UKAS TESTING 1011

NIRAS
Analytical Services

NIRAS

Report

Report Reference: L080402

Customer: IRAS Ltd

Investigation of the Effectiveness of Acid Washing and Autodeposition for Removing Mercury and Radioactive Contamination from Insulation Material, Dust and Other Debris.

Issue date: 10 October 2008

The applicability of UKAS accreditation to this report is detailed in section 3.1

Prepared by: K G Bradshaw	**Keith Bradshaw Laboratory Technical Manager**
Checked and approved for issue by: J. D. Turner	JOE TURNER SENIOR SCIENTIST

NIRAS is a trading name of AMEC Nuclear UK Limited
The Renaissance Centre, 601 Faraday Street, Birchwood Park, Birchwood, Warrington, Cheshire WA3 6GN

Contents

1 Administrative Details

1.1 Laboratory Job Details

1.1.1 Laboratory Job Number

L080402

1.1.2 Quotation/Tender Reference

X2424 (04 April 2008)

1.1.3 Testing Laboratory

Radiometric and radiochemical testing:

NIRAS, AMEC
601 Faraday St
Birchwood Park
Birchwood
Warrington
WA3 6GN

The non-radiometric chemical testing was subcontracted to:

Scientific Analysis Laboratories Ltd
601 Faraday St
Birchwood Park
Birchwood
Warrington
WA3 6GN

Severn Trent Laboratories Ltd
STL Business Centre
Torrington Avenue
Coventry
CV4 9GU

1.1.4 Laboratory Contact

Keith Bradshaw (Tel: 01925 675643 or 675366, e-mail: keith.bradshaw@amec.com).

1.1.5 Sample Receipt Date

02 May 2008

1.2 Customer Details

1.2.1 Customer Name and Address

Andrew Frith
IRAS Ltd
Bold Business Centre
Bold Lane
St Helens
WA9 4TX

1.2.2 Order Numbers

PO 2008014 (1) and PO 2008014 (2)

2 Scope of Work

- Laboratory investigation of conditions for depositing dissolved mercury onto copper metal.
- Analysis of six samples of solid wastes for mercury, radium-226, lead-210 and polonium-210 contents.
- Investigation of leaching the solid wastes and deposition of leached mercury onto metallic copper.
- Investigating radionuclide behaviour in the mercury deposition on copper process.

3 Quality Assurance

3.1 Quality System and Applicability of UKAS Accreditation

The NIRAS laboratory operates a quality system to the requirements of BS EN ISO/IEC 17025:2005 and BS EN ISO 9001:2000.

NIRAS is UKAS accredited for gamma spectrometry testing of aqueous solutions and solids up to a maximum density of 2.5 g cm^{-3} covering an energy range of 60 - 2000 keV. Pb-210 is outside this range and results for this radionuclide are not UKAS accredited.

SAL Ltd are UKAS accredited for mercury and copper in leachates.

Other NIRAS and sub-contractor tests in this report are not UKAS accredited.

Any comments, opinions and interpretations expressed in this report are outside the scope of UKAS accreditation.

3.2 Statement of Uncertainties

Reported uncertainties are expanded combined uncertainties calculated using a coverage factor of 2, which gives a level of confidence of approximately 95%.

4 Tests and Experimental Methods

4.1 Sample Preparation and Pretreatment

The samples were used in their as-received condition, mixing thoroughly before sub-sampling.

4.2 Mercury Deposition Investigation

4.2.1 Selection of Acid Concentration

Solutions of mercury were made in a range of nitric acid concentrations, 20-50% by volume (of concentrated nitric acid). Copper coupons were placed in each and the extent of mercury deposition (as indicated by the silvering effect of mercury on copper) and the effect on the copper itself, were noted.

4.2.2 Mercury Loading

The mercury loading capacity was tested by placing a copper coupon in a portion of mercury solution in 20% nitric acid overnight. This was replaced by a fresh coupon, after withdrawing a small portion of the solution for mercury and copper determination. This was repeated for a total of four successive tests on the same portion of solution.

4.3 Gamma Spectrometry

A known amount of the sample was transferred to an appropriate container to produce a standard counting geometry prior to measurement by high-resolution gamma spectrometry. The high-resolution gamma spectrometry was conducted using high-purity germanium detectors, coupled to computerized multi-channel analysers, with peak search and peak shape functions and a validated radionuclide library. System calibration is undertaken for standardized geometries using a nationally traceable mixed gamma reference solution, in the energy range 60 keV - 1836 keV.

4.4 Polonium-210

A certified solution of polonium-209 is used as internal recovery monitor. The sample material is wet ashed and decomposed with mixed acids. Polonium is deposited on a silver disc, separating polonium-210 from lead-210 and producing a source suitable for alpha spectrometry. The disc is counted on an alpha spectrometer, and the result calculated using the net peak integrals for Po-209 and Po-210. The polonium-210 result is decay-corrected to the lead/polonium separation date.

4.5 Metals by ICP-OES (SAL Ltd)

The sample is digested with nitric/hydrochloric acid. The sample is filtered and then made up to volume. An extract is then applied to ICP instrument, which determines the presence and amount, by the emission spectra from each metal. The intensity of the emission is measured against calibrated standards for qualification.

