# Characteristics of X-Ray Reference Radiation at National Secondary Standards Dosimetry Laboratory of Morocco

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Keywords: SSDL, X-Ray irradiator, ISO 4037-1:1996, Narrow-spectrum NS, radiation quality, HVL, homogeneity coefficient *h*.

Abstract: This study aimed to determine the radiation quality characteristics of narrow-spectrum series NS of X-ray Irradiator used at Secondary Standards Dosimetry Laboratory. The calibration method, requirements, and procedures for establishing the X-ray radiation quality of protection level are described according to ISO 4037-1 standard. Determining the first and second half-value layer (1st HVL,2nd HVL), and homogeneity coefficients (*h*) were required for the HVL measurement approach. Many parameters have to be adjusted in order to study the X-ray beam quality, High-voltage across the X-ray tube, current intensity, thickness, and total filtration, it also depends on the properties of the target materials built in the tube. The results show good agreement between the ISO and the experimental results for the X-ray tube energy range in the narrow-spectrum series. Also, the homogeneity coefficient *h* was between 0.75 to 1,00 according to the ISO standard. The minimum values for 1st HVL and 2nd HVL were 0.47% and 0.12% respectively and the maximum were 4.80% and 4.86% respectively while h was between 0.91 to 1.00. The radiation quality of the narrow-spectrum was established and results were in the range according to ISO of less than 5%.

## 1 INTRODUCTION

Many applications of ionizing radiation in different fields, such as medical, industry, research, and education made it closely related to people's daily life this increased emphasis on radiation protection and calibration of the instrument, sources, and detectors.

To calibrate radiation protection instruments and determine radiation dose, the SSDL should establish the reference radiation used to calibrate the appropriate dosimetry and radiation level. For protection level, X-ray narrow-spectrum series for energy range 30 to 250 keV were recommended internationally by ISO 4037-1. The standard is published by International Standardisation Organisation (ISO) and the last updates were published at the beginning of 2019. Experimentally, narrow-spectrum series NS were used to characterize X-ray reference radiation for energy range 40 to 300 kV. The half-value layer HVL measurement approach was used in purpose to determine the X-ray beam quality by determining 1st HVL and 2nd HVL then calculating and comparing the homogeneity coefficients *h* for every single energy.

The ISO 4037-1 specifies the radiation characteristics and production methods [1]. Based on ISO 4037-1, filtered X radiation of narrow-spectrum series in the range from 40 to 300 kV was established.

Although the quality of a filtered X-ray is characterized by many specifications, for example, mean energy, resolution, and half-value layer (HVL), the X-ray beams can be seen as the reference irradiations that can be used to calibrate radiation protection instruments, only if the installation shall comply with following certain conditions for all established radiation qualities by this experiment.

The inherent filtration of the tube plus the aluminum filters which are added to obtain a total

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fixed filtration is equal to 4 mm Al, with difference 5%.

Other filters, such as copper, tin, lead, have a thickness that is specified with an accuracy of ±5%, and the metals should have purities of more than 99.9%. For the attenuator, the absorber used is copper, and the purities are at least 99.9%.

The first and second HVL in copper agrees with ±5% between the measured values in this experiment and the values given in the standard ISO 4037-1 [2].

## 2 HALF-VALUE LAYER (HVL)

The thickness of the specified material that attenuates the beam of radiation to the extent that the air kerma rate is lowered to half of its original value is defined as HVL (air kerma). The contribution of all scattered radiation, other than that which may have been present initially in the beam, is regarded to be excluded in this definition.

The air kerma (air kerma rate) is lowered to one-quarter of its starting value after the beam has traveled through a thickness of material equal to the sum of the $1^{st}$ HVL and $2^{nd}$ HVL [3].

$$Q = Q_0 . e^{-\mu x}$$

Where:

$Q$: the electrometer reading by charge or current ($nC$) or ($pA$)

$Q_0$: the electrometer reading with thickness x=0 charge or current ($nC$) or ($pA$)

$x$ : Al or Cu filters thickness (mm) $Q/Q_0 \cong 0.5$ at x=$^{1st}$ HVL thickness

μ : Attenuation coefficient for filter materials

Corrections for air temperature, pressure and humidity variation from reference calibration conditions shall be applied for any differences between the conditions during measurement and reference calibration conditions [3],

$$\bar{Q}_{corr} = \bar{Q} .\ C_{T,P.}\ C_h$$

$\bar{Q}_{corr}$ : correction of the average charge values ($nC$) or ($pA$),

$\bar{Q}$ : the average charge repetition values ($nC$) or ($pA$)

