8
REFERÊNCIAS BIBLIOGRÁFICAS

ABNT (2002). Associação Brasileira de Normas Técnicas; **NBR 6023**.

AGEVAP (2007). Associação Pró-Gestão das Águas da Bacia Hidrográfica do Rio Paraíba do Sul. **Diagnóstico dos Recursos Hídricos da Bacia do Paraíba do Sul**. Disponível em: <http://www.ceivap.org.br>. Acesso em: 19 dezembro 2007.

ARAÚJO, Andressa Arruda de. (2005). **Determinação Radioquímica de ^{210}Pb e ^{226}Ra em Borras e Incrustações de Petróleo**. Dissertação de Mestrado. Programa de Pós-Graduação em Tecnologias Energéticas e Nucleares, Universidade Federal de Pernambuco.

BURNETT, William C. et al. (2008). **Radon and Radium Isotopes as Tracers of Submarine Groundwater Discharge e Results from the Ubatuba, Brazil SGD Assessment Intercomparison**. Estuarine, Coastal and Shelf Science, v. 76, p. 501-511.

BUTTS, Jolynn et al. (1988). **A Simplified Method for ^{226}Ra Determinations in Natural Waters**. Marine Chemistry, v. 25, issue 4, p. 349-357.

COCHRAN, J. Kirk et al. (2006). **Natural Radionuclides as Tracers of Coastal Biogeochemical Processes**. Journal of Geochemical Exploration, v. 88, p. 376-379.

DHN. Diretoria de Hidrografia e Navegação / Marinha do Brasil. Disponível em: <http://www.mar.mil.br>. Acesso em: 10 julho 2008.

DIMOVA, N. et al. (2008). **Uncertainties in the Preparation of ^{224}Ra Mn Fiber Standards**. Marine Chemistry, v. 109, p. 220-225.

DULAIOVA, Henrieta; BURNETT, William C. (2008). **Evaluation of the Flushing Rates of Apalachicola Bay, Florida via Natural Geochemical Tracers**. Marine Chemistry, v. 109, p. 395-408.

FEEMA (2007). Fundação Estadual de Engenharia do Meio Ambiente. **Rio Paraíba do Sul**. Disponível em: <http://www.feema.rj.gov.br>. Acesso em: 10 dezembro 2007.

GARCIA-SOLSONA, E. et al. (2008). Uncertainties Associated with ^{223}Ra and ^{224}Ra Measurements in Water via a Delayed Coincidence Counter (RaDeCC). Marine Chemistry, v. 109, p. 198-219.

GIFFIN, Charles et al. (1963). **Delayed Coincidence Counter for the Assay of Actinon and Thoron**. Journal of Geophysical Research, v. 68, nº 6, p. 1749-1757.

GODOY, José Marcus de Oliveira et al. (1994). **Development of a Sequential Method for the Determination of ^{238}U, ^{234}U, ^{232}Th, ^{230}Th, ^{228}Th, ^{226}Ra, ^{228}Ra ^{210}Pb and ^{210}Po in Environmental Samples**. Journal of Radioanalytical and Nuclear Chemistry, v. 182, nº 1, p. 165-169.

GODOY, José Marcus de Oliveira; GODOY, Maria Luiza. (2006). **Natural Radioactivity in Brazilian Groundwater**. Journal of Environmental Radioactivity, v. 85, p. 71-83.

GODOY, José Marcus de Oliveira et al. (2006). **^{228}Ra and ^{226}Ra in Coastal Seawater Samples from the Ubatuba Region – Brazilian Southeastern Coastal Region**. Journal of Brazilian Chemistry Society, v. 17, nº 4, p. 730-736.

GRUBEN, Anna et al. (2002). **A Bacia do Rio Paraíba do Sul:** relatórios preliminares 2001. Projeto Marca D'Água. Disponível em: <http://www.marcadagua.org.br/bacia13.htm>. Acesso em: 18 março 2008.