4.6 Mercury in solids (STL Ltd)

A known weight of dried, ground, homogeneous sample is digested in boiling *Aqua Regia* in order to bring the metals into solution. The digested sample is filtered and diluted to a known volume before being analysed by Hydride Generation ICP-AES. Quantification of the metals concentration is achieved by comparison of the extract against multiple standard solutions containing the appropriate elements at known concentrations. Results are reported as mg/kg related back to the original sample weight taken.

5 Results

5.1 Mercury Deposition on Copper

5.1.1 Effect of Acid Concentration

In order to investigate the effect of different nitric acid concentrations on the mercury deposition process, copper coupons were added to four mercury solutions of different nitric acid concentration. The results are summarised in Table 1 below.

Table 1 Observations on the result of placing copper coupons in mercury solutions with different nitric acid concentrations

Nitric acid concentration (% concentrated acid by volume)	Observation
20	Mercury deposited with slight copper dissolution
30	Some mercury deposited but copper coupon thin when left overnight
40	Coupon dissolved completely overnight
50	Coupon dissolved completely and quickly

On the basis of these observations, subsequent experiments were conducted using 20% (v/v) nitric acid.

Figure 1 Mercury deposition onto copper from 20% (v/v) nitric acid solution

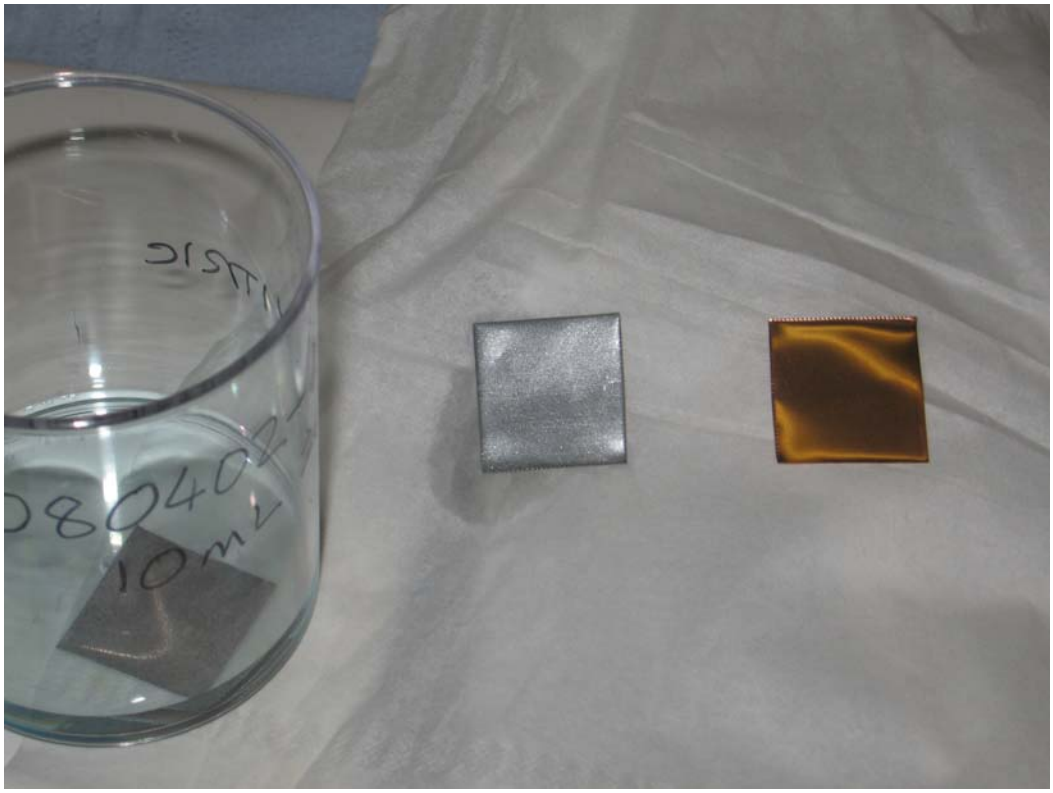


Figure 1 From the left: a copper coupon immersed in solution; copper coupon with mercury deposited on surface; unused copper coupon for comparison.

5.1.2 Effect of Contact Time in 20% (v/v) Nitric Acid Solution

In order to investigate the completeness of mercury removal achievable, fresh coupons were added sequentially to the same mercury solution daily. A small portion of solution was removed for mercury and copper analysis at each coupon change.