$C_{T,P}$ : is a correction factor applied for temperature and pressure, $C_h$ : is a correction factor applied for humidity. $C_{T,P}$ correction factor for air temperature and pressure is given by:

$$C_{T,p} = \frac{p_0 \cdot T}{p \cdot T_0}$$

Where:

$p_0$ is the reference air pressure, 101,325 kPa;

$T_0$ is the reference air temperature, 293,15 K;

The measured value was obtained under the following conditions of measurement: p, T and h:

$p$ is air pressure during measurement;

$T$ is the air temperature during measurement

$C_h$ is the correction factor for any difference in relative humidity between the reference calibration conditions and conditions during measurement. The magnitude of this correction factor is usually small, and it is assumed that $C_h$ = 1,0 for the range of relative humidity values generally encountered [4] .

The difference between the thickness of an absorber required to lower the air kerma (air kerma rate) to one quarter, $x_{1/4}$, and the value of the $1^{st}$ HVL is the $2^{nd}$ HVL. The charge or current with filters is called $Q$ in this case, and $Q_0$ is the original electrometer reading without the filters .

$2^{nd}$ HVL is also calculated the using formula:

$$2^{nd}\ \text{HVL} = x_{1/4} - 1^{st}\ \text{HVL}$$

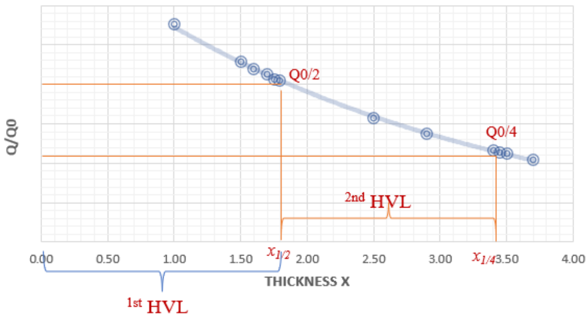


**Figure 1:** Example of determination of the $^{1st}$ HVL and $^{2nd}$ HVL by the interpolation of measured values with $\pm 0.015\ mm$

### 2.2 Homogeneity coefficients *h*

The Homogeneity coefficient $h$ is calculated by the determining the ratio of the first half-value layer $1^{st}$ HVL to the second half-value layer (air kerma) $2^{nd}$ HVL:

$$h = \frac{1^{st}\ \text{HVL}}{2^{nd}\ \text{HVL}}$$

For NS series, $h$ values are approximators between 0.75 to 1.0 for 1m distance measurement setup according to ISO 4037-1:1996 characteristic table.

# 3 MATERIALS AND METHODS

Once the X-ray calibration room is prepared and the X-ray system installed, it will be indeed following the standard approach to determine the first inherent filtration and adjust the fix filter then completing the establishment for reference radiation. Determination the inherent filtration is described in an additional paper in detail [5] [6]. X-ray systems have many components as figures shown and described in the next paragraphs.

## 3.1 X-ray Irradiator

X-Ray Irradiator was used with a maximum voltage of 320 kV, consisting of an X-ray tube, High voltage generator, shielding house for the X-ray tube assembly, Cooling system, System control panel, External filter assembly, the beam shutter, Beam collimation system (Half Value Layer) measurement assembly, Calibration bench, Ancillary devices, 10 position filter wheel NS- series, Fixed filter, 4 aperture wheel collimator, added filtration & HVL assembly, inherent filtration for the X-ray tube. The inherent filter is fixed with 3.53 mm of Al that can be always kept in the beam for all beam qualities NS40 up to NS300 and interlocks for safety. The temperature and humidity inside the local are adjusted by the heating system installed in the basement of the building.

## 3.2 Ionization Chamber IC

The experimental measurement done with PTW, Spherical Ionization Chamber (IC) with an outer diameter is 52.76mm. The ionization chamber should center on the beam axis. Two laser systems were used to allow positioning for IC with the accurate reference point at a specified distance, and alignment it to the beam axis.

The distance was adjusted at 1m from the x-ray tube center to the center of IC, where the IC is fully irradiated within the homogenous beam. PTW Electrometer was used to collect the air kerma $K_a$ values is the amount of energy transferred, $dE$ in (air) per unit mass. For every measurement adjustment we have carful of laser alignment for all component to be in the same level and central of the X-ray exit window and IC center see Figure 5.

