ASSOCIAZIONE ITALIANA di FISICA MEDICA e SANITARIA

AIFM Working Group on Digital Radiology
Subgroup on C-arms

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GUIDELINES FOR QUALITY CONTROL ON C-ARMS WITH FLAT PANEL AND ANALOGUE DETECTORS

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Working Group

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SUMMARY

GLOSSARY

DAP	Dose Area Product
DICOM	Digital Imaging and Communications in Medicine
DSA	Digital subtraction angiography
AEC	Automatic Exposure Control
FOV	Field of view
II	Image Intensifier
KAP	Kerma Area Product
PACS	Picture Archive and Communication System
RDMS	Radiation Dose Monitoring System
RDSR	Radiation Dose Structured Report
RIS	Radiology Information System
HVL	Half Value Layer

INTRODUCTION

This protocol outlines the necessary checks to be performed on X-ray C-arms that do not have an integrated bed, including those with image intensifiers and digital detectors (*flat panel*).
In modern healthcare settings, X-ray equipment, particularly digital systems, are increasingly integrated into the hospital network. Indeed, it is important to ensure that the images produced are saved on PACS (*Picture Archiving and Communication System*), and that dosimetric information is recorded by *Radiation Dose Monitoring Systems* (RDMS). It is useful to consider these aspects in a quality control protocol, as well as to verify the accuracy of the dosimetric information that the equipment makes available to RDMS systems. With this in mind, connectivity tests have been added to the radiological equipment tests in the protocol.
On the other hand, the accurate verification of the technical and physical aspects of certain quantities is very difficult in equipment that is primarily designed for convenience and simplicity in clinical use, but not for testability. This has made some once-fundamental and straightforward tests difficult to perform. It would be desirable for manufacturers to enhance the testability of the equipment they produce.
These general considerations justify the selection of the parameters to be tested and the testing methods in this protocol.
There are three types of tests: acceptance tests before clinical use, correct operation at regular intervals and following relevant maintenance work.
The protocol outlines the parameters to be verified, the verification methods, the types of tests with their corresponding frequencies, tolerances and/or typical values. The latter, identified by the Working Group, were obtained as the median of the values measured in the various Centres.
The tests were divided into two levels: first and second.

- First level controls aim to verify compliance with the limits/threshold values outlined in the technical reference documents. These controls must therefore be considered as fundamental and should be included in the quality control protocol for C-arm equipment.
- Second level checks are optional but recommended tests. Performing these tests requires, for example, exporting images in ‘for processing’ format or requires time and equipment availability not always compatible with hospital requirements. Second-level tests can be helpful in optimising examination protocols in collaboration with physicians.

The table below details the type, frequency and level of the tests.
Functional tests after relevant intervention should be adapted to the type of intervention performed.

LIST OF CONTROLS AND FREQUENCY

1. Verification of image detector characteristics

Quality Control	Type of control	Frequency	Level
Signal non-uniformity	Acceptance, correct operation	annual	1
Conversion function	Acceptance, correct operation	annual	2
Presence of bad pixels	Acceptance, correct operation	annual	2

2. Checking the X-ray tube and generator

Quality Control	Type of control	Frequency	Level
kV accuracy check	Acceptance, correct operation	---	1
HVL verification	Acceptance, correct operation	---	1
Checking X-ray tube output	Acceptance, correct operation	annual	1
Leakage radiation	Acceptance, correct operation	annual	1

3. Verification of the geometric characteristics

Quality Control	Type of control	Frequency	Level
FOV verification	Acceptance, correct operation	annual	1
Focus-detector distance check	Acceptance, correct operation	---	1
Verification of X field centring	Acceptance, correct operation	annual	1

4. Checking the equipment's dose indicators.

Quality Control	Type of control	Frequency	Level
Preliminary visual checks	Acceptance, correct operation	annual	1
Short-term stability of exposure indicators	Acceptance, correct operation	annual	1
Accuracy and calibration of indicators as energy variations, kerma rate, field size	Acceptance, correct operation	annual	1

5. Checking the image quality of the equipment

Quality Control	Type of control	Frequency	Level
Geometric distortion (II only)	Acceptance, correct operation	annual	1
Spatial resolution	Acceptance, correct operation*	annual	1
1) Low contrast/sensitivity threshold (fluorography and fluoroscopy)	Acceptance, correct operation*	annual	1
2) Threshold contrast detail detectability - statistical method (fluorography and fluoroscopy) (alternative to 1)	Acceptance, correct operation*	annual	1
Subtracted image quality-DSA images	Acceptance, correct operation*	annual	2

*In scatter free conditions; as additional proof, evaluations can also be made in conditions with scatter.

6. Verification of the dosimetric characteristics

Quality Control	Type of control	Frequency	Level
Maximum air kerma rate at patient entrance (fluoroscopy)	Acceptance, correct operation	annual only for level 2	1, 2
Air Kerma and its rate at patient entrance (fluoroscopy and fluorography)	Acceptance, correct operation	---	1
Air Kerma and its rate at the detector entrance (fluoroscopy and fluorography)	Acceptance, correct operation	---	2
Reproducibility of the C-arm (fluoroscopy and fluorography)	Acceptance, correct operation	annual	1

7. Verification of connectivity

Quality Control	Type of control	Frequency	Level
Image transmission to PACS and worklist availability	Acceptance, correct operation	---	1
Proper transmission of exposure data to RDMS	Acceptance, correct operation	---	1
Software version	Acceptance, correct operation	annual	1

1. VERIFICATION OF IMAGE DETECTOR CHARACTERISTICS

References	1. Guidelines Flat Panel AMFPD - AIFM 2009. 2. Radiation Protection n. 162, 2012 “Criteria for acceptability of Medical Radiological Equipment used in Diagnostic Radiology, Nuclear Medicine and Radiotherapy”. 3. IPEM Report 91“Recommended Standards for the Routine Performance Testing of Diagnostic X-ray Imaging Systems” (2005). 4. “Acceptance Testing and Quality Control of Photostimulable Storage Phosphor Imaging Systems” American Association of Physicists in Medicine. AAPM Report n. 93, Task Group 10 (2006). 5. ISO 4037-2:2019 “Radiological protection - X and gamma reference radiation for calibrating dosemeters and dose rate meters and for determining their response as a function of photon energy - Part 2: Dosimetry for radiation protection over the energy ranges from 8keV to 1,3MeV and 4MeV to 9 MeV”. 6. IEC 62220-1-3 International standard “medical electrical equipment - Characteristics of X-ray imaging devices - Part 1-3: Determination of the detective quantum efficiency - Detectors used in dynamic imaging. 7. AIFM Report n.14 (1019) “Linee guida per i controlli di qualità in angiografia digitale con rivelatore a flat panel”. 8. EFOMP Protocol - Quality control of dynamic x-ray systems- 2024.
Prerequisites	For comparison with reference values, choose the X-ray beam quality as tabulated in ISO 4037-2:2019 (RQA 5 is closest to the most commonly used clinical practice). Prior to conducting the checks, ensure that both the detector and the X-ray tube window are free from traces of contrast medium. If necessary, clean them thoroughly. Record the date of the last calibration, which can also be found in the DICOM (0018,700C) tag, and ensure that the equipment does not require a detector calibration. Checks are to be performed on “single shot” images. Use images in “for processing” mode, if possible, and convert them to dose after determining the conversion function (ref. AMFPD Flat Panel Guidelines - AIFM 2009).

General procedure	1. Use an ISO reference beam; the RQA5 beam is closest to clinical practice (70 kV, SEV 7.1 mmAl, additional filtration 21 mm Al or alternatively 1 mm Cu). 2. Remove the anti-scatter grid, if possible. 3. Use the maximum available FOV, to examine the entire detector. 4. Verify the cleanliness of the collimator output window and detector input window and acquire a uniform control image to identify any noticeable artefacts. 5. Linearise all kerma images using the conversion function, if possible. 6. Acquire images at the maximum focus-detector distance feasible (or, if there is a difference, at the detector calibration distance).

SIGNAL NON-UNIFORMITY

Purpose	Check for artefacts and inhomogeneity.
Instrumentation	○ 21 mm Al or 1 mm Cu attenuator filter.
Procedure	1. Acquire a uniform image for the standard kerma level (e.g. 2 µGy) for an initial inspection to identify any artefacts and signal persistence effects. 2. For II: inspect the image on the monitor for any artefacts or inhomogeneities. 3. For digital detector: measure and record the mean value of the calculated signal in consecutive 1 cm·1 cm ROIs overlapping by half their area.
Data analysis (digital panel only)	● Local Signal Non-Uniformity (NULS) can be assessed as the ratio of the maximum difference between two contiguous ROIs to the average signal of the ROI under consideration. ● The Global Non-Uniformity of Signal (NUGS) can be evaluated as the ratio between the maximum difference between the values of two ROIs and the half-sum between the maximum and minimum average value of the ROIs. For digital detectors, perform the analysis in the central region of the detector, ensuring that at least 80% of the sensitive area is analysed. To conduct this analysis, the ‘COQ’ plugin of the free ImageJ software can be used (https://www.medphys.it/downloads.htm).