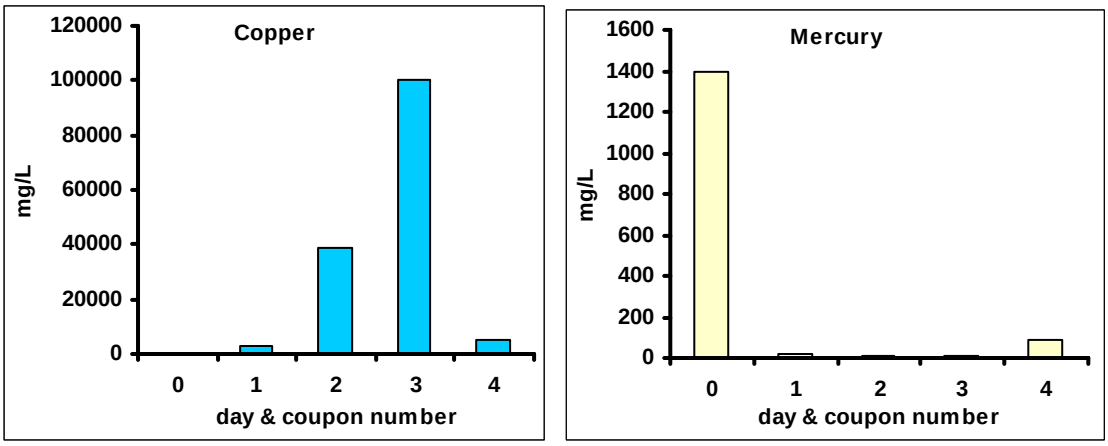
Table 2 Mercury deposition and copper dissolution versus contact time

Sample reference	Day number	Cu (mg L^{-1}) (1)	Hg (mg L^{-1}) (1)
L080402-1 (2)	0	0.26	1400
L080402-11	1	2800	17
L080402-12	2	39000	7.9
L080402-13	3	100000	14
L080402-14	4	5400	89

(1) Conditions: copper coupons 21.5 x 21.5 x 0.25 mm and 10 mL solution

(2) Solution prior to adding copper coupon

Figure 2 Solution metal concentrations and time in 20% (v/v) nitric acid solution



There appears to be little advantage in using longer than overnight deposition periods. There is little decrease in mercury solution concentration after this time, but copper dissolution increases. At present there is no explanation for the apparent decrease in dissolved copper at 4 days, other than that the high concentration may have caused analytical difficulties.

5.1.3 Mercury loading per unit area of copper

It is possible to calculate the mercury deposited overnight per unit area of copper. This is 1.5 mg cm^{-2}.

5.2 Tests With Samples of Waste

Sub-samples of the waste materials were analysed for mercury content before and after leaching. Sub-samples were initially submitted to SAL Ltd, and subsequently to STL Ltd, for confirmatory analysis, so there are two sets of results. Also, there are some client-supplied values for the before-leaching materials. The results are summarised in Table 3.

Table 3 Waste solids analytical results (mercury) before and after leaching

Client Reference	Client-supplied (mg kg^{-1})	SAL Ltd			STL Ltd		
		Before leaching (mg kg^{-1})	After leaching (mg kg^{-1})	% change	Before leaching (mg kg^{-1})	After leaching (mg kg^{-1})	% change
MR6	310000	10000	17000	+70	84000	37000	-56
MR10	27000	4400	6400	+45	5300	7300	+38
MR13	15000	4600	6800	+48	5900	7800	+32
MRV14	120000	74000	95000	+28	120000	68000	-43
MRV6	210000	11000	14000	+27	8800	13000	+48
MRV10	80000	34000	23000	-32	36000	29000	-19
			mean	**31**		**mean**	**-0.18**

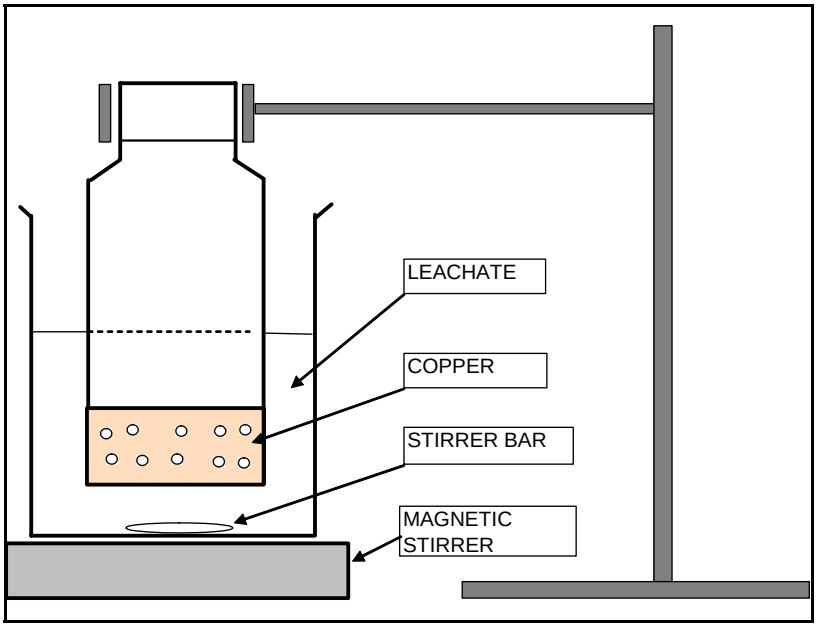
There is clearly quite a large difference in some of the results between laboratories. The largest difference however is between the client-supplied values and the later SAL and STL results, which could be due to volatilisation of metallic mercury during storage. The source of variation between SAL and STL results is conceivably due to heterogeneity and sub-sampling issues. In any case, it is clear that the leaching in 20% (v/v) nitric acid has failed to sufficiently remove mercury from the solid phase.

