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Determination of temporal correction factors for a survey meter detector dedicated to radioprotection in radiology

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Abstract: Radiometric surveying is essential for assessing radiation levels in facilities that use ionizing radiation, ensuring that individual exposures remain within the dose limits established by current regulations. Ionization chambers (ICs) are crucial tools in this evaluation, and understanding their operational limitations—particularly the effects of temporal dependence—is key to ensuring accurate measurements. This study aimed to verify the temporal dependence of the Fluke Victoreen IC (349 cm^3, model 451B-RYR) by analyzing the ambient dose equivalent rate H*(10) over short exposure intervals in its two operational modes: Integrated (Mode A) and Rate (Mode B). Measurements were conducted using N60, N80, and N100 radiation qualities for narrow X-ray beams defined by ISO 4037-1:2019 and characterized at the Laboratory of Radiological Sciences (LCR). The results revealed temporal dependence for times shorter than 0.8 s for N60 and N80, and shorter than 1.5 s for N100 in both operational modes. Correction factors were calculated to adjust the H*(10) values, reducing uncertainties and enabling the definition of cutoff times for each radiometric quality and chamber mode. Mode A exhibited shorter cutoff times for N60 and N100 (0.3 s and 0.4 s, respectively), whereas Mode B proved more suitable for N80 (0.2 s). The highest combined relative uncertainties before stabilization were observed as follows: for N60, 26% in Mode A and 50% in Mode B (both at 0.1 s); for N80, 31% in Mode A and 17% in Mode B (both at 0.5 s); and for N100, 49% in Mode A (0.2 s) and 15% in Mode B (0.6 s). The study concludes that the application of correction factors and cutoff times improves the precision of H*(10) measurements at short exposure intervals, contributing to more reliable radiometric surveys in radiological protection contexts.

Keywords: radiation detector, ionization chamber, radiation protection.

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Determinação dos fatores de correção temporal para uma câmara de ionização dedicada à radioproteção em radiologia

Resumo: O levantamento radiométrico é essencial para avaliar os níveis de radiação em instalações que utilizam radiação ionizante, garantindo que as exposições individuais não excedam os limites de dose estabelecidos pela legislação. As câmaras de ionização (CIs) são ferramentas cruciais nessa avaliação, e compreender suas limitações operacionais – particularmente os efeitos da dependência temporal – é fundamental para garantir medições precisas. Este estudo teve como objetivo verificar a dependência temporal da CI Fluke Victoreen (349 cm^3, modelo 451B-RYR) analisando a taxa de equivalente de dose ambiente H*(10) em intervalos curtos de exposição em seus dois modos operacionais: Integrado (Modo A) e Taxa (Modo B). As medições foram realizadas utilizando qualidades de radiação N60, N80 e N100 para feixes estreitos de raios X definidos pela ISO 4037-1:2019 e caracterizados no Laboratório de Ciências Radiológicas (LCR). Os resultados revelaram dependência temporal para tempos menores que 0,8 s para N60 e N80, e menores que 1,5 s para N100 em ambos os modos operacionais. Fatores de correção foram calculados para ajustar os valores de H*(10), reduzindo as incertezas e permitindo a definição de tempos de corte para cada qualidade radiométrica e modo de câmara. O Modo A apresentou tempos de corte menores para N60 e N100 (0,3 s e 0,4 s, respectivamente), enquanto o Modo B se mostrou mais adequado para N80 (0,2 s). As maiores incertezas relativas combinadas antes da estabilização foram observadas da seguinte forma: para N60, 26% no Modo A e 50% no Modo B (ambos em 0,1 s); para N80, 31% no Modo A e 17% no Modo B (ambos em 0,5 s); e para N100, 49% no Modo A (0,2 s) e 15% no Modo B (0,6 s). O estudo conclui que a aplicação de fatores de correção e tempos de corte melhora a precisão das medições de H*(10) em intervalos curtos de exposição, contribuindo para levantamentos radiométricos mais confiáveis em contextos de proteção radiológica.

Palavras-chave: detector de radiação, câmara de ionização, radioproteção.

1. INTRODUCTION

Ionizing radiation is fundamental in various applications in medicine, industry, commerce, and other services. According to DATASUS, there are 167,000 active diagnostic imaging devices in Brazil. According to the National Nuclear Energy Commission (CNEN), there are 295 radiotherapy facilities and 465 nuclear medicine establishments in the country. In the industrial, research, and commercial sectors, there are 1,345 facilities. The verification that ensures services using ionizing radiation comply with radiological protection standards is carried out through radiometric surveys, as required by RDC 611 [1] and Norma NN 3.01 of CNEN [2].

The radiometric survey is conducted using ionization chambers, which are responsible for real-time monitoring of radiation levels in a facility to estimate the doses received by Occupationally Exposed Individuals (OEI) and members of the public in areas adjacent to rooms housing ionizing radiation-emitting devices. The radiometric survey is the procedure used to ensure that individual exposures do not exceed the dose limits established by legislation.

The ambient dose equivalent H*(d) is an operational quantity for workplace area monitoring and considers the effectiveness of damage for a given type and energy of radiation. For highly penetrating radiation, a depth of 10 mm is adopted. From the obtained value, it is possible to estimate an individual's effective dose. Therefore, H*(10) contributes to the implementation of safety and control measures, ensuring workers' health [3].