IAEA (1999). International Atomic Energy Agency. **Inventory of Radioactive Waste Disposals at Sea**. Technical Document Series 1105, Vienna, 121p.

IAEA (1985). International Atomic Energy Agency. **Behaviour of Radionuclides Released into Coastal Waters**. Technical Document Series 329, Vienna, 183p.

JOSEPH et al. (1971). **Sources of Radioactivity and their Characteristics**. In: Committee on Oceanography National Research Council, Radioactivity in the Marine Environment, chapter 2, National Academy of Sciences, Washington.

KREST, James M. et al. (1999). **^{226}Ra and ^{228}Ra in the Mixing Zones of the Mississippi and Atchafalaya Rivers:** indicators of groundwater input. Marine Chemistry, v. 64, p. 129-152.

LAURIA, Dejanira da Costa. (1999). **Transporte de Radionuclídeos Naturais e Elementos das Terras Raras Leves no Sistema Lagunar de Buena, RJ**. 133 p. Tese de Doutorado-Departamento de Química, Pontifícia Universidade Católica, Rio de Janeiro.

LEE, Jae Seong et al. (2005). **Radium Isotopes in the Ulsan Bay**. Journal of Environmental Radioactivity, v. 82, p. 129-141.

LEVY, David M.; MOORE, Willard S. (1985). **^{224}Ra in Continental Shelf Waters**. Earth and Planetary Science Letters, v. 73, p. 226-230.

LI, Yuan-Hui et al. (1977). **The Flux of ^{226}Ra from Estuarine and Continental Shelf Sediments**. Earth and Planetary Science Letters, v. 37, p. 237-241.

MARENGO, José A.; ALVES, Lincoln M. (2005). **Tendências Hidrológicas da Bacia do Rio Paraíba do Sul**. CPTEC/INPE, São Paulo.

MOORE, Willard S. (1969). **Oceanic Concentrations of ^{228}Radium**. Earth and Planetary Science Letters, v. 6, p. 437-446.

MOORE, Willard S. (1976). **Sampling ^{228}Ra in the Deep Ocean**. Deep-Sea Research, v. 23, p. 647-651.

MOORE, Willard S. (1980). **Radium Isotopes in Sub-Arctic Waters**. Earth and Planetary Science Letters, v. 49, p. 329-340.

MOORE, Willard S. (1981). **The Thorium Isotope Content of Ocean Water**. Earth and Planetary Science Letters, v. 53, issue 3, p. 419-426.

MOORE, Willard S. (1984). **Radium Isotope Measurements Using Germanium Detectors**. Nuclear Instruments and Methods in Physics Research, v. 223, p. 407-411.

MOORE, Willard S. (1996). **Large Groundwater Inputs to Coastal Waters Revealed by ^{226}Ra Enrichments**. Nature, v. 380, p. 612-614.

MOORE, Willard S. (1999). **The Subterranean Estuary: a Reaction Zone of Groundwater and Sea Water**. Marine Chemistry, v. 65, p. 111-125.

MOORE, Willard S. (2008). **Fifteen Years Experience in Measuring ^{224}Ra and ^{223}Ra by Delayed Coincidence Counting**. Marine Chemistry, v. 109, p. 188-197.

MOORE, Willard S.; ARNOLD, Ralph. (1996). **Measurement of ^{223}Ra and ^{224}Ra in Coastal Waters Using a Delayed Coincidence Counter**. Journal of Geophysical Research, v. 101, nº C1, p. 1321-1329.

MOORE, Willard S.; FALKNER, Kelly K. (1999). **Cycling of Radium and Barium in the Black Sea**. Journal of Environmental Radioactivity, v. 43, p. 247-254.

MOORE, Willard S.; OLIVEIRA, Joselene de. (2008). **Determination of Residence Time and Mixing Processes of the Ubatuba, Brazil, Inner Shelf Waters Using Natural Ra Isotopes**. Estuarine, Coastal and Shelf Science, v. 76, p. 512-521.

