AUSTRALIA

Technical Memorandum 21

Interlaboratory comparison of the measurement of uranium in urine

T. Anttonen, B.N. Noller and D.A. Woods

Supervising Scientist for
the Alligator Rivers Region

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TECHNICAL MEMORANDUM 21

INTERLABORATORY COMPARISON OF THE MEASUREMENT OF URANIUM IN URINE

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ABSTRACT

Anttonen, T., Noller, B.N. & Woods, D.A. (1988). Interlaboratory comparison of the measurement of uranium in urine. Technical Memorandum 21, Supervising Scientist for the Alligators Rivers Region.

The measurement of uranium in the urine of workers exposed to uranium dusts and solutions can assist in assessing the effectiveness of protective measures and the significance of actual exposures.

Most laboratories with uranium-in-urine measurement capabilities are not well practised in the measurement, therefore an interlaboratory comparison was undertaken to give laboratories practice in the technique and to check the accuracy of results. Ten laboratories took part in an intercomparison.

This paper describes the preparation of the samples and gives the results and statistical analysis of the results with respect to analytical method and laboratory performance.

Some laboratories experienced difficulty and, if required to perform future determinations of uranium in urine of exposed individuals, would need to demonstrate greater reliability in this type of analysis.

1 INTRODUCTION

The measurement of uranium in the urine of workers exposed to uranium dusts and solutions can, for soluble forms of uranium, assist in assessing the effectiveness of protective measures and the significance of actual exposures (refs 1-5).

Determination of uranium in urine may be performed by in-house, commercial, or government laboratories. One government laboratory currently performs routine analyses for uranium in urine for research staff working with uranium compounds. At present, routine urine sampling and analysis for uranium is not required of the two operating uranium mills in Australia. However, both are expected (ref. 6) to have a viable urine sampling and analysis capability to be implemented in the event of an incident resulting in abnormal intakes of uranium by personnel.

In Australia most laboratories with uranium-in-urine measurement capabilities are not well practised in the measurement, but may be called upon to do such measurements following abnormal intakes of uranium by workers. It is therefore useful (ref. 7) to perform an interlaboratory comparison to give laboratories practice in the technique and to check the accuracy of results. Ten laboratories with existing uranium-in-urine measurement capabilities were approached and volunteered to take part in an intercomparison.

2 METHODS

Two instruments used almost exclusively in Australia for the determination of uranium-in-urine are the Scintrex Nitrogen Laser Fluorimeter and the Jarrell-Ash Fluorometer (hereafter referred to as the Scintrex and Jarrell-Ash, respectively). Both instruments employ a fluorimetric method of measurement. The Scintrex method is based upon the laser-induced fluorescence of the uranyl ion in solution. A pulsed nitrogen laser irradiates the solution with 337 nm light and the fluorescence due to uranium is measured. In the Jarrell-Ash method, uranium is isolated from the sample matrix, the solution is evaporated to dryness and then fused, by heating with sodium fluoride, into a solid pellet on a platinum dish. The solid pellet is then exposed to ultra-violet light and the resultant uranium fluorescence is measured. Alpha spectrometry is also available at some laboratories. Here uranium-232 tracer is added to the solution, uranium is separated from the solution matrix, electro-deposited onto a metal disc, the count rate at relevant alpha-particle energies measured in an alpha-spectrometer and the uranium content determined.

For all three methods digestion of the sample is an essential pre-requisite to destroy all organic matter, which, if it remains, will interfere with the measurement. Full details of the methods are given in refs 8-11. Of the ten laboratories participating, five used the Scintrex, three used the Jarrell-Ash and two used alpha spectrometry. Although only one of these laboratories routinely analyses urine samples for uranium, the others routinely analyse water samples for uranium. Individual laboratory variations in method are given in footnotes with each set of laboratory results in Appendix 2.

