expense of Equipment/ €	NA	NA	NA	NA
			Ease of availability	NA	NA	NA	NA
		Measurement Protocol	Professional performing the test	NA	NA	NA	Performed by or under guidance of Medical Physicist
			Level of Complexity	NA	NA	NA	Simple
		Test frequency	Test frequency	NA	Annually	NA	Annually but wall Bucky's and cassette holders' tests more frequently - semi-annually or every 3 months

		Tolerance Limits	Tolerance Limits	NA	If lamellae visible on image, (should not be visible in the shortest exposure time)	NA	Severity of effects and tolerable misalignment will vary with the ratio of the grid in use and the system SID
	Optical Density	Equipment	Equipment required	Radiographic cassette, screen-film combination, densitometer, attenuation phantom, film marker	NA	NA	NA
			Expense of Equipment/ €	2000-5000	NA	NA	NA
			Ease of availability	Normally available	NA	NA	NA
		Measurement Protocol	Professional performing the test	Performed by or under guidance of Medical Physicist	NA	NA	NA
			Level of Complexity	Simple	NA	NA	NA
		Test frequency	Test frequency	Manufacturer's instructions or at least every 3 months	NA	NA	NA
		Tolerance Limits	Tolerance Limits	± 0.1 of the baseline values	NA	NA	NA
DDR System		Equipment	Equipment required	NA	NA	1mm copper, meter ruler	NA

	Detector Dose Indicator (DDI) monitoring		Expense of Equipment/ €	NA	NA	<500	NA
			Ease of availability	NA	NA	Normally available	NA
		Measurement Protocol	Professional performing the test	NA	NA	User	NA
			Level of Complexity	NA	NA	Simple	NA
		Test frequency	Test frequency	NA	NA	Every 1 - 3 months	NA
		Tolerance Limits	Tolerance Limits	NA	NA	Remedial level: Baseline ±20%, Suspension level: Baseline ± 50%	NA
	Image Uniformity	Equipment	Equipment required	NA	NA	1mm copper, meter ruler	NA
			Expense of Equipment/ €	NA	NA	<500	NA
			Ease of availability	NA	NA	Normally available	NA
		Measurement Protocol	Professional performing the test	NA	NA	User	NA
			Level of Complexity	NA	NA	Simple	NA
		Test frequency	Test frequency	NA	NA	Every 1- 3 months	NA

		Tolerance Limits	Tolerance Limits	NA	NA	Remedial level: lines or rectangles apparent, Suspension level: Gross non-uniformity	NA
	Low contrast sensitivity	Equipment	Equipment required	NA	NA	Test object, 1mm copper	NA
			Expense of Equipment/ €	NA	NA	<500	NA
			Ease of availability	NA	NA	Normally available	NA
		Measurement Protocol	Professional performing the test	NA	NA	Performed by or under guidance of Medical Physicist	NA
			Level of Complexity	NA	NA	Simple	NA
		Test frequency	Test frequency	NA	NA	Every 4-6 months	NA
		Tolerance Limits	Tolerance Limits	NA	NA	Remedial level: Baseline ±2 groups	NA
	Limiting spatial resolution	Equipment	Equipment required	NA	NA	Lead grating resolution bar pattern	NA
			Expense of Equipment/ €	NA	NA	<500	NA
			Ease of availability	NA	NA	Normally available	NA

		Measurement Protocol	Professional performing the test	NA	User	User	NA
			Level of Complexity	NA	NA	Simple	NA
		Test frequency	Test frequency	NA	NA	Every 4-6 months	NA
		Tolerance Limits	Tolerance Limits	NA	<1.6Ip/mm	Remedial level: Baseline - 25%	NA
	DDI Repeatability	Equipment	Equipment required	NA	NA	1mm copper	NA
			Expense of Equipment/ €	NA	NA	<500	NA
			Ease of availability	NA	NA	Normally available	NA
		Measurement Protocol	Professional performing the test	NA	NA	Performed by or under guidance of Medical Physicist	NA
			Level of Complexity	NA	NA	Simple	NA
		Test frequency	Test frequency	NA	NA	Annually	NA
		Tolerance Limits	Tolerance Limits	NA	NA	Remedial level: Baseline ±10%, Suspension level: Baseline ± 20%	NA
	DDI Reproducibility	Equipment	Equipment required	NA	NA	1mm copper	NA
			Expense of Equipment/ €	NA	NA	<500	NA

			Ease of availability	NA	NA	Normally available	NA
		Measurement Protocol	Professional performing the test	NA	NA	Performed by or under guidance of Medical Physicist	NA
			Level of Complexity	NA	NA	Simple	NA
		Test frequency	Test frequency	NA	NA	Annually	NA
		Tolerance Limits	Tolerance Limits	NA	NA	Remedial level: Baseline ±20%, Suspension level: Baseline ± 50%	NA
	Measured uniformity	Equipment	Equipment required	NA	NA	1mm copper	NA
			Expense of Equipment/ €	NA	NA	<500	NA
			Ease of availability	NA	NA	Normally available	NA
		Measurement Protocol	Professional performing the test	NA	NA	Performed by or under guidance of Medical Physicist	NA
			Level of Complexity	NA	NA	Simple	NA
		Test frequency	Test frequency	NA	NA	Annually	NA
		Tolerance Limits	Tolerance Limits	NA	NA	Mean ±5%	NA

	Threshold contrast detail detectability	Equipment	Equipment required	NA	NA	Threshold contrast detail test object, appropriate filter	NA
			Expense of Equipment/ €	NA	NA	<500	NA
			Ease of availability	NA	NA	Normally available	NA
		Measurement Protocol	Professional performing the test	NA	NA	Performed by or under guidance of Medical Physicist	NA
			Level of Complexity	NA	NA	Simple	NA
		Test frequency	Test frequency	NA	NA	Annually	NA
		Tolerance Limits	Tolerance Limits	NA	NA	Compare with baseline curves and values	NA
	Limiting spatial resolution	Equipment	Equipment required	NA	NA	Lead grating resolution bar pattern	NA
			Expense of Equipment/ €	NA	NA	<500	NA
			Ease of availability	NA	NA	Normally available	NA
		Measurement Protocol	Professional performing the test	NA	NA	Performed by or under guidance of Medical Physicist	NA

			Level of Complexity	NA	NA	Simple	NA
		Test frequency	Test frequency	NA	NA	Annually	NA
		Tolerance Limits	Tolerance Limits	NA	NA	Baseline -25%	NA
	Uniformity of resolution	Equipment	Equipment required	NA	NA	Fine wire mesh	NA
			Expense of Equipment/ €	NA	NA	<500	NA
			Ease of availability	NA	NA	Normally available	NA
		Measurement Protocol	Professional performing the test	NA	NA	Performed by or under guidance of Medical Physicist	NA
			Level of Complexity	NA	NA	Simple	NA
		Test frequency	Test frequency	NA	NA	Annually	NA
		Tolerance Limits	Tolerance Limits	NA	NA	Increase in blurring from baseline	NA
	Scaling errors	Equipment	Equipment required	NA	NA	Grid, attenuating object of known dimensions or ruler	NA
			Expense of Equipment/ €	NA	NA	500-1000	NA
			Ease of availability	NA	NA	Normally available	NA

		Measurement Protocol	Professional performing the test	NA	NA	Performed by or under guidance of Medical Physicist	NA
			Level of Complexity	NA	NA	Simple	NA
		Test frequency	Test frequency	NA	NA	Annually	NA
		Tolerance Limits	Tolerance Limits	NA	NA	>2%	NA
	Dark noise	Equipment	Equipment required	NA	NA	An image without exposure of with a very low exposure	NA
			Expense of Equipment/ €	NA	NA	<500	NA
			Ease of availability	NA	NA	Normally available	NA
		Measurement Protocol	Professional performing the test	NA	NA	Performed by or under guidance of Medical Physicist	NA
			Level of Complexity	NA	NA	Simple	NA
		Test frequency	Test frequency	NA	NA	Annually	NA
		Tolerance Limits	Tolerance Limits	NA	NA	Baseline +50%	NA
	Leakage Radiation	Equipment	Equipment required	NA	Dosimeter	NA	NA

			Expense of Equipment/ €	NA	<500	NA	NA
			Ease of availability	NA	Normally available	NA	NA
		Measurement Protocol	Professional performing the test	NA	Performed by or under guidance of Medical Physicist	NA	NA
			Level of Complexity	NA	Complex	NA	NA
		Test frequency	Test frequency	NA	NA	NA	NA
		Tolerance Limits	Tolerance Limits	NA	Ka(1m)>1mGy in one hour at maximum rating specified by the manufacturer	NA	NA
AEC	**Sensitivity**	Equipment	Equipment required	NA	NA	1mm copper in beam, exposure under AEC, dosimeter	fixed kV, attenuator thickness and tube load
			Expense of Equipment/ €	NA	NA	<500	<500
			Ease of availability	NA	NA	Normally available	Normally available
		Measurement Protocol	Professional performing the test	NA	NA	User	Performed by or under guidance of Medical Physicist
			Level of Complexity	NA	NA	Simple	Complex

		Test frequency	Test frequency	NA	NA	At least every 1-3 months	Annually
		Tolerance Limits	Tolerance Limits	NA	NA	Remedial level: Baseline ±25%, Suspension level: Baseline ± 50%	Variation from average values of optical density or exposure > 0.95 & <1.05
	Operation of guard timer	Equipment	Equipment required	NA	NA	Lead blocking the AEC chambers	NA
			Expense of Equipment/ €	NA	NA	<500	NA
			Ease of availability	NA	NA	Normally available	NA
		Measurement Protocol	Professional performing the test	NA	NA	User	Performed by or under guidance of Medical Physicist
			Level of Complexity	NA	NA	Simple	Simple
		Test frequency	Test frequency	NA	NA	Annually	Annually
		Tolerance Limits	Tolerance Limits	NA	Maximal focal spot charge>600mAs	AEC device terminates the exposure at guard timer or terminated quickly when the system calculates that the guard time will be exceeded	Minimum response time of the generator and AEC

	Consistency between chambers	Equipment	Equipment required	NA	NA	Suitable attenuation material e.g. PMMA, water or water equivalent labs	NA
			Expense of Equipment/ €	NA	NA	<500	NA
			Ease of availability	NA	NA	Normally available	NA
		Measurement Protocol	Professional performing the test	NA	NA	Performed by or under guidance of Medical Physicist	NA
			Level of Complexity	NA	NA	Complex	NA
		Test frequency	Test frequency	NA	NA	Annually	NA
		Tolerance Limits	Tolerance Limits	NA	NA	Remedial level: Baseline ±30%, Mean ±20%	NA
	Repeatability	Equipment	Equipment required	NA	NA	Suitable attenuation material e.g. PMMA, water or water equivalent labs	Fixed kV, attenuator thickness and tube load
			Expense of Equipment/ €	NA	NA	<500	<500
			Ease of availability	NA	NA	Normally available	Normally available