Acceptability criteria	NULS< 20% NUGS< 40% The NUGS and NULS values have absolute significance only when the analysis is conducted on the converted dose images. Otherwise, the values obtained during acceptance test or correct operation test after maintenance serve as reference points for periodic correct function tests, with qualitative significance. There should be no noticeable artifacts present. If any artifacts are detected, attempt to determine the cause and check if they can be removed by performing a detector calibration again. The NUGS and NULS values have absolute significance only in cases where the analysis is performed on the converted dose images. Otherwise, the values from the acceptance or status can serve as a reference for periodic tests, helping to highlight any major changes in uniformity. If a quantitative evaluation is not possible, a direct observation of the produced image should not detect obvious artifacts. If not, try to identify the cause and see if it can be removed by performing a detector calibration again.
Typical values	For "for processing" images or linear conversion functions, the values identified by the working group are as follows: (see table below)
Type of control and frequency.	Acceptance, correct operation after maintenance and annually.

	25th percentile	median	75th percentile
NULS	0.2%	0.3%	1.2%
NUGS	5.4%	10.8%	13.5%

PRESENCE OF "BAD PIXELS"

Purpose	Check for inactive pixels - only for digital panels
Instrumentation	○ 21 mm Al or 1 mm Cu attenuator filter.
Procedure	1. Use the same generated image for evaluating uniformity. 2. Calculate the mean value of the evaluated signal in consecutive 1 cm·1 cm ROIs overlapping by half their area.
Data analysis	A bad pixel is defined as any pixel whose value differs by more than 20% from the mean value of the ROI it belongs to. ● Conduct the analysis in the central part of the detector, ensuring that at least 80% of the sensitive area is analysed. ● Use the "COQ" plugin of the free ImageJ software for this analysis (https://www.medphys.it/downloads.htm).
Acceptability criteria	Ensure that the number of bad pixels complies with the limits specified by the manufacturer.

Type of control and frequency	Acceptance, correct operation after maintenance and annually.

CONVERSION FUNCTION

Purpose	Verify the signal conversion function. This check can only be performed if the X-ray tube is capable of operating in manual mode and if images can be exported in "for processing" mode.
Instrumentation	○ 21 mm Al or 1 mm Cu attenuator filter; ○ kerma meter.
Procedure	1. Select a protocol, disabling dynamic gain corrections if possible, but applying flat-field corrections (use the same protocol, even during periodic tests). 2. Acquire at least 5 uniform images at various kerma levels, ranging from about ⅓ to about 3 times the typical kerma level (e.g. in fluoroscopy: 6, 20, 64 nGy/pulse; in single shot 0.6, 2, 6.4 µGy). 3. On certain devices it is possible to interpose filters and use the automatic mode to get different X-ray tube power supplies, which remain unchanged when switching to manual exposure mode. In such a case, acquire a uniform image, then record the X-ray tube setup. Then take the images again with the multimeter sensor in place to measure the kerma, under the conditions previously found. 4. Measuring the incident kerma on the detector using the maximum FOV.
Data analysis	● Plot the mean digital value of a ROI (5 mm·5 mm at the field's centre and near to the kerma measurement point) as a function of the measured kerma. ● Determine the best-fit curve for the system response curve, as a function of kerma, using an appropriate fitting function (e.g.: linear, logarithmic, power law, etc.). ● Evaluate the accuracy and precision of the detector response.
Acceptability criteria	Verify the consistency of the conversion function with the obtained measurement data by evaluating the Pearson correlation index (r^2): ➢ in correct operation tests, $r^2 \geq 0.95$; ➢ in periodic tests, record the parameters of the conversion function.
Type of control and frequency	Acceptance, correct operation after maintenance and annually.

2. CHECKING X-RAY TUBE AND GENERATOR

References	1. Radiation Protection n. 162, 2012 “Criteria for acceptability of Medical Radiological Equipment used in Diagnostic Radiology, Nuclear Medicine and Radiotherapy” 2. IPEM 2005a Institute of Physicists and Engineers in Medicine. Recommended Standards for the Routine Performance Testing of Diagnostic X-Ray Imaging Systems, Report 91. York: Institute of Physicists and Engineers in Medicine 3. IEC 60601-2-54 (2022) Medical electrical equipment - Part 2-54: Particular requirements for the basic safety and essential performance of X-ray equipment for radiography and radioscopy 4. A. Boschini, S. Di Biaso, D. D'Urso, S. Cimolai, D. Maestri, PS03.19 X-ray tube output normalization: a computational approach to meet RP 162/2012 requirements in high filtration settings, Physica Medica, Vol. 125, Suppl. 1, 2024, 104118, ISSN 1120-1797 5. EFOMP Protocol -Quality control of dynamic x-ray systems- 2024 6. EN 60601-1-3 2008 or IEC 60601-1-3: Medical electrical equipment – Part 1-3: General requirements for basic safety and essential performance – collateral standard: radiation protection in diagnostic X-ray equipment” (2021)
Instrumentation	○ Copper and PMMA attenuator filters; ○ kerma meter suitable for the entire measuring range and calibrated for the relevant radiation qualities; ○ multimeter suitable for the entire measuring range and calibrated for the relevant radiation qualities; ○ measuring tape.
Purpose	These tests aim to verify compliance with the limits/threshold values recommended by the technical reference documents. It is essential to specify the measurement conditions in detail.

kV ACCURACY CHECK

Purpose	Check the accuracy of the voltage at the X-ray tube.
Procedure	1. If possible, manually set different kV values (preferably including 80 kV); measure the kV with a kilovoltmeter or multimeter (this is generally feasible when the device operates in manual, in fluorography or in fluoroscopy mode). 2. If manual kV setting is not available, conduct evaluations in automatic fluoroscopy: place copper filters between the X-ray tube and the image detector, underneath the multimeter sensor, to achieve kV values equal to 60% of the maximum kV, ideally in single-shot mode. 3. Alternatively, on some devices it is possible to interpose copper filters and obtain different kV values, which then remain fixed when switching to manual exposure mode. In such cases, record the X-ray tube power supply setup and repeat the exposure with the multimeter sensor in place, to measure the kV under the previously found conditions.
Acceptability criteria	Deviation of measured kV from nominal less than 10% [1][2].
Typical value	3%.
Type of control and frequency	Acceptance, correct operation after maintenance.

HVL VERIFICATION

Purpose	Check the HVL.
Procedure	1. If feasible, manually set various kV values and measure the HVL using the preferred method. This approach is typically possible when the device operates in manual (fluorography or fluoroscopy) mode. 2. If manual kV setting is not available, it is necessary to use the automatic fluoroscopy. For this purpose, place copper filters between the X-ray tube and the image detector, underneath the multimeter sensor, to achieve a delivery with kV values of 60% of the maximum kV possibly in single-shot mode. 3. Alternatively, on some devices it is possible to obtain different kV values by interposing copper filters in automatic mode. In these cases, record the X-ray tube power supply setup and repeat the process by interposing the multimeter sensor to evaluate the HVL under the previously determined conditions.

<table>
<tr><td>Acceptability criteria and typical values</td><td>
Table of reference values for the HVL:
<table>
<tr><th>kV</th><th>minimum HVL (mmAl)*</th><th>minimum HVL (mmAl)**</th><th>typical HVL (mmAl)</th></tr>
<tr><td>50</td><td>1.5</td><td>1.8</td><td>3.0</td></tr>
<tr><td>60</td><td>1.8</td><td>2.2</td><td>3.6</td></tr>
<tr><td>70</td><td>2.1</td><td>2.5</td><td>4.3</td></tr>
<tr><td>80</td><td>2.3</td><td>2.9</td><td>5.0</td></tr>
<tr><td>90</td><td>2.5</td><td>3.2</td><td>5.3</td></tr>
<tr><td>100</td><td>2.7</td><td>3.6</td><td>6.2</td></tr>
<tr><td>110</td><td>3.0</td><td>3.9</td><td>6.6</td></tr>
<tr><td>120</td><td>3.2</td><td>4.3</td><td>6.8</td></tr>
<tr><td>130</td><td>3.5</td><td>4.7</td><td>---</td></tr>
<tr><td>140</td><td>3.8</td><td>5.0</td><td>---</td></tr>
<tr><td>150</td><td>4.1</td><td>5.4</td><td>---</td></tr>
</table>
* Valid reference values for CE marked equipment before 2012 IEC 60601-1-3
** Valid reference values for CE marked equipment after 2012 IEC 60601-1-3 2008
Typical HVL: median values identified by the working group; it should be noted that modern C-arms often have greater beam filtration than in the past.
</td></tr>
<tr><td>Type of control and frequency</td><td>Acceptance, correct operation after maintenance.</td></tr>
</table>