For measurements and data analysis in metrology, the X-ray beam must be continuous and as homogeneous as possible. To standardize such beams, ISO 4037-1:2019 [4] provides a set of X-ray beams covering the various energy ranges used in clinical routines and specific to radiological protection. The standard recommends the use of narrow beams, or N qualities, which have low spectral resolution, improving detector response [5].

Ionization chambers (ICs) are radiation detection devices essential for conducting radiometric surveys. Professionals must understand the limitations of the IC they use to ensure reliability in the results presented, since there may be significant temporal dependence depending on the IC's operating mode, as reported in previous studies [6].

2. MATERIALS AND METHODS

This study was conducted at the Radiological Sciences Laboratory of the Rio de Janeiro State University with the aim of verifying the temporal dependence of the Fluke Victoreen ionization chamber model 451B-RYR by analyzing the ambient dose equivalent rate recorded over short periods, that is, shorter than the response time specified by the manufacturer, in its two operating modes (Integrated and Rate mode), using N60, N80, and N100 qualities characterized by narrow X-ray beams, as specified by ISO 4037-1:2019. After confirming the temporal dependence, the study sought to provide temporal correction factors and cutoff times based on the IC's operating mode.

For the measurements, an industrial X-ray tube COMET model MXR-160/22 was used, featuring a tungsten (W) target, 0.8 mm beryllium (Be) window with an inherent filtration of 0.3 mm aluminum (Al), and nominal voltage and current limits of 160 kV and 40 mA, respectively.

The radiation qualities N60, N80, and N100 from ISO 4037-1 were used with a fixed nominal current value of 10 mA. The average energies of the narrow spectra for N60, N80, and N100 are, respectively, 47, 65, and 83 keV [5]. The focus-to-detector distance was 200 cm.

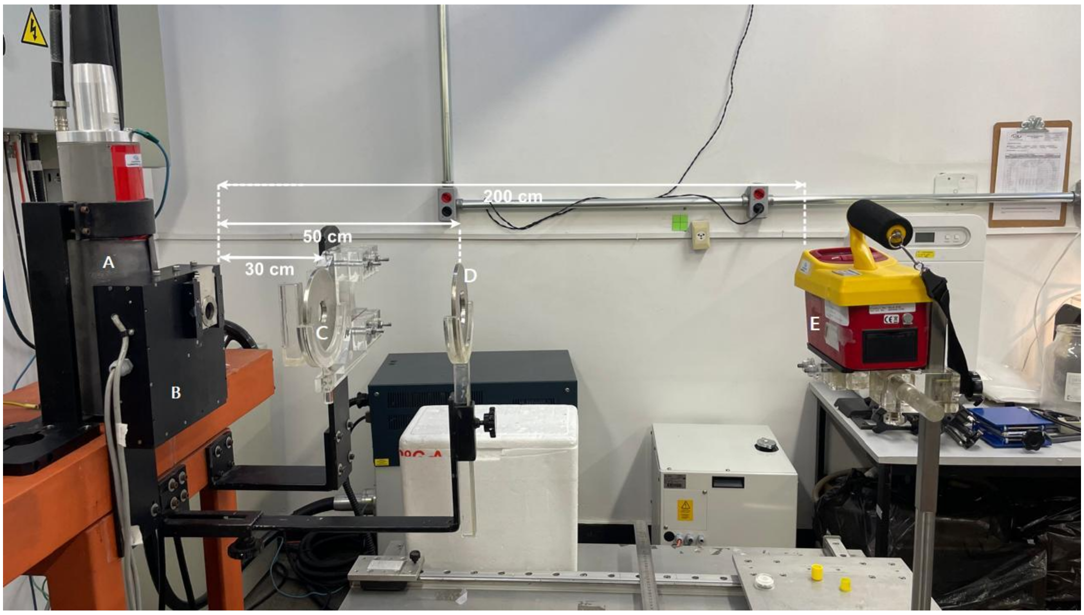
The ionization chamber (IC) used was a Fluke Victoreen with a sensitive volume of 349 cm^3, model 451B-RYR, calibration certificate number RP-0005/2022. It operates in two distinct modes: Integrated and Rate. In the Integrated mode, its response range is from 0 R to 999 R, while in the Rate mode, it ranges from 0 R/h to 50 R/h. For both operating modes, the manufacturer provides an accuracy of ± 10% [7].

For the three radiation protection qualities, X-ray exposure times ranging from 0.1 s to 1.0 s, with increments of 0.1 s, were used, in addition to an exposure time of 1.5 s. To control the X-ray exposure time, a calibrated AGFA shutter was employed to control exposure time. The AGFA shutter is an electronic device that allows or prevents the passage of the X-ray beam. The standard uncertainty of time was estimated to be 0.2 s, as reported in [5]. Measurements were performed in the Integrated mode, referred to as Mode A, and subsequently in the Rate mode, referred to as Mode B. The radiation protection qualities N60, N80, and N100 were used for beam standardization.

The N60 quality requires a filtration of 0.60 mm Cu and 3.7 mm Al. For N80, a filtration of 2 mm Cu and 3.7 mm Al is needed, while for N100, 5 mm Cu and 3.7 mm Al must be used.