		Measurement Protocol	Professional performing the test	NA	NA	Performed by or under guidance of Medical Physicist	Performed by or under guidance of Medical Physicist
			Level of Complexity	NA	NA	Complex	Simple
		Test frequency	Test frequency	NA	NA	Annually	Annually
		Tolerance Limits	Tolerance Limits	NA	DDI or measured Kerma differs by >40% from mean value	Remedial level: Mean ±20%, Suspension level: Mean ± 30%	Variation from average values of optical density or exposure <0.05
	Reproducibility	Equipment	Equipment required	NA	NA	Suitable attenuation material e.g. PMMA, water or water equivalent slabs	kV ranges from 50kV to maximum, attenuator thickness ranging from 5cm to 35cm
			Expense of Equipment/ €	NA	NA	500-1000	500-1000
			Ease of availability	NA	NA	Normally available	Normally available
		Measurement Protocol	Professional performing the test	NA	NA	Performed by or under guidance of Medical Physicist	Performed by or under guidance of Medical Physicist
			Level of Complexity	NA	NA	Complex	Simple
		Test frequency	Test frequency	NA	NA	Annually	Annually

		Tolerance Limits	Tolerance Limits	NA	NA	Remedial level: Baseline ±30%, Suspension level: Baseline ± 60%	fixed attenuator thickness: variation >0.4 OD, fixed kVp variation >0.3 OD
	Image receptor dose	Equipment	Equipment required	NA	NA	Dosimeter, 1mm copper at the tube head	NA
			Expense of Equipment/ €	NA	NA	<500	NA
			Ease of availability	NA	NA	Normally available	
		Measurement Protocol	Professional performing the test	NA	Performed by or under guidance of Medical Physicist	Performed by or under guidance of Medical Physicist	NA
			Level of Complexity	NA	NA	Complex	
		Test frequency	Test frequency	NA	NA	Annually	NA
		Tolerance Limits	Tolerance Limits	NA	≥ 10μGy	Remedial level: Baseline ±30%, Suspension level: Baseline ± 60%	NA
	Verification of AEC at various phantom thicknesses	Equipment	Equipment required	NA	NA	NA	NA
			Expense of Equipment/ €	NA	NA	NA	NA
			Ease of availability	NA	NA	NA	NA

		Measurement Protocol	Professional performing the test	NA	Performed by or under guidance of Medical Physicist	Performed by or under guidance of Medical Physicist	NA
			Level of Complexity	NA	NA	Simple	NA
		Test frequency	Test frequency	NA	NA	NA	NA
		Tolerance Limits	Tolerance Limits	NA	DDI or measured kerma for a given phantom thickness differs by >40% from mean value for all thicknesses	Optical density of 1.5+0.1 OD	NA
	AEC Density Control	Equipment	Equipment required	NA	NA	NA	NA
			Expense of Equipment/ €	NA	NA	NA	NA
			Ease of availability	NA	NA	NA	NA
		Measurement Protocol	Professional performing the test	NA	NA	NA	Performed by or under guidance of Medical Physicist
			Level of Complexity	NA	NA	NA	NA
		Test frequency	Test frequency	NA	NA	NA	Annually
		Tolerance Limits	Tolerance Limits	NA	NA	NA	0.15-0.3 OD/step

A.2 Mammography Results Table

Table A. 2: Comparative Results Extracted from Constancy Testing Documents for Mammography

Sub-system	Thematic Category	Thematic Labels	IEC	EU COMMISSION	IAEA	IPEM	ACR	
	Document Metadata	Document Number	IEC 61223-2-10	EUREF 4th Edition	IAEA Human Health Series Human Health Series No.17	IPEM 89	ACR 2018 Digital Mammography Quality Control Manual	
		Recency	1999	2013	2011	2005	2018	
		Price of Document	€190	€0	€0	€35	€0	
							User	MPE
X-ray/light field alignment	Equipment	Equipment required	Test device with steel balls	Tape measure	NA	Screen-film cassette, markers (e.g. stiff wire/coins), steel ruler	NA	5 coins or flat opaque objects, collimation test tool
		Expense of Equipment/ €	<500	<500	NA	<500	NA	<500
		Ease of availability	Specially purchased	Normally available	NA	Normally available	NA	Normally available
	Measurement Protocol	Professional performing the test	Performed by or under guidance of	Performed by or under guidance of Medical Physicist	NA	Performed by or under guidance	NA	Performed by or under guidance of Medical Physicist

			Medical Physicist			of Medical Physicist		
		Level of Complexity	Simple	Simple	NA	Simple	NA	Simple
	Test frequency	Test frequency	After maintenance or service	Annually	NA	Every 6 months	NA	Annually and after relevant service
	Tolerance Limits	Tolerance Limits	At least five balls at each side of the high-contrast test deice are totally visible	X-ray field extending beyond the image receptor >5mm on any side, Chest wall side: distance between image receptor and edge> 5mm	NA	Misalignment >5mm along any edge	NA	< +±2% of SID
Alignment of x-ray field to film	Equipment	Equipment required	NA	NA	2 rulers, opaque material, 5 phosphorescent pieces and PMMA slabs	Screen-film cassette, markers (e.g. stiff wire/coins), steel ruler	NA	5 coins or flat opaque objects, collimation test tool
		Expense of Equipment/ €	NA	NA	500-1000	<500	NA	<500
		Ease of availability	NA	NA	Normally available	Normally available	NA	Normally available
	Measurement Protocol	Professional performing the test	NA	NA	Performed by or under guidance of Medical Physicist	Performed by or under guidance of Medical Physicist	NA	Performed by or under guidance of Medical Physicist

		Level of Complexity	NA	NA	Simple	Simple	NA	Simple
	Test frequency	Test frequency	NA	NA	Annually and after x-ray tube service/ replacement	Every 6 months	NA	Annually and after relevant service
	Tolerance Limits	Tolerance Limits	NA	NA	Achievable: ≤5mm, Acceptable: ≤7mm,	Remedial: >5mm or <0mm overlap along all sides, Suspension: >10mm overlap or >2mm unexposed border or >19mm overlap along left or tight edge	NA	< +±2% of SID
Image field for digital mammography	Equipment	Equipment required	NA	NA	NA	Markers or radio-opaque scale	NA	NA
		Expense of Equipment/ €	NA	NA	NA	<500	NA	NA
		Ease of availability	NA	NA	NA	Normally available	NA	NA
	Measurement Protocol	Professional performing the test	NA	NA	NA	Performed by or under guidance of Medical Physicist	NA	NA

		Level of Complexity	NA	NA	NA	Simple	NA	NA
	Test frequency	Test frequency	NA	NA	NA	Annually	NA	NA
	Tolerance Limits	Tolerance Limits	NA	NA	NA	>5% less than stated nominal size	NA	NA
Separation between film edge and edge of the breast support	Equipment	Equipment required	NA	NA	2 rulers, opaque material, 5 phosphorescent pieces and PMMA slabs	Screen-film cassette, markers, steel rule	NA	NA
		Expense of Equipment/ €	NA	NA	500-1000	<500	NA	NA
		Ease of availability	NA	NA	Normally available	Normally available	NA	NA
	Measurement Protocol	Professional performing the test	NA	NA	Performed by or under guidance of Medical Physicist	Performed by or under guidance of Medical Physicist	NA	NA
		Level of Complexity	NA	NA	Simple	Simple	NA	NA
	Test frequency	Test frequency	NA	NA	Annually and after x-ray tube service/replacement	Annually	NA	NA

	Tolerance Limits	Tolerance Limits	NA	NA	Acceptable: Paddle not visible in image and edge of paddle ≤5mm beyond chest wall edge	> 5mm between the edge of the film and front edge of the breast support platform	NA	NA
Leakage Radiation	Equipment	Equipment required	NA	Dosimeter and appropriate detector	NA	Ionisation chamber, cassettes fitted with intensifying screens, x-ray tube rating charts	NA	NA
		Expense of Equipment/ €	NA	500-1000	NA	500-1000	NA	NA
		Ease of availability	NA	Normally available	NA	Normally available	NA	NA
	Measurement Protocol	Professional performing the test	NA	Performed by or under guidance of Medical Physicist	NA	Performed by or under guidance of Medical Physicist	NA	NA
		Level of Complexity	NA	Simple	NA	Simple	NA	NA
	Test frequency	Test frequency	NA	At acceptance and after tube changes	NA	NA	NA	NA

	Tolerance Limits	Tolerance Limits	NA	< 1 mGy in 1 hour at 1m from the focus	NA	> 1mGy in 1 hour at 1m from the focus	NA	NA
Compression	Equipment	Equipment required	Force balance that ranges between 50N and 300N, water or air-filled bag 20 mm to 50mm thick and 100mm to 150mm long and wide/ soft rubber block with similar dimensions	Balance scale	Bathroom scales, Bath towels, slabs of PMMA used for AEC testing	Force balance, strain gauge or scales, compressible object	Calibrated bathroom scales, several towels, digital gauges	NA
		Expense of Equipment/ €	<500	<500	500-1000	<500	<500	NA
		Ease of availability	Normally available	Normally available	Normally available	Normally available	Normally available	NA
	Measurement Protocol	Professional performing the test	User	User	User	Performed by or under guidance of Medical Physicist	User	NA
		Level of Complexity	Simple	Simple	Simple	Simple	Simple	NA
	Test frequency	Test frequency	Every 6 months	Every 6 months	Annually, Semi-annually	Every 6 months	Every 6 months	NA

	Tolerance Limits	Tolerance Limits	Manually measured: compression force ±10N of baseline values, Motorized pre-compression: ±20% of baselines values	Force of at least 150N and it shall be unable to apply a force exceeding 200N, Change in force>20N	Powered: 150 to ≤200N; Manual: ≤300N, Displayed value accuracy ±20N	Remedial: deviation >20N, Suspension: maximum power-driven compression force <150N or >200N, max. compression force >300N any mode of operation, >20N change in compression over 30s	111N to <200N	NA
Indication of thickness	Equipment	Equipment required	NA	NA	NA	Perspex slabs of known thickness, steel rule	NA	NA
		Expense of Equipment/ €	NA	NA	NA	<500	NA	NA
		Ease of availability	NA	NA	NA	Normally available	NA	NA
	Measurement Protocol	Professional performing the test	NA	NA	NA	Performed by or under guidance of Medical Physicist	NA	NA
		Level of Complexity	NA	NA	NA	Simple	NA	NA