CHECKING X-RAY TUBE OUTPUT

Purpose	Check the output of the X-ray tube at 1 meter under standard conditions.
Procedure	1. If manual fluorography mode is available, set various kV values (preferably including 80 kV), mA and exposure time; 2. Measure the exposure time and air kerma with a multimeter to calculate the output (µGy/mAs). 3. If manual fluoroscopy mode is available, set different kV (including 80 kV if possible) and mA values. 4. Measure the exposure time and air kerma using a multimeter and obtain the output (µGy/mAs). 5. Otherwise, use automatic fluoroscopy. For this purpose, place copper filters between the X-ray tube and the image detector, underneath the multimeter sensor, to achieve kV values at approximately 60% of the maximum kV, ideally in single-shot mode. 6. Alternatively, on some devices it is possible to interpose copper filters in automatic mode to obtain different kV values, which can be set manually afterward. In such cases, record the X-ray tube supply setup and repeat the exposure with the multimeter sensor in place to measure air kerma under the previously determined conditions. 7. Measure the kerma in the air.
Acceptability criteria	➢ In acceptance tests, the kerma/mAs value at 1 meter at 80 kV and 2.5 mmAl filtration must be between 25 and 80 µGy/mAs. Adjust this criterion for cases with substantially different filtration levels (refer to the section on typical values).
Typical values	For filtration significantly different from 2.5 mmAl, the performance at 80 kV can typically be compared with the previously cited limits by correcting it for the y-factor as follows [4]: ⧫ total filtration (TF) between 3 mmAl and 15 mmAl: $y = 0.026 \cdot TF^2 + 0.12 \cdot TF + 0.62$ ⧫ filtration 0.1 mm Cu + F between 2.5 mmAl and 5 mmAl: $y = 0.437 \cdot F + 0.98$ ⧫ filtration (F) between 2.5 mmAl and 5 mmAl + 0.2 mm Cu: $y = 0.528 \cdot F + 1.97$ ⧫ filtration (F) between 2.5 mmAl and 5 mmAl + 0.3 mm Cu: $y = 0.633 \cdot F + 3.08$ Alternatively, for unknown total filtration and if the ratio between the measured outputs at 80 kV and 60 kV (r) is in the range between 1.7 and 2.4: $y = 3.40 \cdot r - 4.73$ For proper operation tests at regular intervals, ensure that performance deviation from the acceptance-measured value remains within 25%.

Type of control and frequency	Acceptance, correct operation after maintenance and annually.

MEASUREMENT OF LEAKAGE RADIATION

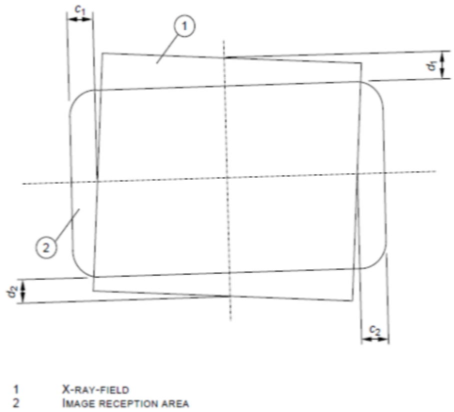
Purpose	Assessing leakage radiation from the X-ray tube housing.
Procedure	1. Select the exposure mode specified by the manufacturer or, if unavailable, select a value of approximately 80% of the maximum kV value with a medium/high mA load and measure the exposure time under these conditions with a multimeter in the beam. 2. Close the collimators as much as possible. 3. Add at least 2 mm of Pb at the X-ray tube output. 4. With a radiation survey meter in integral mode, measure exposure at several different points in space (at least 4) located 1 m away from the X-ray tube housing, with 4π angular coverage. 5. Calculate the escape radiation in one hour, also taking into account the input surface of the instrument used.
Acceptability criteria	<1 mGy/h at 1 m [6].
Type of control and frequency	Acceptance, correct operation after maintenance and annually.

3. VERIFICATION OF THE GEOMETRIC CHARACTERISTICS

Riferimenti	1. CEI EN 60601-2-43:(2023) "Prescrizioni particolari per la sicurezza fondamentale e le prestazioni essenziali degli apparecchi radiologici per procedure interventistiche" 2. Radiation Protection n. 162, 2012 "Criteria for acceptability of Medical Radiological Equipment used in Diagnostic Radiology, Nuclear Medicine and Radiotherapy" 3. IPEM Report 91"Recommended Standards for the Routine Performance Testing of Diagnostic X-ray Imaging Systems" (2005) 4. CEI EN 60601-1-3 (CEI 62-69): Apparecchi elettromedicali. Parte 1: Prescrizioni generali per la sicurezza. 3: Norma collaterale: Prescrizioni generali per la radioprotezione in apparecchi radiologici per diagnostica. 5. EFOMP Protocol -Quality control of dynamic x-ray systems- 2024

FOV VERIFICATION

CORRESPONDENCE BETWEEN X-RAY FIELD AND REAL IMAGE RECEPTOR AREA 1/2

Purpose	Check that the X-Ray beam is collimated so that the total exposed area remains within the edges of the image receiver.
Instrumentation	○ Test object to verify field collimation (e.g. Leeds T.O. M1 test); ○ Measuring tape; ○ Bubble level; ○ Gafchromic film or CR plate.
Procedure	1. Level the test object for alignment and position it to cover the largest FOV. 2. Expose the test object, acquire an image and measure the effective size of the X-ray field using a detector-independent system (e.g. gafchromic film or CR plate). 3. Conduct the test for at least the maximum FOV and, if feasible, in two positions (e.g. with vertical and horizontal beam) in order to evaluate the stability of the collimator positions as the X-ray tube angle changes. 4. Repeat the check for the most frequently used FOV, as well as for the maximum FOV at the maximum detector-to-X-ray tube distance. 1. For systems with virtual collimation, the same test procedure can be applied.
Data analysis	● Evaluate the FOV size on the image and calculate the total irradiated area on film or CR plate. ● Consider any scaling factors when assessing the correspondence between the incident X-ray field on the detector and the displayed image area. ● Assess in the various directions whether the X-ray field corresponds with the size of the image reception area. ● Compute the maximum deviation in all four directions and verify that it remains within the specified tolerances.
Data analysis	

Acceptability criteria	➢ Assess whether the X-ray field's surface area matches the actual image reception area, i.e. whether the relationship [1, 2] holds: $$0.80 \leq \frac{X - ray\ beam\ area}{Imaged\ beam\ area} \leq 1.25$$ ➢ In the direction of greatest misalignment, the X-ray field measured from the centre of the image detector should not extend beyond the effective image edge by more than 2% of the SDD. This additional criterion applies to all magnification levels (FOV), the minimum and maximum image detector distances and both horizontal and vertical gantry positions [1]. $\lvert c_1\rvert + \lvert c_2\rvert \leq 0.03 \cdot SSD$ $\lvert d_1\rvert + \lvert d_2\rvert \leq 0.03 \cdot SSD$ $\lvert c_1\rvert + \lvert c_2\rvert + \lvert d_1\rvert + \lvert d_2\rvert \leq 0.04 \cdot SSD$[1, 2] ➢ For systems using virtual collimation, apply the same quality and acceptability criteria outlined in the previous points.
Type of control and frequency	Acceptance, correct operation after maintenance and annually.

FOCUS-DETECTOR DISTANCE CHECK

Purpose	Check that the focus-detector distance, i.e. the Source to Image Distance (SID), matches the declared value.
Instrumentation	○ measuring tape.
Procedure	1. Use the measuring tape to determine the distance between the external reference points for the focal spot position and the image receptor. Perform an exposure. 2. Repeat the procedure, varying the distance if feasible.
Data analysis	Compare measured SIDs with nominal SIDs, as well as those displayed on the console for variable SIDs. Additionally, compare these values with the corresponding DICOM tag (0018,1110 Distance Source to Detector) in the DICOM header of the acquired image.
Acceptability criteria	Nominal SID and the corresponding measured SID values are within 1.5% of the SID.
Type of control and frequency	Acceptance, correct operation after maintenance.

VERIFICATION OF X-FIELD CENTRING

Purpose	Check that the X-field is centred on the image detector.
Instrumentation	○ measuring tape; ○ 1-2 mm Cu attenuators (or similar, see Appendix 2).
Procedure	1. Shield the detector's centre with 1-2 mm thick Cu filters or material with similar attenuation properties. 2. Adjust the collimators to have the smallest achievable X-ray field or, in the case of completely closed collimators, an X-ray field of the order of 0.5 cm.
Analisi dei dati	● Visually inspect the X-ray field images as displayed on the monitor. ● Measure the position of the irradiated area and calculate its distance from the centre of the image.
Acceptability criteria	Within ± 2% SID.
Type of control and frequency	Acceptance, correct operation after maintenance and annually.

4. VERIFICATION OF THE DOSE INDICATORS

References	1. IEC 60601-2-43:(2022) "Particular requirements for the basic safety and essential performance of X-ray equipment for interventional procedures". 2. IEC 61910-1: 2014 "Radiation dose Documentation – Part 1: Radiation dose structured reports for radiography and radioscopy". 3. DICOM Supplement 94: "Diagnostic X-Ray Radiation kerma Reporting (kerma SR)", 2011. 4. AAPM TG 190, Accuracy and Calibration of Integrated Radiation Output Indicators in Diagnostic Radiology- 2015. 5. IEC 62494-1:2008 "Medical electrical equipment - Exposure index of digital X-ray imaging systems - Part 1: Definitions and requirements for general radiography". 6. EFOMP Protocol -Quality control of dynamic x-ray systems- 2024 7. Radiation Protection n. 162, 2012 "Criteria for acceptability of Medical Radiological Equipment used in Diagnostic Radiology, Nuclear Medicine and Radiotherapy".
Purpose	Verify the functionality of the devices that measure and/or calculate the cumulative kerma ($K_{a,r}$) at the reference point and the kerma-area product (KAP), which are installed on the equipment.
Instrumentation	○ Attenuating filters (e.g. copper and/or aluminium plates of various thicknesses or 20 cm PMMA) covering the entire area of the radiant beam at detector level; ○ kerma-area product meter (suitable for the entire measuring range, and calibrated for the relevant radiation qualities) or integrating dosimeter (suitable for the entire measuring range and calibrated for the relevant radiation qualities); ○ measuring tape; ○ device for measuring the radiation field (e.g. plate with radio-opaque graduated scale in two directions, gafchromic film, etc.) with appropriate fixing system; ○ fixing/holding system for the kerma meter.