The filters were positioned next to the first collimator (Figure 1). The first beam collimator has a diameter of 3 cm and a lead thickness of 5 mm, placed 30 cm from the X-ray tube focal point. The second collimator has a diameter of 5 cm and a lead thickness of 4 mm, positioned 50 cm from the focal point. To align the beam with the ionization chamber, transverse and longitudinal positioning lasers were used.

Figure 1: Experimental arrangement, where there is the x-ray tube (A), the shutter (B), the first collimator (C), the second collimator (D), and the ionization chamber (E).



The Integrated mode of the ionization chamber provides the exposure obtained from a given irradiation time. Thus, the exposure rate per hour was calculated. The Rate mode already provides the exposure rate per hour. The values were multiplied by the respective calibration coefficients from the most recent calibration certificate of the ionization chamber to obtain the ambient dose equivalent rate H*(10). Data analysis was performed, and temporal correction factors were calculated.

The H*(10) rate at each stabilization time was adopted as the reference value, i.e., the expected H*(10) rate. Based on the relationship in Equation 1, temporal correction factors were calculated for the radiometric qualities N60, N80, and N100, where T_{ref} is the reference rate of the respective radiometric quality, and T_t is the rate obtained at time t.

$$k_t = \frac{T_{ref}}{T_t} \quad (1)$$

The factors were calculated for H*(10) rates acquired in both operating modes of the ionization chamber.

The correction factor is a parameter used to adjust the readings of measurement instruments. In this case, its purpose is to correct the values and minimize uncertainties in the readings caused by temporal dependence.

3. RESULTS AND DISCUSSIONS

3.1. Ionization Chamber Stabilization Time

Figure 2 shows the H*(10) rate as a function of time for the Integrated and Rate modes for the N60 radiometric quality. It can be observed that the H*(10) rate obtained in the Integrated mode (represented by triangles) starts at a higher value at 0.1 s, with greater initial stability, which is maintained with pronounced oscillations until approximately 0.6 s. The H*(10) rate acquired in the Rate mode of the ionization chamber (represented by circles) exhibits an increasing behavior, also showing oscillations, but with greater amplitude and less consistency until 0.7 s, when it begins to stabilize. From 0.8 s onward, both modes reach a stability that is maintained until the end of the observed period. For simplification purposes, the authors defined Mode A as the Integrated operation mode of the ionization chamber and Mode B as the Rate operation mode.

Thus, the stabilization time of the H*(10) rate obtained in Mode A is approximately 0.8 s, where the rate is 2.11 $mSv.h^{-1}$, while for Mode B, it is also approximately 0.8 s with a rate of 2.97 $mSv.h^{-1}$. Both modes tend toward the same ambient dose equivalent rate value.

The highest combined uncertainties obtained were 26% in Mode A and 50% in Mode B at 0.1 s. These uncertainties may be associated with the shutter opening time for exposure times shorter than 0.5 s, due to its mechanical and electronic operation.

Figure 2: H*(10) rate for radiation quality N60.

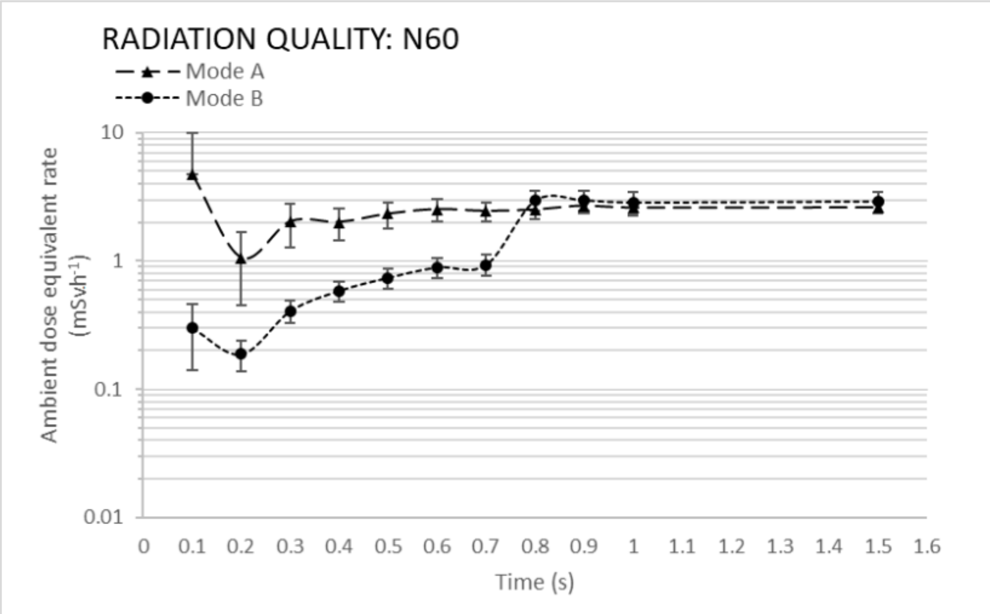


Figure 3 shows the H*(10) rate over time for modes A and B for the radiometric quality N80. The H*(10) rate obtained by mode A shows, for N80, greater initial instability, decreasing with sharp variations until approximately 0.4 s, at which point it starts to stabilize. After 0.4 s, the rate continues with some oscillations; however, as a conservative measure, the stability time was considered from 0.8 s onwards. Mode B, in turn, displays moderate instability, tends to stabilize around 0.5 s, but due to oscillations, stability was adopted after 0.8 s. Both modes maintain satisfactory stability after these times, which characterizes the temporal dependence of the ionization chamber (IC). The stabilization time for mode A is approximately 0.8 s, where the H*(10) rate is 2.25 $mSv.h^{-1}$, while for mode B it is approximately 0.8 s with a rate of 1.35 $mSv.h^{-1}$.