PÓS-GRADUAÇÃO PUC-Rio. (2001). **Normas para Apresentação de Teses e Dissertações** / Pontifícia Universidade Católica do Rio de Janeiro.

RAMA et al. (1987). **A New Method for the Rapid Measurement of ^{224}Ra in Natural Waters**. Marine Chemistry, v. 22, p. 43-54.

RAMA; MOORE, Willard S. (1984). **Mechanism of Transport of U-Th Series Radioisotopes from Solids into Groundwater**. Geochimica et Cosmochimica Acta, v. 48, issue 2, p. 395-399.

RAMA; MOORE, Willard S. (1996). **Using the Radium Quartet for Evaluating Groundwater Input and Water Exchange in Salt Marshes**. Geochimica et Cosmochimica Acta, v. 60, nº 23, p. 4645-4652.

REID, David F. et al. (1979). **Radium, Thorium, and Actinium Extraction from Seawater Using an Improved Manganese-Oxide-Coated Fiber**. Earth and Planetary Science Letters, v. 43, issue 2, p. 223-226.

REID, David F. et al. (1979). **Temporal Variation of ^{228}Ra in the Near-Surface Gulf of Mexico**. Earth and Planetary Science Letters, v. 43, p. 227-236.

SIGMA PLOT. Versão 9.0: **Exact Graphs and Data Analysis**.

SOUZA JR, Daniel I. de. (2004). **A Degradação da Bacia do Rio Paraíba do Sul**. Engevista, v. 6, nº 3, p. 99-105.

TORGERSEN, Thomas et al. (1996). **^{224}Ra Distribution in Surface and Deep Water of Long Island Sound:** sources and horizontal transport rates. Continental Shelf Research, v. 16, nº 12, p. 1545-1559.

TUREKIAN, K.K. et al. (1996). **Transfer Rates of Dissolved Tracers Through Estuaries Based on ^{228}Ra: a study of Long Island Sound**. Continental Shelf Research, v. 16, nº 7, p. 863-873.

VEGUERÍA, Sergio F. Jerez et al. (2002). Environmental Impact in Sediments and Seawater due to Discharges of Ba, ^{226}Ra, ^{228}Ra, V, Ni and Pb by Produced Water from the Bacia de Campos Oil Field Offshore Platforms. Environmental Forensics, v. 3, p. 115-123.

9
ANEXOS

9.1.
Cálculo da Incerteza de Medição

9.1.1.
Isótopo ^{224}Ra

$$A^{224}Ra = \frac{(CPM\ 220 - CorreçãoCC - BG)}{60 * \varepsilon * V * Ft}$$

Onde:

A = Atividade do isótopo de ^{224}Ra (Bq m^{-3});

CPM 220 = Número de contagens do decaimento de ^{220}Rn por minuto;

Correção CC = Correção das contagens em relação ao decaimento do ^{223}Ra;

BG = Taxa de contagem total do background (CPM);

ε = Eficiência do sistema de medição;

V = Volume de amostra (L);

Ft = Fator de tempo (tempo decorrido entre a amostragem e a contagem).

Equações intermediárias da incerteza

(1) $$CPM\,220 = \frac{CPM\,220}{\mathrm{T}_{220}}$$

$$\delta CPM = \sqrt{\left(\frac{CPM\,220}{\mathrm{T}_{220}}\right)}$$

(2) $$BG = \frac{BG}{\mathrm{T}_{220}}$$

$$\delta BG = \sqrt{\left(\frac{BG}{\mathrm{T}_{220}}\right)}$$

(3) $$Correção CC = \frac{(CPMtotal - CPM\,219 - CPM\,220)^2 * 0{,}01}{1 - (CPMtotal - CPM\,219 - CPM\,220) * 0{,}01}$$

$$\delta Correção CC = Correção CC \sqrt{\left[2\left(\frac{\delta X}{X}\right)^2 + \left(\frac{\delta Y}{Y}\right)^2\right]}$$