	Test frequency	Test frequency	NA	NA	NA	Every 6 months	NA	NA
	Tolerance Limits	Tolerance Limits	NA	NA	NA	Remedial: variation >5mm, Suspension: variation > 10mm	NA	NA
Focal Spot Dimensions	Equipment	Equipment required	NA	Resolution pattern	NA	Measuring device, jig or support, mammographic screen-film or non-screen film, magnifying glass	NA	NA
		Expense of Equipment/ €	NA	<500	NA	<500	NA	NA
		Ease of availability	NA	Normally available	NA	Normally available	NA	NA
	Measurement Protocol	Professional performing the test	NA	Performed by or under guidance of Medical Physicist	NA	Performed by or under guidance of Medical Physicist	NA	NA
		Level of Complexity	NA	Simple	NA	Simple	NA	NA
	Test frequency	Test frequency	NA	At acceptance and when resolution changes	NA	Annually	NA	NA

	Tolerance Limits	Tolerance Limits	NA	None	NA	Measured dimension >150%	NA	NA
Tube potential	Equipment	Equipment required	NA	kV meter	NA	Digital kV meter, oscilloscope	NA	kVp meter, lead sheet
		Expense of Equipment/ €	NA	<500	NA	500-1000	NA	<500
		Ease of availability	NA	Normally available	NA	Normally available	NA	Normally available
	Measurement Protocol	Professional performing the test	NA	Performed by or under guidance of Medical Physicist	NA	Performed by or under guidance of Medical Physicist	NA	Performed by or under guidance of Medical Physicist
		Level of Complexity	NA	Simple	NA	Simple	NA	Simple
	Test frequency	Test frequency	NA	Every 6 months	NA	Every 6 months	NA	After component replacement, after relevant service
	Tolerance Limits	Tolerance Limits	NA	Deviation of tube voltage >2 kVp from set value	NA	Remedial: difference >1kV, Suspension: >2kV	NA	< ±1.5kVp at 30kVp or < ± 5%
HVL	Equipment	Equipment required	NA	Electrometer, filters	Dosimeter, aluminium filters, measuring tape, metal plate	Aluminium foils, ionisation chamber, electrometer, support for foils	NA	Ionization chamber, electrometer/dosimetry, aluminium sheets of 0.1 mm

		Expense of Equipment/ €	NA	<500	<500	500-1000	NA	500-1000
		Ease of availability	NA	Normally available	Normally available	Normally available	NA	Normally available
	Measurement Protocol	Professional performing the test	NA	Performed by or under guidance of Medical Physicist	Performed by or under guidance of Medical Physicist	Performed by or under guidance of Medical Physicist	NA	Performed by or under guidance of Medical Physicist
		Level of Complexity	NA	Simple	Simple	Simple	NA	Simple
	Test frequency	Test frequency	NA	Annually	Annually and after X-ray tube change	Annually	NA	After relevant services
	Tolerance Limits	Tolerance Limits	NA	<0.28 mm Al at 28 kVp for Mo, Mo	kV/100 + 0.03 ≤HVL≤ kV/100 +C	Remedial: HVL <0.3mmAl & >0.44mmAl at 28kV Mo/Mo compression plate in, Suspension: derived total filtration (compression plate out) <0.5mmAl or 0.03mm Mo	NA	20 kV: >0.2 mm Al 25 kV: >0.25 mm Al 30 kV: >0.3 mm Al
Repeatability of output	Equipment	Equipment required	NA	kVp-meter	NA	Ionisation chamber and electrometer	NA	NA

		Expense of Equipment/ €	NA	<500	NA	500-1000	NA	NA
		Ease of availability	NA	Normally available	NA	Normally available	NA	NA
	Measurement Protocol	Professional performing the test	NA	Performed by or under guidance of Medical Physicist	NA	Performed by or under guidance of Medical Physicist	NA	NA
		Level of Complexity	NA	Simple	NA	Simple	NA	NA
	Test frequency	Test frequency	NA	Every 6 months	NA	Every 6 months	NA	NA
	Tolerance Limits	Tolerance Limits	NA	< ±1kV	NA	Maximum deviation of output values from mean >5%	NA	NA
Specific radiation output	Equipment	Equipment required	NA	Dosimeter, exposure timer	NA	Ionisation chamber and electrometer, suitable support	NA	NA
		Expense of Equipment/ €	NA	<500	NA	500-1000	NA	NA
		Ease of availability	NA	Normally available	NA	Normally available	NA	NA
	Measurement Protocol	Professional performing the test	NA	Performed by or under guidance of Medical Physicist	NA	Performed by or under guidance	NA	NA

						of Medical Physicist		
		Level of Complexity	NA	Simple	NA	Simple	NA	NA
	Test frequency	Test frequency	NA	At least every 6 months	NA	Every 6 months	NA	NA
	Tolerance Limits	Tolerance Limits	NA	≤ 120µGy/mAs at 50cm,28 kVp, Mo, Mo	NA	<120µGy/mAs at 50cm, 28 kVp, Mo, Mo, <70% of output value at commissioning	NA	NA
Variation of output mAs	Equipment	Equipment required	NA	NA	NA	Ionisation chamber and electrometer, suitable support	NA	NA
		Expense of Equipment/ €	NA	NA	NA	500-1000	NA	NA
		Ease of availability	NA	NA	NA	Normally available	NA	NA
	Measurement Protocol	Professional performing the test	NA	NA	NA	Performed by or under guidance of Medical Physicist	NA	NA
		Level of Complexity	NA	NA	NA	Simple	NA	NA
	Test frequency	Test frequency	NA	NA	NA	Every 6 months	NA	NA

	Tolerance Limits	Tolerance Limits	NA	NA	NA	Maximum deviation of output/ms from mean >10%	NA	NA
Exposure Time	Equipment	Equipment required	NA	4.5 cm PMMA	NA	NA	NA	NA
		Expense of Equipment/ €	NA	<500	NA	NA	NA	NA
		Ease of availability	NA	Normally available	NA	NA	NA	NA
	Measurement Protocol	Professional performing the test	NA	Performed by or under guidance of Medical Physicist	NA	NA	NA	NA
		Level of Complexity	NA	Simple	NA	NA	NA	NA
	Test frequency	Test frequency	NA	NA	NA	NA	NA	NA
	Tolerance Limits	Tolerance Limits	NA	>2s for standard breast	NA	NA	NA	NA
Sensitivity variations and plate uniformity	Equipment	Equipment required	Attenuation phantom 40mm, Optical densitometer	Standard test object covering complete detector	45mm thick PMMA test object, contrast object	Aluminium sheet, Perspex slabs, screen-film cassette or envelope wrapped no-screen film, densitometer	NA	NA

		Expense of Equipment/ €	2000-5000	500-1000	500-1000	500-1000	NA	NA
		Ease of availability	Specially purchased	Normally available	Normally available	Normally available	NA	NA
	Measurement Protocol	Professional performing the test	Performed by or under guidance of Medical Physicist	Performed by or under guidance of Medical Physicist	Performed by or under guidance of Medical Physicist	Performed by or under guidance of Medical Physicist	NA	NA
		Level of Complexity	Simple	Simple	Simple	Simple	NA	NA
	Test frequency	Test frequency	At least annually	Monthly	Annually, after updates or any changes	Annually	NA	NA
	Tolerance Limits	Tolerance Limits	Optical density from mean value ±0.20	No artefacts should be present	No artefacts should be present	Remedial: at the centre: >0.2 and at the left or right point: >0.15, any significant artefacts should be investigated	NA	NA
Image Density	Equipment	Equipment required	Test cassette, optical densitometer, 20mm,30mm, 40 mm thickness attenuation phantom	Three 150mmx180mm PMMA (10mm thick), two spacers (10 mm thick), ten 20mm x 40mm PMMA (2mm thick)	Test object, densitometer, magnifying lens, transparent ruler and radiologist view box	Aluminium sheet,4 cm Perspex slabs, screen-film cassette or envelope wrapped no-	NA	NA

						screen film, densitometer		
		Expense of Equipment/ €	2000-5000	2000-5000	2000-5000	1000-2000	NA	NA
		Ease of availability	Normally available	Normally available	Normally available	Normally available	NA	NA
	Measurement Protocol	Professional performing the test	Performed by or under guidance of Medical Physicist	Performed by or under guidance of Medical Physicist	Performed by or under guidance of Medical Physicist	Performed by or under guidance of Medical Physicist	NA	NA
		Level of Complexity	Complex	Complex	Complex	Simple	NA	NA
	Test frequency	Test frequency	At least every 3 months	Every 6 months, or after AEC software upgrades	Annually	Every 6 months	NA	NA
	Tolerance Limits	Tolerance Limits	Optical density ±0.20 of the baseline values	The SNR of each image should be within 20% of the average SNR	All density steps should be distinct	Remedial: maximum deviation >0.2 or 1.5-1.9, suspension: 1.3-2.1	NA	NA
Artefacts	Equipment	Equipment required	Film illuminator, magnifying lens	None	45mm thick slab of PMMA or 2-3mm thick sheet of aluminium,	NA	NA	NA

					suitable software			
		Expense of Equipment/ €	<500	NA	500-1000	NA	NA	NA
		Ease of availability	Normally available	NA	Normally available	NA	NA	NA
	Measurement Protocol	Professional performing the test	Performed by or under guidance of Medical Physicist	Performed by or under guidance of Medical Physicist	Performed by or under guidance of Medical Physicist	NA	NA	NA
		Level of Complexity	Simple	Simple	Simple	NA	NA	NA
	Test frequency	Test frequency	At least every 3 months	Annually	Annually and after detector change	NA	NA	NA
	Tolerance Limits	Tolerance Limits	If visible deterioration across the radiogram, any pattern which was not present before of presence of grid lines should lead to further actions	No significant artefacts should be visible	If dead pixels or unacceptable artefacts are noted, investigation has to be carried out immediately	NA	NA	NA

