ENERGY AND ANGULAR DEPENDENCE OF RADIATION MONITORS IN STANDARD X RADIATION BEAMS

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Abstract

In Brazil, most of the monitoring instruments are calibrated in terms of exposure rate and dose rate in X, gamma and beta radiations, using reference systems calibrated at primary and secondary standard laboratories. In this work, the ionization chambers were calibrated in standard X radiation beams with the objective to study their response in relation to the energy and angular dependence in the operational quantity ambient dose equivalent H*(10), as recommended by the International Organization for Standardization (ISO 4037). For the energy dependence study, the ionization chambers were tested in standard beams, at the distance of 2.5 m from the tube. The X-rays system utilized was a Pantak/Seifert equipment, model MXR-160/22, with effective energies of 48, 65, 83 and 118keV, respectively for the N-60, N-180, N-100 and N-150 radiation qualities. For the angular response of the detectors, a special holder was made of PMMA with a goniometer for the monitor rotation. The results obtained were satisfactory, according to the international standards ISO 4037-1(ISO, 1996) and ISO 4037-3 (ISO,1999) and to the Brazilian standard ABNT-NBR 10011 (ABNT, 1987).

Introduction

Since the discovery of X-rays, the use of ionizing radiation has been intensified and expanded in several areas of applications, as in medicine and in industry. Many investments have been applied in research and technology. All this innovation requires the use of irradiators, X-ray equipment, particle accelerators, and radioactive sources. To regulate the use of ionization radiation, the International Commission on Radiation Units and Measurements (ICRU) and the International Commission on Radiological Protection (ICRP) established standards with the objective of the risk perception and optimization of radiation protection, using the ALARA principle (“as low as reasonably achievable”). One form of ionizing radiation control is through the use of measurement instruments such as dosimeters in the clinical area, and portable detectors, which quantify and qualify radiations. There are some types of clinical dosimeters made of various materials as well as different types of radiation detectors such as Geiger-Müller detectors, scintillation detectors, proportional detectors, semiconductor detectors, ionization chambers. Working with portable area detectors requires a quality control that is guaranteed in part by the calibration, which certifies the good functionality of the equipment and offers reliability in their measurements. The instrument calibration can ensure if it is working properly and determines the indication of an instrument as a function of the measurement (the quantity intended to be measured).

In this work, the radiation monitors were calibrated at the Calibration Laboratory of IPEN which offers calibration services of gamma, X, beta and alpha radiation detectors. The objective was to study the energy dependence of radiation monitors for low and medium energy X-rays, using the ambient dose equivalent quantity, $H^*(d)$ and the angular dependence. Theses tests can show if the instrument is working correctly.

Materials and methods

The system of X radiation, in the Calibration Laboratory of IPEN, consists of a Pantak / Seifert, ISOVOLT HS 160, model 160, equipament with mean energies of 48 keV to 118 keV. The characteristics of the X radiation beams, used in this work, are described in Table 1. The caractrization of the X radiation beams, radioprotection level, was performed using the ionization chamber PTW, model w32002 – 35, calibrated at the German Laboratory Deutscher Kalibrierdienst (DKD) for the radiation qualities N-60, N-80, N-100, N-150, N-200 and N-250 (DKD, 1995). This ionization chamber has an expanded uncertainty of 3.0%, and it was used with the electrometer PTW UNIDOS, model 10001, with an uncertainty estimated as 0.5%, composing a measurement system with a total uncertainty of 3.5% for the value corresponding to the calibration factor. The uncertainties were determined according to the recommendations of the ISO 15572 (ISO 1998) and Brazilian standards (ISO 2003) for a coverage factor k = 2 and confidence level of 95.45%.

Table 1. Characteristics of X radiation beams (series of narrow spectrum), radiation protection levels established in the Pantak/Seifert system.

Radiation quality	Mean energy (keV)	Voltage (kV)	Half-value layer (HVL) (mmCu)	Additional filtration (mm)
N-60	48	60	0.25	0.6(Cu)
N-80	65	80	0.61	2.0(Cu)
N-100	83	100	1.14	5.0(Cu)
N-150	118	150	2.40	2.5(Sn)

Twenty one ionization chambers of six manufactures and eleven different models were tested in X radiation beams. Of the twenty one ionization chambers, nineteen were studied in relation to their energy dependence and four of them were tested in relation to their angular dependence.