**Figure 2**: Ionization Chamber IC [7]

**Figure 3**: 10 position filter wheel NS- series 30 to 300keV

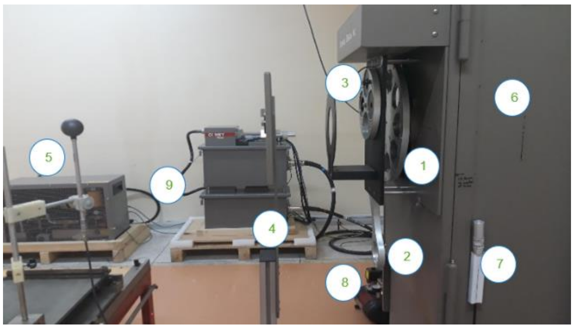


**Figure 4**: Experimental Set-up of the X-ray irradiator MODEL X80-320 kV

Figure 4 show the X-ray component order and distance the number is describe as following: (1) 10 position filter wheel NS- series, (2) Fixed filter, (3) 4 aperture wheel collimator, (4) added filtration & HVL assembly (5) Spherical ionization chamber (6) x-ray tube center (7) Temperature and humidity sensor (8) Porometers (9) Cooling and voltage potential.

At 1m from the tube center, the inherent filtration was measured using 60 kV without any additional filtration only in the Ion Chamber. Al filters with different thicknesses were added to the beam to calculate the HVL; the inherent filtration was measured at a maximum tube current of 22 mA for 60 sec.

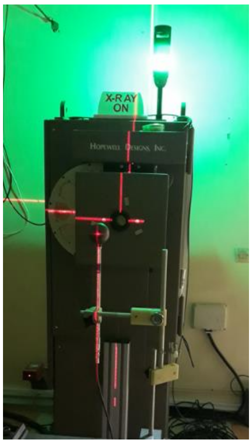


**Figure 5**: Laser alignment with X-ray Irradiator and HVL assembly

All the system measurement has to be adjusted and determine from the X-ray irradiator control room using the software window showed in Figure 6.

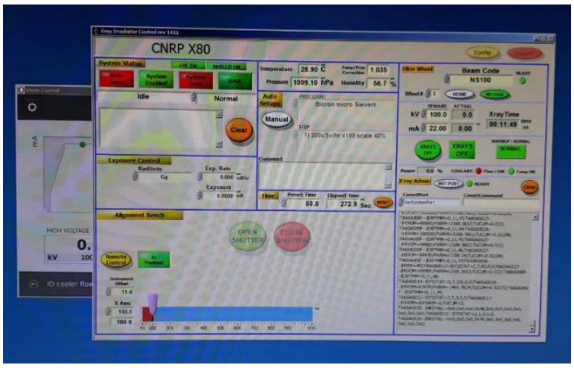


**Figure 6**: X-ray Irradiator Software Control Window

The 1st HVL (mm Al) is determined. The resulting 1st HVL is 0.386 mmAl based on the standard, the inherent filtration was calculated using an extrapolation with a sixth-order polynomial to plot the inherent filtration according to the first HVL in mm Al. The inherent filtration obtained is 0.294 mm Al this value is added to the fixed 3.706 mm and the total is built up to 4 mm Al.

### 3.4.1 Half Value layers HVL measurement

After adjusting the inherent filter and adding the fixed filter to the setup of the x-ray system measurements sure HVL for narrow-spectrum N series. HVL is measured for every single kV from 40 to 300 kV by adding copper filters in the beam according to ISO. The thickness of copper filters can be used around the 1st HVL and 2nd HVL in ISO see Table 1. value for each beam quality. Using muilty thickness values for every single beam with ten measure frequent, then taking the average and plotting the linear function the calculation of the f 1st HVL and 2nd HVL values were from the slope of the alignment as liner attenuation curves show for all energy and thickness.

**Table 1**: comparisons between the ISO 4037-1:1996 and experimental half-value layer results for the N series using mm Cu filters

| N | ISO | | Measured | | Deviation from standards (%) | | homogeneity |
|---|---|---|---|---|---|---|---|
| | 1st HVL mm | 2nd HVL mm | 1st HVL mm | 2nd HVL mm | 1st HVL mm | 2nd HVL mm | |
| 40 | 0.084 | 0.091 | 0.083 | 0.091 | 1.35% | 0.12% | 0.91 |
| 60 | 0.240 | 0.260 | 0.241 | 0.259 | 0.47% | -0.38% | 0.93 |
| 80 | 0.580 | 0.620 | 0.609 | 0.639 | 4.80% | 3.04% | 0.95 |
| 100 | 1.110 | 1.170 | 1.166 | 1.177 | 4.80% | 0.58% | 0.99 |
| 120 | 1.710 | 1.770 | 1.771 | 1.815 | 3.47% | 2.45% | 0.99 |
| 150 | 2.360 | 2.470 | 2.400 | 2.596 | 1.68% | 4.86% | 0.92 |
| 200 | 3.990 | 4.050 | 4.137 | 4.201 | 3.56% | 3.59% | 0.98 |
| 250 | 5.190 | 5.230 | 5.391 | 5.458 | 3.73% | 4.17% | 0.99 |
| 300 | 6.120 | 6.150 | 6.357 | 6.359 | 3.73% | 3.29% | 1.00 |