Contact between intensifying screens and film	Equipment	Equipment required	Film-screen contact test device, wire mesh	NA	NA	NA	NA	NA
		Expense of Equipment/ €	<500	NA	NA	NA	NA	NA
		Ease of availability	Normally available	NA	NA	NA	NA	NA
	Measurement Protocol	Professional performing the test	Performed by or under guidance of Medical Physicist	NA	NA	NA	NA	NA
		Level of Complexity	Simple	NA	NA	NA	NA	NA
	Test frequency	Test frequency	At least annually	NA	NA	NA	NA	NA
	Tolerance Limits	Tolerance Limits	Visible impairment requires corrective action	NA	NA	NA	NA	NA
Mammographic film	Equipment	Equipment required	Different exposures, sensitometer	NA	NA	NA	NA	NA
		Expense of Equipment/ €	1000-2000	NA	NA	NA	NA	NA

		Ease of availability	Normally available	NA	NA	NA	NA	NA
	Measurement Protocol	Professional performing the test	Performed by or under guidance of Medical Physicist	NA	NA	NA	NA	NA
		Level of Complexity	Simple	NA	NA	NA	NA	NA
	Test frequency	Test frequency	New film batches shall be tested	NA	NA	NA	NA	NA
	Tolerance Limits	Tolerance Limits	Baseline ±0.03	NA	NA	NA	NA	NA
Noise	Equipment	Equipment required	NA	Aluminium plate 2mm thick, suitable software tools	PMMA slabs of a total thickness of 45mm, QC software	NA	NA	NA
		Expense of Equipment/ €	NA	<500	500-1000	NA	NA	NA
		Ease of availability	NA	Normally available	Normally available	NA	NA	NA
	Measurement Protocol	Professional performing the test	NA	Performed by or under guidance of Medical Physicist	Performed by or under guidance of Medical Physicist	NA	NA	NA
		Level of Complexity	NA	Simple	Simple	NA	NA	NA

	Test frequency	Test frequency	NA	Every 6 months	Annually and after detector service	NA	NA	NA
	Tolerance Limits	Tolerance Limits	NA	Quantum noise should be the largest noise component for the pixel value range that is used clinically	MPV ≤ 10%, Standard deviation ≤ 5%	NA	NA	NA
Image receptor homogeneity	Equipment	Equipment required	NA	Standard test block covering complete detector, appropriate software tools.	NA	NA	NA	NA
		Expense of Equipment/ €	NA	<500	NA	NA	NA	NA
		Ease of availability	NA	Normally available	NA	NA	NA	NA
	Measurement Protocol	Professional performing the test	NA	Performed by or under guidance of Medical Physicist	NA	NA	NA	NA
		Level of Complexity	NA	Simple	NA	NA	NA	NA
	Test frequency	Test frequency	NA	Weekly, optional: daily	NA	NA	NA	NA
	Tolerance Limits	Tolerance Limits	NA	ROI variance <30%	NA	NA	NA	NA

Low contrast characters	Equipment	Equipment required	NA	MoniQA test pattern	Resolution pattern, PMMA slabs, magnifier lens	NA	NA	NA
		Expense of Equipment/ €	NA	500-1000	500-1000	NA	NA	NA
		Ease of availability	NA	Normally available	Normally available	NA	NA	NA
	Measurement Protocol	Professional performing the test	NA	Performed by or under guidance of Medical Physicist	Performed by or under guidance of Medical Physicist	NA	NA	NA
		Level of Complexity	NA	Simple	Simple	NA	NA	NA
	Test frequency	Test frequency	NA	Daily, optional: weekly	Annually after equipment changes	NA	NA	NA
	Tolerance Limits	Tolerance Limits	NA	Score obtained from MoniQA pattern should be ≥95	<20%	NA	NA	NA
Optical Density Range	Equipment	Equipment required	NA	Suitable densitometer, TG18-PQC test pattern	NA	NA	NA	NA
		Expense of Equipment/ €	NA	500-1000	NA	NA	NA	NA

		Ease of availability	NA	Normally available	NA	NA	NA	NA
	Measurement Protocol	Professional performing the test	NA	Performed by or under guidance of Medical Physicist	NA	NA	NA	NA
		Level of Complexity	NA	Simple	NA	NA	NA	NA
	Test frequency	Test frequency	NA	Every 6 months	NA	NA	NA	NA
	Tolerance Limits	Tolerance Limits	NA	Dmin≤0.25 OD, Dmax ≥3.6 OD	NA	NA	NA	NA
Noise Power Spectrum (NPS)	Equipment	Equipment required	NA	2mmAl filter, calibrated dose meter, software for calculating objective image quality parameters	NA	NA	NA	NA
		Expense of Equipment/ €	NA	500-1000	NA	NA	NA	NA
		Ease of availability	NA	Normally available	NA	NA	NA	NA
	Measurement Protocol	Professional performing the test	NA	Performed by or under guidance of Medical Physicist	NA	NA	NA	NA
		Level of Complexity	NA	Complex	NA	NA	NA	NA
	Test frequency	Test frequency	NA	Every 6 months	NA	NA	NA	NA

	Tolerance Limits	Tolerance Limits	NA	≥± 15% change in NPS at 0.5mm-1 and 2mm-1 from previous QC and baseline	NA	NA	NA	NA
Positions of the edge for MTF	Equipment	Equipment required	NA	Radio-opaque edge of minimum dimensions 60mmx60mm, 2mmAl filter, calibrated dose meter, software for calculating objective image quality parameters	NA	NA	NA	NA
		Expense of Equipment/ €	NA	500-1000	NA	NA	NA	NA
		Ease of availability	NA	Normally available	NA	NA	NA	NA
	Measurement Protocol	Professional performing the test	NA	Performed by or under guidance of Medical Physicist	NA	NA	NA	NA
		Level of Complexity	NA	Simple	NA	NA	NA	NA
	Test frequency	Test frequency	NA	Every 6 months	NA	NA	NA	NA
	Tolerance Limits	Tolerance Limits	NA	≤±10% change in spatial frequency	NA	NA	NA	NA

				for the 50% MTF point				
Detective Quantum Efficiency (DQE)	Equipment	Equipment required	NA	2mmAl filter, calibrated dose meter, spectral modelling tool, software for calculating objective image quality parameters	PMMA slabs, aluminium contrast object, QC software	NA	NA	NA
		Expense of Equipment/ €	NA	500-1000	500-1000	NA	NA	NA
		Ease of availability	NA	Normally available	Normally available	NA	NA	NA
	Measurement Protocol	Professional performing the test	NA	Performed by or under guidance of Medical Physicist	Performed by or under guidance of Medical Physicist	NA	NA	NA
		Level of Complexity	NA	Complex	Complex	NA	NA	NA
	Test frequency	Test frequency	NA	Every 6 months	After equipment changes	NA	NA	NA
	Tolerance Limits	Tolerance Limits	NA	None	None	NA	NA	NA
Threshold contrast	Equipment	Equipment required	High contrast test device with periodic	CDMAM structure plate, four 10 ±0.2mm PMMA	NA	NA	NA	NA

			patterns, 40 mm phantom, test cassette, magnifying lens					
		Expense of Equipment/ €	500-1000	500-1000	NA	NA	NA	NA
		Ease of availability	Normally available	Normally available	NA	NA	NA	NA
	Measurement Protocol	Professional performing the test	Performed by or under guidance of Medical Physicist	Performed by or under guidance of Medical Physicist	NA	NA	NA	NA
		Level of Complexity	Simple	Simple	NA	NA	NA	NA
	Test frequency	Test frequency	Every 6 months	Every 6 months	NA	NA	NA	NA
	Tolerance Limits	Tolerance Limits	Shall not be reduced by more than one-line pair group compared with the cut-off frequency in the initial constancy test	>0.85% 5-6mm, >2.35% 0.5 mm, >5.45% 0.25 mm, >23% 0.1mm	NA	NA	NA	NA

Mean glandular dose to standard breast	Equipment	Equipment required	NA	Calibrated mammographic dosimeter, 20-70mm thick blocks of PMMA	Dosimeter, PMMA slabs	NA	NA	Ionization chamber, electrometer / dosimeter
		Expense of Equipment/ €	NA	500-1000	500-1000	NA	NA	500-1000
		Ease of availability	NA	Normally available	Normally available	NA	NA	Normally available
	Measurement Protocol	Professional performing the test	NA	Performed by or under guidance of Medical Physicist	Performed by or under guidance of Medical Physicist	NA	NA	Performed by or under guidance of Medical Physicist
		Level of Complexity	NA	Simple	Simple	NA	NA	Simple
	Test frequency	Test frequency	NA	Every 6 months	Annually and after equipment changes	NA	NA	Annually and after relevant service

	Tolerance Limits	Tolerance Limits	NA	20mm: Acceptable ≤ 1mGy, Achievable≤ 0.6mGy, 30mm: Acceptable ≤ 1.5mGy, Achievable≤ 1mGy,40mm: Acceptable ≤ 2mGy, Achievable≤ .6mGy,45mm: Acceptable ≤ 2.5mGy, Achievable≤ 2mGy,50mm: Acceptable ≤ 3mGy, Achievable≤ 2.4mGy,60mm: Acceptable ≤ 4.5mGy, Achievable≤ 3.6mGy,70mm: Acceptable ≤ 6.5mGy, Achievable≤ 5.1mGy,	Tables found in the document different values for different target-filter combination	NA	NA	<±25 % of the calculated average glandular dose
Mean glandular	Equipment	Equipment required	NA	Calibrated mammographic	NA	NA	NA	NA

dose to patients				dosimeter, 20-70mm thick blocks of PMMA				
		Expense of Equipment/ €	NA	500-1000	NA	NA	NA	NA
		Ease of availability	NA	Normally available	NA	NA	NA	NA
	Measurement Protocol	Professional performing the test	NA	Performed by or under guidance of Medical Physicist	NA	NA	NA	NA
		Level of Complexity	NA	Simple	NA	NA	NA	NA
	Test frequency	Test frequency	NA	Every 6 months	NA	NA	NA	NA
	Tolerance Limits	Tolerance Limits	NA	2 cm > 1mGy, 3 cm > 1.5mGy, 4 cm > 2mGy, 4.5 cm > 2.5mGy, 5 cm > 3mGy, 6 cm > 4.5mGy, 7 cm > 6.5mGy	NA	NA	NA	NA
Spatial linearity and geometric distortion of the detector	Equipment	Equipment required	NA	NA	Geometric distortion test tool	NA	NA	ACR digital mammography phantom, line-pair pattern
		Expense of Equipment/ €	NA	NA	<500	NA	NA	500-1000

