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An analytical method to determine activity concentrations of uranium- and thorium-series in the inhaled air during arc welding

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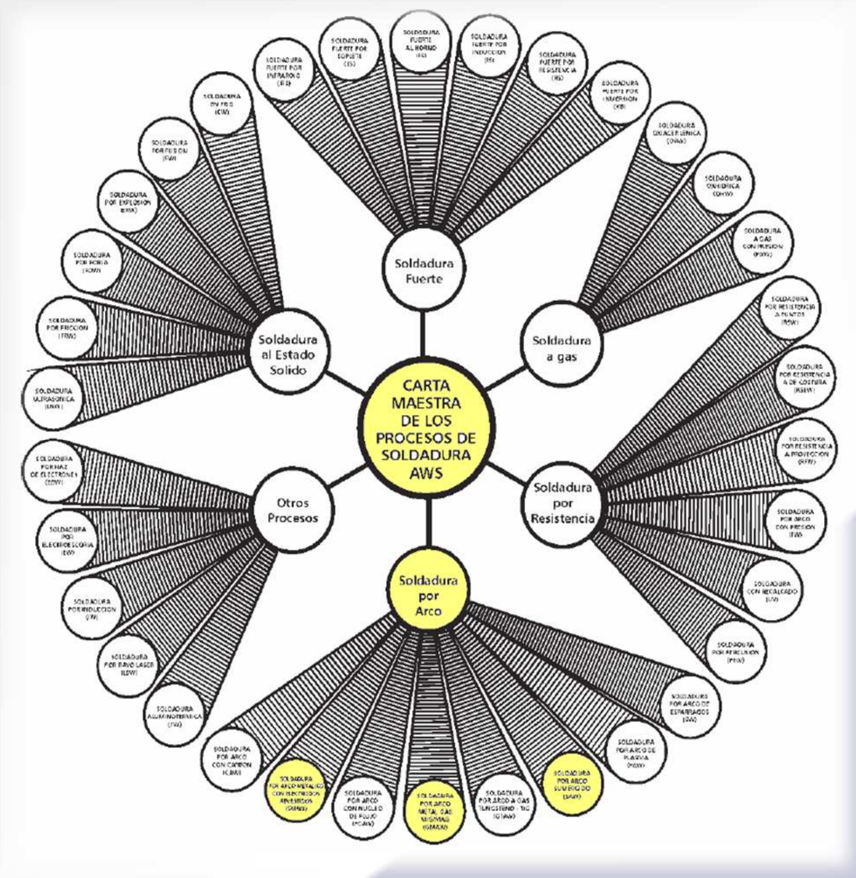

Welding processes according to AWS

Arc welding

- Arc
  - ✓ Electric current set up in air or gas between two conductor pieces
- Processes using consumables
  - ✓ SMAW ⟶ Covered electrode
  - ✓ GMAW ⟶ Wire
  - ✓ FCAW ⟶ Flux cored wire
  - ✓ SAW ⟶ Flux

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CONSUMABLES

- **Electrodes** – Covered
  - *70% rod*
  - *30% covering*
  - → **SMAW** → *Slag*
- **Wire**
  - Solid → **GMAW and SAW**
  - Flux cored
    - *85% metal wire*
    - *15% flux*
    - → **FCAW**
- **Flux** → **SAW** → *Slag*

- Rutile
  - ✓ Most used consumable type
  - ✓ Mineral from group IV (oxides and hydroxides)
  - ✓ 85 – 95% TiO_2
  - ✓ 0,1 – 1,1 Bq g^{-1} of ^{238}U
  - ✓ 0,07 – 0,45 Bq g^{-1} of ^{232}Th

Hypotheses

- During SMAW and FCAW processes aerosols and particles are sent into the air and inhaled, and slag is produced
- Aerosols and particles contain radionuclides, which could be concentrated in filters and inhaled

Objectives

- To develop an analytical method to determine activity concentrations in the inhaled air
- To assess effective dose, via inhalation

2. Materials and methods

2.1. *Sampling*

2.1.1. Aerosols and particles

- ✓ During SMAW and FCAW processes
- ✓ By an active air-sampling device:
  - Filter: fibreglass
  - Air flow rate: 60 l min^{-1}
- ✓ In an industrial facility with air extraction switched off

2.1.2. Slag

- ✓ After SMAW process

2. Materials and methods

2.2. *Measurement*

2.2.1. Fibreglass filters

- ✓ Gamma-ray spectrometry
  - Immediate and sequential 1200 s measurements
  - To determine AC of unsupported radon daughters
- ✓ U, Th, Ra, Pb and Po isolation
- ✓ Alpha and gamma spectrometry and beta counting