## 4 RESULTS AND DISCUSSION

The HVLs of energy beams are determined and calculated. The ISO-4037 recommends a 5% agreement between the measured and standard HVL. Table 1 shows that all the values are <5%. Also, h is between 0.75 and 1.0 are within the standard range.

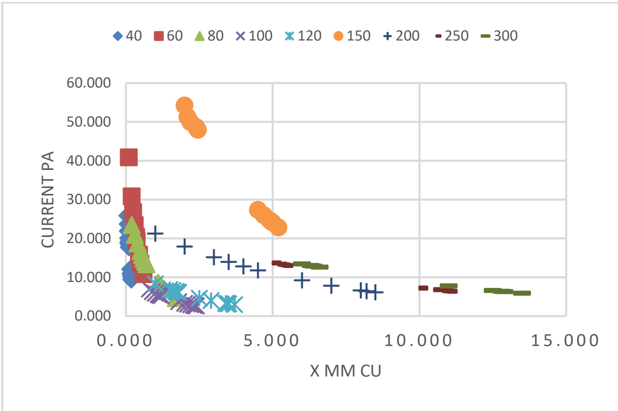


**Figure 7:** N-40 to N-300 of experimental attenuation curves

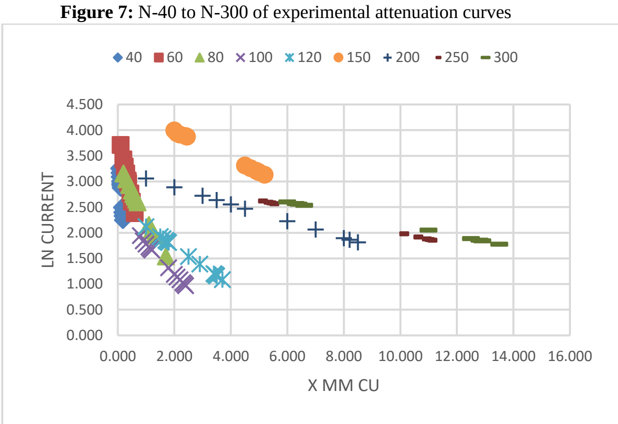


**Figure 8**: N-40 to N-300 of experimental linear curves

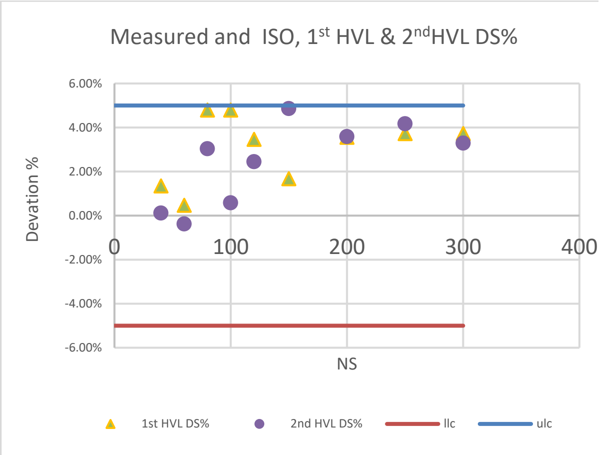


**Figure 9**: Deviation standards between measured and ISO 4037-1:1996

Table 2 show a comparison with international results for radiation refence of narrow series characteristics. Figures 10 and 11 also show two graphical comparison way. All comparison results is acceptable and within the standards range.