		Ease of availability	NA	NA	Normally available	NA	NA	Normally available
	Measurement Protocol	Professional performing the test	NA	NA	Performed by or under guidance of Medical Physicist	NA	NA	Performed by or under guidance of Medical Physicist
		Level of Complexity	NA	NA	Simple	NA	NA	Simple
	Test frequency	Test frequency	NA	NA	Annually and after detector change	NA	NA	Annually and after relevant services
	Tolerance Limits	Tolerance Limits	NA	NA	Width & length: dimensions should be within 5% of each other, image size: within 10%, distances: within 5% of the true size, <2% deviation in 100 mm straight line in the centre	NA	NA	2D images ≥ 4 lp/mm, magnification mode: ≥ 6 lp/mm
AEC device consistency	Equipment	Equipment required	NA	Standard test block	3 slabs of PMMA (one 20mm thick and two 25 mm thick), contrast object and suitable spacers	4cm Perspex, electrometer, software to measure pixel value	NA	Compression paddles, four or more tissue-equivalent attenuators, magnification stand,

		Expense of Equipment/ €	NA	<500	500-1000	500-1000	NA	500-1000
		Ease of availability	NA	Normally available	Normally available	Normally available	NA	Normally available
	Measurement Protocol	Professional performing the test	NA	Performed by or under guidance of Medical Physicist	Performed by or under guidance of Medical Physicist	Performed by or under guidance of Medical Physicist	NA	Performed by or under guidance of Medical Physicist
		Level of Complexity	NA	Simple	Simple	Simple	NA	Simple
	Test frequency	Test frequency	NA	Every 6 months	Annually and after changes	Every 6 months	NA	Annually and after relevant services
	Tolerance Limits	Tolerance Limits	NA	Deviation from mean value of 10 exposures ≤±5%, achievable ≤±2%	Different system brands testing with thicknesses have different tolerances	mAs: baseline>5%, average pixel value: baseline >10%	NA	SNR must be ≤±15%
AEC device breast thickness compensation	Equipment	Equipment required	NA	Other thicknesses of PMMA, 0.2 mm Al	Slabs of PMMA one 20mm and two 25mm, contrast object, suitable spacers	2,4,6,7, cm Perspex, known mAs, software to measure pixel value, electrometer	NA	NA
		Expense of Equipment/ €	NA	500-1000	500-1000	500-1000	NA	NA
		Ease of availability	NA	Normally available	Normally available	Normally available	NA	NA

	Measurement Protocol	Professional performing the test	NA	Performed by or under guidance of Medical Physicist	Performed by or under guidance of Medical Physicist	Performed by or under guidance of Medical Physicist	NA	NA
		Level of Complexity	NA	Simple	Simple	Simple	NA	NA
	Test frequency	Test frequency	NA	NA	Annually or after changes to AEC software	Every 6 months	NA	NA
	Tolerance Limits	Tolerance Limits	NA	2 cm <115%,3 cm <110%, 4cm <105%, 4.5 cm <103%, 5cm <100%, 6cm <95%, 7cm<90%	Exposure time should not exceed 2s for 45mm, 4s for 70mm of PMMA	Manufacturer's instructions	NA	NA

A.3 Fluoroscopy Results Table

Table A. 3: Comparative Results Extracted from Constancy Testing Documents for Fluoroscopy

Subsystem	Thematic Category	Thematic Labels	IEC	EU Commission	IPEM	AAPM
	Document Metadata	Document Number	IEC 61223-2-9 (Image Intensifier)	RP 162 (Image Intensifier)	IPEM 91 (Image Intensifier)	AAPM 74 (Flat Panel Detectors/ Image Intensifier)
		Recency	1999	2012	2005	2002
		Price of Document	€135	€0	€30	€0
Dose rate reproducibility under AEC	Equipment	Equipment required	NA	NA	Dosimeter/DAP meter, attenuation material	NA
		Expense of Equipment/ €	NA	NA	500-1000	NA
		Ease of availability	NA	NA	Normally available	NA
	Measurement Protocol	Professional performing the test	NA	NA	User	NA

		Level of Complexity	NA	NA	Simple	NA
	Test frequency	Test frequency	NA	NA	At least every 1-3 months	NA
	Tolerance Limits	Tolerance Limits	NA	NA	Remedial level: Baseline ± 25%, Suspension level: Baseline ± 50%	NA
Display monitor set-up	Equipment	Equipment required	NA	NA	Grayscale step wedge	NA
		Expense of Equipment/ €	NA	NA	<500	NA
		Ease of availability	NA	NA	Specially purchased	NA
	Measurement Protocol	Professional performing the test	NA	NA	User	NA
		Level of Complexity	NA	NA	Simple	NA
	Test frequency	Test frequency	NA	NA	At least every 1-3 months	NA
	Tolerance Limits	Tolerance Limits	NA	NA	All steps visible and black/white circles	NA

Limiting spatial resolution	Equipment	Equipment required	NA	NA	Resolution test pattern	Line pair phantom, copper plate
		Expense of Equipment/ €	NA	NA	<500	<500
		Ease of availability	NA	NA	Normally available	Normally available
	Measurement Protocol	Professional performing the test	NA	NA	User	Performed by or under guidance of Medical Physicists (Same individual should do this test from time to time)
		Level of Complexity	NA	NA	Simple	Simple
	Test frequency	Test frequency	NA	NA	At least every 1-3 months	Annually
	Tolerance Limits	Tolerance Limits	NA	NA	Baseline reduced by 2 groups	Highest spatial frequency should be visible
Threshold contrast	Equipment	Equipment required	NA	NA	Low contrast detail test object	Phantom with different

						contrasts range objects
		Expense of Equipment/ €	NA	NA	<500	500-1000
		Ease of availability	NA	NA	Normally available	Normally available
	Measurement Protocol	Professional performing the test	NA	NA	User	Performed by or under guidance of Medical Physicist
		Level of Complexity	NA	NA	Simple	Simple
	Test frequency	Test frequency	NA	NA	At least every 1-3 months	Annually
	Tolerance Limits	Tolerance Limits	NA	NA	Baseline ± 2 discs	11mm discs at a contrast level <2%
Radiation/image field size and virtual collimation	Equipment	Equipment required	NA	NA	Film or CR plate, collimation test tool/collimators visible on TV image	Collimation test tool
		Expense of Equipment/ €	NA	NA	500-1000	500-1000

		Ease of availability	NA	NA	Normally available	Normally available
	Measurement Protocol	Professional performing the test	NA	User	User	Performed by or under guidance of Medical Physicist
		Level of Complexity	NA	Simple	Simple	Simple
	Test frequency	Test frequency	NA	NA	Annually	Annually
	Tolerance Limits	Tolerance Limits	NA	Radiation/field size: Radiation area>1.25 image area; Collimation limits: Deviation>3% of SID in either direction or >4% for the sum of two directions	Remedial level: Ratio of areas >1.15, Suspension level: X-ray field outside image receptor housing	±2% of the SID in all edges
Dose rate at the entrance surface of a phantom under automatic exposure control	Equipment	Equipment required	NA	Dose rate meter, measuring tape, phantom, grid in place	Dose rate meter, 20cm tick water phantom with sufficient width to cover the largest available field size	NA

		Expense of Equipment/ €	NA	2000-5000	2000-5000	NA
		Ease of availability	NA	Normally available	Normally available	NA
	Measurement Protocol	Professional performing the test	NA	Performed by or under guidance of Medical Physicist	Performed by or under guidance of Medical Physicist	NA
		Level of Complexity	NA	Simple	Simple	NA
	Test frequency	Test frequency	NA	Annually	Annually	NA
	Tolerance Limits	Tolerance Limits	NA	>100mGy/min at appropriate position	Remedial level: Baseline ± 25%/50mGy min-1, Suspension level: Baseline ± 50%/100mGy min-1	NA
Dose rate to the input face of the image receptor under AEC	Equipment	Equipment required	NA	NA	Dose rate meter with suitable chamber for positioning close to image receptor, copper/aluminium filters	NA

		Expense of Equipment/ €	NA	NA	500-1000	NA
		Ease of availability	NA	NA	Normally available	NA
	Measurement Protocol	Professional performing the test	NA	Performed by or under guidance of Medical Physicist	Performed by or under guidance of Medical Physicist	NA
		Level of Complexity	NA	Simple	Simple	NA
	Test frequency	Test frequency	NA	NA	Annually	NA
	Tolerance Limits	Tolerance Limits	NA	>1μGy/second	Remedial level: Baseline ± 25%, Suspension level: Baseline ± 50%	NA
Video voltage	Equipment	Equipment required	NA	NA	Lead edge, suitable storage oscilloscope, copper filter	Non-invasive kV meter
		Expense of Equipment/ €	NA	NA	500-1000	500-1000
		Ease of availability	NA	NA	Normally available	Normally available

	Measurement Protocol	Professional performing the test	NA	NA	Performed by or under guidance of Medical Physicist	Performed by or under guidance of Medical Physicist
		Level of Complexity	NA	NA	Complex	Simple
	Test frequency	Test frequency	NA	NA	Annually	Annually
	Tolerance Limits	Tolerance Limits	NA	NA	Vp < 75% baseline	10%
Limiting spatial resolution	Equipment	Equipment required	High-contrast test device, correction test filter device	NA	Lead grating resolution bar pattern	NA
		Expense of Equipment/ €	<500	NA	500-1000	NA
		Ease of availability	Normally available	NA	Normally available	NA
	Measurement Protocol	Professional performing the test	Performed by or under guidance of Medical Physicist	Performed by or under guidance of Medical Physicist	Performed by or under guidance of Medical Physicist	NA
		Level of Complexity	Simple	Simple	Simple	NA

	Test frequency	Test frequency	At least every 3 months	NA	Annually	NA
	Tolerance Limits	Tolerance Limits	+2/-3 visible patterns	<0.8 Ip/mm for field sizes > 25 cm, <1 Ip/mm for field sizes ≤25	Baseline reduced by 2 groups or 36-40cm: ≤ 0.7 line pairs mm-1, 30-35 cm: ≤ 0.8 line pairs mm-1,25-29 cm: ≤ 0.9 line pairs mm-1, 20-24 cm: ≤ 1.0 line pairs mm-1, 15-18 cm: ≤ 1.25 line pairs mm-1,	NA
Threshold contrast	Equipment	Equipment required	Attenuation phantom, low contrast test device	NA	Test object containing varying low contrast details and suitable filter	NA
		Expense of Equipment/ €	2000-5000	NA	500-1000	NA
		Ease of availability	Normally available	NA	Normally available	NA
	Measurement Protocol	Professional performing the test	Performed by or under guidance	Performed by or under guidance of Medical Physicist	Performed by or under guidance of Medical Physicist	NA

			of Medical Physicist			
		Level of Complexity	Simple	Simple	Simple	NA
	Test frequency	Test frequency	Daily for the first week, then every 2 weeks for 6 months, then at least annually	NA	Annually	NA
	Tolerance Limits	Tolerance Limits	±1 disk visible	>4%	Compare with baseline curves and standard reference curves	NA
Image Resolution uniformity	Equipment	Equipment required	NA	NA	An array of resolution test gratings of a large diameter mesh test object	NA
		Expense of Equipment/ €	NA	NA	500-1000	NA
		Ease of availability	NA	NA	Normally available	NA
	Measurement Protocol	Professional performing the test	NA	NA	Performed by or under guidance of Medical Physicist	NA