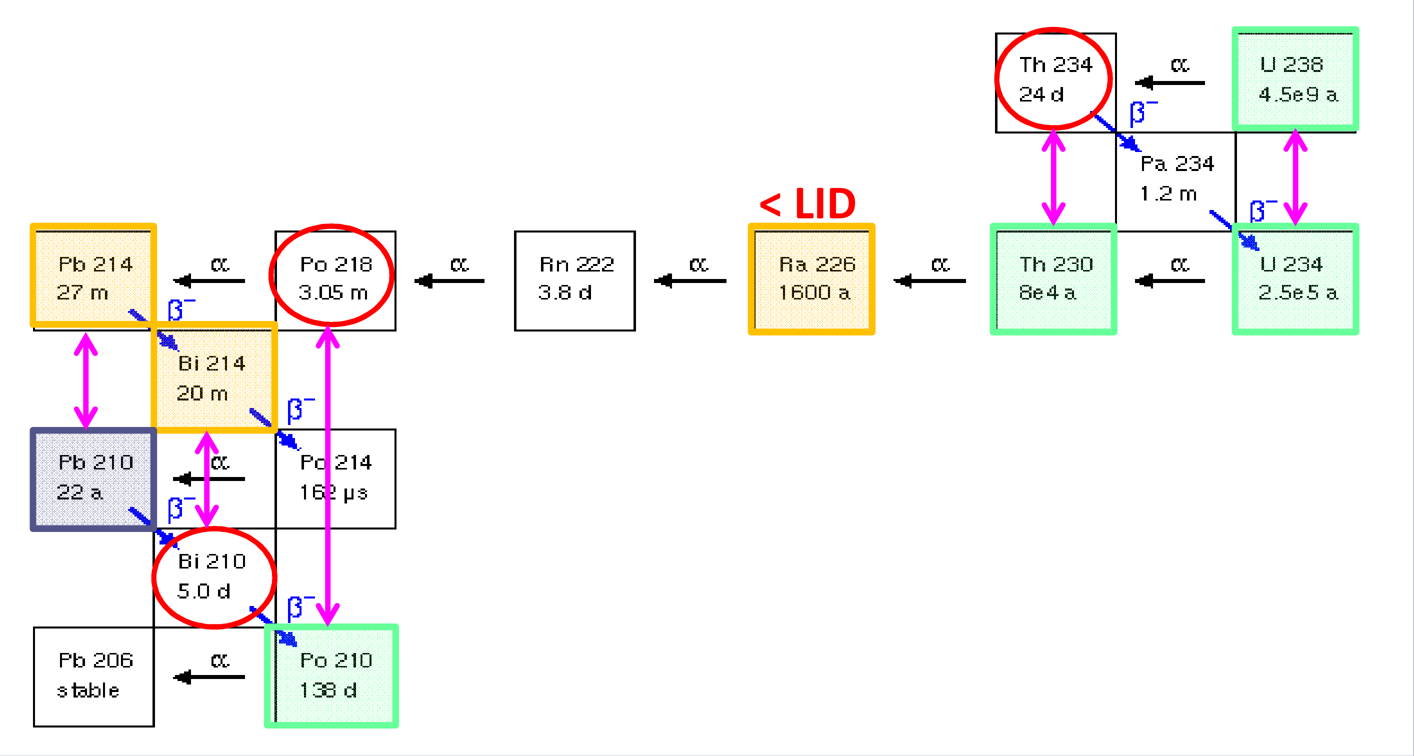
Alpha	PIPS detector	^{238}U, ^{234}U, ^{232}Th, ^{230}Th, ^{228}Th and ^{210}Po
Gamma	HPGe detector	^{226}Ra
Beta	Gas flow proportional detector	^{210}Pb

2.2.2. Slag

- ✓ Gamma-ray spectrometry
  - After sampling
  - Again, after being milled

2.3. *Activity concentration determination, uranium-series*

- ✓ Temperature and chemical reactions affect elements differently
- ✓ Ratio between AC of U- and Th-series in consumables persists in each element in air
- ✓ AC in the inhaled air is constant during arc welding