Onde:

$$\delta X = \sqrt{\left[(\delta CPMtotal)^2 + (\delta CPM\,219)^2 + (\delta CPM\,220)^2\right]}$$

$$\delta Y = \sqrt{\left[(\delta CPMtotal)^2 + (\delta CPM\,219)^2 + (\delta CPM\,220)^2\right]}$$

Logo: $\delta X = \delta Y$

Simplificando:

$$\delta Correção CC = Correção CC \sqrt{\left[3\left(\frac{\delta X}{X}\right)^2\right]}$$

(4) $$\varepsilon = \frac{(CPM\,220 - Correção CC - BG)}{60 * A^{228}Ra * Ft}$$

$$\delta\varepsilon = \varepsilon \sqrt{\left[\left(\frac{\delta W}{W}\right)^2 + \left(\frac{\delta Z}{Z}\right)^2\right]}$$

Onde:

$$\delta W = \sqrt{\left[(\delta CPM\,220)^2 + (\delta Correção CC)^2 + (\delta BG)^2\right]}$$

$$\delta Z = \delta A^{228}Ra = 0{,}75\%$$

(5) Volume (L)

$$\delta V \cong 5\%$$

Equação final da incerteza

$$\delta A^{224}Ra = A^{224}Ra\sqrt{\left[\left(\frac{\delta U}{U}\right)^2 + \left(\frac{\delta \varepsilon}{\varepsilon}\right)^2 + \left(\frac{\delta V}{V}\right)^2\right]}$$

Onde:

$$\delta U = \sqrt{\left[(\delta CPM\,220)^2 + (\delta CorreçãoCC)^2 + (\delta BG)^2\right]}$$

9.1.2. Isótopo ^{223}Ra

$$A^{223}Ra = \frac{(CPM\ \ 219\ -\ CorreçãoCC\ \ -\ BG\ )}{60\ *\ \varepsilon\ *\ V\ *\ Ft}$$

Onde:

A = Atividade do isótopo de ^{223}Ra (Bq m^{-3});

CPM 219 = Número de contagens do decaimento de ^{219}Rn por minuto;

Correção CC = Correção das contagens em relação ao decaimento do ^{224}Ra;

BG = Taxa de contagem total do background (CPM);

E = Eficiência do sistema de medição;

V = Volume de amostra (L);

Ft = Fator de tempo (tempo decorrido entre a amostragem e a contagem).

Equações intermediárias da incerteza

(1) $CPM\,219 = \frac{CPM\,219}{\mathrm{T}_{219}}$

$$\delta CPM = \sqrt{\left(\frac{CPM\,219}{\mathrm{T}_{219}}\right)}$$

(2) $BG = \frac{BG}{\mathrm{T}_{219}}$

$$\delta BG = \sqrt{\left(\frac{BG}{\mathrm{T}_{219}}\right)}$$

(3) $Correção CC = \frac{(CPMtotal - CPM\,219 - CPM\,220)^2 * 0{,}000095}{1-(CPMtotal - CPM\,219 - CPM\,220) * 0{,}000095}$

$$\delta Correção CC = Correção CC \sqrt{\left[2\left(\frac{\delta X}{X}\right)^2 + \left(\frac{\delta Y}{Y}\right)^2\right]}$$

Onde:

$$\delta X = \sqrt{\left[(\delta CPMtotal)^2 + (\delta CPM\,219)^2 + (\delta CPM\,220)^2\right]}$$

$$\delta Y = \sqrt{\left[(\delta CPMtotal)^2 + (\delta CPM\,219)^2 + (\delta CPM\,220)^2\right]}$$

Logo: $\delta X = \delta Y$

Simplificando:

$$\delta Correção CC = Correção CC \sqrt{\left[3\left(\frac{\delta X}{X}\right)^2\right]}$$

(4) $\varepsilon = \frac{(CPM\,219 - Correção CC - BG)}{60 * A^{228}Ra * Ft}$

$$\delta\varepsilon = \varepsilon \sqrt{\left[\left(\frac{\delta W}{W}\right)^2 + \left(\frac{\delta Z}{Z}\right)^2\right]}$$