		Level of Complexity	NA	NA	Simple	NA
	Test frequency	Test frequency	NA	NA	Annually	NA
	Tolerance Limits	Tolerance Limits	NA	NA	Any noticeable non-uniformity in resolution should be compared with baseline results	NA
Radiation output	Equipment	Equipment required	Radiation meter, attenuation phantom	NA	NA	NA
		Expense of Equipment/ €	2000-5000	NA	NA	NA
		Ease of availability	Normally available	NA	NA	NA
	Measurement Protocol	Professional performing the test	Performed by or under guidance of Medical Physicist	Performed by or under guidance of Medical Physicist	NA	NA
		Level of Complexity	Simple	Simple	NA	NA
	Test frequency	Test frequency	Daily for the first week, then	NA	NA	NA

			every 2 weeks for 6 months, then at least annually			
	Tolerance Limits	Tolerance Limits	Manual control: ±20% of baseline, AEC: ±25 % of baseline (copper/lead)/ +25%: -20% (water/PMMA)	Deviation of radiation output from mean value >20%	NA	NA
Grey-scale image and Automatic Intensity Control	Equipment	Equipment required	Attenuation phantom, grey-scale test device	NA	NA	NA
		Expense of Equipment/ €	2000-5000	NA	NA	NA
		Ease of availability	Normally available	NA	NA	NA
	Measurement Protocol	Professional performing the test	Performed by or under guidance of Medical Physicist	NA	NA	NA
		Level of Complexity	Simple	NA	NA	NA

	Test frequency	Test frequency	Daily for the first week, then every 2 weeks for 6 months, then at least annually	NA	NA	NA
	Tolerance Limits	Tolerance Limits	Both black and white spots equally visible, tube voltage: baseline ±5kV, tube current: baseline ±20% baseline	NA	NA	NA
Integrated "dose indicator" calibration (DAP/KAP meter accuracy)	Equipment	Equipment required	NA	NA	NA	NA
		Expense of Equipment/ €	NA	NA	NA	NA
		Ease of availability	NA	NA	NA	NA
	Measurement Protocol	Professional performing the test	NA	Performed by or under guidance of Medical Physicist	NA	NA
		Level of Complexity	NA	Simple	NA	NA

	Test frequency	Test frequency	NA	NA	NA	NA
	Tolerance Limits	Tolerance Limits	NA	Deviation of the measured and indicated values>35%	NA	NA
HVL	Equipment	Equipment required	NA	NA	NA	Several 1mm sheets of aluminium, dosimeter
		Expense of Equipment/ €	NA	NA	NA	<500
		Ease of availability	NA	NA	NA	Normally available
	Measurement Protocol	Professional performing the test	NA	Performed by or under guidance of Medical Physicist	NA	Performed by or under guidance of Medical Physicist
		Level of Complexity	NA	Simple	NA	Simple
	Test frequency	Test frequency	NA	NA	NA	Annually
	Tolerance Limits	Tolerance Limits	NA	Different thicknesses for different kVs,	NA	Manufacturer specifications

				tabulated values in the document		
Image Intensifier Input Exposure Rate (IIER)	Equipment	Equipment required	NA	NA	NA	Aluminium filters, ionization chamber
		Expense of Equipment/ €	NA	NA	NA	500-1000
		Ease of availability	NA	NA	NA	Normally available
	Measurement Protocol	Professional performing the test	NA	NA	NA	Performed by or under guidance of Medical Physicist
		Level of Complexity	NA	NA	NA	Simple
	Test frequency	Test frequency	NA	NA	NA	Annually
	Tolerance Limits	Tolerance Limits	NA	NA	NA	1.5 to 2.5μR
Maximum Exposure Rate	Equipment	Equipment required	NA	NA	NA	A sheet of lead, radiotransparent dosimeter, measuring tape
		Expense of Equipment/ €	NA	NA	NA	<500

		Ease of availability	NA	NA	NA	Normally available
	Measurement Protocol	Professional performing the test	NA	NA	NA	Performed by or under guidance of Medical Physicist
		Level of Complexity	NA	NA	NA	Simple
	Test frequency	Test frequency	NA	NA	NA	Annually/more frequently if indicated
	Tolerance Limits	Tolerance Limits	NA	NA	NA	>10R/min normal operation, 20R/min in HDR

A.4 Computed Tomography Results Table

Table A. 4: Comparative Results Extracted from Constancy Testing Documents for Computed Tomography

Sub-system	Thematic Category	Thematic Labels	IEC	EU COMMISSION	IAEA		IPEM		AAPM	ACR	
	Document Metadata	Document Number	IEC 61223-3-5:2019	RP 162	IAEA Human Health Series No. 19		IPEM 91		AAPM 74/ AAPM66	ACR CT Quality Control Manual	
		Recency	2019	2012	2012		2005		2002 /2003	2017	
		Price of Document	€300	€0	€0		€30		€0	€0	
					User	MPE	User	MPE		User	MPE
Image noise	Equipment	Equipment required	Two cylindrical phantoms (small or large) of specified size containing a uniform medium	Water-filled phantom	Manufacturer's phantom/ commercial phantom/ simple phantom	Manufacturer's phantom/ commercial phantom/ simple phantom	System manufacturer's quality control phantom	Head and body sized water or equivalent phantoms	Water-filled phantom	Water phantom	NA
		Expense of Equipment/ €	2000-5000	2000-5000	2000-5000	2000-5000	2000-5000	2000-5000	2000-5000	2000-5000	NA

		Ease of availability	Normally available	Normally available	Normally available	Normally available	Normally available	Normally available	Normally available	Normally available	NA
	Measurement Protocol	Professional performing the test	Performed by or under guidance of Medical Physicist	Performed by or under guidance of Medical Physicist	User	Performed by or under guidance of Medical Physicist	User	Performed by or under guidance of Medical Physicist	Performed by or under guidance of Medical Physicist	User	NA
		Level of Complexity	Complex	Simple	Simple	Simple	Simple	Simple	Simple	Simple	NA
	Test frequency	Test frequency	At least monthly	Daily	Monthly	Annually	Daily to weekly	Annually	Daily	Daily	NA
	Tolerance Limits	Tolerance Limits	Small phantom: Baseline values ± 0.5 HU or ± 10%	Deviation of noise from specified values >15%	Acceptable ±25% baseline value, Achievable ±10% baseline value	Acceptable ±25% of baseline, Achievable ±10% of baseline	Remedial level: Baseline ± 10%, Suspension level: Baseline ± 25%	Remedial level: Water: Baseline ± 10% Inter slice variation mean ± 10%, Suspension level: Baseline ± 25%	Manufacturer specifications	0 ± 5 HU	NA
Scan plane localisa	Equipment	Equipment Required	NA	Markers	CT phantom	CT phantom, test device	Film or radio-	NA	Markers	NA	A phantom that has

tion from alignment lights						including a thin absorber ex. a 1mm diameter wire	opaque markers				radiopaque markers
		Expense of Equipment/ €	NA	<500	2000-5000	2000-5000	<500	NA	<500	NA	2000-5000
		Ease of availability	NA	Normally available	Normally available	Normally available	Normally available	NA	Normally available	NA	Normally available
	Measurement Protocol	Professional performing the test	NA	Performed by or under guidance of Medical Physicist	User	Performed by or under guidance of Medical Physicist	User	NA	Performed by or under guidance of Medical Physicist	NA	Performed by or under guidance of Medical Physicist
		Level of Complexity	NA	Simple	Simple	Simple	Simple	NA	Simple	NA	Simple
	Test frequency	Test frequency	NA	Annually	Monthly	Annually	Every 1-3 months	NA	Annually	NA	Annually or after relevant service
	Tolerance Limits	Tolerance Limits	NA	>± 5mm	Acceptable ± 5mm, Achievable ± 1mm	Acceptable ± 5mm, Achievable ± 1mm	>± 2mm	NA	± 1mm over the scan range	NA	> ± 2mm

Scan plane localisation from SPR	Equipment	Equipment Required	NA	Alignment tools or phantom	SPR accuracy test tool	SPR accuracy test tool	Phantom containing markers with defined z-axis separation	NA	Alignment tools or phantom	NA	A phantom that has radiopaque markers
		Expense of Equipment/ €	NA	<500/ 2000-5000	2000-5000	2000-5000	2000-5000	NA	<500/2000-5000	NA	2000-5000
		Ease of availability	NA	Normally available	Normally available	Normally available	Specially purchased	NA	Normally available	NA	Normally available
	Measurement Protocol	Professional performing the test	NA	Performed by or under guidance of Medical Physicist	User	Performed by or under guidance of Medical Physicist	User	NA	Performed by or under guidance of Medical Physicist	NA	Performed by or under guidance of Medical Physicist
		Level of Complexity	NA	Simple	Simple	Simple	Simple	NA	Simple	NA	Simple
	Test frequency	Test frequency	NA	Monthly or semi-annually	Monthly	Annually	Every 1-3 months	NA	Monthly or semi-annually	NA	Annually or after relevant service
	Tolerance Limits	Tolerance Limits	NA	>± 2mm	Acceptable ±2 mm, Achievable ±1 mm	Acceptable ±2 mm, Achievable ±1 mm	NA	>± 2mm	± 2mm	NA	> ± 2mm