PRELIMINARY VISUAL CHECKS:

- Display;

- Correctly working indicator light.

CORRECTLY WORKING ZERO INDICATION

Parameter of interest (applicable only to devices with ionisation chambers)

Procedure	Visually verify, without irradiation, the functionality of the air kerma rate indicators at the reference point, cumulative air kerma $K_{a,r}$ and product kerma-area KAP.
Acceptability criteria	Functionality is consistent with the specifications outlined in the user manual.

SHORT-TERM STABILITY OF EXPOSURE INDICATORS

Test method (reference conditions)	Measurement geometry: ● Vertical beam, without additional attenuators if possible; fix the object used for determining the size of the radiant field and the dosimeter on the test object. The exclusion or inclusion of the patient couch during acquisition must align with the calibration and verification mode specified by the equipment manufacturer. ● If the SID is variable, use the maximum focus-imaging distance. ● Dosimeter position: perform dosimetric measurements in the absence of scattered radiation. If the instrumentation does not have a built-in shield against backscattering, position the instrumentation midway between the tube and the radiation detector, or at the isocenter or reference point defined by the manufacturer. Ensure a minimum distance of >10 cm from diffusing surfaces. ● Additional filtration (necessary if manual selection of the tube power parameters is not possible – otherwise, 1 or 2 mmCu to protect the detector): place the additional filtration downstream of the kerma meter and in front of the image receptor, ensuring that it intercepts the entire beam. Choose a thickness that ensures sufficiently high voltage to minimize uncertainty in the measurement. It is suggested to use filtrations equal to 3 mm Cu or 20 cm PMMA for this purpose. This will help optimize the equipment's performance and maintain accurate measurements under various clinical conditions. ● FOV: select a medium-sized radiating field or follow the specifications provided in the calibration. ● Collimation: choose a visible collimation on the monitor, such as 20 cm side or diameter.

Procedure	1. Check the test conditions; if using a free-air ionization chamber, note temperature T and pressure p; note the dimensions of the radiant field. 2. Record the zeroing values of $K_{a,r}$ and KAP before each exposure for both the dosimeter and kerma indicators. 3. Ensure that the irradiance is sufficiently high, so the measurement uncertainty is not limited by the accuracy of the display (reading should be at least 50 times the last digit). 4. Record the measured values of $K_{a,r}$ and KAP, as well as those reported by the kerma meter and exposure data (kV, mA, additional filtration, field size, etc.). If the instrumentation cannot measure $K_{a,r}$ and KAP simultaneously, perform the measurements separately. 5. In the case of a point dosimeter, measure the radiant field area in the detector plane and calculate the radiant field area at the reference point. 6. Repeat the measurement three times.

Calculation method	a. If the device provides kerma at the reference point, calculate the KAP at the reference point. For a measurement with a point dosimeter placed on the detector: $$K_{a,r\,meas} = K_{a,r\,meas} \cdot fg$$ $$KAP = K_{a,r\,meas} \cdot AREA \cdot fg$$ where: - AREA is the area of the radiant beam at the interventional reference point; - fg is the geometric correction factor for the inverse of the square of the distance calculated according to the formula: $$fg = \left(\frac{SDD}{focus - reference\ point\ distance}\right)^2$$ where SDD is the Source-Detector Distance. b. Calculate: b1) the correction coefficient: $C_{KAP} = KAP_{meas}/KAP_{nom}$ where: - KAP_{meas} is the KAP value determined with the dosimeter at the reference point; - KAP_{nom} is the nominal value provided by the kerma meter, separately for each irradiation b2) the average value over the measurements made: $C_{KAP,mean}$ b3) the correction coefficient: $C_K = K_{a,r\,meas}/K_{a,r\,nom}$ where: - $K_{a,r\,meas}$ is the $K_{a,r}$ value determined with the dosimeter outside the reference point; - $K_{a,r\,nom}$ is the nominal value provided by the kerma meter, separately for each irradiation b4) the average value over the measurements made: $C_{k,mean}$
Acceptability criteria	➢ $\max\lvert C_{KAP} - C_{KAPmean}\rvert \le 5\%$ ➢ $\max\lvert C_K - C_{Kmean}\rvert \le 5\%$
Type of control and frequency	Acceptance, correct operation after maintenance and annually.

ACCURACY AND CALIBRATION OF INDICATORS AS ENERGY, KERMA RATE, FIELD SIZE CHANGE

Procedure	Under the reference conditions mentioned in the previous section, vary the following parameters: 1. *kerma rate:* repeat the measurement for other clinically relevant exposure modes, such as high kerma rate, low kerma rate, in fluoroscopy and in fluorography; 2. *energy:* if possible, vary the kV (in the range 60 - 120 kV) or vary the additional filtration to obtain a couple of irradiations at different energies and repeat the measurement; 3. *field size:* repeat the measurement for a smaller field size (e.g. 15 cm·15 cm). It is preferable to obtain different fields not only through different magnification, but also through different mechanical collimations.
Acceptability criteria	The correction coefficient C of the nominal value with respect to the measured value must be: $0.65 \le C \le 1.35$ achievable: $0.80 \le C \le 1.20$* * provisional value
Type of control and frequency	Acceptance, correct operation after maintenance and annually.

5. VERIFICATION OF IMAGE QUALITY

References	1. Linee Guida Flat Panel AMFPD - AIFM 2009. 2. Radiation Protection n. 162, 2012 "Criteria for acceptability of Medical. Radiological Equipment used in Diagnostic Radiology, Nuclear Medicine and Radiotherapy". 3. IPEM Report 91"Recommended Standards for the Routine Performance Testing of Diagnostic X-ray Imaging Systems" (2005). 4. Acceptance Testing and Quality Control of Photostimulable Storage Phosphor Imaging Systems" dell'American Association of Physicists in Medicine. AAPM Report n. 93, Task Group 10 (2006). 5. R.T Droege A practical method to measure the MTF of CT scanners Medical Physics 9(5):758-60 · September 1982. 6. IEC 61223-3-3 -Imaging performance of X-ray equipment for digital subtraction angiography. 7. EFOMP Protocol -Quality control of dynamic x-ray systems- 2024. 8. PARUCCINI, Nicoletta, et al. A single phantom, a single statistical method for low-contrast detectability assessment. Physica Medica, 2021, 91: 28-42.
General remarks	This chapter explores image quality checks performed using standard commercial phantoms on "**FOR PRESENTATION"** images. Acquire images using the most frequently used clinical protocols in various modalities, such as fluoroscopy, fluorography, etc. Use the FOV most commonly applied in clinical practice. Note that the proposed evaluations are carried out under scatter-free conditions, which do not represent the C-arm's actual operation. However, it is possible to replicate the proposed measurements under scatter conditions, more closely resembling clinical settings. This condition can be achieved by inserting the test objects in a phantom with layers of adequate thickness, e.g. 20 cm PMMA.

GEOMETRIC DISTORTION (II ONLY)

Purpose	Check the image for geometric distortion.
Instrumentation	○ Test object containing a high-contrast square grid clearly resolvable on the image.
Procedure	1. Place the test object on the input window of the II. 2. Acquire image in automatic exposure settings with maximum FOV.

Data analysis	Examine the produced image on the monitor and identify any geometric distortion that may be present. If possible, quantify the distortion by measuring it with a ruler or by exporting the image. It may be helpful to calculate the integral geometric distortion (IGD), which defined as follows: $$IGD = \frac{\left(\frac{D_{small}}{D_{big}}\right)_{img}}{\left(\frac{D_{small}}{D_{big}}\right)_{true}}$$ where: • IGD: integral geometric distortion • D_{small}: grid mesh size in central position • D_{big}: size of a mesh group covering a large part of the FOV • img: evaluation made on the image • true: evaluation made on the true dimensions of the grid.
Acceptability criteria	The observed geometric distortion should be negligible. If quantitatively measured, the integral geometric distortion must be less than 10%. Please note that certain types of geometric distortion (e.g. “pincushion”, “barrel”) are dependent on the device’s video system, while others (e.g. “sigma”) rely on the magnetic surroundings of the device.
Type of control and frequency	Acceptance, correct operation after maintenance and annually.