5.2.1 Deposition of Leached Mercury onto Copper

Deposition of mercury from the leachates onto copper turnings was attempted. 100g of copper turnings were placed in 200 mL polythene bottles. The bottles had many holes cut in them, so as to allow free access to liquid, whilst retaining the copper turnings in the bottle. The bottles were held suspended in the leachates as shown in Figure 3.

The liquid enters the bottle up to the level of the highest hole when the bottle is immersed as shown. The liquid level in the bottle can be increased to cover all the copper by loosening the cap of the bottle to allow air to escape.

Figure 3 Mercury deposition from leachates



The leachate was stirred rapidly overnight using the magnetic stirrer. After this time, the bottle was raised out of the liquid and held by the clamp above the beaker for several minutes, so as to allow leachate to drain out of the copper turnings and back into the beaker.

The leachates were analysed for mercury and copper after this experiment, by both SAL Ltd and STL Ltd, and the results are given in Tables 4 and 5.

Table 4 Post-deposition leachate metals analysis results (SAL Ltd)

Niras Reference	Client reference	Leachate mass (g)	Copper mg/L	Mercury mg/L	Amount Cu (g)	Amount Hg (g)
L080402-34	MR6 leachate	715.81	16000	11	11.5	0.0079
L080402-35	MR10 leachate	319.34	430	0.54	0.14	0.00017
L080402-36	MR13 leachate	226.08	44	0.37	0.01	0.00008
L080402-37	MRV14 leachate	269.53	120	0.64	0.03	0.00017
L080402-38	MRV6 leachate	223.19	85	0.94	0.02	0.00021
L080402-39	MRV10 leachate	206.16	140	0.91	0.03	0.00019

Table 5 Post-deposition leachate metals analysis results (STL Ltd)

Niras Reference	Client reference	Leachate mass (g)	Copper mg/L	Mercury mg/L	Amount Cu (g)	Amount Hg (g)
L080402-34	MR6 leachate	715.81	4300	9.1	3.1	0.0065
L080402-35	MR10 leachate	319.34	580	0.73	0.19	0.00023
L080402-36	MR13 leachate	226.08	1500	0.14	0.34	0.00003
L080402-37	MRV14 leachate	269.53	940	0.38	0.25	0.00010
L080402-38	MRV6 leachate	223.19	1600	0.87	0.36	0.00019
L080402-39	MRV10 leachate	206.16	1500	5.7	0.31	0.0012

All of the mercury results agree reasonably well between the two laboratories with the exception of MRV10 leachate. The copper results are more variable between laboratories with some in reasonable agreement and others not.

It can be seen that MR6 leachate has both higher copper dissolution and higher residual mercury than the other leachates, and it is likely that these are connected, that is, a high rate of copper dissolution reduces the efficiency of mercury deposition. It is not known with certainty why MR6 leachate was apparently more aggressive to the copper than the other leachates; perhaps other leachable components in the waste have an effect on this.

5.2.2 Radionuclide Determinations

The solids were analysed by gamma spectrometry before and after leaching and the results are given in Table 6.

Table 6 Gamma spectrometry results for solids before and after leaching in 20% (v/v) nitric acid

Niras Reference	Client Reference	Determinand	Result			Unit
L080402-5	MR6	Ac-228	0.0687	±	0.0049	Bq/g
		Bi-212	0.076	±	0.030	Bq/g
		Bi-214	0.930	±	0.035	Bq/g
		Cs-137		<	0.0012	Bq/g
		K-40	0.342	±	0.024	Bq/g
		Pa-234m		<	0.25	Bq/g
		Pb-210	0.827	±	0.043	Bq/g
		Pb-212	0.0624	±	0.0027	Bq/g
		Pb-214	0.944	±	0.036	Bq/g
		Ra-226	1.42	±	0.059	Bq/g
		Th-234	0.028	±	0.019	Bq/g
		Tl-208	0.0213	±	0.0020	Bq/g
		U-235	0.00131	±	0.00087	Bq/g
L080402-6	MR10	Ac-228	0.1032	±	0.0093	Bq/g
		Bi-212	0.103	±	0.026	Bq/g
		Bi-214	0.200	±	0.025	Bq/g
		Cs-137		<	0.0028	Bq/g
		K-40	0.380	±	0.057	Bq/g
		Pa-234m		<	0.26	Bq/g
		Pb-210	3.23	±	0.11	Bq/g
		Pb-212	0.1022	±	0.0041	Bq/g
		Pb-214	0.2218	±	0.0074	Bq/g
		Ra-226	0.458	±	0.047	Bq/g
		Th-234	0.075	±	0.029	Bq/g
		Tl-208	0.0298	±	0.0030	Bq/g
		U-235	0.0035	±	0.0014	Bq/g
L080402-7	MR13	Ac-228	0.107	±	0.014	Bq/g
		Bi-212	0.131	±	0.064	Bq/g
		Bi-214	0.288	±	0.034	Bq/g
		Cs-137	0.0047	±	0.0031	Bq/g
		K-40	0.411	±	0.067	Bq/g
		Pa-234m		<	0.78	Bq/g
		Pb-210	2.027	±	0.095	Bq/g