Sample preparation. Polyethylene vials and polyethylene containers used were pre-washed with 10% HCl acid and deionised water 24 h prior to use. Urine samples were collected from a non-exposed group of volunteers at the OSS Alligator Rivers Region Research Institute, Jabiru East, Northern Territory. The samples were bulked to form one composite

3 L urine sample, which was thoroughly shaken and then divided into four 0.5 L lots (A,B,E and F) and one 1.0 L lot (C and D). Each lot was acidified with HCl (1%) and spiked (with the exception of lot B) with a known quantity of uranium from a uranyl nitrate stock solution containing 100 μg/L uranium. The 1.0 L spiked lot was divided in two, to provide two identical 0.5 L lots (C and D). A 0.5 L deionised water sample (G) was also spiked to 20 μg/L uranium.

The nominal uranium concentration of each lot was:

Lot	A	B	C	D	E	F	G
U (μg/L)	80	Nil	20	20	6	60	20

After spiking and shaking, each lot was further subdivided into approximately 40 mL samples in labelled, 50 mL polyethylene vials. A 40 mL 1% HCl solution blank was also dispensed.

All samples were frozen overnight and delivered in insulated packs to participating laboratories within 48 h of sample collection. The samples were accompanied by the instruction sheet and the result sheet shown in Appendix 1. Laboratories were informed that all samples contained less than 100 μg/L uranium and requested to analyse duplicate samples for total uranium content (solution plus suspended solids) giving the results in μg/L to two significant figures, with an estimate of the uncertainty attributable to these values and a brief statement of the analytical method (refs 8-11).

3 RESULTS

Laboratories were allocated code numbers UU01-UU10. The results reported by each are summarised in Table 1 and given in detail in Appendix 2. Of the ten participating laboratories, one (UU05) was unable to analyse samples within the requested time due to pressure of other work and the samples were discarded without being analysed. One laboratory (UU09) presented more results than requested and only the first two are shown in the summary table. Another laboratory (UU07) was excluded from statistical analysis as 78% of the data were missing.

As the aim of the study was to determine the analytical accuracy of participating laboratories on known sample concentrations, a variable T was constructed for statistical purposes such that:

T = measured concentration - nominal concentration

If a laboratory's accuracy of uranium determination is good, then the values of T will tend towards zero for all concentrations (see Figs 1-3).

A factorial analysis of the variance of T was used to test for differences between laboratories and concentrations, as well as interaction effects, and orthogonal comparisons were used to explain any significant main effects. All hypothesis tests were determined at the 95% confidence level (ref. 12) by either F-tests or t-tests as appropriate.

Table 1. Summary of results

All values given in $\mu g/L$ uranium

	Sample													
	A		B		C		D		E		F		G	
Laboratory: method	1	2	1	2	1	2	1	2	1	2	1	2	1	2
UU01: Scintrex	99	70	1.2	0.5	0.1	1.6	29	11	6.9	1.6	20	8.6	26	11
UU02: ∝-spectrometry	70	-	0.15	-	17	-	19	-	5	-	54	-	17	-
UU03: Scintrex	72	71	< 5	< 5	15	15	14	18	5	6	57	55	17	18
UU04: Scintrex	42	62	43	13	29	45	26	28	18	13	41	30	45	38
UU06: Jarrell-Ash	76	76	2	2.2	18	17	19	15	3.6	4.3	57	53	22	22
UU07: ∝-spectrometry	57	-	-	-	-	-	-	-	-	-	17	-	25	-
UU08: Scintrex	62	62	< 1	1	20	20	14	15	6	6	50	48	20	20
UU09: Jarrell-Ash	94	98	< 5	< 5	17	18	17	18	5	5	56	49	13	15
UU10: Jarrell-Ash	97	94	< 3	< 3	19	21	29	28	< 3	< 3	83	86	42	44
Nominal concentration	80		Nil		20		20		6		60		20	

The factorial analysis gave the following results:

1) A significant difference between laboratories ($F = 13.38$, $\alpha = 5\%$, df = 7,49)[1] led to rejection of the hypothesis that the mean of T_L was the same for all laboratories.