SPATIAL RESOLUTION (FLUOROSCOPY AND FLUOROGRAPHY)

Purpose	Check the maximum spatial resolution for setups of clinical interest.
Instrumentation	○ Leeds 18FG phantom or line pairs test pattern.
Procedure	1. Position the phantom as close to the detector as possible, removing the grid if feasible 2. Orient the phantom so that the spatial resolution bars are at 45-degrees angle to the digitising matrix. 3. Acquire images in automatic exposure settings for the most frequently used FOV values or for the reference FOV used for kerma measurements at patient entrance. 4. Acquire images in different modes. 5. Count on the monitor the number of inserts in which B/W line pairs are visible and identify the limiting spatial frequency. 1. Record the mode used, protocol, kV, mA/mAs, SID, FOV and spatial resolution limit value.
Data analysis	Export images, if necessary. Note that when exporting from certain devices, the pixel size may vary. For an objective evaluation, place a circular ROI on the insets corresponding to the spatial frequency of interest. Calculate the MTF using Droege's method and determine the frequency value for which the MTF drops below 20% [5].

Acceptability criteria	➢ For fluoroscopic images, the spatial resolution limit should be greater than 0.8 lp/mm for field sizes larger than 25 cm and greater than 1 lp/mm for field sizes equal to or smaller than 25 cm. ➢ During periodic tests, the limiting frequency should not deviate by more than 25% from the initial test results.
Typical values	The reference values for maximum spatial resolution provided in the acceptability criteria are outdated, as they are associated with devices using image intensifiers. The working group has identified typical spatial resolution values: ● II diameter (cm) / lp/mm: 20 ÷ 23 — 2.0; 14 ÷ 18 — 2.8; 10 ÷ 13 — 2.8 ● digital detector size (cm) / lp/mm: 30 ÷ 32 — 1.6; 20 ÷ 23 — 2.5; 14 ÷ 17 — 2.8; 11 ÷ 13 — 2.8
Type of control and frequency	Acceptance, correct operation after maintenance and annually.

Typical values – II:

diameter (cm)	lp/mm
20 ÷ 23	2.0
14 ÷ 18	2.8
10 ÷ 13	2.8

Typical values – digital detector:

size (cm)	lp/mm
30 ÷ 32	1.6
20 ÷ 23	2.5
14 ÷ 17	2.8
11 ÷ 13	2.8

1. LOW CONTRAST/SENSITIVITY THRESHOLD (FLUOROGRAPHY AND FLUOROSCOPY)

Purpose	Assess the contrast threshold for large inserts or evaluate low-contrast sensitivity (contrast-detail curve), based on the available phantoms.
Instrumentation	○ Leeds 18FG phantom (or similar phantoms), TO20 (or similar); ○ 1 mm Cu or the attenuator supplied with the phantom being used. Note: some phantom manufacturers provide nominal contrasts only for specific attenuator thickness ranges and certain kV ranges.

Procedure	1. Filter the X-ray beam with the attenuator. 2. Place the phantom as close to the detector as possible. 3. Acquire images in automatic exposure settings for the most frequently used FOV values. 4. Record the mode, protocol, kV, mA, SID, FOV and the number of visible inserts (if possible, for each set of details with the same diameter). 5. Count the total number of visible discs at an observation distance of at least four times the diameter of the displayed image on the monitor. 6. Obtain images in various modes: fluoroscopy, fluorography.
Data analysis	To determine the minimum detectable contrast, convert the number of visible inserts using the tables provided for the specific phantom being used, interpolating the data if necessary. As an example, refer to the conversion table for the Leeds 18FG phantom.
Acceptability criteria	➢ In fluoroscopy mode and for large details (with diameter in the order of cm), the insert corresponding to the 4% contrast should be visible. ➢ During periodic proper operation tests, the last visible large detail must be within ±1 detail from the acceptance test results.
Typical values	Contrast threshold range in fluoroscopy: ⧫ II: 2.2% - 2.7% ⧫ digital detector: 1.7%- 2.4%
Type of control and frequency	Acceptance, correct operation after maintenance and annually.

Leeds 18FG phantom conversion table (1 mmCu added)

Disk number	Contrast at 60 kVp	Contrast at 70 kVp	Contrast at 80 kVp
1	0.213	0.167	0.149
2	0.190	0.148	0.132
3	0.165	0.128	0.114
4	0.141	0.109	0.097
5	0.113	0.088	0.078
6	0.096	0.075	0.067
7	0.088	0.067	0.060
8	0.067	0.053	0.047
9	0.059	0.045	0.040
10	0.046	0.039	0.036
11	0.038	0.032	0.030
12	0.032	0.027	0.025
13	0.025	0.022	0.020
14	0.020	0.017	0.016
15	0.018	0.015	0.015
16	0.015	0.013	0.012
17	0.013	0.011	0.010
18	0.010	0.009	0.008

2. THRESHOLD CONTRAST DETECTABILITY – STATISTICAL METHOD (FLUOROGRAPHY AND FLUOROSCOPY)

Purpose	Check the contrast-detail curve [8].
Instrumentation	○ LCD (Low Contrast Detectability) phantom consisting of e.g. aluminium step wedges with at least 5 steps of variable and known thickness (e.g. 0.25 mm, 0.50 mm, 0.75 mm, 1.00 mm and 1.25 mm) and a homogeneous region of size 4·4 cm^2 and known thickness (e.g. 0.50 mm aluminium). ○ 1.5 mm Cu attenuator filter. ○ PMMA thicknesses (e.g. 10 cm, 15 cm, 20 cm).
Procedure	1. Position the 1.5 mm Cu filter at the X-ray tube outlet. 2. Place the LCD phantom in such a way that the aluminium insert is centered on the detector and the aluminium step wedge is perpendicular to the anode-cathode direction. 3. Acquire images with the various available modes of operation (e.g. fluoroscopy, fluorography, angiography). 4. If necessary, repeat the acquisitions with the addition of PMMA phantoms of varying thicknesses (e.g., 10 cm, 15 cm, and 20 cm).

Data analysis	• First, export the images.
	• Calculate the threshold values of contrasts C_t expressed in mmAl, for the different low-contrast inserts by analysing the runs acquired with the programme downloadable from https://www.lcdlab.org/downloads. The calculation method consists of the following steps:
	    ○ select a ROI (typically 120·120 pixels) in the homogeneous aluminium region.
	    ○ Subdivide the ROI into smaller-sized ROI (e.g. 5·5 pixels) to obtain a 24·24 matrix of smaller ROIs.
	    ○ Calculate the average value of each of these 24·24 ROIs.
	    ○ Calculate the standard deviation (s) of the mean values.
	    ○ Calculate the value $C_{th} = 3.29 \cdot s$
	• Perform the same steps for additional ROIs of varying sizes.
	• To generate the contrast-detail curve, plot the product of the smaller ROI size (in pixels) multiplied by the pixel size (in mm) on the x-axis and the corresponding C_{th} contrast threshold on the y-axis.
	• Employ the aluminium step wedges to convert the signal into mmAl units. If the aluminium step wedge is not available, the statistical method can also be applied to a homogeneous image as well (e.g. an image for uniformity testing). By doing so, the C_{th} value will be expressed in relative terms (percentage) rather than absolute terms (mmAl), removing the dependence on the energy of the incident X-ray beam, for example. Compute C_{th} using the method outlined in this section and obtain the C_{th} % value by dividing C_{th} by the mean value of the ROI under examination.

Typical values	Preliminary typical value in fluoroscopy per digital panel: C_{th}=0.9% or 0.36 mmAl for the 2.5 mm detail.

Type of control and frequency	Acceptance, correct operation after maintenance and annually.

SUBTRACTED IMAGE QUALITY- DSA IMAGES

Purpose	Assess the performance of subtracted images, if applicable, by evaluating various aspects such as dynamic range, contrast resolution, contrast uniformity, artefacts and logarithmic errors.
Instrumentation	○ X-CHECK DSA (formerly NORMI 8) DSA Test Object described in EN 61223-3-3 or similar phantoms.
Procedure	1. Place the phantom on the patient couch, ensuring that the low-contrast insert is centered at the isocenter. 2. Obtain images in DSA mode using automatic exposure conditions, using a subtractive angiographic protocol for a duration of 10 s. 3. Acting on the pump device, move the low-contrast inserts contained in the phantom and acquire for a further 10 s; take note of the kV, mA, SID and FOV values.
Data analysis	• Examine the subtracted images carefully. If the acquisition kV falls within the range 70÷80 kV, it is possible to associate the insert number with a concentration value of iodine solution (e.g. for the X-CHECK DSA phantom, aluminium inserts of 0.05 mm to 0.40 mm thickness correspond to an iodine solution of 5 mg/cm^2 to 10 mg/cm^2).
Acceptability criteria	The data acquired from the proper function evaluations serve as a baseline for subsequent tests. When utilizing the X-CHECK DSA, the subtracted image should generally allow for the visualization of details as follows: ➢ Dynamic range: the vessel with the maximum thickness (0.40 mm Al) should be visible under all thicknesses of the copper step wedge (vascular test). ➢ Contrast resolution: all four aluminium inserts (0.40 mm, 0.20 mm, 0.10 mm and 0.05 mm) should be visible below the 0.8 mm Cu step. ➢ Uniformity of contrast: the aluminium inserts should exhibit uniform density and width across the entire image. ➢ Artifacts: no registration artefacts should be present on the self-subtracted images. ➢ Logarithmic error: assess the density of the first and last equivalent step.
Type of control and frequency	Acceptance, correct operation after maintenance and annually.