The rate values for this time are different, which can be explained by the electronics of the ionization chamber itself in accounting for the charges in each mode. Another factor contributing to the differences is the response time of the IC, which, according to the manufacturer, has a minimum time of 2 s. Although they differ, the H*(10) rates converge to the same point. Since the study aims to analyze behavior for shorter times, such differences were expected. The combined most significant uncertainties obtained were 31% for mode A and 17% for mode B at 0.5 s.

Figure 3: H*(10) rate for radiation quality N80.

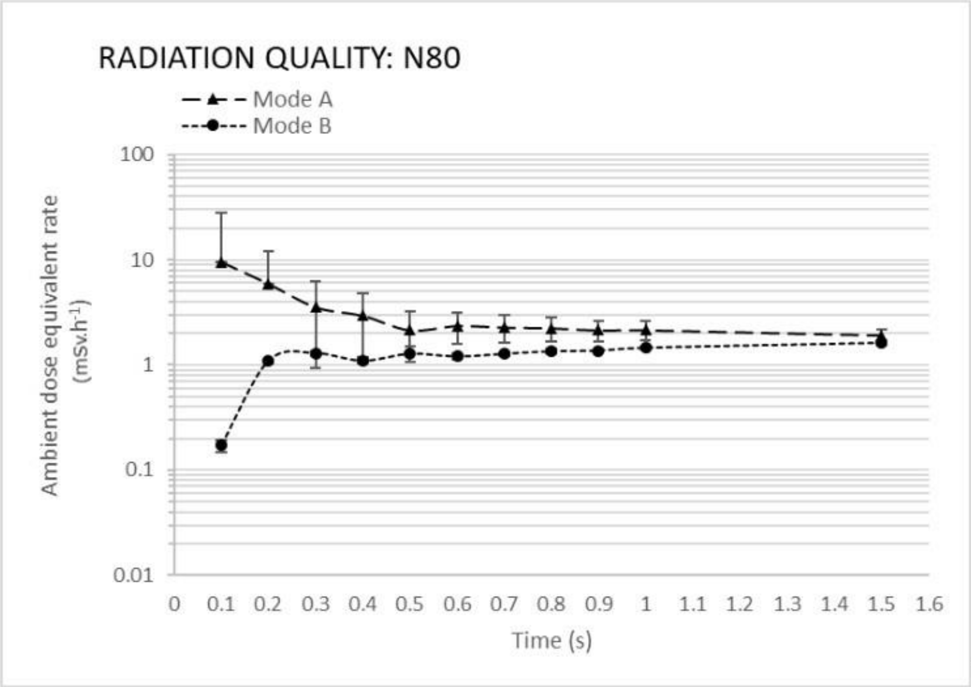
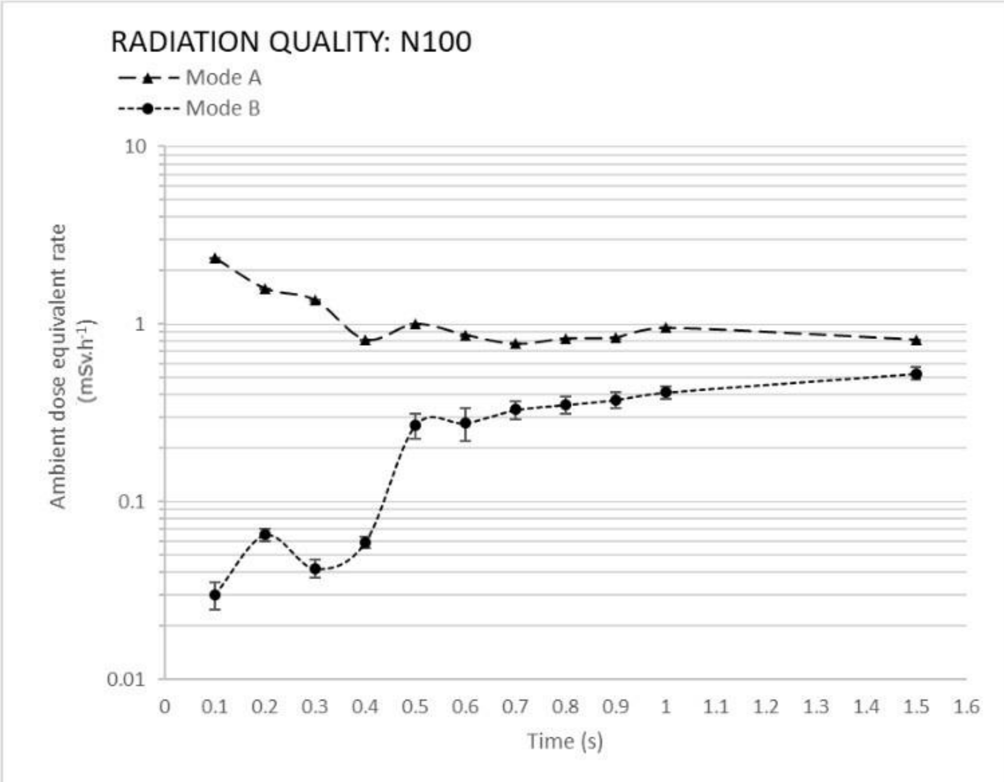


