# Characterization of NIS X-ray machine for Dosimetry in diagnostic application

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**Abstract**

The international protocols addressed finite beam qualities for each type of diagnostic radiology such as conventional, fluoroscopy, computed tomography and mammography. Moreover, for the dosimetry of each type in diagnostic radiology a certain ion chamber is used. In this work a set of X-ray beam qualities were established in accordance with the Technical Report Series (TRS) No.457-2007 of the International Atomic Energy Agency (IAEA). At the Ionizing Radiation Metrology Laboratory (IRML) of the National Institute of Standards (NIS), traceability is established for a set of ion chambers at the recommended beam qualities, ensuring dosimetry traceability to SI units through calibrations performed at the International Bureau of Weights and Measures (BIPM). The remaining ion chambers were calibrated locally at IRML-NIS. Two X-ray beam qualities were established for fluoroscopy and radiographic applications called RQR5 and RQR8. Moreover, three beam qualities were established for Computed Topography (CT) applications called RQT 8, 9 and 10. In mammography application, only one beam quality was validated by adding Mo filter with Half Value Layer (HVL) of 0.36 mm Al at 18 kV.

*Keywords*: Diagnostic radiology, Beam Quality, Dosimetry

## 1 Introduction

Dosimetry in diagnostic radiology is a field of an increasing importance. There is a realization amongst health professionals that the radiation dose received by patients from modern X-ray examinations and procedures could be at a level of significance for the induction of cancer across a population. Optimizing all medical procedures in compliance with radiation safety principles is a primary objective of the International Commission on Radiological Protection (ICRP) [1,2] as well as the implementation of dosage limitations in contemporary diagnostic techniques. Healthcare has greatly benefited from using X-rays in mammography and CT because they allow early disease detection and accurate diagnosis. These imaging tools have revolutionized patient care by facilitating timely interventions and improving outcomes in a wide range of medical situations, including breast cancer and a wide range of other diseases and accidents [ 3].

Metrology laboratories currently use international recommendations for ionizing radiation worldwide to establish reference radiation as an effort to ensure uniformity among metrology X-ray beams. Radiation beam standardization ensures the metrological dependability of equipment by allowing it to be tested and calibrated in multiple laboratories under the same parameters and conditions. The formulation and measurement procedures of diagnostic radiology dosimetry have recently been standardized through an international code of practice which describes the methodologies necessary to address the diverging imaging modalities used [4]. Both RQR (Radiation Quality Tomography) and RQA (Radiation Quality Added) are important in ensuring accurate dose measurements, calibration of equipment, and consistency across diagnostic radiology and CT imaging practices. Once the RQR (Radiation Quality Reference) series radiation qualities have been determined, it is simple to obtain the RQT series radiation qualities by adding more filtration in accordance with IAEA TRS 457 standards.

It is crucial to provide traceable calibration for the instruments used in diagnostic radiology due to the growing need for dosimetry measurements in this field [5]. Reference beam qualities should be established and used for the calibration of diagnostic radiology instruments, according to IAEA TRS 457. To ensure the accuracy of the measurement of the air kerma from the X-ray device under defined conditions, such measurements need to be made with appropriate instrumentation that is traceable to a standards laboratory.

Ionizing Radiation Metrology Laboratory (IRML) is part of National Metrology Institute in Egypt (National Institute of Standards), its main role is to provide traceability for customers in different radiation fields. This work aims to use the lab facilities to cover almost all diagnostic radiology ranges either by establishing the needed beam qualities or by calibrating ion chambers suitable for each type of diagnostic radiology.

## 2 Material & Experimental Methods

### *2.1 X-ray machine*

The metal-ceramic Philips double pole model MCN-323 X-ray tube with tungsten target was utilized in this investigation. The ranges for adjusting the tube current and high voltage (HV) were 0–10 mA and 15–180 kV, respectively. During irradiation, the power supply was isolated from the tube to maintain a stable environment. Oil closed loop was used in the X-ray machine's cooling system. The X-ray tube setup was done in accordance with TRS No. 469 [6,7] of the International Atomic Energy Agency (IAEA) in order to obtain the beam as a reference beam.

### *2.2. Dosimetry system*

A secondary standard system composed of an electrometer model (PTW UNIDOS, 10001-10522) with PTW 0.6 ion chamber (model TM 30013) and mammography chamber (PTW TM34069) which was calibrated at the primary dosimetry standard of the Bureau International des Poids et Measures (BIPM), France (2023), this system can be traced back to the SI unit (Gy). Other chamber was used as the CT pencil chamber (model TM30009) which was calibrated at NIS. Using a calibrated thermometer and barometer, the temperature and pressure were measured both before and after the radiation.