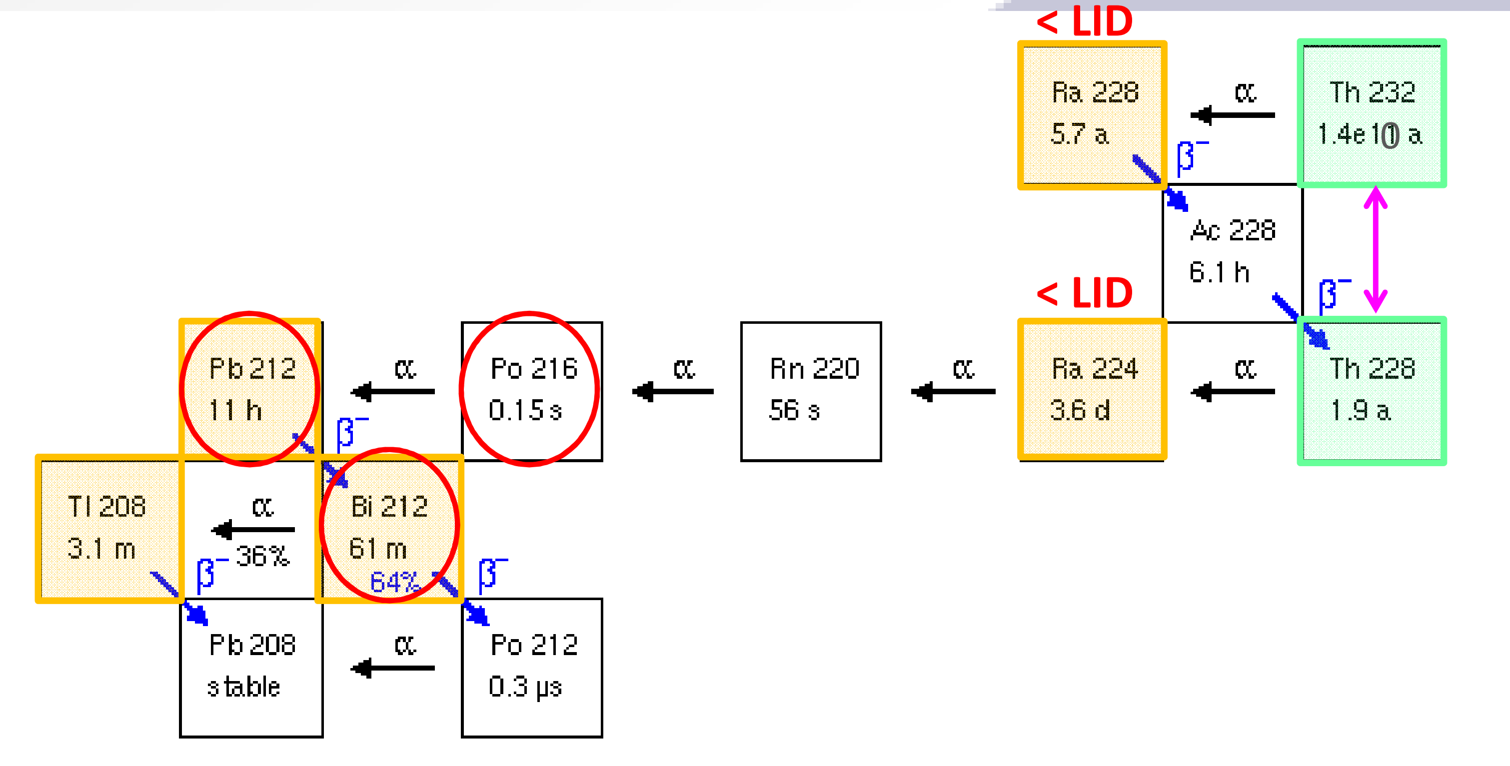
2.3.1. Equations for uranium-series

Radionuclide	Sampling	Decay
U 238	$\frac{dN}{dt} = \frac{n}{V}q - \lambda_{U\,238}N_{U\,238}$	$\frac{dN}{dt} = -\lambda_{U\,238}N_{U\,238} \sim 0$
Th 234	$\frac{dN}{dt} = \frac{n}{V}q - \lambda_{U\,238}N_{U\,238} - \lambda N$	$\frac{dN}{dt} = \lambda_{U\,238}N_{U\,238} - \lambda N \sim 0$
U 234	$\frac{dN}{dt} = \frac{n}{V}q - \lambda_{Pa\,234}N_{Pa\,234} - \lambda N$	$\frac{dN}{dt} = \lambda_{Pa\,234}N_{Pa\,234} - \lambda N \sim 0$
Th 230	$\frac{dN}{dt} = \frac{n}{V}q - \lambda_{U\,234}N_{U\,234} - \lambda N$	$\frac{dN}{dt} = \lambda_{U\,234}N_{U\,234} - \lambda N \sim 0$
Po 218	$\frac{dN}{dt} = \frac{n}{V}q - \lambda_{Rn\,222}N_{Rn\,222} - \lambda N$	$\frac{dN}{dt} = \lambda_{Rn\,222}N_{Rn\,222} - \lambda N$
Pb 214	$\frac{dN}{dt} = \frac{n}{V}q - \lambda_{Po\,218}N_{Po\,218} - \lambda N$	$\frac{dN}{dt} = \lambda_{Po\,218}N_{Po\,218} - \lambda N$
Bi 214	$\frac{dN}{dt} = \frac{n}{V}q - \lambda_{Pb\,214}N_{Pb\,214} - \lambda N$	$\frac{dN}{dt} = \lambda_{Pb\,214}N_{Pb\,214} - \lambda N$
Pb 210	$\frac{dN}{dt} = \frac{n}{V}q - \lambda_{Bi\,214}N_{Bi\,214} - \lambda N$	$\frac{dN}{dt} = \lambda_{Bi\,214}N_{Bi\,214} - \lambda N$
Bi 210	$\frac{dN}{dt} = \frac{n}{V}q - \lambda_{Pb\,210}N_{Pb\,210} - \lambda N$	$\frac{dN}{dt} = \lambda_{Pb\,210}N_{Pb\,210} - \lambda N \sim 0$
Po 210	$\frac{dN}{dt} = \frac{n}{V}q - \lambda_{Bi\,210}N_{Bi\,210} - \lambda N$	$\frac{dN}{dt} = \lambda_{Bi\,210}N_{Bi\,210} - \lambda N \sim 0$

$$Counting\ rate = \frac{\int_0^t \lambda_i N_i(t)dt \cdot \gamma_{\varepsilon,i} \cdot Efficiency}{t}$$

2.3. *Activity concentration determination, thorium-series*