Figure 4 shows the ambient dose equivalent rate as a function of time for modes A and B acquired with the radiometric quality N100. The initial instability is more pronounced in mode B. There is a sharp increase in the H*(10) rate from 0.4 s to 0.5 s. From 0.6 s onwards, the curve continues to increase and oscillate until 1.5 s. The H*(10) rate obtained by mode A also shows initial oscillations, decreasing over time until 0.7 s. After this time, it continues oscillating subtly until 1.5 s. Due to the behaviors of the curves, the stabilization time considered for both modes was 1.5 s, at 0.82 $mSv.h^{-1}$ for mode A and 0.53 $mSv.h^{-1}$ for mode B.

It can be noted that the exposure rates for both modes at 1.5 s differ from each other but tend to converge to similar values. The oscillations observed for times less than 0.5 s can be justified by the response time of the ionization chamber. The largest combined uncertainties obtained were 49% for mode A at 0.2 s and 15% for mode B at 0.6 s.

Figure 4: Rate of H*(10) for radiation quality N100.



From the graphical analysis, it can be observed that for N60 and N100, the H*(10) rate obtained by mode A shows greater initial stability, with smaller amplitude oscillations and reaching stability slightly earlier than the rate from mode B. These results indicate that mode A exhibits a slightly faster stabilization for these radiation protection qualities, meaning the time to reach stability is shorter. Thus, for measurements that require less oscillation from the very beginning, mode A of the ionization chamber appears to be more suitable even without applying correction factors. An analysis considering such factors was made and is presented in section 3.2.1.

For the H*(10) rate of N80, however, mode B proved to be more stable compared to mode A. Therefore, for measurements with shorter time intervals, it is recommended to use mode B without correction factors.

As mentioned earlier, the uncertainties observed in the experimental data for times less than 0.5 s may be associated with the shutter opening time of the measurement system. This behavior, marked by oscillations and instability in initial values of the ambient dose equivalent rate, has already been identified in other studies [5]. However, the precise correlation between the shutter opening time and instability in the initial values remains unclear and requires further investigation. This aspect will be addressed in future studies, aiming to deepen the analysis of the causes and possible solutions for mitigating these uncertainties.

3.2. Correction Factors

The H*(10) rate in the same beam should be the same, regardless of the irradiation time. However, due to electronic and mechanical factors in the detector's construction, a temporal dependence is observed in the equipment. For times less than 1.5 s, the H*(10) rate exhibits a significant temporal dependence, thus requiring temporal correction factors.

When analyzing the H*(10) rates obtained in each mode, it is possible to observe a specific stability at a given time. Table 1 shows the stabilization times considered by the authors for obtaining the H*(10) rate for each radiation quality based on the mode used in the chamber.

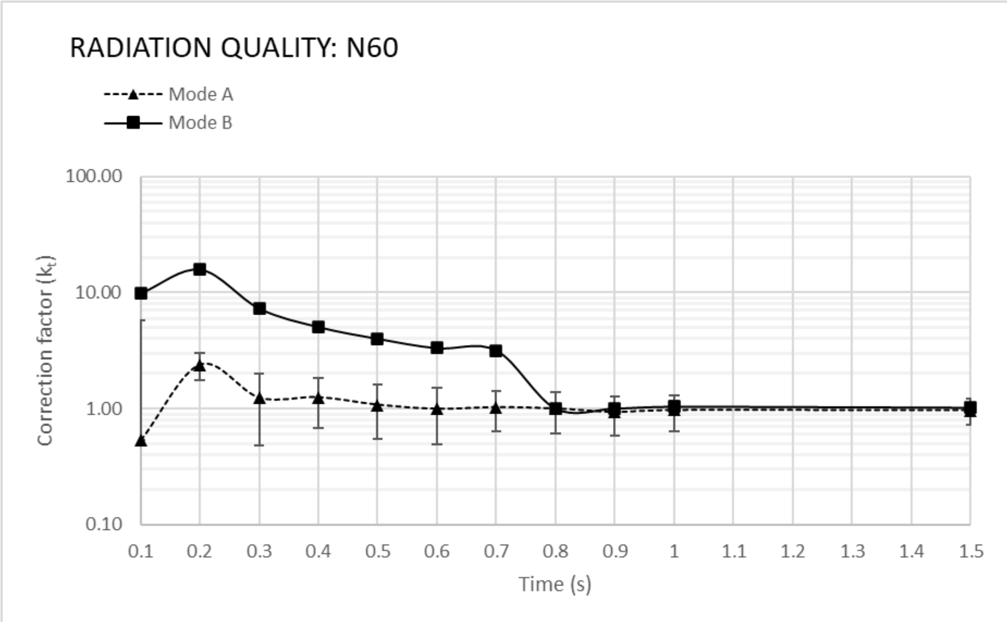
Tabela 1 : Stabilization time for each radiation quality.