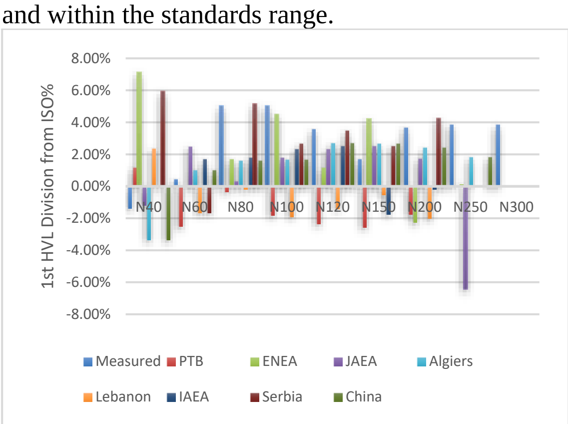


**Figure 10**: 1st HVL values Deviation % comparison [8][9] [10] [11][2]

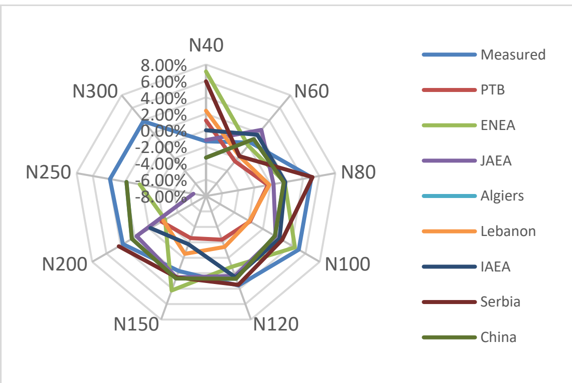


**Figure 11**: 1st HVL values comparison using Rader chart

# 4 CONCLUSIONS

All the characteristics of the narrow spectrum beams presented in this work are in the acceptable range. Subsequent N series beam parameters established were found to agree with the standard values of ISO 4037 within the permissible tolerance limits of ±5% for the first HVL. All reference radiations were reproduced with success within the ISO 4037-1:1996, since other laboratories may use the methodology described in this ISO and compare some results. Therefore, the calibration methods are ensured that the calibration services could provide are internationally accepted as it follows metrological standards.

# ACKNOWLEDGMENTS

We would like to express very great appreciation to ***Mr. Mohammed TAZI – Director of the National Centre of Radiation Protection CNRP - Ministry of Health- Morocco*** for his gracious facilitation of our research work and encouragement.

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**Table 2**: Comparison with international results

| N | 1st HVL* | | | | | | | | | 1st HVL Division from ISO% | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ISO | PTB | ENEA | JAEA | Algiers | Lebanon | IAEA | Serbia | China | PTB | ENEA | JAEA | Algiers | Lebanon | IAEA | Serbia | China |
| 40 | 0.084 | 0.085 | 0.09 | 0.076 | | 0.086 | | 0.089 | | 1.19 | 7.14 | 1.19 | | 2.38 | | 5.95 | |
| 60 | 0.240 | 0.234 | 0.24 | 0.221 | 0.232 | 0.236 | 0.24 | 0.236 | 0.232 | -2.50 | 0.00 | 2.50 | -3.33 | -1.67 | 0.00 | -1.67 | -3.33 |
| 80 | 0.580 | 0.578 | 0.59 | 0.600 | 0.586 | 0.579 | 0.59 | 0.610 | 0.586 | -0.34 | 1.72 | 0.34 | 1.03 | -0.17 | 1.72 | 5.17 | 1.03 |
| 100 | 1.110 | 1.090 | 1.16 | 1.181 | 1.128 | 1.089 | 1.13 | 1.140 | 1.128 | -1.80 | 4.50 | 1.80 | 1.62 | -1.89 | 1.80 | 2.70 | 1.62 |
| 120 | 1.710 | 1.670 | 1.73 | 1.833 | 1.739 | 1.686 | 1.75 | 1.770 | 1.739 | -2.34 | 1.17 | 2.34 | 1.70 | -1.40 | 2.34 | 3.51 | 1.70 |
| 150 | 2.360 | 2.300 | 2.46 | 2.516 | 2.424 | 2.348 | 2.42 | 2.420 | 2.424 | -2.54 | 4.24 | 2.54 | 2.7 | -0.51 | 2.54 | 2.54 | 2.71 |
| 200 | 3.990 | 3.920 | 3.90 | 4.250 | 4.097 | 3.910 | 3.92 | 4.160 | 4.097 | -1.75 | -2.26 | 1.75 | 2.68 | -2.01 | -1.75 | 4.26 | 2.68 |
| 250 | 5.190 | | 5.20 | 5.524 | 5.316 | | 5.18 | | 5.316 | | 0.19 | 100.0 | 2.43 | | -0.19 | | 2.43 |
| 300 | 6.120 | | | | 6.232 | | | | 6.232 | | | | 1.83 | | | | 1.83 |