Niras Reference	Client Reference	Determinand	Result			Unit
		Pb-212	0.1078	±	0.0065	Bq/g
		Pb-214	0.290	±	0.014	Bq/g
		Ra-226	0.58	±	0.087	Bq/g
		Th-234	0.094	±	0.061	Bq/g
		Tl-208	0.0314	±	0.0039	Bq/g
		U-235	0.0044	±	0.0029	Bq/g
L080402-8	MRV14	Ac-228	0.074	±	0.019	Bq/g
		Bi-212	0.086	±	0.032	Bq/g
		Bi-214	0.403	±	0.038	Bq/g
		Cs-137	0.0042	±	0.0021	Bq/g
		K-40	0.387	±	0.059	Bq/g
		Pa-234m		<	0.96	Bq/g
		Pb-210	2.42	±	0.11	Bq/g
		Pb-212	0.0728	±	0.0049	Bq/g
		Pb-214	0.442	±	0.018	Bq/g
		Ra-226	0.731	±	0.071	Bq/g
		Th-234	0.084	±	0.042	Bq/g
		Tl-208	0.0250	±	0.0037	Bq/g
		U-235	0.0039	±	0.0020	Bq/g
L080402-9	MRV6	Ac-228	0.0224	±	0.0055	Bq/g
		Bi-212	0.049	±	0.029	Bq/g
		Bi-214	2.89	±	0.13	Bq/g
		Cs-137		<	0.0023	Bq/g
		K-40	0.328	±	0.042	Bq/g
		Pa-234m		<	0.18	Bq/g
		Pb-210	5.73	±	0.26	Bq/g
		Pb-212	0.0244	±	0.0029	Bq/g
		Pb-214	3.06	±	0.13	Bq/g
		Ra-226	4.98	±	0.22	Bq/g
		Th-234	0.085	±	0.034	Bq/g
		Tl-208	0.0081	±	0.0043	Bq/g
		U-235	0.0040	±	0.0016	Bq/g
L080402-10	MRV10	Ac-228	0.074	±	0.011	Bq/g
		Bi-212	0.132	±	0.045	Bq/g
		Bi-214	2.93	±	0.12	Bq/g
		Cs-137		<	0.0030	Bq/g
		K-40	0.456	±	0.058	Bq/g
		Pa-234m		<	0.63	Bq/g

Niras Reference	Client Reference	Determinand	Result			Unit
		Pb-210	4.10	±	0.17	Bq/g
		Pb-212	0.0718	±	0.0044	Bq/g
		Pb-214	3.11	±	0.12	Bq/g
		Ra-226	5.43	±	0.23	Bq/g
		Th-234		<	0.064	Bq/g
		Tl-208	0.0226	±	0.0025	Bq/g
		U-235		<	0.024	Bq/g
L080402-16	MR6-leached	Ac-228	0.048	±	0.020	Bq/g
		Bi-212	0.107	±	0.080	Bq/g
		Bi-214	0.209	±	0.063	Bq/g
		Cs-137		<	0.013	Bq/g
		K-40	0.28	±	0.15	Bq/g
		Pa-234m		<	0.54	Bq/g
		Pb-210	0.255	±	0.045	Bq/g
		Pb-212	0.0470	±	0.0066	Bq/g
		Pb-214	0.225	±	0.019	Bq/g
		Ra-226	0.35	±	0.12	Bq/g
		Th-234	0.107	±	0.062	Bq/g
		Tl-208	0.0111	±	0.0058	Bq/g
		U-235	0.0050	±	0.0029	Bq/g
L080402-17	MR10-leached	Ac-228	0.074	±	0.027	Bq/g
		Bi-212		<	0.16	Bq/g
		Bi-214	0.114	±	0.061	Bq/g
		Cs-137		<	0.0063	Bq/g
		K-40	0.22	±	0.14	Bq/g
		Pa-234m		<	1.7	Bq/g
		Pb-210	3.66	±	0.18	Bq/g
		Pb-212	0.0434	±	0.0082	Bq/g
		Pb-214	0.107	±	0.015	Bq/g
		Ra-226	0.32	±	0.11	Bq/g
		Th-234		<	0.093	Bq/g
		Tl-208	0.0146	±	0.0060	Bq/g
		U-235		<	0.026	Bq/g
L080402-18	MR16-leached	Ac-228	0.069	±	0.026	Bq/g
		Bi-212		<	0.091	Bq/g
		Bi-214	0.170	±	0.072	Bq/g
		Cs-137		<	0.016	Bq/g
		K-40	0.32	±	0.16	Bq/g