Initially, the measurements of the exposure rates and air kerma rates were converted to ambient dose equivalent rates. The conversion coefficients from air kerma to ambient dose equivalent are presented in Table 2.

Table 2. Conversion coefficients from air kerma to ambient dose equivalent for the radiation qualities of ISO 4037-3 (ISO, 1999), at the reference distance of 2m.

Radiation quality	Conversion coefficients (Sv/Gy)
N-60	1.59
N-80	1.73
N-100	1.71
N-150	1.58

Then, the calibrations factors, C_f, were determined. The calibration factor is the ratio between the conventional true value (reference), C_{TV}, and the measured (indicated value), M, by the radiation detector, for the N-60, N-80, N-100 and N-150 radiation qualities (narrow beams), according to Equation 1.

$$C_f = \frac{C_{TV}}{M} \qquad \text{Equation 1}$$

For the angular response of the detectors, a special holder, Figure 1, was made of PMMA with a goniometer for the monitor rotation. The response of the ionization chambers in relation to the angular dependence was taken for the angles 0^0, $\pm 15^0$, $\pm 30^0$, $\pm 45^0$, $\pm 60^0$ and $\pm 90^0$.

The characteristics of the ionization chambers tested in this work are presented in Table 3.

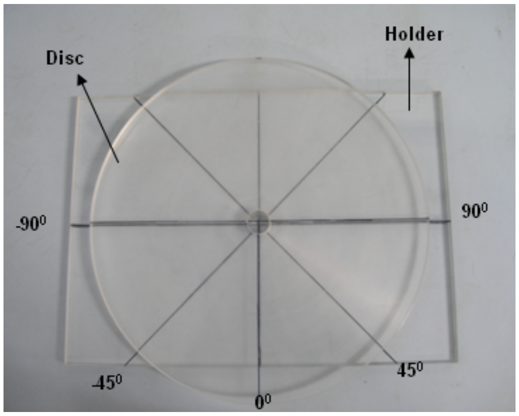

Fig.1. Goniometer for the angular dependence study of the ionization chambers.

Table 3. Characteristics of the ionization chambers

Ionization chamber	Model	Chamber code	Radiation detected	Operating ranges
Babyline	81	A1	β, gamma, X	0 a 100 R/h
Fluke Biomedical	451 B-ryr	B1 e B2	β, gamma, X	0 a 50 R/h ou 0 a 500 mSv/h
Inovision	451P	C1 e C2	gamma, X	0 a 5 R/h ou 0 a 50 mSv/h
	451B	D1	α, β, gamma, X	0 a 50 R/h ou 0 a 500 mSv/h
Radcal	9010/10X5-1800	E1...E4	X	0,01 mR/h a 65 R/h
	9015/10X5-1800	F1	X	0,01 mR/h a 65 R/h
	2026C/20X6-180	G1	X	1 mR/h a 1 kR/h
Step	RGD 27091	H1	gamma, X	20 mSv/h a 2 Sv/h
Victoreen	450P	I1	gamma, X	0 a 5 R/h
	451B	J1...J4	α, β, gamma, X	0 a 50 R/h
	451P	K1...K3	gamma, X	0 a 5 R/h ou 0 a 50 mSv/h

Results and discussion

The calibration factors of the ionization chambers in standard X-ray beams were determined, and the results are presented in Table 4.

Table 4. Calibration factors of the ionization chambers for X radiation.