6. VERIFICATION OF THE DOSIMETRIC CHARACTERISTICS

The dosimetric characteristics of X-ray equipment are crucial in ensuring patient radiation protection.
To achieve this, it is essential to test these characteristics under conditions that closely resemble those commonly employed in clinical practice. Unfortunately, the Medical Physicist conducts acceptance tests using protocols that still require adaptation to the clinical needs. In such situations, it is recommended to perform the tests in PART II of this section after the clinical protocols have been finalised, whenever feasible.

Type of control	**PART I: basic dosimetric controls** • Maximum air kerma rate at patient entry - fluoroscopy mode • Air Kerma and its rate at patient entry - fluoroscopy and fluorography • Air Kerma and its rate at detector entrance – fluoroscopy and fluorography
Purpose	These controls are designed to verify compliance with the limits/threshold values advised by the technical reference documents. For these controls, it was considered appropriate to clearly define the measurement conditions in detail.

Type of control	**PART II: Checks aimed at verifying the reproducibility of C-arm operation.** Reproducibility of equipment operation for all protocols of clinical interest - fluoroscopy and fluorography.
Purpose	For this particular type of control, it is not deemed necessary to rigidly determine the measurement conditions; it is suggested to establish a sequence of controls that can be repeated more frequently than those in PART I, using copper or aluminum filters as attenuators. For tests of proper operation, it may be sufficient to verify that the exposure parameters automatically selected by the system remain constant.

References	1. Functionality and Operation of Fluoroscopic Automatic Brightness Control/Automatic Kerma Rate Control Logic in Modern Cardiovascular and Interventional Angiography systems – A Report of AAPM Task Group 125. 2. Radiation Protection n. 162, 2012 "Criteria for acceptability of Medical Radiological Equipment used in Diagnostic Radiology, Nuclear Medicine and Radiotherapy". 3. IAEA 457: Dosimetry in Diagnostic Radiology: an International Code of Practice IAEA Technical reports series 457, 2007. 4. A. Dowling, A. Gallagher, U. O' Connor et al "Acceptance testing and QA of interventional cardiology systems" Radiation Protection Dosimetry 2008, pp. 1-4. 5. C J Martin, DG Sutton, A. Workman et al "Protocol for measurement of patient entrance surface kerma rates for fluoroscopic x-ray equipment" Br J Radiol 1998 Dec; 71 (852): 1283-7. 6. IPEM 2005a Institute of Physicists and Engineers in Medicine. Recommended Standards for the Routine Performance Testing of Diagnostic X-Ray Imaging Systems, Report 91. York: Institute of Physicists and Engineers in Medicine. 7. Choice of Phantom Material and Test Protocols to Determine Radiation Exposure Rates for Fluoroscopy Jon A. Anderson, PhD • Jihong Wang, PhD • Geoffrey D. Clarke, PhD RadioGraphics 2000; 20:1033–1042. 8. Survey of Pediatric Fluoroscopic Air Kerma Rate Values and Recommended Application of Results The Report of AAPM Task Group 251 April 2022.
Instrumentation	○ Attenuating filters, 2 mm Pb, or at least 30 cm of PMMA or equivalent material (Al, Cu) with sufficient dimensions to completely cover the radiant beam area at the detector level; ○ kerma rate meter suitable for the entire measurement range and calibrated for relevant radiation qualities; ○ measuring tape; ○ kerma meter attachment/support system.
Dosimetric parameters	• $K_{a,e}$ (entrance air kerma with backscatter) for backscatter measurements • $K_{a,i}$ (incident air kerma without backscatter) for scatter-free measurements.

PART I: BASIC DOSIMETRIC CONTROLS

MAXIMUM AIR KERMA RATE AT PATIENT ENTRY (FLUOROSCOPY MODE)

Procedure	The measured quantity is $K_{a,i}$ (incident air kerma without backscatter). If an ionization chamber is used, it is necessary to correct the reading with the appropriate backscattering factor (typical value of 1.3) or refer to IAEA Table 457 (Appendices Table 1a and 1b). The measurement should be made in fluoroscopy mode, aiming to achieve the highest possible kerma rate. As it is not possible to determine beforehand whether this condition occurs at the maximum or minimum source-detector distance, the verification process should be conducted under both conditions during the acceptance test. During subsequent verifications, perform the measurement solely under the condition that previously resulted in the highest kerma rate. Select the smallest FOV, or the FOV with the highest exposure, along with the exposure mode with the highest number of pulses per second. Perform measurements in the fluoroscopy mode with the highest dose setting, without removing the grid. **Mode 1 (with Lead filter)** 1. Place a 2 mm lead filter on the detector. 2. Using a suitable support, place the dosimeter 30 cm from the detector, in the air. As an alternative, obtain the measurement at 30 cm from the detector by placing the dosimeter on the lead filter and applying the inverse square law correction to its reading based on the distance from the X-ray tube. **Mode 2 (with 30 cm PMMA)** Do the measurement in PA or in lateral projection, as is most convenient. *PA projection* 1. Place the PMMA phantom on the patient table, ensuring there is enough space between the table and the first slab to insert the detector. Maintain contact between the detector and the phantom, using small polystyrene shims, if needed. Place the dosimeter under the phantom, facing the X-ray tube, in a central position that doesn't interfere with the AEC system. *Lateral projection* 1. Place the phantom with the detector placed in contact with the first PMMA slab facing the X-ray tube. Position it centrally but in a manner that doesn't affect the AEC system. 2. Adjust the height of the table so that the phantom is almost in contact with the detector, thereby maintaining a 30 cm distance between the measuring point and the detector.
Acceptability criteria	Maximum air kerma rate at patient entrance: ➢ "Normal level" <88 mGy/min [1] ➢ "High level" <176 mGy/min [1]
Typical value	"Normal level" ≈ 44 mGy/min
Type of control and frequency	Acceptance, proper operation after maintenance (annual only level 2).

AIR KERMA AND ITS RATE AT THE PATIENT'S ENTRANCE (FLUOROSCOPY AND FLUOROGRAPHY)

<table>
<tr><td>Instrumentation</td><td>

Kerma meter suitable for the entire measurement range, calibrated for relevant radiation qualities;
measuring tape;
20 cm thick attenuator phantom with sufficient dimensions to completely cover the radiant beam area at detector level. The phantom material should be either PMMA or as an alternative, a container filled with 20 cm water. For dedicated extremity C-arms, use a 5 cm PMMA phantom or a 5 cm water-filled container.

Keep in mind that PMMA results in an approximately 1.22 times increase in kerma rate compared to water for the same thickness, as per reference [5]. The equivalent thickness of PMMA to 20 cm of water is 18.5 cm (refer to Appendix, Table 2).
</td></tr>
<tr><td>Procedure</td><td>

Position the C-arm and choose the rotation 0° (PA projection) or 90° (lateral projection)
PA projection: Position the phantom on the patient table, ensuring there is enough space between the table and the phantom to insert the detector. Use small polystyrene shims if needed. Place the dosimeter in contact with the phantom, facing the X-ray tube, in a central position that doesn’t interfere with the AEC system.
Lateral projection: Place the kerma detector in contact with the phantom and facing the X-ray tube. Position it centrally but in a manner that doesn’t affect the AEC system.
Set the source-detector distance to 100 cm, if possible.
Adjust the table height so that the phantom's surface is 10 cm away from the image detector. Measure and record the source-detector distance for reference.
Ensure that the grid is inserted for all measurements.
Select the most frequently used clinical protocol(s).
Perform measurements in both fluoroscopy and fluorography modes, according to the clinical use.
Record the exposure parameters automatically selected by the system (kV, mA, pulses/s, additional filtering applied).
Repeat the $K_{a,e}$ or $K_{a,e}$ per frame rate to assess their stability, while also monitoring the variability of the parameters.
If using a solid-state dosimeter, multiply the measured value by the backscattering factor (typical value of 1.3) or refer to IAEA Table 457 (Appendices Table 1a and 1b) for appropriate correction.
Perform measurements for the most clinically relevant FOV values according to clinical use.