Niras Reference	Client Reference	Determinand	Result			Unit
		Pa-234m		<	0.50	Bq/g
		Pb-210	1.65	±	0.12	Bq/g
		Pb-212	0.0501	±	0.0086	Bq/g
		Pb-214	0.151	±	0.017	Bq/g
		Ra-226	0.35	±	0.17	Bq/g
		Th-234		<	0.076	Bq/g
		Tl-208	0.016	±	0.011	Bq/g
		U-235		<	0.021	Bq/g
L080402-19	MRV14-leached	Ac-228	0.068	±	0.022	Bq/g
		Bi-212		<	0.11	Bq/g
		Bi-214	0.267	±	0.068	Bq/g
		Cs-137		<	0.011	Bq/g
		K-40	0.32	±	0.13	Bq/g
		Pa-234m		<	2.0	Bq/g
		Pb-210	2.05	±	0.13	Bq/g
		Pb-212	0.0366	±	0.0071	Bq/g
		Pb-214	0.222	±	0.015	Bq/g
		Ra-226	0.543	±	0.099	Bq/g
		Th-234		<	0.034	Bq/g
		Tl-208	0.0128	±	0.0081	Bq/g
		U-235		<	0.020	Bq/g
L080402-20	MRV6-leached	Ac-228	0.052	±	0.025	Bq/g
		Bi-212		<	0.14	Bq/g
		Bi-214	1.20	±	0.11	Bq/g
		Cs-137		<	0.0094	Bq/g
		K-40	0.34	±	0.12	Bq/g
		Pa-234m		<	1.8	Bq/g
		Pb-210	4.84	±	0.23	Bq/g
		Pb-212	0.0271	±	0.0070	Bq/g
		Pb-214	1.192	±	0.046	Bq/g
		Ra-226	4.51	±	0.23	Bq/g
		Th-234		<	0.043	Bq/g
		Tl-208		<	0.0097	Bq/g
		U-235		<	0.041	Bq/g
L080402-21	MRV10-leached	Ac-228	0.087	±	0.024	Bq/g
		Bi-212		<	0.21	Bq/g
		Bi-214	1.99	±	0.13	Bq/g
		Cs-137		<	0.0071	Bq/g

Niras Reference	Client Reference	Determinand	Result			Unit
		K-40	0.187	±	0.094	Bq/g
		Pa-234m		<	1.5	Bq/g
		Pb-210	2.64	±	0.15	Bq/g
		Pb-212	0.0351	±	0.0072	Bq/g
		Pb-214	1.902	±	0.071	Bq/g
		Ra-226	4.44	±	0.23	Bq/g
		Th-234		<	0.052	Bq/g
		Tl-208		<	0.013	Bq/g
		U-235		<	0.020	Bq/g

Results are referenced to the count dates of the samples: 30-Jun to 05-Aug-2008

The leaching efficacy of key radionuclides is summarised in Tables 7 and 8 below. The activity concentrations before and after leaching are compared and the percent removal is calculated.

Table 7 Leaching of radium-226

Ra-226 before leaching (Bq/g)	Ra-226 after leaching (Bq/g)	% change
1.42	0.35	-75
0.458	0.32	-30
0.58	0.35	-40
0.731	0.543	-26
4.98	4.51	-9
5.43	4.44	-18
	mean	**-33**

Table 8 Leaching of lead-210

Pb-210 before leaching (Bq/g)	Pb-210 after leaching (Bq/g)	% change
0.827	0.255	-69
3.23	3.66	+13
2.027	1.65	-19
2.42	2.05	-15
5.73	4.84	-16
4.10	2.64	-36
	mean	**-23**

Leaching of these radionuclides appears more effective than that of mercury, although far from complete.

The post-deposition leachates were analysed by gamma spectrometry. These results are given in Table 9 below.

Table 9 Gamma spectrometry results for post-deposition leachates

Niras Reference	Client Reference	Determinand	Result			Unit
L080402-34	MR6-leachate post extraction	Ac-228		<	0.0075	Bq/g
		Bi-212		<	0.040	Bq/g
		Bi-214		<	0.016	Bq/g
		Cs-137		<	0.0023	Bq/g
		K-40		<	0.038	Bq/g
		Pa-234m		<	0.31	Bq/g
		Pb-210		<	0.17	Bq/g
		Pb-212		<	0.0031	Bq/g
		Pb-214		<	0.0029	Bq/g
		Ra-226		<	0.043	Bq/g
		Th-234		<	0.028	Bq/g
		Tl-208		<	0.0025	Bq/g
		U-235		<	0.0025	Bq/g
L080402-35	MR10-leachate post extraction	Ac-228		<	0.0086	Bq/g
		Bi-212		<	0.038	Bq/g
		Bi-214		<	0.017	Bq/g
		Cs-137		<	0.0016	Bq/g
		K-40		<	0.030	Bq/g
		Pa-234m		<	0.11	Bq/g
		Pb-210	0.033	±	0.014	Bq/g
		Pb-212	0.0021	±	0.0017	Bq/g
		Pb-214		<	0.0045	Bq/g
		Ra-226		<	0.026	Bq/g
		Th-234		<	0.0087	Bq/g
		Tl-208		<	0.0041	Bq/g
		U-235		<	0.0015	Bq/g
L080402-36	MR16-leachate post extraction	Ac-228		<	0.012	Bq/g
		Bi-212		<	0.027	Bq/g
		Bi-214		<	0.014	Bq/g
		Cs-137		<	0.0014	Bq/g
		K-40		<	0.054	Bq/g
		Pa-234m		<	0.12	Bq/g
		Pb-210	0.017	±	0.010	Bq/g
		Pb-212		<	0.0027	Bq/g
		Pb-214		<	0.0019	Bq/g