Onde:

$$\delta W = \sqrt{\left[(\delta CPM\,220)^2 + (\delta Correção CC)^2 + (\delta BG)^2\right]}$$

$$\delta Z = \delta A^{228} Ra = 0{,}75\%$$

(5) Volume (L)

$$\delta V \cong 5\%$$

Equação final da incerteza

$$\delta A^{223} Ra = A^{223} Ra \sqrt{\left[\left(\frac{\delta U}{U}\right)^2 + \left(\frac{\delta \varepsilon}{\varepsilon}\right)^2 + \left(\frac{\delta V}{V}\right)^2\right]}$$

Onde:

$$\delta U = \sqrt{\left[(\delta CPM\ 220)^2 + (\delta Correção CC\ )^2 + (\delta BG)^2\right]}$$

9.1.3. Isótopo ^{226}Ra

$$A^{226} Ra = \frac{CPS\,226 - BG}{Q * Rq * \varepsilon_{\alpha 226}\left(\eta + KL\left(1 - EXP\left(-\lambda_{222\,Rn} * \Delta t\right)\right)\right)}$$

Onde:

$A^{226}Ra$ = Atividade do isótopo de ^{226}Ra (Bq m^{-3});

CPS226 = Taxa de contagem total da amostra (CPS);

BG = Taxa de contagem total do background (CPS);

Q = Quantidade de amostra utilizada para análise (L);

Rq = Rendimento químico;

$\varepsilon_{\alpha 226}$ = Eficiência de contagem α do ^{226}Ra;

η = Coeficiente de auto-absorção;

KL = Coeficiente linear;

λ_{222Rn} = Constante de desintegração do ^{222}Rn = 0,181 $dias^{-1}$;

Δt = Intervalo de tempo transcorrido entre a precipitação do ^{226}Ra e a contagem.

Equações intermediárias da incerteza

(1) $CPS226 = \frac{CPS226}{T_{226}}$

$$\delta CPS226 = \sqrt{\frac{CPS226}{T_{226}}}$$

(2) $BG = \frac{BG}{T_{226}}$

$$\delta BG = \sqrt{\frac{BG}{T_{226}}}$$

(3) $CPS226LIQ = CPS226 - BG$

$$\delta CPS226LIQ = \sqrt{(\delta CPS226)^2 + (\delta BG)^2}$$

(4) $LC_0 = K + \delta CPS226 * \sqrt{1 + \frac{T_{226}}{T_{226(BG)}}}$

(5) $d = Q * Rq * \varepsilon_\alpha (\eta + KL(1 - EXP(-\lambda_{222Rn} * \Delta t))$

a. $X = Q * Rq * \varepsilon_\alpha$

$$\delta X = \sqrt{\left(\frac{\delta Q}{Q}\right)^2 + \left(\frac{\delta Rq}{Rq}\right)^2 + \left(\frac{\delta \varepsilon_\alpha}{\varepsilon_\alpha}\right)^2} * X$$

b. $Y = \eta + KL$

$$\delta Y = \sqrt{(\delta \eta)^2 + (\delta KL)^2}$$

$$\delta d = \sqrt{\left(\frac{\delta X}{X}\right)^2 + \left(\frac{\delta Y}{Y}\right)^2} * d$$

(6) $LC = \frac{LC_0}{d}$

Equação final da incerteza

$$A^{226}Ra = \frac{CPS226LIQ}{d}$$

$$\boxed{\delta A^{226}Ra = \sqrt{\left(\frac{\delta CPS226LIQ}{CPS226LIQ}\right)^2 + \left(\frac{\delta d}{d}\right)^2} * A^{226}Ra}$$

9.1.4. Isótopo ^{228}Ra

$$\boxed{A^{228}Ra = \frac{CPS228 - BG}{Q * Rq * \varepsilon_{\beta 228}} - \frac{\varepsilon_{\beta 226} * A^{226}Ra(1 - EXP(-\lambda_{222Rn} * \Delta t)}{\varepsilon_{\beta 228}}}$$