</td></tr>
</table>

<table>
<tr>
<td>Reference values</td>
<td>
Fluoroscopy with a water phantom 20 cm thick [5].
<table>
<tr><th colspan="4">Rate of air kerma at patient entrance (mGy/min)</th></tr>
<tr><th>FOV</th><td>Low</td><td>Normal</td><td>High</td></tr>
<tr><td>11-14</td><td><25</td><td>25-50</td><td>51-75</td></tr>
<tr><td>15-18</td><td><23</td><td>23-46</td><td>47-79</td></tr>
<tr><td>22-27</td><td><15</td><td>15-30</td><td>31-45</td></tr>
<tr><td>28-33</td><td><12</td><td>12-24</td><td>25-36</td></tr>
</table>
Fluoroscopy with a water phantom 20 cm thick and FOV 30 cm [8]
<table>
<tr><th>Modality</th><th>Air kerma rate at patient entrance
Median [25th - 75th percentile]</th></tr>
<tr><td>Pulsed fluoroscopy 7.5 p/s</td><td>3.7 [3.2-4.5] mGy/min</td></tr>
<tr><td>Continuous fluoroscopy</td><td>12.5 [10.3-16.8] mGy/min</td></tr>
<tr><td>Single shot fluorography</td><td>0.48 [0.47-0.53] mGy/frame</td></tr>
</table>
</td>
</tr>
<tr>
<td>Acceptability criteria</td>
<td>
Rate of kerma at phantom entrance ($K_{a,e}$), for “Normal” fluoroscopic mode: <100 mGy/min [2, 5, 6]

Kerma at phantom entrance per frame ($K_{a,e}$/frame):
➢ Angiographic mode < 2.0 mGy/frame [2, 6]
➢ Cardiac mode < 0.2 mGy/frame [2, 4]

Limits are given for measurements in 20-cm water phantom under the exposure conditions given in the document [5].
</td>
</tr>
<tr>
<td>Typical values</td>
<td>
Typical values identified by the working group for normal fluoroscopy and FOV 20-30 cm:
⧫ 4.5 mGy/min pulsed fluoroscopy, normalized to 7.5 p/s;
⧫ 26.4 mGy/min continuous fluoroscopy.
</td>
</tr>
<tr>
<td>Type of control and frequency</td>
<td>
Acceptance, correct operation after maintenance.
It is important to repeat this verification immediately after the clinical protocols have been established.
</td>
</tr>
</table>

AIR KERMA AND ITS RATE AT DETECTOR ENTRANCE (FLUOROSCOPY AND FLUOROGRAPHY)

Instrumentation	○ Cu filters with a thickness of approximately 2 mm or Al filters with a thickness of about 20 mm. For extremity imaging devices, use a 0.5 mm thick Cu filter or an equivalent attenuation material; ○ kerma meter suitable for the entire measuring range and calibrated for relevant radiation qualities; ○ measuring tape.
Procedure	1. Position the C-arm to 0° rotation (PA projection). 2. Place the filters in contact with the collimator. 3. Set the source-detector distance of 100 cm, or the distance most frequently used in clinical practice. 4. Remove the grid (if the grid factor is measured during acceptance, it can be omitted in subsequent tests by correcting the measured rate value accordingly). 5. Place the dosimeter on the image receptor. 6. Select the most frequently used clinical protocol(s). 7. Perform measurements in “Normal Level” mode. 8. Record the exposure parameters automatically selected by the system (kV, mA, pulses/s, additional filtering). 9. Repeat the kerma rate measurement to assess their stability while monitoring the variability of the parameters. 10. Perform measurements for the most clinically relevant FOVs according to clinical use.
Acceptability criteria	Typical values for devices with II [2, 4, 6] and 20-cm water phantom: ➢ <1 µGy/s in normal fluoroscopy mode, with FOV 25 cm; ➢ < 5 µGy/frame in angiographic mode; ➢ <0.5 µGy/frame in cardiac mode.
Typical value	0.35 µGy/s for digital detector in normal fluoroscopy mode with FOV 30 cm.
Type of control and frequency	Acceptance, correct operation after maintenance. It is important to repeat this verification immediately after the clinical protocols have been established.

AEC SYSTEM VERIFICATION (FLUOROSCOPY MODE)

Instrumentation	● Cu or Al metal attenuators, with at least two different thickness (Cu between 1 and 2.5mm; Al between 10 and 20mm); for extremity machines Cu between 0.5mm and 1mm or other material of equivalent attenuation; ● kerma meter suitable for the whole measurement range and calibrated for the relevant beam qualities; ● tape measure.
Procedure	1. Set the C-arm and select the 0° position (PA projection). 2. Remove the grid (if in acceptance the attenuation factor of the grid is measured, thereafter it is possible not to remove it but to correct the measured rate with the attenuation factor). 3. Select the 100cm SID, or the SID more used in clinical practice. 4. Place the dosimeter on the image detector. 5. Perform measurements for the most significant FOVs according to clinical use. 6. Place the first filter in contact with the collimator. 7. Select a reference protocol, or the most frequently used clinical protocols if already present. 8. Make the measurement in the “Normal Level” mode. 9. Record the exposure parameters automatically selected by the system (kV, mA, pulse/s, filtration). 10. Change the filter and repeat points 7, 8, 9. 11. Calculate CVmax, that is, the maximum deviation of the kerma rate value associated with the individual filter from the average kerma value for all the filters used.
Acceptability criteria	The proper operation of the automatic exposure control system is an indispensable element in ensuring the optimization of the examination. Therefore, it is considered to adopt the typical value recorded during intercomparison measurements as a provisional acceptability criterion.
Typical value	CVmax< 30%
Type of control and frequency	Acceptance, correct operation after maintenance.

PART II: REPRODUCIBILITY OF THE C-ARM (FLUOROSCOPY AND FLUOROGRAPHY)

Instrumentation	○ Cu or Al or PMMA filters (see Appendix 2)
Procedure	Fluoroscopy mode: 1. Position the C-arm and choose 0° rotation (PA projection). 2. Place the filters in contact with the collimator, or in another suitable location that allows them to intercept the entire beam effectively. 3. Set the focus-detector distance to 100 cm, or the distance most commonly used in clinical practice. 4. Select the most frequently used clinical protocol(s). 5. When varying the field size, the most commonly used clinical modes (fluoroscopy, fluorography, cinematography, low/normal/high dose) and the thickness of the phantom (for example, from 1 to 4 mm Cu or similar absorbing materials, see Appendix 2), record the filtration added by the equipment, kV, mA, pulse rate and pulse width selected by the automatic system. As a second level, if the sensor does not influence the AEC, it is also possible to measure the dose rate at the entrance of the detector window or, alternatively, the dose rate at the entrance of the attenuator filters. In the latter case, however, the attenuators must be positioned on the detector, so they must be larger in size in order to intercept the entire beam.
Frequency	In order to test the performance of the C-arm, it is advised to set a frequency of at least once a year, taking into account how the C-arm is used.
Acceptability criteria	Check the constancy of these parameters (tolerances with respect to baseline values): ➢ kV: 5%; ➢ mA: 20%; ➢ mAs: 20%; ➢ pulse width: 20%; ➢ reproducible filtration and pulse rate; ➢ dose rate (if measured): 25%.
Considerations	When possible, it is more practical to use metallic attenuators for testing. However, be aware that some manufacturers' automatic exposure control devices may not work correctly with metallic attenuators. In such cases, it is the responsibility of the Medical Physicist to assess the practical feasibility of conducting this test using low-Z attenuators, such as water or PMMA. In the event that it is still decided to proceed with the use of metallic attenuators, the test may remain valid for the evaluation of reproducibility. However, the attached data and the setups selected by the equipment cannot be used to draw conclusions about the parameters that the radiological equipment automatically selects when used with patients.

7. VERIFICATION OF CONNECTIVITY

The tests in this section are designed to monitor the connectivity. However, in healthcare settings, the organizational structure often leads to Medical Physicists conducting acceptance tests on radiological equipment that has not been fully configured for connectivity. This circumstance may pose challenges in organizing and carrying out a comprehensive evaluation of certain aspects addressed in this section, potentially affecting the overall testing process and results.

IMAGES TRANSMISSION TO PACS AND WORKLIST AVAILABILITY

Instrumentation	None
Procedure	1. On the equipment console, verify that a patient can be selected from the worklist. 2. After completing the acquisitions, close the study and send it to PACS, ensuring that the patient's data is properly stored.
Acceptability criteria	-
Type of control and frequency	Acceptance, correct operation after maintenance.

SOFTWARE VERSION

Instrumentation	None
Procedure	At power-up, read and note the version of the equipment application software in the dedicated area or on the DICOM header. On the images, the DICOM tag is (0018,1020). In case of software version changes, inquire from the manufacturer what the variations are between the two versions. In case the variations may have a dosimetric or image quality impact, or if such information is not available, schedule a proper function test that affects the aspects that are assumed to have been affected by the software variation.
Acceptability criteria	-
Type of control and frequency	Acceptance, correct operation after maintenance and annually.

PROPER TRANSMISSION OF EXPOSURE DATA TO RDMS (GEOMETRIC AND DOSIMETRIC)

Instrumentation	None
Procedure	1. Verify that the C-arm is configured to transmit data to the Radiation Dose Structured Report (RDMS). 2. Check that a study performed on the equipment and containing known geometric information (e.g., that relating to source-detector distance verification) is present on the RDMS. Verify that data taken at the console, including linear positions and angular C-arm positions, are consistently reported on both DICOM header and RDMS. Relevant DICOM tags include: ○ 0018,1110 Distance Source to Detector; ○ 0018,1510 Positioner Primary Angle; ○ 0018,1511 Positioner Secondary Angle. A comprehensive table with DICOM TAGs of interest can be found in Appendix 4. 3. Verify that a study performed on the C-arm containing exposures with known dosimetric indicators, such as those related to verification of integrated dose indicators and Exposure Index (EI), is present in the RDMS. Verify the consistency of the exposure data recorded in the DICOM header and RDMS with the data detected at the console. Relevant DICOM tags include: ○ 0018,115E Image and Fluoroscopy Area Dose Product ○ 0018,1411 Exposure Index ○ 113722 Dose Area Product Total (in the RDSR) ○ 113738 Dose at Reference Point (in the RDSR).
Acceptability criteria	Complete consistency between data at console and data recorded in RDMS.
Type of control and frequency	Acceptance, correct operation after maintenance.