Orthogonal comparisons were then structured to test whether the difference in analytical method was responsible for the laboratory effect (Fig. 1). The comparisons used were:

(a) UU02 vs the rest gave a non-significant result ($t = 1.21$, df = 49) showing that the means from the laboratory using alpha-spectrometry were no different from the means from the other laboratories;

(b) Scintrex (UU01, UU03, UU04, UU08) vs Jarell-Ash (UU06, UU09, UU10) gave a significant result ($t = 5\ .66$, df = 49): therefore the means from the laboratories using the Scintrex method were different from the means from those using the Jarrell-Ash method; and

(c) The two within Jarrell-Ash method comparisons were both significant ($t = 3.58$, df = 49; $t = 3.97$, df = 49), as were the three within Scintrex method comparisons ($t = 2.21$, df = 49, $t = -5.10$, df = 49; $t = 2.89$, df = 49).

---

[1] F = F-test value; t = t-test value; $1 - \alpha$ = confidence level; df = degrees of freedom.

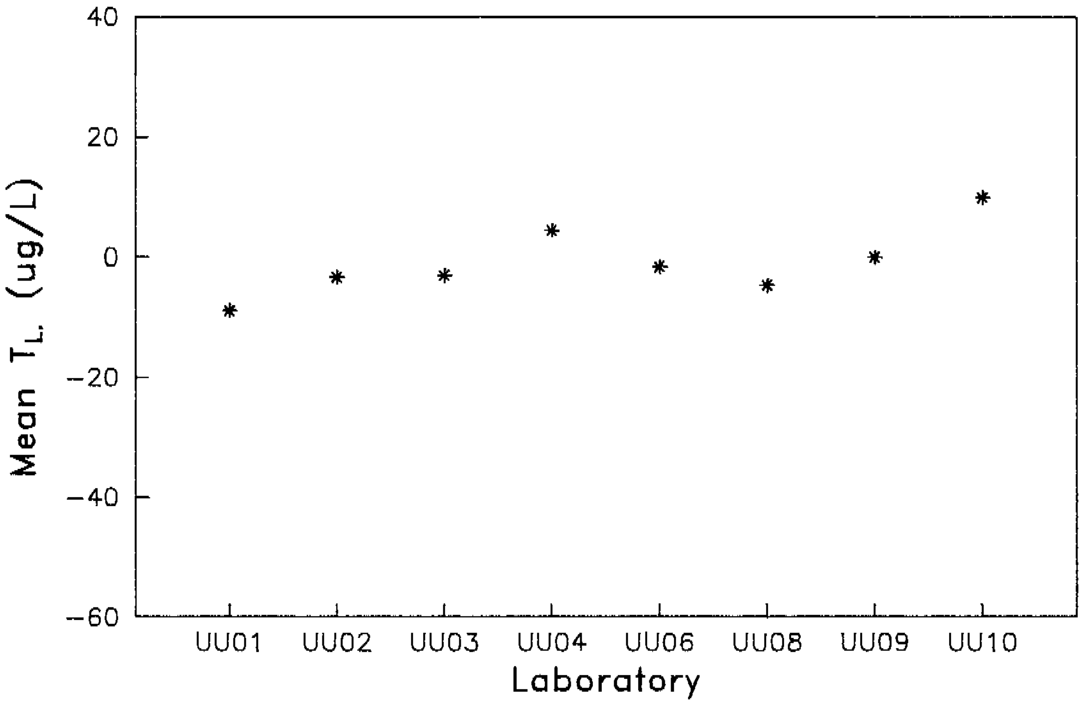

Figure 1. Diagram showing the mean accuracy of determinations by each laboratory

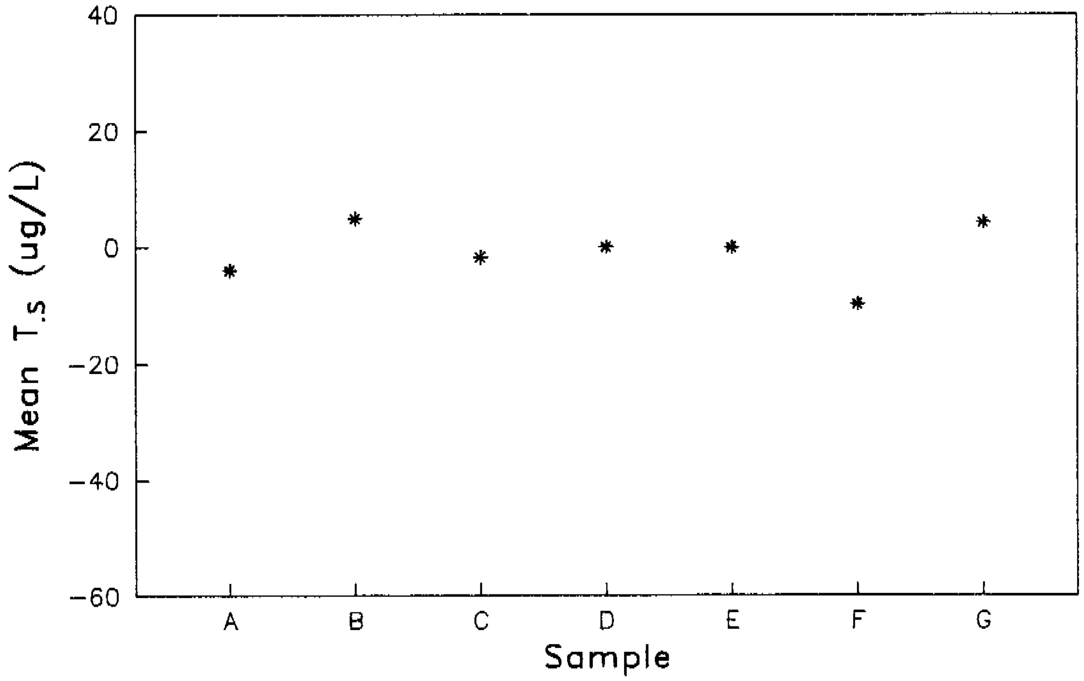

Figure 2. Diagram showing the mean accuracy of determination of a particular concentration by all laboratories