*Beam quality specification*

Radiation quality is one of many factors as recommended by ISO 4037 [8]. Specifically, the Half Value Layer (HVL) along with other attributes to characterize the beam quality [9]. HVL determination is made according to ISO 4037. IRML X-ray machine has a variable kV. In this work, beam quality specification for different diagnostic applications was studied and established for a certain kV and precise HVL according to TRS-457 proposed method selecting a finite added filtration for this purpose. The complete setting up of the X-ray was made according to TRS No. 369 which is represented in Fig. 1.

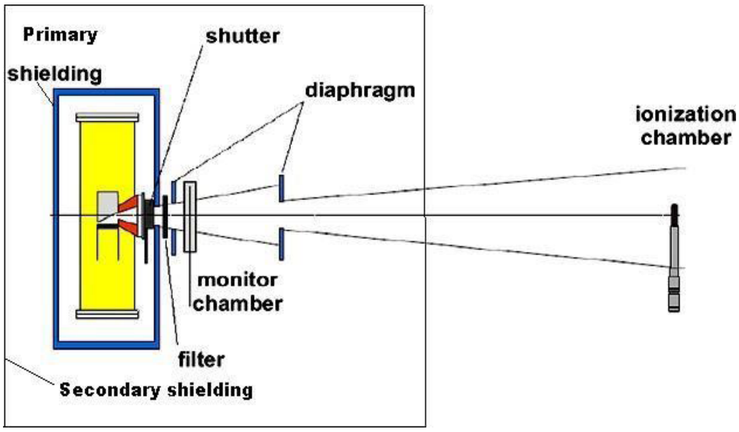


**Figure 1:** X-ray setting as in TRS 469.

## 3 Results and Discussion

### *3.1. Conventional radiography and fluoroscopy: RQR*

X-ray beam quality is specified by the used HVL in a standard reference material such as Cu or Al at a certain kV. Added filters are used to inherent the beam to get the specified required beam quality. At IRML-NIS, some beam qualities were established as RQR8 and RQR5 for fluoroscopy and convention radiography and compared by those of literature, which are represented in table 1:

**Table 1**: *Values of RQR at NIS.*

| RQR | kV | HVL in Al (TRS 457) | HVL in Al (NIS) |
|---|---|---|---|
| **RQR5** | 70 | 2.58 | 2.9 |
| **RQR8** | 100 | 3.97 | 4.1 |

### *3.2. X Ray dosimetry in Conventional radiography and Fluoroscopy*

As recommended by international protocols, the dosimetry of X-ray beam used in convention radiography or fluoroscopy may be performed using a plan parallel ion chamber. In this work, a plan parallel chamber model TM34069 was used. The default use of this chamber is dosimetry of low-energy X-rays in mammography range; however, in this work, the chamber was extensively used for dosimetry in the above beam qualities. Figure 2 shows the calibration factor of the used chamber at different kV. The data with its uncertainty is represented in Table 2.

**Table2:** *shows the Nk of TM34069 chamber at different CCRI beam qualities.*

| **kV** | 25 | 30 | 50 | 100 | 135 |
|---|---|---|---|---|---|
| **Nk (mGy/nC)** | 4.589 | 4.784 | 4.163 | 4.136 | 4.099 |
| **Uc (mGy/nC)** | 0.018 | 0.019 | 0.017 | 0.002 | 0.002 |

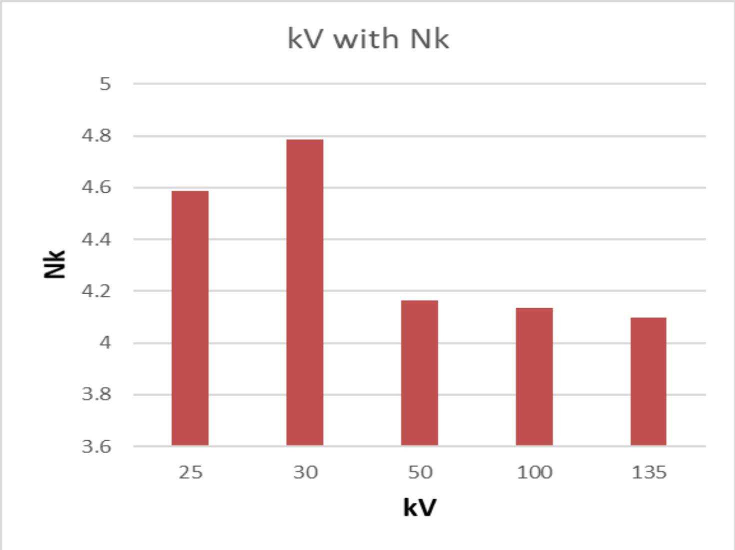


**Figure 2:** The calibration factor of the ion chamber with X ray applied volt kV.

From the above table, the values of NK at 25, 30, and 50 kV were performed at BIPM, while for the values of 100, and 135 kV were performed at NIS.[10]

From the above data, it is clear that IRML has the capability to calibrate the convention and fluoroscopy X-ray machines at beam quality in table (1) and get the output dose in Gy according to the TRS-457 procedures.