APPENDIX

APPENDIX 1 – TABLES

TABLE 1A - BACKSCATTER FACTOR (IAEA TECHNICAL REPORT N°457)

TABLE VIII.1. BACKSCATTER FACTORS, *B*, FOR WATER, ICRU TISSUE AND PMMA FOR 21 DIAGNOSTIC X RAY BEAM QUALITIES AND FOR THREE FIELD SIZES AT A FOCUS TO SKIN DISTANCE OF 1000 mm*

Tube voltage (kV)	Filter	Field size	100 mm × 100 mm			200 mm × 200 mm			250 mm × 250 mm		
		HVL (mm Al)	Water	ICRU tissue	PMMA	Water	ICRU tissue	PMMA	Water	ICRU tissue	PMMA
50	2.5 mm Al	1.74	1.24	1.25	1.33	1.26	1.27	1.36	1.26	1.28	1.36
60	2.5 mm Al	2.08	1.28	1.28	1.36	1.31	1.32	1.41	1.31	1.32	1.42
70	2.5 mm Al	2.41	1.30	1.31	1.39	1.34	1.36	1.45	1.35	1.36	1.46
70	3.0 mm Al	2.64	1.32	1.32	1.40	1.36	1.37	1.47	1.36	1.38	1.48
70	3.0 mm Al +0.1 mm Cu	3.96	1.38	1.39	1.48	1.45	1.47	1.58	1.46	1.47	1.59
80	2.5 mm Al	2.78	1.32	1.33	1.41	1.37	1.39	1.48	1.38	1.39	1.50
80	3.0 mm Al	3.04	1.34	1.34	1.42	1.39	1.40	1.51	1.40	1.41	1.52
80	3.0 mm Al +0.1 mm Cu	4.55	1.40	1.40	1.49	1.48	1.50	1.61	1.49	1.51	1.63
90	2.5 mm Al	3.17	1.34	1.34	1.43	1.40	1.41	1.51	1.41	1.42	1.53
90	3.0 mm Al	3.45	1.35	1.36	1.44	1.42	1.43	1.53	1.42	1.44	1.55
90	3.0 mm Al +0.1 mm Cu	5.12	1.41	1.41	1.50	1.50	1.51	1.62	1.51	1.53	1.65
100	2.5 mm Al	3.24	1.34	1.34	1.42	1.40	1.41	1.51	1.41	1.42	1.53
100	3.0 mm Al	3.88	1.36	1.37	1.45	1.44	1.45	1.55	1.45	1.46	1.57

TABLE 1B - BACKSCATTER FACTOR (IAEA TECHNICAL REPORT N° 457)

TABLE VIII.1. BACKSCATTER FACTORS, *B*, FOR WATER, ICRU TISSUE AND PMMA FOR 21 DIAGNOSTIC X RAY BEAM QUALITIES AND FOR THREE FIELD SIZES AT A FOCUS TO SKIN DISTANCE OF 1000 mm* (cont.)

Tube voltage (kV)	Filter	Field size	Backscatter factor (*B*) 100 mm × 100 mm			200 mm × 200 mm			250 mm × 250 mm		
		HVL (mm Al)	Water	ICRU tissue	PMMA	Water	ICRU tissue	PMMA	Water	ICRU tissue	PMMA
100	3.0 mm Al +0.1 mm Cu	5.65	1.41	1.42	1.50	1.51	1.53	1.64	1.53	1.55	1.66
110	2.5 mm Al	3.59	1.35	1.35	1.43	1.42	1.43	1.53	1.43	1.44	1.55
120	3.0 mm Al	4.73	1.37	1.38	1.46	1.46	1.48	1.58	1.48	1.49	1.60
120	3.0 mm Al +0.1 mm Cu	6.62	1.41	1.42	1.50	1.53	1.54	1.64	1.54	1.56	1.67
130	2.5 mm Al	4.32	1.36	1.36	1.44	1.44	1.45	1.55	1.45	1.47	1.57
150	2.5 mm Al	4.79	1.36	1.36	1.44	1.45	1.46	1.55	1.46	1.48	1.58
150	3.0 mm Al	6.80	1.39	1.39	1.47	1.50	1.51	1.61	1.52	1.53	1.63
150	3.0 mm Al +0.1 mm Cu	8.50	1.40	1.41	1.48	1.53	1.54	1.64	1.55	1.57	1.67

* Data taken from Petoussi-Henss et al. [VIII.1].

APPENDIX 2 - EQUIVALENT THICKNESSES

Thicknesses of various materials to obtain approximately equivalent attenuation, for beam generated at constant 80 kVp, HVL 3.4 mmAl.

However, the output beam spectrum will not have the same shape.

Water	Al	Cu	PMMA
20 cm	50 mm	2,8 mm	18 cm
30 cm	80 mm	5,0 mm	28 cm

APPENDIX 3 - TYPICAL VALUES

The table shows the distribution of the data found by the working group, for the main parameters measured.

Parameter	25th percentile	median	75th percentile
Non-Uniformity - NULS	0.2	0.3	1.2
Non-Uniformity - NUGS	5.4	10.8	13.5
Inaccuracy kV - maximum errors for individual equipment	2%	3%	4%
HVL (mmAl) - 40 kV	1.6	1.6	1.7
HVL (mmAl) - 50 kV	2.7	2.7	3.2
HVL (mmAl) - 60 kV	3.4	3.4	3.9
HVL (mmAl) - 70 kV	4.1	4.1	4.6
HVL (mmAl) - 80 kV	4.8	4.8	5.3
HVL (mmAl) - 90 kV	5.2	5.2	5.8
HVL (mmAl) - 100 kV	5.9	5.9	6.4
HVL (mmAl) - 110 kV	6.4	6.4	6.9
HVL (mmAl) - 120 kV	6.6	6.6	7.3
Limiting spatial resolution (lp/mm) per II of 20÷23 cm diameter	1.8	2.0	2.0
Limiting spatial resolution (lp/mm) per II of 14÷18 cm diameter	2.2	2.8	2.8
Limiting spatial resolution (lp/mm) per II of 13÷10 cm diameter	2.8	2.8	3.0
Limiting spatial resolution (lp/mm) for digital panel of 30÷32 cm side.	1.4	1.6	2.0
Limiting spatial resolution (lp/mm) for digital panel of 20÷23 cm side.	2.0	2.5	2.5
Limiting spatial resolution (lp/mm) for digital panel of 14÷17 cm side.	2.4	2.8	2.8
Limiting spatial resolution (lp/mm) for digital panel of 11÷13 cm side.	2.7	2.8	3.0

Parameter	25th percentile	median	75th percentile
Contrast threshold (fluoroscopy) – II.	2.0%	2.6%	3.2%
Contrast threshold (fluoroscopy) - digital panel.	1.5%	1.9%	2.5%
Contrast threshold with LCD statistical method - digital panel.	0.71% - 0.27mmAl	0.87% - 0.28mmAl	1.13% - 0.36mmAl
Maximum air kerma rate at patient entrance (fluoroscopy) (mGy/min) - "normal level".	24	44	57
Rate of air kerma at patient entrance: normal fluoroscopy and FOV 20÷30 cm (mGy/min) - normalized pulsed at 7.5 p/s.	3.4	4.5	5.4
Rate of air kerma at patient entrance: normal continuous fluoroscopy and FOV 20÷30 cm (mGy/min).	15	26	38
Rate of air kerma at detector input (µGy/s) - normal fluoroscopy, digital panel, FOV 30 cm.	0.23	0.35	0.57

APPENDIX 4 - DICOM TAGS

The DICOM TAGs of interest for connectivity tests are shown in the table.

Header name	Header Tag	RDSR Name	RDSR Tag
Distance Source to Detector (mm)	0018,1110	Distance Source to Detector (mm)	113750
Exposed Area (cm, cm)	0040,0303	---	---
---	---	Collimated Field Height (mm)	113788
---	---	Collimated Field Width (mm)	113789
kVp	0018,0060	kVp	113733
Positioner Primary Angle (^{o})	0018,1510	Positioner Primary Angle (^{o})	112011
Positioner Secondary Angle (^{o})	0018,1511	Positioner Secondary Angle (^{o})	112012
Image and Fluoroscopy Area Dose product (dGycm^2)	0018,115E	Dose Area Product (Gym^2)	122130
---	---	Dose Area Product Total (Gycm^2)	113722
---	---	Fluoro Dose Area Product Total (Gym^2)	113726
---	---	Acquisition Dose Area Product Total (Gym^2)	113727
Acquired Image Area Dose Product (dGycm^2)	0018,9473	---	---
Exposure Index	0018,1411	Exposure Index	113845
---	---	Dose (RP) (Gy)	113738
Entrance Dose (dGy)	0040,0302	---	---
Study Date	0008,0020	Study Date	111060
-	-	Date Time Started	111526
Acquisition Date	0008,0022	Acquisition Date	126201
Calibration Date	0014,407E	Calibration Date	113723
Acquisition Time	0008,0032	Acquisition Time	126202
Study Time	0008,0030	Study Time	111061
Software Version	0018,1020	---	---
Algorithm version	0066,0031	Algorithm version	111003