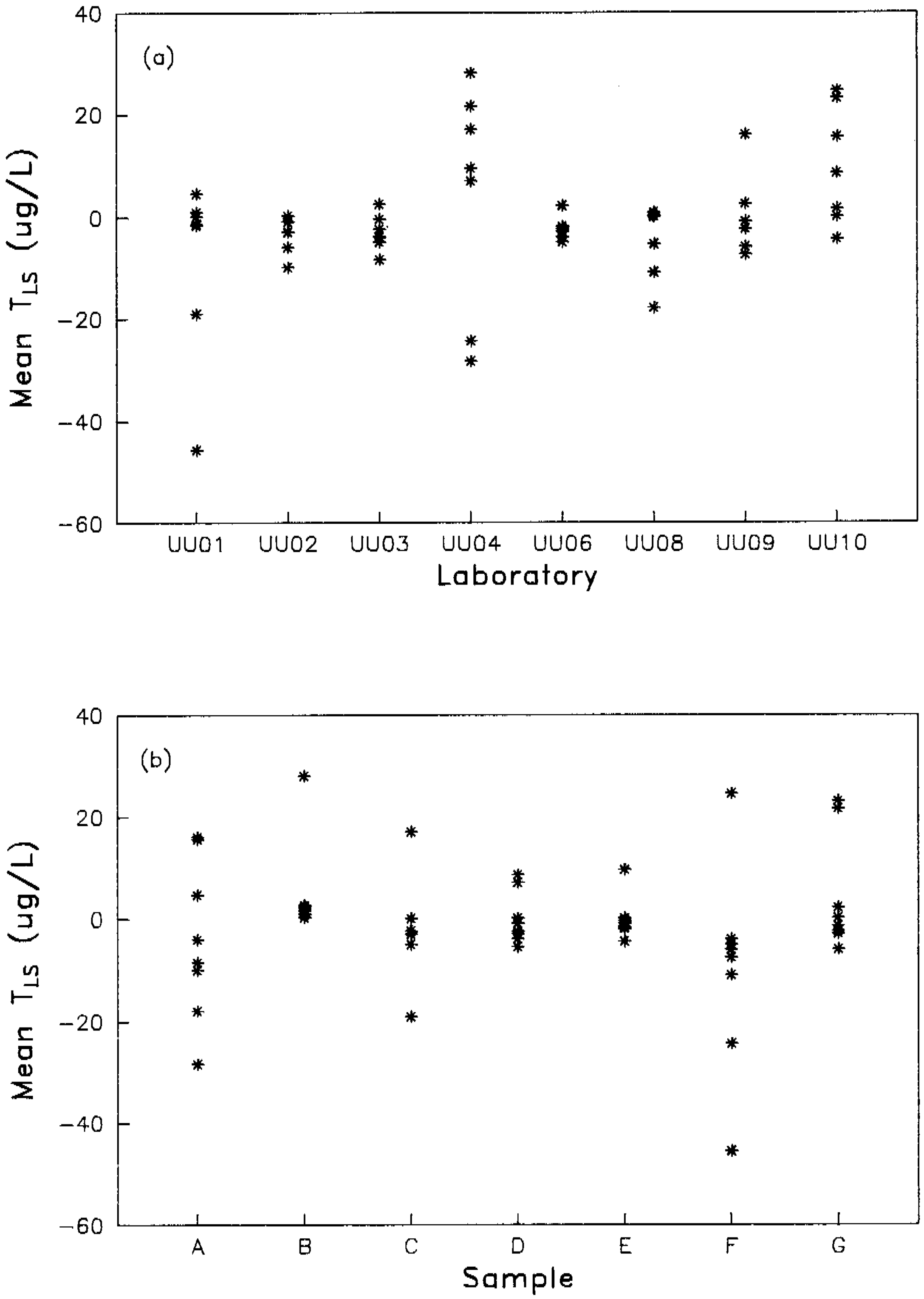

Figure 3. Diagram showing the laboratory x concentration interaction effect

Therefore all laboratories had significantly differing degrees of accuracy regardless of the analytical method used.

2) Concentration had a significant effect ($F = 11.58$, $\alpha = 5\%$, df = 6, 49), leading to the conclusion that the mean of $T_{.S}$ was not the same at all concentrations and implying that some uranium concentrations were analysed with a greater degree of accuracy than others by all laboratories (Fig. 2).

   Orthogonal comparisons between the mean value of $T_{.S}$ for different concentrations were designed to show whether less accuracy was encountered when analysing samples with low, medium or high uranium concentration. The comparisons used were:

   (a) G vs C,D: these samples each had a nominal uranium concentration of 20 µg/L, G being a water sample and C and D being urine samples. As this test was significant ($t = 4.29$, df = 49) it is concluded that the accuracy of analysis of a water sample was different to that of the two urine samples with the same nominal uranium concentration.

   (b) C vs D: the test between the two urine samples of the same nominal concentration was not significant ($t = 0.94$, df = 49).

   (c) the four remaining comparisons: A,F vs C,D ($t = 6.62$, df = 49); B,E vs C,D ($t = 4.70$, df = 49); B vs E ($t = -2.53$, df = 49); and A vs F ($t = -3.45$, df = 49) were all significant. From these comparisons it is concluded that the apparent differences in accuracy are associated with a particular sample concentration.