Chamber code	C_f: Calibration factor			
	(N – 60)	*(N – 80)*	*(N – 100)*	*(N – 150)*
A1	1.01	1.03	1.00	0.90
B1	0.88	0.81	0.78	0.81
B2	0.99	0.99	0.97	1.05
C1	1.09	1.05	1.05	0.91
C2	1.30	1.26	1.20	1.01
D1	0.96	0.93	0.95	0.99
E1	1.00	1.03	1.09	1.05
E2	0.98	1.01	1.08	1.06
E3	1.01	1.04	1.11	1.06
E4	0.98	1.01	1.09	1.06
F1	0.97	1.00	1.07	1.06
G1	1.01	1.04	1.09	1.04
H1	1.03	1.13	1.10	0.98
I1	1.20	1.14	1.15	0.91
J1	1.05	0.98	1.02	0.93
J2	1.11	1.00	0.96	0.82
K1	1.15	1.08	1.07	0.94
K2	1.12	1.07	1.07	0.95
K3	0.96	0.93	0.95	0.99

The calibration factor shall not be higher than 1,2 (IRD, 2004). In this case, the ionization chamber B2 would not be able to measure radiation intensity in the radiation quality N-100 and the ionization chamber C2 would not be able to measure the radiation intensity in the qualities N-60 and N-80.

The data of Table 4 can be visualized in Figures 2, 3 and 4. In the case of the ionization chambers D1 and H1, the response was presented for the radiation energies of the ^{137}Cs and ^{60}Co sources too.

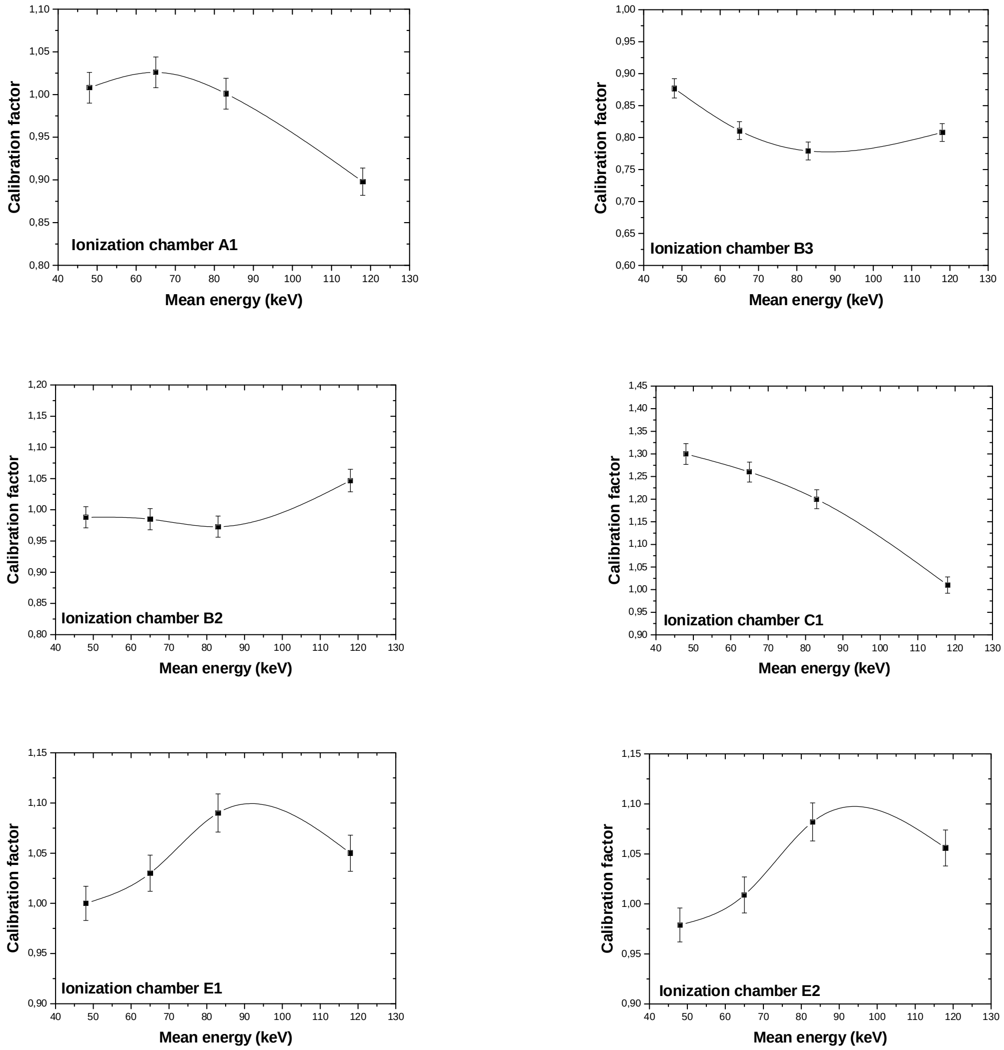

Fig.2. Calibration factors of the ionization chambers: A1, B1, B2, C1, E1 and E2 for different X radiation qualities.