Niras Reference	Client Reference	Determinand	Result			Unit
		Ra-226		<	0.021	Bq/g
		Th-234		<	0.020	Bq/g
		Tl-208		<	0.00098	Bq/g
		U-235		<	0.0012	Bq/g
L080402-37	MR14-leachate post extraction	Ac-228		<	0.0060	Bq/g
		Bi-212		<	0.015	Bq/g
		Bi-214		<	0.021	Bq/g
		Cs-137		<	0.0017	Bq/g
		K-40		<	0.050	Bq/g
		Pa-234m		<	0.074	Bq/g
		Pb-210		<	0.018	Bq/g
		Pb-212		<	0.0016	Bq/g
		Pb-214		<	0.0016	Bq/g
		Ra-226		<	0.021	Bq/g
		Th-234		<	0.012	Bq/g
		Tl-208	0.0018	±	0.0013	Bq/g
		U-235		<	0.0012	Bq/g
L080402-38	MRV6-leachate post extraction	Ac-228		<	0.0060	Bq/g
		Bi-212		<	0.016	Bq/g
		Bi-214	0.040	±	0.015	Bq/g
		Cs-137		<	0.0030	Bq/g
		K-40		<	0.038	Bq/g
		Pa-234m		<	0.14	Bq/g
		Pb-210	0.813	±	0.049	Bq/g
		Pb-212		<	0.0027	Bq/g
		Pb-214	0.0402	±	0.0042	Bq/g
		Ra-226	0.156	±	0.033	Bq/g
		Th-234		<	0.034	Bq/g
		Tl-208		<	0.0020	Bq/g
		U-235		<	0.0098	Bq/g
L080402-39	MRV10-leachate post extraction	Ac-228		<	0.0081	Bq/g
		Bi-212		<	0.020	Bq/g
		Bi-214		<	0.014	Bq/g
		Cs-137		<	0.0030	Bq/g
		K-40		<	0.058	Bq/g
		Pa-234m		<	0.39	Bq/g
		Pb-210	0.243	±	0.028	Bq/g
		Pb-212	0.0031	±	0.0019	Bq/g
		Pb-214		<	0.0043	Bq/g

Niras Reference	Client Reference	Determinand	Result			Unit
		Ra-226		<	0.034	Bq/g
		Th-234		<	0.012	Bq/g
		Tl-208		<	0.0034	Bq/g
		U-235		<	0.0026	Bq/g

Results are referenced to the count dates of the samples: 30-Jun to 05-Aug-2008

The copper used in the mercury deposition was also analysed by gamma spectrometry. These results are given in Table 10.

Table 10 Gamma spectrometry results for post-deposition copper

Niras Reference	Client Reference	Determinand	Result			Unit
L080402-28	MR6 post-deposition copper	Ac-228		<	0.016	Bq/g
		Bi-212		<	0.075	Bq/g
		Bi-214		<	0.062	Bq/g
		Cs-137		<	0.0034	Bq/g
		K-40		<	0.072	Bq/g
		Pa-234m		<	1.2	Bq/g
		Pb-210		<	0.22	Bq/g
		Pb-212	0.0052	±	0.0041	Bq/g
		Pb-214	0.0246	±	0.0064	Bq/g
		Ra-226		<	0.11	Bq/g
		Th-234		<	0.062	Bq/g
		Tl-208		<	0.0060	Bq/g
		U-235		<	0.0062	Bq/g
L080402-29	MR10 post-deposition copper	Ac-228		<	0.017	Bq/g
		Bi-212		<	0.034	Bq/g
		Bi-214		<	0.020	Bq/g
		Cs-137		<	0.0044	Bq/g
		K-40		<	0.054	Bq/g
		Pa-234m		<	0.51	Bq/g
		Pb-210		<	0.024	Bq/g
		Pb-212		<	0.0031	Bq/g
		Pb-214		<	0.0071	Bq/g
		Ra-226		<	0.036	Bq/g
		Th-234		<	0.024	Bq/g
		Tl-208		<	0.0039	Bq/g
		U-235		<	0.0021	Bq/g
L080402-30	MR13 post-deposition copper	Ac-228		<	0.0070	Bq/g
		Bi-212		<	0.032	Bq/g