### *3.3. Beam qualities for CT applications*

As reported in TRS 457, different beam qualities used for CT application are called RQT. Some of them were fulfilled at NIS as represented in table 3:

**Table 3:** Beam qualities for CT applications.

| **RQT** | **kV** | **HVL in Al (TRS 457)** | **HVL in Al (NIS)** | **Needed Added filters (Cu)** |
|---|---|---|---|---|
| **RQT8** | 100 | 6.9 | 7.2 ±0.1 | 0.102 |
| **RQT9** | 120 | 8.4 | 8.25±0.1 | 0.199 |
| **RQT10** | 150 | 10.1 | 9.6±0.1 | 0.201 |

### *3.4. Dosimetry of CT machines*

For dosimetric measurement of CT machine, a pencil ion chamber with known length is used. Since the dose unit is in Gy.cm, CT dose is called air kerma length product. NIS has a pencil chamber with a length of 10 cm. The chamber is calibrated at NIS which is traceable to set of ion chambers calibrated by BIPM. Based on the established X-ray beam quality (table 3) and the traceable ion chamber, the lab is capable of calibrating CT X-ray machines.

*3.5. Beam qualities for mammography applications*

At NIS, only one beam quality is validated using Mo filter (W/Mo) according to TRS 457 as shown in table 4:

**Table 4:** Beam qualities for mammography applications

| RQR | kV (NIS) | HVL in Al (TRS 457) | HVL in Al (NIS) |
|---|---|---|---|
| **RQR-M4** | 18 | 0.36 | 0.43±0.09 |

*3.5. Dosimetry in mammography*

In this work, mammography chamber PTW TM34069, calibrated at BIPM for mammographic applications was used. In addition, it was calibrated at NIS for different beam qualities to be used in different diagnostic applications. Based on the established X ray beam quality and the traceable chamber, the lab has the capability to calibrate mammography machines.

The public's use of radiodiagnosis is steadily increasing. Moreover, National Metrology Institutes should have a facility for quality assurance and calibration of diagnostic machines to reduce undesired radiation exposure to patients. X-rays beam quality in diagnostic radiology needs a quality assurance and precise dosimetry. Dosimetry of such beam is difficult due to high energy dependency of the used dosimeters. The technical report series of the IAEA defined the finite X ray beam quality of each type of diagnostic radiology as well as the type of ion chamber used. The National Metrology Institute should have facilities like a standard dosimeter traceable to SI unite for each type of beam quality and X-ray machine suitable to fulfill the needed beam quality used in diagnostic radiology. In IRML – NIS, a set of beam qualities were fulfilled for convention, fluoroscopy (RQR5 and RQR8), CT (RQT 8, RQT 9 and RQT 10) and mammography (RQR-M4) with reasonable agreement with that recommended by the TRS 457, that reflects the use of such beam in providing traceability to customers [11].

Some beam qualities are deviated from TRS 457 values as RQR5, which may be attributed to the intensity of the x-ray beam delivered by the used x-ray machine. The calibration factor of the chamber (Nk) has a standard deviation of 0.78% for x-ray energy from 50 to 135 kV (see table 2), corresponding to a wide range of HVL. therefore, the effect of that difference is minimal in the dose calculation.

A plan parallel chamber used in mammography was extensively used for dosimetry of other beam qualities in a wide range of X-ray energies from 25 to 180 kV, that facilitates the dosimetry of any beam quality with a reasonable accuracy. The calibrated CT pencil ion chamber can be used for an accurate dosimetry of CT machines. Based on the fulfilled X ray beam qualities, the IRML of Egypt is capable of calibrating and providing traceability for hospitals in the field of diagnostic radiology dosimetry. Since the lab has participated in an intercomparison APMP-K3 [12] and achieved an excellent degree of equivalence with other international labs, thus the lab is capable for calibrating the ion chambers for any beam quality.

## 5 Conclusions

From this work, it was concluding that:

1. The beam quality needed for diagnostic instruments calibration (RQR, RQT, RQR-M) is fulfilled in Ionizing Radiation Metrology Laboratory, National Institute of Standards (IRML-NIS) and now is ready for providing traceability to hospitals.
2. Mammography chamber is calibrated for different beam qualities from energy of 25 to 180 kV which cover the convention and fluoroscopy dosimetry.
3. IRML-NIS has established X ray CT beam quality and pencil ion chamber calibration in terms of mGy. cm/nC used for CT machine calibration.
4. All recommendations of the TRS-457 by IAEA are now fulfilled in IRML-NIS which became ready for diagnostic machines calibration.

## 6 Declarations

*Study Limitations*

, None.

*Funding source*

None.

*Competing Interests*

The authors have no financial or proprietary interests in any material discussed in this article.

*Ethical Approval*

Not Required

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