	Mode A		**Mode B**	
Radiometric quality	Stabilization time (s)	H*(10) rate ($mSv.h^{-1}$)	Stabilization time (s)	H*(10) rate ($mSv.h^{-1}$)
N60	0.8 ± 0.2	2.11 ± 0.71	0.8 ± 0.2	2.97 ± 0.01
N80	0.8 ± 0.2	2.25 ± 0.59	0.8 ± 0.2	1.35 ± 0.07
N100	1.5 ± 0.2	0.82 ± 0.07	1.5 ± 0.2	0.53 ± 0.04

Thus, the correction factor is applied by multiplying it by the H*(10) rate, considering the time the ionization chamber was exposed. The correction factor to be used should correspond to the operating mode, meaning that for rates obtained in mode A, the correction factor calculated for mode A should be used, and similarly for mode B.

In Figure 5, the variation of the correction factor for the H*(10) rate as a function of time is observed, considering the radiation quality N60.

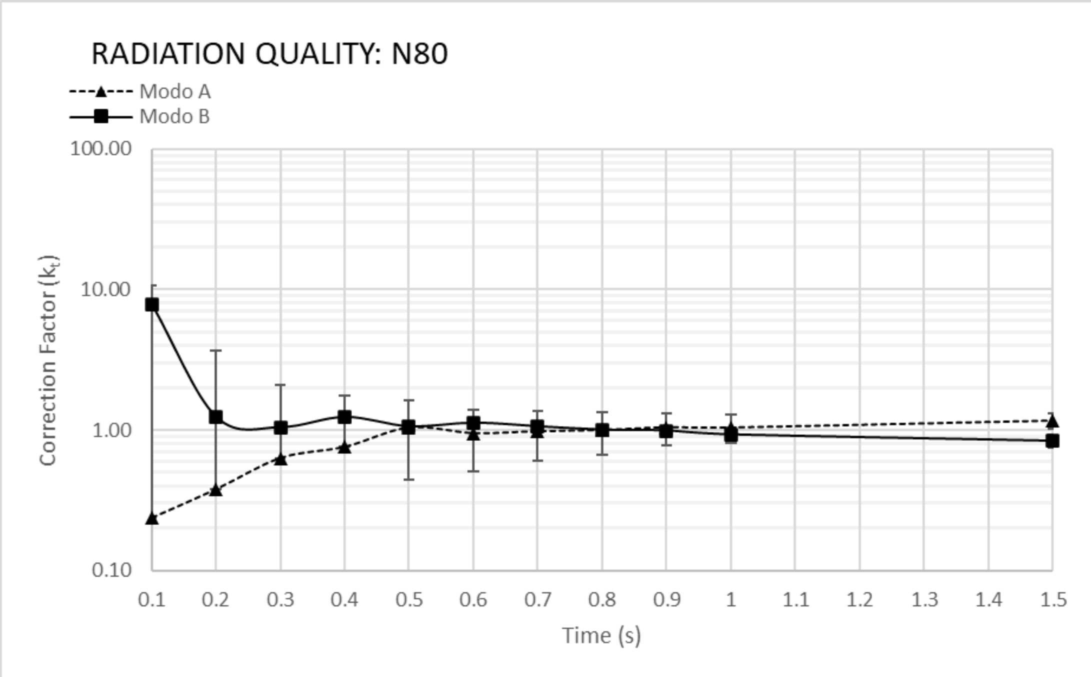
Figure 5: Time correction factor for radiation quality N60.



For the radiation quality N60, a marked discrepancy is observed between mode A (represented by triangles) and mode B (represented by squares) throughout the analyzed time interval (0.5 s to 1.5 s). Mode A shows a correction factor close to 1 starting from 0.3 s, indicating good agreement with the reference H*(10) rate, which corresponds to the stability of the measurements. On the other hand, mode B displays a significantly higher correction factor between 0.3 s and 0.8 s, varying from approximately 8 to 2 as time increases. This indicates that mode A, for N60, is more suitable for recording measurements starting from 0.3 s. Mode B is appropriate as well, but it requires a longer exposure time of the ionization chamber, starting from 0.8 s.

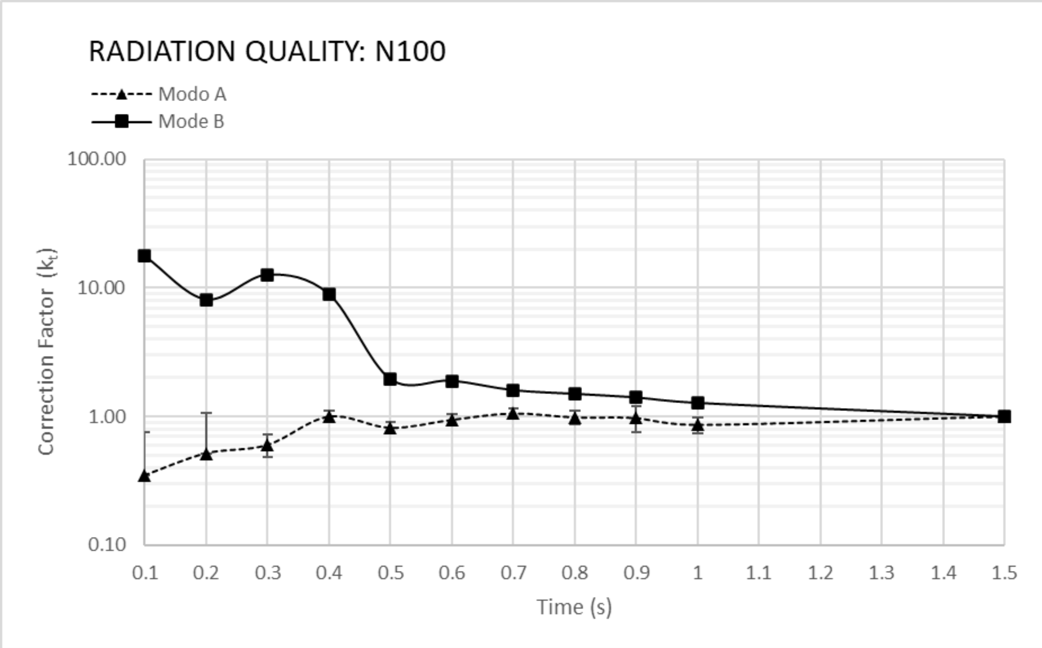
For the radiation quality N80 (Figure 6), the behavior of the measurement modes shows a distinct pattern compared to that observed for N60.