Niras Reference	Client Reference	Determinand	Result			Unit
		Bi-214		<	0.025	Bq/g
		Cs-137		<	0.0041	Bq/g
		K-40		<	0.043	Bq/g
		Pa-234m		<	0.25	Bq/g
		Pb-210		<	0.031	Bq/g
		Pb-212		<	0.0051	Bq/g
		Pb-214		<	0.0030	Bq/g
		Ra-226		<	0.038	Bq/g
		Th-234		<	0.033	Bq/g
		Tl-208		<	0.0055	Bq/g
		U-235		<	0.0022	Bq/g
L080402-31	MRV14 post-deposition copper	Ac-228		<	0.011	Bq/g
		Bi-212		<	0.021	Bq/g
		Bi-214		<	0.028	Bq/g
		Cs-137		<	0.0017	Bq/g
		K-40		<	0.040	Bq/g
		Pa-234m		<	0.31	Bq/g
		Pb-210		<	0.031	Bq/g
		Pb-212		<	0.0029	Bq/g
		Pb-214		<	0.0041	Bq/g
		Ra-226		<	0.020	Bq/g
		Th-234		<	0.018	Bq/g
		Tl-208		<	0.0022	Bq/g
		U-235		<	0.0012	Bq/g
L080402-32	MRV6 post-deposition copper	Ac-228		<	0.023	Bq/g
		Bi-212		<	0.040	Bq/g
		Bi-214		<	0.047	Bq/g
		Cs-137		<	0.0035	Bq/g
		K-40		<	0.085	Bq/g
		Pa-234m		<	0.42	Bq/g
		Pb-210		<	0.061	Bq/g
		Pb-212		<	0.0027	Bq/g
		Pb-214		<	0.0053	Bq/g
		Ra-226		<	0.029	Bq/g
		Th-234		<	0.045	Bq/g
		Tl-208		<	0.0050	Bq/g
		U-235		<	0.0017	Bq/g
L080402-33	MRV10 post-deposition copper	Ac-228		<	0.028	Bq/g
		Bi-212		<	0.14	Bq/g

Niras Reference	Client Reference	Determinand	Result			Unit
		Bi-214		<	0.025	Bq/g
		Cs-137		<	0.0092	Bq/g
		K-40		<	0.056	Bq/g
		Pa-234m		<	1.7	Bq/g
		Pb-210		<	0.032	Bq/g
		Pb-212		<	0.0061	Bq/g
		Pb-214		<	0.0082	Bq/g
		Ra-226		<	0.068	Bq/g
		Th-234		<	0.019	Bq/g
		Tl-208		<	0.0071	Bq/g
		U-235		<	0.0039	Bq/g

Results are referenced to the count dates of the samples: 30-Jun to 05-Aug-2008

The evidence in Tables 9 and 10 supports the conclusion that radium-226 and progeny gamma-emitting radionuclides are not deposited to a significant extent onto copper from 20% (v/v) nitric acid solution.

Polonium-210 analyses were conducted on the solids prior to leaching and on the leachates after mercury deposition. The results are given below in Table 11.

Table 11 Polonium-210 in solids prior to leaching and in leachates post-deposition

Niras Reference	Client Reference	Determinand	Result			Unit
L080402-16	MR6-leached	Po-210	1.07	±	0.21	Bq/g
L080402-17	MR10-leached	Po-210	2.20	±	0.14	Bq/g
L080402-18	MR16-leached	Po-210	1.529	±	0.093	Bq/g
L080402-19	MRV14-leached	Po-210	1.77	±	0.26	Bq/g
L080402-20	MRV6-leached	Po-210	N. D. [1]			
L080402-21	MRV10-leached	Po-210	N. D. [1] [2]			
L080402-34	MR6-leachate post-deposition	Po-210	N.D. [1]			
L080402-35	MR10-leachate post-deposition	Po-210	0.00184	±	0.00033	Bq/g
L080402-36	MR16-leachate post-deposition	Po-210	0.00200	±	0.00037	Bq/g
L080402-37	MRV14-leachate post-deposition	Po-210	0.00078	±	0.00022	Bq/g
L080402-38	MRV6-leachate post-deposition	Po-210	0.0759	±	0.0063	Bq/g
L080402-39	MRV10-leachate post-deposition	Po-210	0.0236	±	0.0023	Bq/g

The reference dates are L080402-16 to 19, 31-Jul-08, and 35-39, 11-Aug-08.

[1] ND = not determined. The resolution of the alpha spectrum was too poor to generate a result.

[2] Although it is not possible to give a quantified result, it can be concluded from the spectrum that the Po-210 concentration is relatively high in this sample.

The alpha spectra for the solids in general showed poor resolution. The uncertainty in results for the solids is inevitably considerably greater than the calculated values in Table 11 suggest. The spectra for the leachates are generally better (except for MR6 leachate) and tentatively it appears that Po-210 concentrations are significantly lower than the corresponding Pb-210 concentrations. With current information however, it is not possible to say whether this is because of differences in leaching efficiency, or because of greater co-deposition of Po-210 in the mercury deposition experiment.

6 Conclusions

- The maximum nitric acid concentration for successful deposition of dissolved mercury on copper metal is around 20% (v/v) or approximately 3 mol L^{-1}.
- The loading of mercury onto copper increases with contact time, but a good compromise between mercury loading and copper dissolution is a contact period of approximately 16 hours or overnight.
- A mercury loading on copper of at least 1.5 mg cm^{-2} can be achieved overnight in 20% (v/v) nitric acid solution.
- Leaching of mercury from the waste materials by overnight leaching in 20% (v/v) nitric acid is not effective.
- Radium-226 and progeny gamma-emitting radionuclides do not appear to significantly co-deposit with mercury onto copper.
- Tentatively, Pb-210 and Po-210 are out of equilibrium in the leachates post-deposition. It is not known if this is because of differences in leaching or deposition behaviour.