

Table 4c
Uranium and Thorium Mass Fraction (NDA)

Method	Technique	Instrument*	Material (homogeneous)	Element	Mass fraction range	Uncertainty (% rel., k=1)			Notes
						u(r)	u(s)	u(c)	
HRGS	T1	XMCG	Powder, solution, slurry	NU	1 % to 25 %	2.0	3.0	3.6	DX, IT, KE, LZ, EG=185.7, WT=5, LT=1000, FLD, HY
MRGS	T1	XMCL	Powder, solution, slurry	NU	1 % to 25 %	2.0	3.5	4.0	IT, KE, LZ, EG=185.7, WT=5, LT=1000, FLD, HY
		XMCC	Powder, solution, slurry	NU	1 % to 25 %	5.0	4.0	6.4	IT, KE, LZ, EG=185.7, WT=5, LT=1000, FLD, HY
HRGS	T1	XMCG	Powder, solution, slurry	DU	1 % to 25 %	14	3.5	14	D1, D2, IT, RE, LZ, EG=185.7, ISO-LO, WT=1, LT=1000, FLD, HY
		XMCG	Powder, solution, slurry	NU	1 % to 25 %	7.4	3.4	8.2	D1, D2, IT, RE, LZ, EG=185.7, ISO-LO, WT=1, LT=1000, FLD, HY
		XMCG	Powder, solution, slurry	LEU	1 % to 25 %	5.7	3.7	6.8	D1, D2, IT, RE, LZ, EG=185.7, ISO-LO, WT=1, LT=1000, FLD, HY
		XMCG	Powder, solution, slurry	DU	1 % to 25 %	18	3.2	18	D2, D3, IT, RE, LZ, EG=185.7, ISO-HI, WT=1, LT=1000, FLD, HY
		XMCG	Powder, solution, slurry	NU	1 % to 25 %	17	3.0	17	D2, D3, IT, RE, LZ, EG=185.7, ISO-HI, WT=1, LT=1000, FLD, HY
		XMCG	Powder, solution, slurry	LEU	1 % to 25 %	14	3.0	14	D2, D3, IT, RE, LZ, EG=185.7, ISO-HI, WT=1, LT=1000, FLD, HY
		XMCG	Powder, slurry, sludge	NU	> 25 %	2.0	0.7	2.1	DX, TS, KE, SM=2, EG=185., LT=1000, TD
	T2	XMCG	Solution (organic and aqueous)	NU	1 % to 25 %	1.8	0.8	2.0	DX, TS, KE, SM=10 mL, EG=185.7, LT=1000, TD
		XMCG	Powder	LEU	> 25 %	1.4	0.4	1.5	D2, TS, RE, SM=50 to 100, EG=1001, ISO-LO, LT=2000, TD
		XMCG	Powder, ore	Th	0.1 % - 1 %	5.0	4.0	6.4	D2, D3, TS, SM=10, EG=583/911, LT=3000, FLD, TD
		XMCG	Powder, ore	Th	> 1 wt%	1.5	1.0	1.8	D2, D3, TS, SM=10, EG=583/911, LT=1000, FLD, TD
	T3	XMCG	Powder, ore	Th	0.1 % - 1 %	0.8	4.4	4.5	D2, D3, TS, RE, EG=583/911/2614, PA-911=30,000, LAB, TD
		XMCG	Powder, ore	Th	> 1 %	0.6	1.5	1.6	D2, D3, TS, RE, EG=583/911/2614, PA-911=30,000, LAB, TD
		XMCG	Powder, solution	LEU	> 25 %	13.0	3.0	13.3	D2, D3, TS, RE, SM>=150, EG=185.7/1001, LT=1000, FLD, TD
XRF	T4	ED-XRF	Powder, solution	U/Th	0.1 % - 25 %	3.0	3.0	4.2	XRF Literature listed in Narrative
		WD-XRF	Solution (organic and aqueous)	U	1 % - 25 %	3.0	3.0	4.2	Refinery Plant Report
	T5	WD-XRF	Powder, ore	Th	0.1 % - 10 %	3.3	6.0	6.8	SGAS-NML Measurements

*click a hyperlink to open method's narrative

Uncertainty categories:

Prospective Values: are presented in [blue font](#)

Assumptions:

- Only homogeneous material (no sampling error included)
- For method T1, systematic uncertainty includes sample matrix, calibration, wall thickness determination and detector specific spectrum fitting components

Method categories:

HRGS High Resolution Gamma Spectrometry
MRGS Medium Resolution Gamma Spectrometry
XRF X-Ray Fluorescent Analysis

Technique categories:

- T1 Concentration meter principle (in-situ measurements)
T2 Absolute gamma-spectrometry calibrated against reference materials (on-site laboratory setup)
T3 In-situ absolute gamma-spectrometry calibrated mathematically (e.g. by Monte Carlo or ISOCs) in situations when no appropriate calibration standard is available
T4 XRF using a calibration curve
T5 XRF using fundamental parameters

Notes:

EG Assay gamma ray energy (keV)
IT Infinitely thick samples (≥ 5 mfp at the assay gamma ray energy)
TS Thin samples (< 1 mfp at the assay gamma ray energy)
KE Material with known enrichment (e.g., NU at concentration, refinery and conversion plants)
LZ Low-Z matrix, known contents of high-Z additives
RE Radioactive equilibrium. In the case of uranium, enrichment can be measured using a complementary peak ratio method (MGAU, FRAM or similar)
SM Sample mass (g)
WT Container wall thickness (mm)
LT Measurement live time (s)
ISO-LO Low-energy isotopic analysis (60 keV to 250 keV)
ISO-HI High-energy isotopic analysis (120 keV to 1010 keV)
PA-XXX Number of counts (area) of the peak at energy XXX keV
LAB Laboratory measurements
FLD Field measurements

Instrument categories:

XMCG HPGe detectors, including both electrically or LN2 cooled, coupled to any MCA
XMCC CZT, active volume $\geq 1500 \text{ mm}^3$, collimator: $\varnothing 15 \times 5 \text{ mm}$, any MCA
XMCL LABR, crystal $\varnothing 50 \times 13 \text{ mm}$ (or larger), collimator: $\varnothing 44 \times 20 \text{ mm}$, any MCA

XMCG types:

- D1 Energy resolution $< 750 \text{ eV}$ @ 122 keV . Active area $> 500 \text{ mm}^2$. Thickness $> 10 \text{ mm}$. Typical detectors in XMCG-D1 category: planar and semi-planar detectors (GL1015, BE1015, BE2830, BE3830, BE5030, Profile S/SP, GLP).
D2 Energy resolution $< 1.0 \text{ keV}$ @ 122 keV and $< 2.0 \text{ keV}$ @ 1332 keV . Relative efficiency $> 15\%$. Typical detectors in XMCG-D2 category: semi-planar and small volume coaxial detectors (BE2830, BE3830, BE5030, Profile S/SP/C/M, GMX, Falcon, Aegis).
D3 Energy resolution $< 1.5 \text{ keV}$ @ 122 keV and $< 2.3 \text{ keV}$ @ 1332 keV . Relative efficiency $> 15\%$. Typical detectors in XMCG-D3 category: portable electrically cooled coaxial detectors and large volume coaxial detectors (Micro-Detective (ECGS), Aegis, GC9023, Profile C/M, GMX).

Method used to derive ITVs:

TD Top-down
BU Bottom-up
HY Hybrid