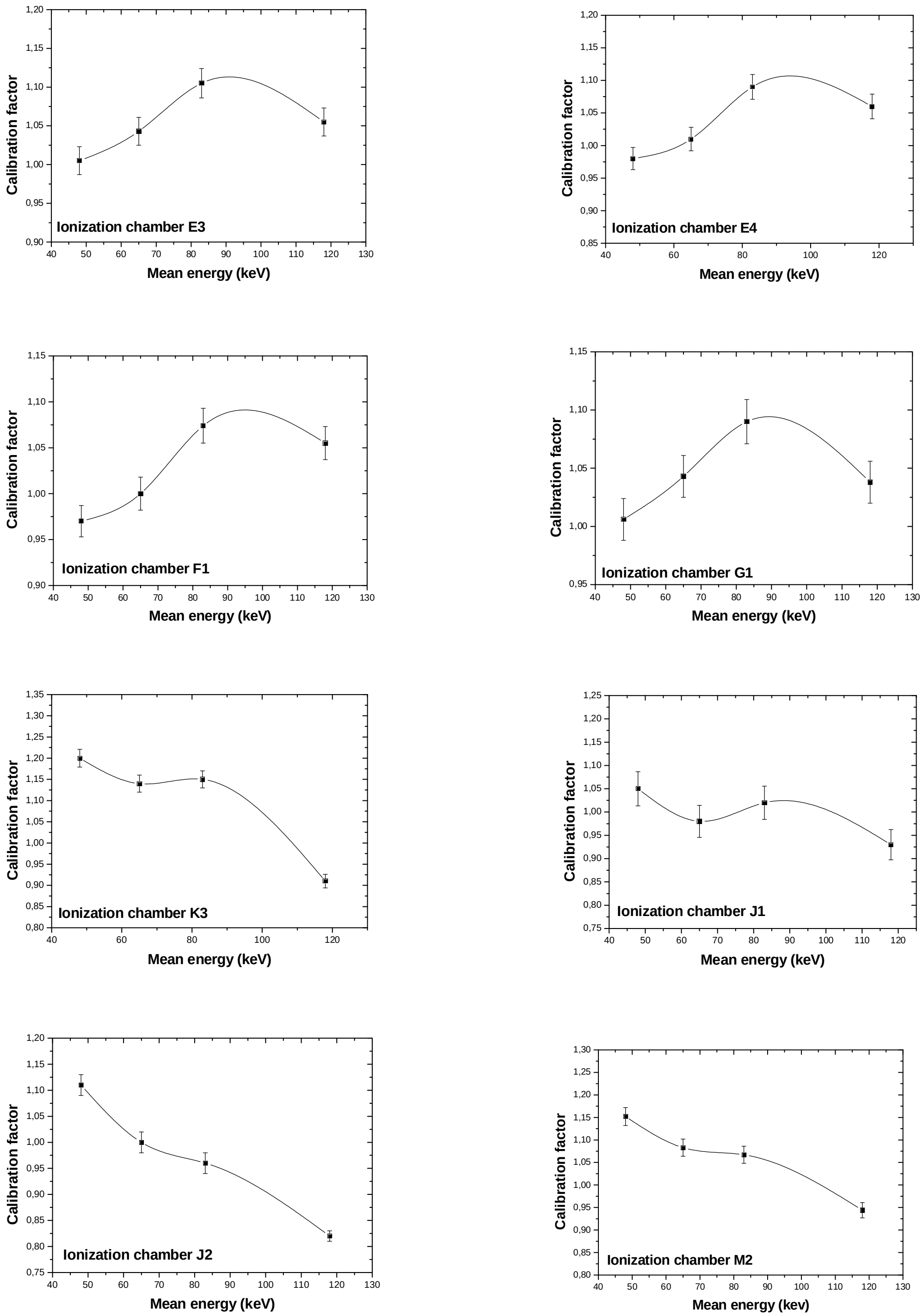

Fig.3. Calibration factors of the ionization chambers: E3, E4, F1, G1, I1, J1, J2 and K1 for different X radiation qualities.