Onde:

$A^{228}Ra$ = Atividade do isótopo de ^{228}Ra (Bq m^{-3});

CPS228 = Taxa de contagem total da amostra (CPS);

BG = Taxa de contagem total do background (CPS);

Q = Quantidade de amostra utilizada para análise (L);

Rq = Rendimento químico;

$\varepsilon_{\beta 228}$ = Eficiência de contagem β do ^{228}Ra;

$\varepsilon_{\beta 226}$ = Eficiência de contagem β do ^{226}Ra;

$A^{226}Ra$ = Atividade do isótopo de ^{226}Ra (Bq m^{-3});

λ_{222Rn} = Constante de desintegração do ^{222}Rn = 0,181 $dias^{-1}$;

Δt = Intervalo de tempo transcorrido entre a precipitação do ^{228}Ra e a contagem.

$$\boxed{A^{228}Ra = \frac{(CPS228 - BG) - (Q * Rq * \varepsilon_{\beta 226} * A^{226}Ra(1 - EXP(-\lambda_{222Rn} * \Delta t))}{Q * Rq * \varepsilon_{\beta 228}}}$$

Equações intermediárias da incerteza

(1) $CPS228 = \frac{CPS228}{T_{228}}$

$$\delta CPS228 = \sqrt{\frac{CPS228}{T_{228}}}$$

(2) $BG = \frac{BG}{T_{228}}$

$$\delta BG = \sqrt{\frac{BG}{T_{228}}}$$

(3) $CPS228LIQ^* = Q * Rq * \varepsilon_{\beta 226} * A^{226}Ra(1 - EXP(-\lambda_{222Rn} * \Delta t)$

$$\delta CPS228LIQ^* = \sqrt{\left(\frac{\delta Q}{Q}\right)^2 + \left(\frac{\delta Rq}{Rq}\right)^2 + \left(\frac{\delta \varepsilon_{\beta 226}}{\varepsilon_{\beta 226}}\right)^2 + \left(\frac{\delta A^{226}Ra}{A^{226}Ra}\right)^2} * CPS228LIQ^*$$

(4) $CPS228LIQ = CPS228 - (BG + CPS228LIQ^*)$

a. $BG^* = BG + CPS228LIQ^*$

$$\delta BG^* = \sqrt{(\delta BG)^2 + (\delta CPS228LIQ^*)^2}$$

$$\delta CPS228LIQ = \sqrt{(\delta CPS228)^2 + (\delta BG^*)^2} * CPS228LIQ$$

(5) $LC_0 = K + (\delta CPS228^*) * \sqrt{1 + \frac{T_{228}}{T_{228(BG)}}}$

(6) $d = Q * Rq * \varepsilon_{\beta 228}$

$$\delta d = \sqrt{\left(\frac{\delta Q}{Q}\right)^2 + \left(\frac{\delta Rq}{Rq}\right)^2 + \left(\frac{\delta \varepsilon_{\beta 228}}{\varepsilon_{\beta 228}}\right)^2} * d$$

(7) $LC = \frac{LC_0}{d}$

Equação final da incerteza

$$A^{228}Ra = \frac{CPS228LIQ}{d}$$

$$\boxed{\delta A^{228}Ra = \sqrt{\left(\frac{\delta CPS228LIQ}{CPS228LIQ}\right)^2 + \left(\frac{\delta d}{d}\right)^2} * A^{228}Ra}$$