3) A significant laboratory x concentration interaction effect ($F = 7.26$, $\alpha = 5\%$, df = 42, 49) leads to the conclusion that no particular concentration was measured with a consistent degree of accuracy by all laboratories. Graphs of concentration x laboratory interaction means (Fig. 3) explain the source of the significant interaction effect.

   Figure 3(a) shows the set of interaction means (T_{LS}) plotted for each laboratory. It is apparent that laboratory UU04 experienced the most difficulty with uranium determination and that laboratory UU06 had the least difficulty. Similarly, Fig. 3(b) shows the interaction means (T_{LS}) plotted for each concentration, from which it is apparent that more difficulty was experienced in the determination of higher uranium concentrations (samples A and F).

4 DISCUSSION

All laboratories performed with significantly differing degrees of accuracy regardless of the analytical method used.

The three most accurate laboratories (Fig. 3a) represented each of the three analytical methods:

UU06 - Jarrell-Ash
UU02 - Alpha spectrometry
UU03 - Scintrex

The two least accurate laboratories, UU01 and UU04, both used the Scintrex technique. It is suggested that the difficulties experienced using the Scintrex technique were due, in part, to the incomplete digestion of organics. Great care is required to ensure complete digestion and more reagent is required to destroy organics in urine samples than is required for water samples. With the Jarrell-Ash, organics are destroyed when the sample pellet is fused at high temperature, this step being performed without much need for skill.

All participating laboratories are asked to evaluate critically their own results, and where appropriate, to investigate the sources of any significant differences between their results and the consensus (excluding laboratory UU07) means (Fig. 1) determined for each test.

Some laboratories experienced some difficulty and, if required to perform future determinations of uranium in urine of exposed individuals, would need to demonstrate greater reliability in this type of analysis.

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APPENDIX 1

AUSTRALIA

Supervising Scientist
For the Alligator Rivers Region

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Telephone: (02) 387 0666
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Facsimile: (02) 389 0681

Our Ref:
Your Ref:

Jabiru Laboratory
15 October 1985

URANIUM IN URINE INTERLABORATORY COMPARISON

1. Your laboratory has been allocated the following code number for this program:

2. You have been supplied with:

   6 x 40 mL urine samples A, B, C, D, E, F
   1 x 40 mL aqueous sample G
   1 x 40 mL HCl blank

3. The urine samples are acidified with HCl (1%); the blank is provided as an HCl impurity check.

4. Samples A-F are to be analysed for total uranium content (solution plus suspended solids). The results are to be quoted in μg/L to two significant figures with the lab's estimate of the error. All samples contain less than 100 μg/L uranium.

5. Sample G is to be analysed for total uranium content. The results to be quoted in μg/L to two significant figures. (This sample is to be used as a calibration check).

6. Analyse samples A-G a second time.

7. Report all results on the result sheet attached.

8. In addition indicate on the result sheet:

   Lab code no.; the date samples received; condition of samples on receipt; brief description of lab method and signature.

9. Samples are to be analysed as soon as possible after receipt, preferably on Wednesday 16 October and Thursday 17 October.

10. Please make any comments you may have on variations in method on a separate sheet.

11. Please forward all results to OSS Sydney Office (address above) no later than 31 October 1985.

Thank you for your co-operation.

Yours faithfully,

D.A. Woods

URANIUM IN URINE INTERLABORATORY COMPARISON

RESULT SHEET

Laboratory Code No .... Time Samples Received .... Date Samples Received ....

Condition of Samples on Receipt ....

	Total uranium µg/L (2 significant figures)		Lab's error estimate ± %		Test date	
	Result 1	Result 2	Result 1	Result 2	Result 1	Result 2
Sample A						
Sample B						
Sample C						
Sample D						
Sample E						
Sample F						
Sample G						

Brief Description of Lab Method ....

....

....