Figure 6: Time correction factor for radiation quality N80.



Mode Asim starts with a correction factor around 0.25, increasing over time until it reaches values close to 1 at 0.5 s. Mode B, on the other hand, starts with a high correction factor but, within a short period, decreases, reaching values close to 1 for times greater than 0.2 s. The intersection of the curves occurs around 0.8 s, where both modes show similar correction factors close to 1. It can be concluded that for the N80 radiometric quality, mode B is the most suitable for estimating the ambient dose equivalent rate compared to mode A, as it exhibits greater stability from 0.2 s, while in mode A, this occurs only from 0.5 s onwards. Figure 7 shows how the conversion factors differ for N100.

Figure 7: Time correction factor for radiation quality N100.



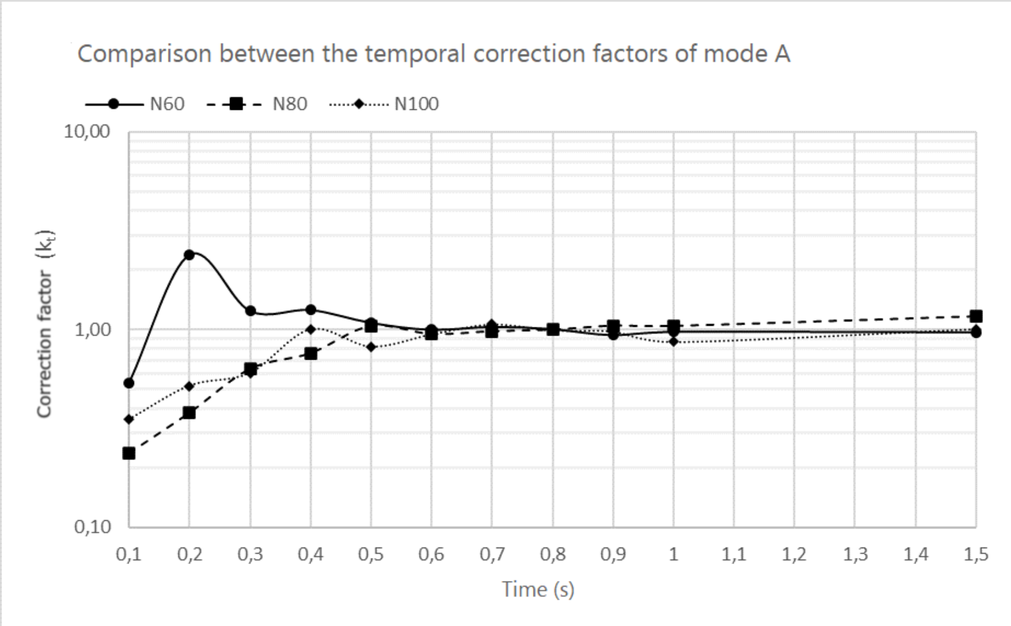
The curve representing the conversion factors for mode A shows smooth variations, close to 1 from 0.4 s, confirming that the Integrated mode is suitable for measurements at these times. Mode B showed factors up to 11, decreasing until 0.7 s, at which point the factor started approaching 1. Due to the longer required time, this behavior suggests a greater discrepancy compared to the reference value. It can be concluded that mode A is more suitable for measuring H*(10) for short times compared to mode B. Therefore, it is possible to define cutoff times for each mode, now considering the use of correction factors.

3.2.1. Cutoff Time

The cutoff time is the minimum exposure time of the chamber, ensuring that, by applying correction factors, more accurate measurements can be obtained in situations that deviate from the minimum exposure time recommended by the manufacturer. To determine the minimum cutoff times for each operating mode and radiometric quality, graphs comparing the temporal correction factors were generated for both operational conditions. Note that the cutoff time is a nominal value, that is, it is a suggestion from the authors, and there are no uncertainties.