Table top travel	Equipment	Equipment Required	NA	Constant load, ruler attached to a fixed part	NA	NA	NA	Ruler or reference distance, film	Constant load, ruler attached to a fixed part	NA	A phantom with two markers of known separation
		Expense of Equipment/ €	NA	<500	NA	NA	NA	<500	<500	NA	2000-5000
		Ease of availability	NA	Normally available	NA	NA	NA	Normally available	Normally available	NA	Normally available
	Measurement Protocol	Professional performing the test	NA	Performed by or under guidance of Medical Physicist	NA	NA	NA	User	Performed by or under guidance of Medical Physicist	NA	Performed by or under guidance of Medical Physicist
		Level of Complexity	NA	Simple	NA	NA	NA	Simple	Simple	NA	Simple
	Test frequency	Test frequency	NA	Monthly	NA	NA	NA	Every 1-3 months	Monthly	NA	Annually or after relevant service
	Tolerance Limits	Tolerance Limits	NA	Deviation >2mm from specified distance	NA	NA	NA	>± 2mm	±1mm over the range of the table motion	NA	> ± 2mm

CT number values	Equipment	Equipment Required	Two cylindrical phantoms (small or large) of specified size containing a uniform medium	Test phantom, head and body phantoms	Manufacturer's phantom/ commercial phantom/ simple phantom	Test phantom, head and body phantoms	NA	Water or water equivalent phantom containing a range of different density materials	Water-filled phantom	Water phantom	A phantom containing a number of materials with different CT numbers values
		Expense of Equipment/ €	2000-5000	2000-5000	2000-5000	2000-5000	NA	2000-5000	2000-5000	2000-5000	2000-5000
		Ease of availability	Normally available	Normally available	Normally available	Normally available	NA	Specially purchased	Normally available	Normally available	Specially purchased
	Ease of measurement	Professional performing the test	Performed by or under guidance of Medical Physicist	Performed by or under guidance of Medical Physicist	User	Performed by or under guidance of Medical Physicist	NA	Performed by or under guidance of Medical Physicist	Performed by or under guidance of Medical Physicist	User	Performed by or under guidance of Medical Physicist
		Level of Complexity	Complex	Complex	Simple	Complex	NA	Complex	Complex	Simple	Complex
	Test frequency	Test frequency	At least monthly	Annually	Monthly	Annually	NA	Annually	Daily	Daily	Annually or after relevant service

	Tolerance Limits	Tolerance Limits	Small phantom: Baseline values ± 5HU, Large phantom: Baseline values ± 7HU	±10 HU for water or up to 30 cm diameter	Acceptable ±5 HU, Achievable ±4 HU	Acceptable: ±5 HU from baseline value, Achievable: ±4HU from baseline value	NA	Remedial level: Water Baseline ± 5 HU, Other materials ±10 HU, Suspension level: Water Baseline ± 20 HU, Other materials ± 30 HU	For water, 0±5HU	0 ± 5 HU	Manufacturer's specification or a table of provided in the document for different materials used.
CT number uniformity	Equipment	Equipment Required	Two cylindrical phantoms (small or large) of specified size containing a uniform medium	Test phantom, head and body phantoms	Manufacturer's phantom/ commercial phantom/ simple phantom	Test phantom, head and body phantoms	NA	Head and body sized water or water equivalent phantoms	A phantom containing a number of materials with a wide range of CT numbers	NA	Water phantom
		Expense of Equipment/ €	2000-5000	2000-5000	2000-5000	2000-5000	NA	2000-5000	2000-5000	NA	2000-5000

		Ease of availability	Normally available	Normally available	Normally available	Normally available	NA	Normally available	Specially purchased	NA	Normally available
	Measurement Protocol	Professional performing the test	Performed by or under guidance of Medical Physicist	Performed by or under guidance of Medical Physicist	User	Performed by or under guidance of Medical Physicist	NA	Performed by or under guidance of Medical Physicist	Performed by or under guidance of Medical Physicist	NA	Performed by or under guidance of Medical Physicist
		Level of Complexity	Complex	Complex	Simple	Complex	NA	Complex	Complex	NA	Complex
	Test frequency	Test frequency	At least monthly	Annually	Monthly	Annually	NA	Annually	Semi-annually	NA	Annually or after relevant service
	Tolerance Limits	Tolerance Limits	Small phantom: Baseline values ± 4HU, Large phantom: Baseline values ± 8HU	Deviation of CT number from specified value>10 HU for water up to 20cm diameter. Deviation of CT number from specified value>20 HU for water above 20cm diameter.	Acceptable ±10 HU, Achievable ±4 HU	Acceptable : ±10 HU, Achievable : ±4 HU	NA	Head phantom: > ± 10 HU, Body phantom: > ± 20 HU	± 5 HU	NA	>±5 HU

High contrast spatial resolution	Equipment	Equipment Required	Test device consisting of a properly sized high contrast wire in a protecting tube of minimally attenuating material such that the SNR is high	Phantom containing suitable resolution objects in the x-y plane	NA	Line pair phantom with a range of spatial frequencies /MTF phantom with a high-density tungsten carbide bead	NA	Phantom containing a high contrast edge, pin, bead or bar insert	Phantom containing suitable resolution objects in the x-y plane	NA	Phantoms with high-contrast targets of known resolution
		Expense of Equipment/ €	500-1000	500-1000	NA	500-1000	NA	500-1000	500-1000	NA	2000-5000
		Ease of availability	Normally available	Normally available	NA	Normally available/ Specially purchased	NA	Normally available	Normally available	NA	Normally available
	Measurement Protocol	Professional performing the test	Performed by or under guidance of Medical Physicist	Performed by or under guidance of Medical Physicist	NA	Performed by or under guidance of Medical Physicist	NA	Performed by or under guidance of Medical Physicist	Performed by or under guidance of Medical Physicist	NA	Performed by or under guidance of Medical Physicist
		Level of Complexity	Simple	Simple	NA	Simple	NA	Simple	Simple	NA	Simple

	Test frequency	Test frequency	At annually	Annually	NA	After maintenance/ changes	NA	Annually	Annually	NA	Annually or after relevant service
	Tolerance Limits	Tolerance Limits	0.7lp/cm or Baseline ± 15%	Deviation >= 10% from manufacturer's specification or 0.5 lp/mm whichever is greater	NA	Within manufacturer's specifications	NA	Baseline ± 20%	Manufacturer specifications	NA	Abdomen: 6 lp/CM High-resolution Chest: 8 lp/cm
CT Dose Index (CTDI)	Equipment	Equipment Required	Dosimetry phantom, radiation detector	Dosimeter, CT dose phantoms, chamber stands	NA	Dosimeter, CT dose phantoms, chamber stands	NA	Dosimeter and pencil ion chamber on-axis in air	CTDI phantoms of PMMA diameter 16cm &32 cm, cylindrical ion chamber with an active length of 14cm	NA	Calibrated electrometer, CTDI pencil ionization chamber, Head CTDI phantom, Body CTDI phantom
		Expense of Equipment/ €	2000-5000	2000-5000	NA	2000-5000	NA	2000-5000	2000-5000	NA	2000-5000
		Ease of availability	Normally available	Normally available	NA	Normally available	NA	Normally available	Normally available	NA	Normally available
		Professional	Performed by or under	Performed by or under	NA	Performed by or	NA	Performed by or	Performed by or under	NA	Performed by or

	Measurement Protocol	performing the test	guidance of Medical Physicist	guidance of Medical Physicist		under guidance of Medical Physicist		under guidance of Medical Physicist	guidance of Medical Physicist		under guidance of Medical Physicist
		Level of Complexity	Complex	Complex	NA	Complex	NA	Complex	Complex	NA	Complex
	Test frequency	Test frequency	At least semi-annually & after maintenance	Annually, after service	NA	Annually, after service	NA	Annually	Annually or after major replacements	NA	Annually or after relevant replacements
	Tolerance Limits	Tolerance Limits	Baseline value ±20% or ± 1 mGy	From manufacturer's specification > 20%	NA	<±20% compared with manufacturer's specifications and measured, annually <±20% compared with baseline	NA	Remedial level: Baseline ± 15%, Suspension level: Baseline ± 40%	20% of manufacturer specifications	NA	Manufacturer specifications or <±20% compared with baseline or <±5% for yearly identical protocols
CTDIvol for single slice or	Equipment	Equipment Required	Test devices	Test devices	NA	Dosimeter, CT dose phantoms, chamber stands	NA	Pencil ionisation chamber in appropriate CT	NA	NA	Calibrated electrometer, CTDI pencil ionization

rotation								dosimetry phantom			chamber, Head CTDI phantom, Body CTDI phantom
		Expense of Equipment/ €	2000-5000	2000-5000	NA	2000-5000	NA	2000-5000	NA	NA	2000-5000
		Ease of availability	Normally available	Normally available	NA	Normally available	NA	Normally available	NA	NA	Normally available
	Measurement Protocol	Professional performing the test	Performed by or under guidance of Medical Physicist	Performed by or under guidance of Medical Physicist	NA	Performed by or under guidance of Medical Physicist	NA	Performed by or under guidance of Medical Physicist	NA	NA	Performed by or under guidance of Medical Physicist
		Level of Complexity	Complex	Complex	NA	Complex	NA	Complex	NA	NA	Complex
	Test frequency	Test frequency	At least semi-annually & after maintenance	At least semi-annually & after maintenance	NA	Annually, after service	NA	3 yearly	NA	NA	Annually or after relevant replacements
	Tolerance Limits	Tolerance Limits	Baseline value ±20% or ± 1 mGy	Deviation of measured dose from	NA	<±20% between manufacturer's and	NA	> National reference dose	NA	NA	Manufacturer specifications or

				indicated dose>20%		measured, <±20% between displayed and measured					<±20% compared with baseline or <±5% for yearly identical protocols
Irradiated beam thickness	Equipment	Equipment Required	NA	A strip of therapy localization film/gafchromic film/an array of thin thermoluminescent dosimeter chips loaded in a holder	NA	A strip of therapy localization film/gafchromic film/an array of thin thermoluminescent dosimeter chips loaded in a holder	NA	Film or thermoluminescent dosimeters stacked in a holder	Packaged film on the phantom surface	NA	Detector, flat radiation attenuator
		Expense of Equipment/ €	NA	500-1000	NA	500-1000	NA	500-1000	500-1000	NA	500-1000
		Ease of availability	NA	Normally available	NA	Normally available	NA	Normally available	Normally available	NA	Normally available