- ✓ Temperature and chemical reactions affect elements differently
- ✓ Ratio between AC of U- and Th-series in consumables persists in each element in air
- ✓ AC in the inhaled air is constant during arc welding



2.3.2. Equations for thorium-series

Radionucleide	*Sampling*	*Decay*
Th 232	$\frac{dN}{dt} = \frac{n}{V} q - \lambda_{Th\ 232} N_{Th\ 232}$	$\frac{dN}{dt} = -\lambda_{Th\ 232} N_{Th\ 232} \sim 0$
Th 228	$\frac{dN}{dt} = \frac{n}{V} q + \lambda_{Ac\ 228} N_{Ac\ 228} - \lambda N$	$\frac{dN}{dt} = \lambda_{Ac\ 228} N_{Ac\ 228} - \lambda N \sim 0$
Po 216	$\frac{dN}{dt} = \frac{n}{V} q + \lambda_{Rn\ 220} N_{Rn\ 220} - \lambda N$	$\frac{dN}{dt} = \lambda_{Rn\ 220} N_{Rn\ 220} - \lambda N$
Pb 212	$\frac{dN}{dt} = \frac{n}{V} q + \lambda_{Po\ 216} N_{Po\ 216} - \lambda N$	$\frac{dN}{dt} = \lambda_{Po\ 216} N_{Po\ 216} - \lambda N$
Bi 212	$\frac{dN}{dt} = \frac{n}{V} q + \lambda_{Pb\ 212} N_{Pb\ 212} - \lambda N$	$\frac{dN}{dt} = \lambda_{Pb\ 212} N_{Pb\ 212} - \lambda N$
Tl 208	$\frac{dN}{dt} = \frac{n}{V} q + \lambda_{Bi\ 212} N_{Bi\ 212} - \lambda N$	$\frac{dN}{dt} = \lambda_{Bi\ 212} N_{Bi\ 212} - \lambda N$

$$Counting\ rate = \frac{\int_0^t \lambda_i N_i(t) dt \cdot \gamma_{\varepsilon,i} \cdot Efficiency}{t}$$

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2. Materials and methods

2.1. *Effective internal dose assessment*

- ✓ Committed effective dose coefficients e(50) from DCAL for slow lung absorption and 5 µm AMAD

$$E(50) = \sum_i a_i \cdot e(50)_{i,inh} \cdot Q \cdot t$$

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3.1. *Activity concentration in the inhaled air*