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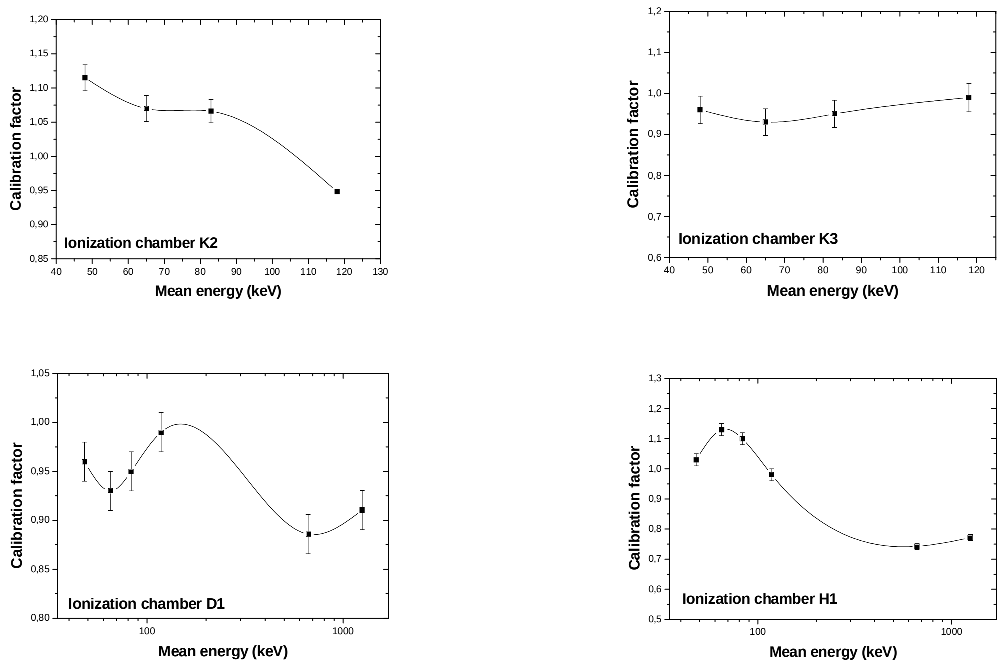

Fig.4. Calibration factors of the ionization chambers: K2 and K3 for different X radiation qualities; and D1 and H1 for gamma and X radiation qualities.

Different behaviors are observed in the response of the ionization chambers of different models. When comparing the curves, the behavior of the response of ionization chambers of the same model is quite similar, such as in the case of E1, E2, E3 and E4 ionization chambers. The curves obtained for the ionization chambers D1 and H1 in Figure 4 show that the calibration factors for X radiation is higher than the calibration factors for gamma radiation.

The energy dependence of these monitors is presented in Table 5, using the calibration factor data presented in Table 4.

Table 5. Energy dependence of the ionization chambers, radiation protection level, for X-rays (48keV-118 kev).

Chamber code	Energy dependence	Expanded uncertainty (U)
A1	1.14	0.07
B1	1.13	0.06
B2	1.08	0.06
C1	1.20	0.07
C2	1.29	0.06
D1	1.06	0.06
E1	1.09	0.06
E2	1.10	0.06
E3	1.10	0.06
E4	1.11	0.06
F1	1.10	0.06
G1	1.08	0.06
H1	1.15	0.06
I1	1.32	0.07
J1	1.13	0.06
J2	1.35	0.08
K1	1.22	0.07
K2	1.18	0.07
K3	1.06	0.06

The energy dependence of the ionization chambers varied between 6% and 35% (Table 5), according to the ionization chambers K3 and J2, which respectively showed energy dependence of (1.06 ± 0.06) and (1.35 ± 0.08). Monitors utilized at radioprotection level are divided into different classes, according to ABNT 10011 (ABNT, 1987). In this standard, the ionization chambers studied in this work are within the definition of Class II, where the maximum variation may be ± 25%. Only the ionization chamber J2 showed no agreement with the standard.