9.2. Cálculo da Eficiência

9.2.1. Eficiência 219 (1)

$$\boxed{CPM\,219(1) = CPM\,219 - CC\,219(1)}$$

(1) $CPM\,219 = \frac{CNT\,219}{T_{219}}$

$$\delta CPM\,219 = \sqrt{\frac{CPM\,219}{T_{219}}}$$

(2) $C\,219(1) = \frac{(CPMTOTAL - CPM\,220 - CPM\,219)^2 * 0{,}000095}{1 - (CPMTOTAL - CPM\,220 - CPM\,219) * 0{,}0000095}$

a. $CPMTOTAL = \frac{CNTTOTAL}{T_{TOTAL}}$

$$\delta CPMTOTAL = \sqrt{\frac{CPMTOTAL}{T_{TOTAL}}}$$

b. $CPM\,220 = \frac{CNT\,220}{T_{220}}$

$$\delta CPM\,220 = \sqrt{\frac{CPM\,220}{T_{220}}}$$

c. $$CPM\,219 = \frac{CNT\,219}{T_{219}}$$

$$\delta CPM\,219 = \sqrt{\frac{CPM\,219}{T_{219}}}$$

d. $$X = \left(CPMTOTAL - CPM\,220 - CPM\,219\right)$$

$$\delta X = \sqrt{\left(\delta CPMTOTAL\right)^2 + \left(\delta CPM\,220\right)^2 + \left(\delta CPM\,219\right)^2}$$

e. $$Y = \left(CPMTOTAL - CPM\,220 - CPM\,219\right)^2 = X^2 = X * X$$

$$\delta Y = \sqrt{\left(\frac{\delta X}{X}\right)^2 + \left(\frac{\delta X}{X}\right)^2} * Y = \sqrt{2\left(\frac{\delta X}{X}\right)^2} * Y$$

$$\delta CC\,219(1) = \sqrt{\left(\frac{\delta X}{X}\right)^2 + \left(\frac{\delta Y}{Y}\right)^2} * CC\,219(1)$$

$$\boxed{\delta CPM\,219(1) = \sqrt{\left(\delta CPM\,219\right)^2 + \left(\delta CC\,219(1)\right)^2}}$$

9.2.2. Eficiência 220 (1)

$$\boxed{CPM\,220(1) = CPM\,220 - CC\,220(1)}$$

(1) $$CPM\,220 = \frac{CNT\,220}{T_{220}}$$

$$\delta CPM\,220 = \sqrt{\frac{CPM\,220}{T_{220}}}$$

(2) $$C\,220(1) = \frac{\left(CPMTOTAL - CPM\,220 - CPM\,219\right)^2 * 0{,}01}{1 - \left(CPMTOTAL - CPM\,220 - CPM\,219\right) * 0{,}01}$$

a. $CPMTOTAL = \frac{CNTTOTAL}{T_{TOTAL}}$

$$\delta CPMTOTAL = \sqrt{\frac{CPMTOTAL}{T_{TOTAL}}}$$

b. $CPM\,220 = \frac{CNT\,220}{T_{220}}$

$$\delta CPM\,220 = \sqrt{\frac{CPM\,220}{T_{220}}}$$

c. $CPM\,219 = \frac{CNT\,219}{T_{219}}$

$$\delta CPM\,219 = \sqrt{\frac{CPM\,219}{T_{219}}}$$

d. $X = (CPMTOTAL - CPM\,220 - CPM\,219)$

$$\delta X = \sqrt{(\delta CPMTOTAL)^2 + (\delta CPM\,220)^2 + (\delta CPM\,219)^2}$$

e. $Y = (CPMTOTAL - CPM\,220 - CPM\,219)^2 = X^2 = X * X$

$$\delta Y = \sqrt{\left(\frac{\delta X}{X}\right)^2 + \left(\frac{\delta X}{X}\right)^2} * Y = \sqrt{2\left(\frac{\delta X}{X}\right)^2} * Y$$

$$\delta CC220(1) = \sqrt{\left(\frac{\delta X}{X}\right)^2 + \left(\frac{\delta Y}{Y}\right)^2} * CC220(1)$$

$$\boxed{\delta CPM\,220(1) = \sqrt{(\delta CPM\,220)^2 + (\delta CC220(1))^2}}$$