REPORT ALL RESULTS TO OSS SYDNEY OFFICE BY 31 OCTOBER 1985 Signed:

Results of analyses as presented by the participating laboratories

RESULTS FROM LABORATORY UU01

Date and time samples received: 15.10.85 at 5pm
Condition of samples on receipt: good

	Total uranium (μg/L)		Error estimate (± %)		Date of test	
Sample	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2
A	99	70	-	2	17.10.85	22.10.85
B	1.2	0.5	-	-	"	"
C	0.1	1.6	-	-	"	"
D	29	11	72	91	"	"
E	6.9	1.6	49	< 1	"	"
F	20	8.6	130	72	"	"
G	26	11	41	-	"	"
G*	19	17	-	-	"	"

* undigested

Second set
This laboratory was provided with two full sets of samples, the second set to be analysed a week after the first

	Total uranium (μg/L)		Error estimate (± %)		Date of test	
Sample	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2
A	22		-		24.10.85	
B	1.6		-		"	
C	14		-		"	
D	9.5		-		"	
E	4.4		-		"	
F	25		-		"	
G	-		-		-	
G*	25		-		24.10.85	

* undigested

Brief description of method: Scintrex Application brief 79-2, Analytical Procedures for UA-3 Uranium Analyser - 'Uranium in Urine' pp. F1-F3.

RESULTS FROM LABORATORY UU02

Date and time samples received: -
Condition of samples on receipt: -

	Total uranium (μg/L)		Error estimate Absolute error		Date of test	
Sample	Test 1	Test 2	Counting stats	Total error	Test 1	Test 2
A	70		3	5		
B	0.15		0.38	0.38		
C	17		1	2		
D	19		2	2		
E	5.0		0.8	0.9		
F	54		3	4		
G	17		1	2		

Brief description of method: Alpha spectrometry (Martin et al. 1985). ^{232}U used as a tracer. Error in column 1 is that due to counting error only. Error in column 2 is total expected error due to counting statistics, systematic errors, etc.

Full results

Uranium in μg/L (1 mBq ^{238}U = 0.08095 μg Uranium)
Errors shown in brackets are counting statistics errors only

Sample	^{238}U (mBq/L)	^{235}U (mBq/L)	^{234}U (mBq/L)	Uranium (μg/L)	^{234}U/^{238}U	^{235}U/^{238}U
A	863(39)	47(10)	380(25)	70(3)	0.44(0.03)	0.054(0.011)
B	2(5)	3(4)	6(10)	0.2(0.4)		
C	208(17)	12(5)	80(13)	17(1)	0.39(0.07)	0.056(0.023)
D	240(22)	10(6)	93(16)	19(2)	0.39(0.07)	0.041(0.027)
E	61(10)	2(5)	37(11)	5(0.8)	0.61(0.20)	0.039(0.081)
F	668(34)	43(10)	286(22)	54(3)	0.43(0.04)	0.065(0.015)
G	208(16)	10(4)	62(11)	17(1)	0.30(0.06)	0.048(0.019)
HCl	0.3(4)	0.9(4)	1(8)	0.03(0.3)		

RESULTS FROM LABORATORY UU03

Date and time samples received: 15.10.85
Condition of samples on receipt: partially thawed

Sample	Total uranium (μg/L)		Error estimate (± %)		Date of test	
	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2
A	72	71	20	20	25.10.85	28.10.85
B	< 5	< 5	20	20	"	"
C	15	15	20	20	"	"
D	14	18	20	20	"	"
E	5	6	20	20	"	"
F	57	55	20	20	"	"
G	17	18	20	20	"	"

Brief description of method: Scintrex method. Samples were analysed in duplicate: all samples in the past have been analysed in duplicate. Our convention is to report results less that 5 μg/L as '< 5 μg/L' and to report values between 5 and 10 as integers. N.B. Sample G analysed using procedure for water analysis - analysis was not in duplicate.