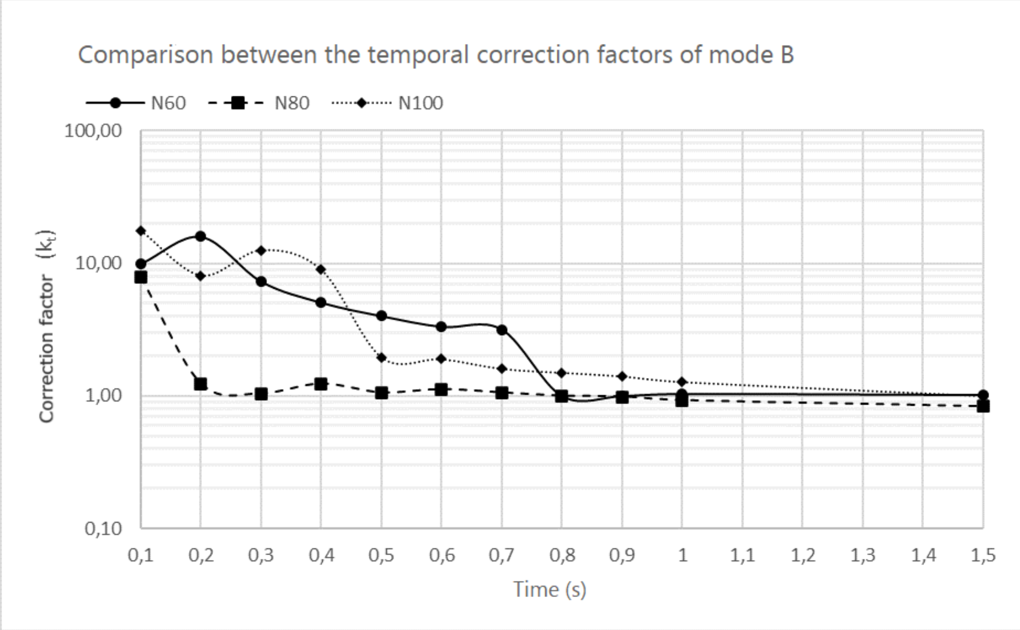
Figure 8 shows the comparative analysis of the temporal correction factors obtained in mode A.

Figure 8: Comparative graph of the correction factors for N60, N80, and N100 in mode A.



It is noted that the temporal correction factors in mode A for the three radiometric qualities tend to approach 1 over time. For N60, a cutoff time of 0.3 s can be defined, as this is the point at which the correction factors begin to converge. At this point, the correction factor is 1.24. For N80, this behavior starts at 0.4 s, where the factor is 0.73. In N100, the point where the factors begin to converge is at 0.4 s, with a correction factor of 1.01.

Figure 9: Comparative graph of the correction factors for N60, N80, and N100 in mode B.



The graphical analysis of the comparative temporal correction factors designated for mode B (Figure 9) indicates that the correction factors for N60 approach 1 at 0.8 s, with a factor of 1.5. Therefore, this is the cutoff time considered for this radiometric quality. For N80, the approximation to 1 occurs from 0.2 s, with a factor of 1.09, and it continues with some oscillations around 1. Thus, for radiometric quality N80, the cutoff time to consider is 0.2 s. Analyzing the N100 curve, it is concluded that at 0.8 s, with a temporal correction factor of 1.50, these factors decrease and reach 1 at 1.5 s. This suggests a cutoff time of 0.8 s for this radiometric quality.

Table 2 presents the recommended cutoff times for each operating mode of the ionization chamber.

Table 2 : Cutoff Time

Cutoff Time (s)		
Radiometric quality	Mode A	Mode B
N60	0.3	0.8
N80	0.4	0.2
N100	0.4	0.8

It is observed that for N60 and N100, when applying the temporal correction factors, the cutoff time in mode A is shorter compared to mode B. Therefore, mode A is more suitable for obtaining measurements at short exposure times. For N80, considering the correction factors, mode B is more appropriate, as it has a slicing time of 0.2 s.

4. CONCLUSIONS

This study demonstrated the time dependence of the Fluke Victoreen 451B-RYR ionization chamber when used in the Integrated (Mode A) and Rate (Mode B) operating modes, under the narrow beam radiation qualities N60, N80, and N100 standardized by ISO 4037-1:2019. Both settling time and H*(10) rate varied depending on the mode and radiation quality. Mode A generally reached stabilization faster than Mode B for N60 and N100, indicating that it is better suited for shorter irradiation times under these conditions. For N80, Mode B proved to be more reliable for shorter exposures. This conclusion can guide users in selecting the most appropriate operating mode based on beam quality and measurement conditions.

The application of temporal correction factors allowed for the adjustment of measured values, reducing the effects of temporal dependence, particularly for exposure times shorter than the minimum recommended by the manufacturer. Cutoff times were defined for each mode and radiation quality, establishing the minimum exposure duration at which correction factors can reliably approximate the stabilized H*(10) rate. As shown in Table 2, Mode A exhibited shorter cutoff times for N60 and N100, reaffirming its advantage for measurements at shorter exposure times, while Mode B proved more suitable for N80. Future studies will focus on detailed investigations of the factors that influence initial oscillations, such as shutter mechanics and chamber energy dependence, aiming to optimize the equipment's operating conditions and expand its applicability in measurements.

The results highlight the importance of understanding the dynamic behavior of ionization chambers in radiometric surveys, particularly when operating with short exposure times. Establishing correction factors and cutoff times increases the accuracy and reliability of H*(10) measurements, contributing to improved radiation protection practices in medical, industrial, and research facilities.

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CONFLICT OF INTEREST

All authors declare that they have no conflicts of interest.

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