9.2.3. Eficiência 219 (2)

$$\boxed{CPM\,219(2) = CPM\,219(1) - CC219(2)}$$

(1) $CPM\,219(1)$

$\delta CPM\,219(1)$

(2) $C219(2) = CPM\,220(1) * \left(1 - EXP\left(-\lambda_{216} * \Delta T\right)\right) = CPM\,220(1) * 0{,}0255$

a. $CPM\,220(1)$

$\delta CPM\,220(1)$

$$\delta CC219(2) = \sqrt{\left(\delta CPM\,220(1)\right)^2} * 0{,}0255$$

$$\boxed{\delta CPM\,219(2) = \sqrt{\left(\delta CPM\,219(1)\right)^2 + \left(\delta CC\,219(2)\right)^2}}$$

9.2.4. Eficiência 220 (2)

$$\boxed{CPM\,220(2) = CPM\,220(1) - CC220(2)}$$

(1) $CPM\,220(1)$

$\delta CPM\,220(1)$

(2) $$C220(2) = \frac{\left(1{,}6 * CPM\,219(2)\right)^2 * 0{,}01}{1 + \left(1{,}6 * CPM\,219(2)\right) * 0{,}01}$$

a. $CPM\,219(2)$

$\delta CPM\,219(2)$

b. $X = \left(1{,}6 * CPM\,219(2)\right)$

$\delta X = \delta CPM\,219 * 1{,}6$

c. $Y = \left(1{,}6 * CPM\,219(2)\right)^2 = X^2 = X * X$

$$\delta Y = \sqrt{\left(\frac{\delta X}{X}\right)^2 + \left(\frac{\delta X}{X}\right)^2} * Y = \sqrt{2\left(\frac{\delta X}{X}\right)^2} * Y$$

$$\delta CC220(2) = \sqrt{\left(\frac{\delta X}{X}\right)^2 + \left(\frac{\delta Y}{Y}\right)^2} * CC220(2)$$

$$\boxed{\delta CPM\,220(2) = \sqrt{(\delta CPM\,220(1))^2 + (\delta CC220(2))^2}}$$

9.2.5. Eficiência 219 (3)

$$\boxed{CPM\,219(3) = CPM\,219(2) - CPM\,219(BG)}$$

(1) $CPM\,219(2)$

$\delta CPM\,219(2)$

(2) $CPM\,219(BG)$

$$\delta CPM\,219(BG) = \sqrt{\frac{CPM\,219(BG)}{T_{219(BG)}}}$$

$$\boxed{\delta CPM\,219(3) = \sqrt{(\delta CPM\,219(2)^2 + (\delta CPM\,219(BG))^2}}$$

9.2.6. Eficiência 220 (3)

$$\boxed{CPM\,220(3) = CPM\,220(2) - CPM\,220(BG)}$$

(1) $CPM\,220(2)$

$\delta CPM\,220(2)$

(2) $CPM\,220(BG)$

$\delta CPM\,220(BG)$

$$\boxed{\delta CPM\,220(3) = \sqrt{(\delta CPM\,220(2))^2 + (\delta CPM\,220(BG))^2}}$$

Equações Finais da Incerteza

$$\varepsilon_{219} = \frac{CPM\,219(3)}{60 * A_{TH\,228} * M_{TH\,228}}$$

$$\delta\varepsilon_{219} = \sqrt{\left(\frac{\delta CPM\,219(3)}{T_{219}}\right)^2 + \left(\frac{\delta A_{TH\,228}}{A_{TH\,228}}\right)^2 + \left(\frac{\delta M_{TH\,228}}{M_{TH\,228}}\right)^2} * \varepsilon_{219}$$

$$\varepsilon_{220} = \frac{CPM\,220(3)}{60 * A_{TH\,228} * M_{TH\,228}}$$

$$\delta\varepsilon_{220} = \sqrt{\left(\frac{\delta CPM\,220(3)}{T_{220}}\right)^2 + \left(\frac{\delta A_{TH\,228}}{A_{TH\,228}}\right)^2 + \left(\frac{\delta M_{TH\,228}}{M_{TH\,228}}\right)^2} * \varepsilon_{220}$$