The angular dependence was obtained for the ionization chambers A1, C2, J3 and J4 without changing the measurement quantity to dose equivalent ambient. The two last models were not tested in relation to the energy dependence. The angle variation was from 0^0 to ± 90^o and only the radiation quality N-150 was utilized. The curves are presented in Figure 5.

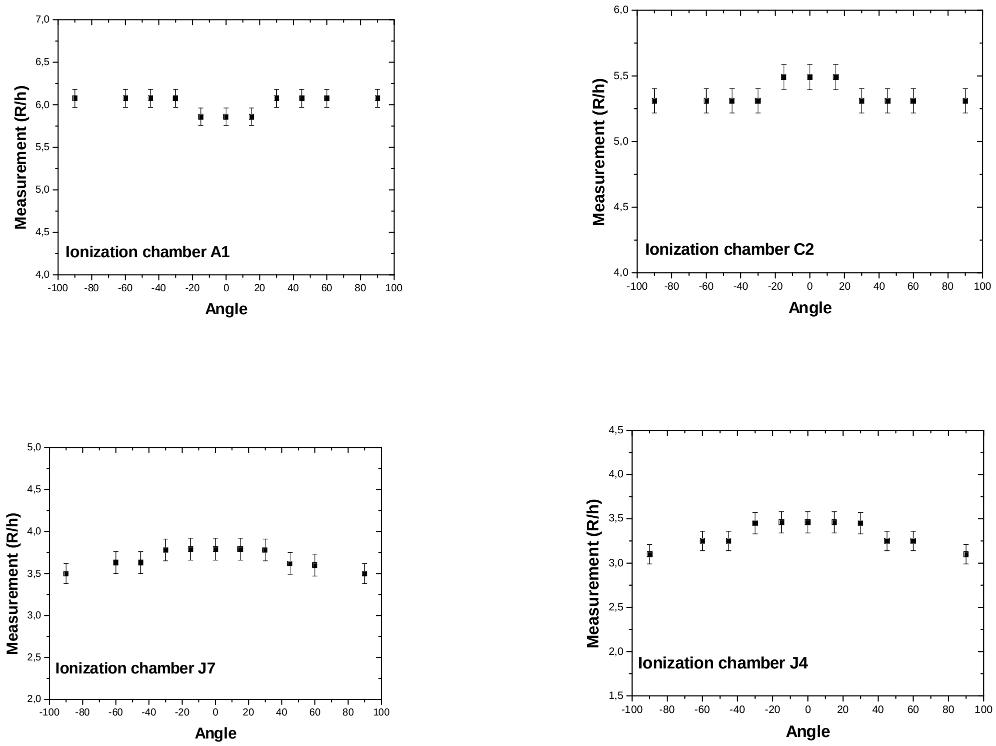

Fig.5. Angular dependence of the ionization chambers: A1, C2, J3 and J4; radiation quality: N-150.

The ionization chambers (Figure 5) presented low or almost no angular dependence for certain angle intervals. Their measurements are stable when varying the positioning of the ionization chamber in relation to the beam incidence. The ionization chambers J3 and J4 present higher angular dependence than models A1 and C2, because of their radiation entrance windows. The ionization chamber A1 has just an external wall (protection cap for build-up), but during the calibration with X-rays it is not utilized. The ionization chamber C2 is pressurized, and does not have an entrance window. All ionization chambers with x-rays agree with the standard EN 60846 (EN, 2004) that determines that the angular dependence may vary up to 40%.

Conclusions

The results obtained for the calibration factors and energy dependence for the ionization chambers were satisfactory, according to the ISO-4037-1 (ISO,1996); ISO-4037-3 (ISO,1999) and IAEA SRS16 (IAEA, 2000) recommendations. Only one of all nineteen ionization chambers presented an energy dependence higher than 25%. The energy dependence curves presented differents behaivors, depending on the ionization chamber model. The angular dependence of the monitors showed agreement with the standard EN 60846 (EN, 2004).

References

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