	Measurement Protocol	Professional performing the test	NA	Performed by or under guidance of Medical Physicist	NA	Performed by or under guidance of Medical Physicist	NA	Performed by or under guidance of Medical Physicist	Performed by or under guidance of Medical Physicist	NA	Performed by or under guidance of Medical Physicist
		Level of Complexity	NA	Simple	NA	Simple	NA	Simple	Simple	NA	Simple
	Test frequency	Test frequency	NA	After maintenance/ changes	NA	After maintenance/ changes	NA	Annually	Annually (Optional if the CTDI accuracy has been verified)	NA	Annually or after relevant service
	Tolerance Limits	Tolerance Limits	NA	Deviates from manufacturers' specifications	NA	Within manufacturers specifications	NA	Baseline ± 20% or ±1mm, whichever is greater	Manufacturer specifications	NA	Manufacturer specifications or > ± 3mm or > ± 30%
Image slice thickness	Equipment	Equipment Required	Test device containing one ramp with attenuation coefficient of aluminium	Test phantom with a thin metal plate and inclined	NA	Test phantom with a thin metal plate and inclined	NA	Test phantom with inclined pated for axial scans or a thin disc phantom or bead	Test phantom, aluminium or wire ramps for axial, bead phantom for helical mode	NA	NA

								ramps for helically acquired images			
		Expense of Equipment/ €	<500	<500	NA	<500	NA	500-1000	500-1000	NA	NA
		Ease of availability	Normally available	Normally available	NA	Normally available	NA	Normally available	Normally available	NA	NA
	Measurement Protocol	Professional performing the test	Performed by or under guidance of Medical Physicist	Performed by or under guidance of Medical Physicist	NA	Performed by or under guidance of Medical Physicist	NA	Performed by or under guidance of Medical Physicist	Performed by or under guidance of Medical Physicist	NA	NA
		Level of Complexity	Simple	Simple	NA	Simple	NA	Simple	Simple	NA	NA
	Test frequency	Test frequency	At least annually	Annually	NA	Annually	NA	Annually	Monthly/Semi-annually	NA	NA
	Tolerance Limits	Tolerance Limits	± 1mm for thickness >2mm; ±50 % for 1-2mm; ± 0.5mm for thickness <1mm	>± 0.5 mm for slices <1mm; >± 50% mm for slices of 1-2mm; >± 1mm for slices above 2mm	NA	± 0.5mm for thickness <1mm; ±50 % for thickness 1-2mm; ± 1mm	NA	Baseline ± 20% or ±1mm, whichever is greater	Manufacturer specifications	NA	NA

						thickness above 2mm					
Tube to detector alignment	Equipment	Equipment Required	NA	NA	NA	NA	NA	Film	Manufacturer specification	NA	NA
		Expense of Equipment/ €	NA	NA	NA	NA	NA	<500	NA	NA	NA
		Ease of availability	NA	NA	NA	NA	NA	Normally available	NA	NA	NA
	Measurement Protocol	Professional performing the test	NA	NA	NA	NA	NA	Performed by or under guidance of Medical Physicist	Performed by or under guidance of Medical Physicist	NA	NA
		Level of Complexity	NA	NA	NA	NA	NA	Simple	Simple	NA	NA
	Test frequency	Test frequency	NA	NA	NA	NA	NA	Annually	After replacement of components	NA	NA
	Tolerance Limits	Tolerance Limits	NA	NA	NA	NA	NA	> 1mm	±1mm of nominal value	NA	NA

Positioning of the patient support	Equipment	Equipment Required	60 cm ruler or larger	NA	NA	NA	NA	NA	Constant load, ruler attached to a fixed part	NA	NA
		Expense of Equipment/ €	<500	NA	NA	NA	NA	NA	<500	NA	NA
		Ease of availability	Normally available	NA	NA	NA	NA	NA	Normally available	NA	NA
	Measurement	Professional performing the test	Performed by or under guidance of Medical Physicist	NA	NA	NA	NA	NA	Performed by or under guidance of Medical Physicist	NA	NA
		Level of Complexity	Simple	NA	NA	NA	NA	NA	Simple	NA	NA
	Test frequency	Test frequency	At least annually	NA	NA	NA	NA	NA	Annually	NA	NA
	Tolerance Limits	Tolerance Limits	Longitudinal positioning: ±1mm, Backlash of the patient support: ±1mm	NA	NA	NA	NA	NA	±1mm over the range of the table motion	NA	NA

Sagittal and coronal patient positioning light accuracy	Equipment	Equipment Required	Test device which consists of a thin absorber diameter less than 1mm	NA	NA	NA	NA	NA	Test phantom	NA	NA
		Expense of Equipment/ €	<500	NA	NA	NA	NA	NA	<500	NA	NA
		Ease of availability	Normally available	NA	NA	NA	NA	NA	Normally available	NA	NA
	Measurement Protocol	Professional performing the test	Performed by or under guidance of Medical Physicist	NA	NA	NA	NA	NA	Performed by or under guidance of Medical Physicist	NA	NA
		Level of Complexity	Simple	NA	NA	NA	NA	NA	Simple	NA	NA
	Test frequency	Test frequency	At least annually	NA	NA	NA	NA	NA	Monthly/after laser adjustments	NA	NA
	Tolerance Limits	Tolerance Limits	<± 2mm from either the centre of any position	NA	NA	NA	NA	NA	± 2mm over the length of laser projection	NA	NA

kV and HVL	Equipment	Equipment Required	NA	NA	NA	Manufacturer specifications	NA	NA	Manufacturer specifications	NA	NA
		Expense of Equipment/ €	NA	NA	NA	NA	NA	NA	NA	NA	NA
		Ease of availability	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Measurement Protocol	Professional performing the test	NA	NA	NA	Performed by or under guidance of Medical Physicist	NA	NA	Performed by or under guidance of Medical Physicist	NA	NA
		Level of Complexity	NA	NA	NA	Simple	NA	NA	Simple	NA	NA
	Test frequency	Test frequency	NA	NA	NA	After maintenance or changes	NA	NA	After replacement of components	NA	NA
	Tolerance Limits	Tolerance Limits	NA	NA	NA	Acceptable: kV ± 5%, Achievable: kV ± 2%, HVL ≥ specified by	NA	NA	Manufacturer specifications	NA	NA

						radiation protection regulations and within tolerances specified by manufacturer					
Low-Contrast Detectability	Equipment	Equipment Required	NA	NA	NA	NA	NA	NA	Phantoms with objects of less than 1% contrast	NA	Phantoms with low-contrast targets of known contrast
		Expense of Equipment/ €	NA	NA	NA	NA	NA	NA	2000-5000	NA	2000-5000
		Ease of availability	NA	NA	NA	NA	NA	NA	Normally available	NA	Normally available
	Measurement Protocol	Professional performing the test	NA	NA	NA	NA	NA	NA	Performed by or under guidance of Medical Physicist	NA	Performed by or under guidance of Medical Physicist
		Level of Complexity	NA	NA	NA	NA	NA	NA	Simple	NA	Simple

	Test frequency	Test frequency	NA	NA	NA	NA	NA	NA	Every 3 months to annually	NA	Annually or after relevant service
	Tolerance Limits	Tolerance Limits	NA	NA	NA	NA	NA	NA	Visibility of large objects should improve with increasing technique. Small object visibility will also improve, but will be constrained by spatial resolution limitations.	NA	Manufacturer's specification or table is provided with CNR values in the ACR document
Alignment of gantry lasers with centre of imaging plane	Equipment	Equipment Required	Test device with a thin absorber	NA	NA	NA	NA	NA	Alignment tool or phantom	NA	NA
		Expense of Equipment/ €	<500	NA	NA	NA	NA	NA	<500/ 2000-5000	NA	NA
		Ease of availability	Normally available	NA	NA	NA	NA	NA	Normally available	NA	NA

	Measurement Protocol	Professional performing the test	Performed by or under guidance of Medical Physicist	NA	NA	NA	NA	NA	Performed by or under guidance of Medical Physicist	NA	NA
		Level of Complexity	Simple	NA	NA	NA	NA	NA	Simple	NA	NA
	Test frequency	Test frequency	at least every 3 months	NA	NA	NA	NA	NA	Daily	NA	NA
	Tolerance Limits	Tolerance Limits	±2mm	NA	NA	NA	NA	NA	±2mm	NA	NA
Orientation of gantry lasers with respect to the imaging plane/scan plane/imaging plane	Equipment	Equipment Required	NA	NA	NA	NA	NA	NA	Alignment tool or phantom	NA	NA
		Expense of Equipment/ €	NA	NA	NA	NA	NA	NA	<500/ 2000-5000	NA	NA
		Ease of availability	NA	NA	NA	NA	NA	NA	Normally available	NA	NA
	Measurement Protocol	Professional performing the test	NA	NA	NA	NA	NA	NA	Performed by or under guidance of Medical Physicist	NA	NA
		Level of Complexity	NA	NA	NA	NA	NA	NA	Simple	NA	NA

	Test frequency	Test frequency	NA	NA	NA	NA	NA	NA	Monthly and after laser adjustments	NA	NA
	Tolerance Limits	Tolerance Limits	NA	NA	NA	NA	NA	NA	±2mm over the length of laser projection	NA	NA
Gantry tilt position accuracy	Equipment	Equipment Required	NA	NA	NA	NA	NA	NA	Ready pack film, laser QA device, square acrylic or water equivalent plastic sheet from 2 to 4 cm thick	NA	NA
		Expense of Equipment/ €	NA	NA	NA	NA	NA	NA	500-1000	NA	NA
		Ease of availability	NA	NA	NA	NA	NA	NA	Normally available	NA	NA
	Measurement Protocol	Professional performing the test	NA	NA	NA	NA	NA	NA	Performed by or under guidance of Medical Physicist	NA	NA

		Level of Complexity	NA	NA	NA	NA	NA	NA	Simple	NA	NA
	Test frequency	Test frequency	NA	NA	NA	NA	NA	NA	Annually	NA	NA
	Tolerance Limits	Tolerance Limits	NA	NA	NA	NA	NA	NA	±1° or ±1mm from nominal position	NA	NA
Field uniformity	Equipment	Equipment Required	NA	NA	NA	NA	NA	NA	Body and head phantoms, suitable software	NA	NA
		Expense of Equipment/ €	NA	NA	NA	NA	NA	NA	2000-5000	NA	NA
		Ease of availability	NA	NA	NA	NA	NA	NA	Normally available	NA	NA
	Measurement Protocol	Professional performing the test	NA	NA	NA	NA	NA	NA	Performed by or under guidance of Medical Physicist	NA	NA
		Level of Complexity	NA	NA	NA	NA	NA	NA	Simple	NA	NA

	Test frequency	Test frequency	NA	NA	NA	NA	NA	NA	Monthly with most commonly used kVp, Annually with other kVp settings	NA	NA
	Tolerance Limits	Tolerance Limits	NA	NA	NA	NA	NA	NA	Within ±5HU	NA	NA