✓ SMAW using rutile-covered electrodes

U-series		Act. Conc. (*Bq m^{-3}*)	u, k = 1 (*Bq m^{-3}*)	*Th-series*		Act. Conc. (*Bq m^{-3}*)	u, k = 1 (*Bq m^{-3}*)
α M	^{238}U	1.36E-03	9.39E-05	α M	^{232}Th	4.89E-04	5.18E-05
Eq.	^{234}Th	1.35E-03	8.80E-05	Eq.	^{228}Ra	-	
-	^{234}Pa	-		γ M	^{228}Ac	-	
α M	^{234}U	1.74E-03	1.09E-04	α M	^{228}Th	5.29E-04	5.46E-05
α M	^{230}Th	1.35E-03	8.80E-05	γ M	^{224}Ra	-	
γ M	^{226}Ra	-		-	^{220}Rn	-	
-	^{222}Rn	-		Eq.	^{216}Po	1.19E-02	5.38E-04
Eq.	^{218}Po	3.03E-02	1.37E-03	Eq.	^{212}Pb	1.03E-02	9.65E-04
C, Eq.	^{214}Pb	2.64E-02	2.48E-03	Eq.	^{212}Bi	1.04E-02	
C	^{214}Bi	2.66E-02		C	^{208}Tl	1.12E-02	
β M	^{210}Pb	2.64E-02	2.48E-03				
C, Eq.	^{210}Bi	2.66E-02					
α M	^{210}Po	3.03E-02	1.37E-03				

x 17

x 0.4

3.1. *Activity concentration in the inhaled air*

✓ FCAW using rutile flux cored wire

U-series		Act. Conc. (*Bq m*$^{-3}$)	u, k = 1 (*Bq m*$^{-3}$)	*Th-series*		Act. Conc. (*Bq m*$^{-3}$)	u, k = 1 (*Bq m*$^{-3}$)
α M	^{238}U	9.42E-04	8.86E-05	α M	^{232}Th	3.08E-04	2.90E-05
Eq.	^{234}Th	9.75E-04	2.44E-04	Eq.	^{228}Ra	-	
-	^{234}Pa	-		γ M	^{228}Ac	-	
α M	^{234}U	9.33E-04	8.08E-05	α M	^{228}Th	3.08E-04	2.90E-05
α M	^{230}Th	9.75E-04	2.44E-04	γ M	^{224}Ra	-	
γ M	^{226}Ra	-		-	^{220}Rn	-	
-	^{222}Rn	-		Eq.	^{216}Po	4.04E-03	2.85E-04
Eq.	^{218}Po	1.28E-02	8.30E-04	Eq.	^{212}Pb	4.92E-03	7.51E-04
C, Eq.	^{214}Pb	1.56E-02	2.38E-03	Eq.	^{212}Bi	4.96E-03	
C	^{214}Bi	1.57E-02		C	^{208}Tl	4.64E-03	
β M	^{210}Pb	1.56E-02	2.38E-03				
C, Eq.	^{210}Bi	1.57E-02					
α M	^{210}Po	1.28E-02	8.30E-04				

x 15

x 0,3

3.2. *Activity concentration in slag*

Radionuclide	Activity (*Bq kg^{-1}*)	Uncertainty (*Bq kg^{-1}*)
^{228}Ra (via ^{228}Ac)	63.7	6.97
^{228}Th (via ^{224}Ra)	65.2	16.8
^{238}U (via ^{234}Th)	110	13.0
^{226}Ra (via ^{214}Pb)	91.6	22.2
^{210}Pb	12.3	6.44
^{235}U	9.75	2.73
^{40}K	1037	72.2

3.3. *Effective dose*

- ✓ Security Guide 11.3 published by CSN: 5 µm and S

	Rutile-covered electrodes		Rutile flux cored wire	
Series	*E(50) (µSv h^{-1})*	*Uncertainty (µSv h^{-1})*	*E(50) (µSv h^{-1})*	*Uncertainty (µSv h^{-1})*
Uranium	0.469	0.023	0.254	0.022
Thorium	0.036	0.003	0.038	0.002
Total	0.538	0.023	0.325	0.022

- ✓ E(50) to 1700 h yr^{-1} → **0.91 mSv yr^{-1}** < 1 mSv yr^{-1}

1. The developed analytical method allows to determine activity concentration in the inhaled air from:
   - ✓ *^{214}Pb and ^{214}Bi early gamma-ray measurements*
   - ✓ *15 – 17 factor between isotopes before and after Rn*
   - ✓ *Ratio between U- and Th-series activities in consumables*
2. Long-lived nuclides before Rn and ^{40}K remain mainly in slag or bead
3. Internal dose, via inhalation is < 1 mSv yr^{-1}
4. The use of individual protective equipment is convenient

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Thank you for your attention

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