Duplicate results
Reported by telephone following receipt of above results

Sample	Total uranium (μg/L)	
	Test 1	Test 2
A	79; 66	73; 68
B	1; 2	1; 0
C	15; 16	16; 15
D	14; 13	20; 16
E	6; 4	7; 5
F	56; 58	55; 54
G	17	18
HCl	3.9	2.5

RESULTS FROM LABORATORY UU04

Date and time samples received: 15.10.85
Condition of samples on receipt: intact

Sample	Total uranium (μg/L)		Error estimate (± %)		Date of test	
	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2
A	42	62	see below		20.10.85	22.10.85
B	43	13			"	"
C	29	45			"	"
D	26	28			"	"
E	18	13			"	"
F	41	30			"	"
G	45	38			"	"

Brief description of method: As per Scintrex manual except that water bath was used for evaporation and 60 g/L $NaHCO_3$ for neutralisation. No error estimates are given as we have no previous experience of this type of analysis and data generated by these tests were insufficient for a statistical analysis of error. Aqueous sample G was treated as a urine sample.

RESULTS FROM LABORATORY UU06

Date and time samples received: 16.10.85 at 12.00 p.m.
Condition of samples on receipt: liquid (not frozen), red/orange precipitate, orange deposit on container walls

Sample	Total uranium (μg/L)		Error estimate (± %)		Date of test	
	Test 1	Test 2	Test 1	Test 2	Test 1 Chemist 1	Test 2 Chemist 2
A	76	76	5	5	21.10.85	29.10.85
B	2.0	2.2	50	50	"	"
C	18	17	10	10	"	"
D	19	15	10	10	"	"
E	3.6	4.3	25	25	"	"
F	57	53	5	5	"	"
G	22	22	10	10	"	"
HCl	1.1	1.0	100	100	"	"

Brief description of method: Sample transferred to beaker and oxidised with $HNO_3/HClO_4$. Container leached twice with conc. HCl/H_2O_2 mixture. Digest made up to original volume and suitable fractions extracted into 10% tri-n-butyl phosphate in cyclohexane. Extract fused with $Na_2CO_3/K_2CO_3/NaF$ flux and fluorescence determined on a Jarrell Ash Reflectance Fluorimeter. Standardisation with aqueous U_3O_8 standards.

RESULTS FROM LABORATORY UU07

Date and time samples received: 15.10.85 at 4.30 p.m.
Condition of samples on receipt: okay

	Total uranium (μg/L)		Error estimate (± %)		Date of test	
Sample	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2
A	57 ± 11		19		22.10.85	
B	below detection limit					
C	below detection limit					
D	below detection limit					
E	below detection limit					
F	17 ± 15		88		28.10.85	
G	25 ± 14		56		22.10.85	

Brief description of method: 100 mL sample + 10 g tracer (^{232}U 0.03724 Bq/10 g). Wet ash with conc. HNO_3 (HASL E-U-03-01), take up in 8 M HNO_3, extraction with TBP (Martin et al. 1985). Electrodeposition on S.S. disc (Short 1985). Overnight counting in alpha-spectrometer. Activity estimate for ^{238}U ex. count cf. ^{232}U standard. All errors estimated ex counting statistics (2σ).

RESULTS FROM LABORATORY UU08

Date and time samples received: 16.10.85 at 9.30 a.m.
Condition of samples on receipt: intact, no evidence of leaking

	Total uranium (μg/L)		Error estimate (± %)		Date of test	
Sample	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2
A	62	62			17.10.85	22.10.85
B	< 1	1			"	"
C	20	20			"	"
D	14	15	± 5% at 20 ppb level		"	"
E	6	6			"	"
F	50	48			"	"
G	20	20			"	"

Brief description of method: Ethyl acetate extraction using aluminium nitrate as a salting agent followed by evaporation and perchloric acid digestion with a Scintrex laser fluorimetry finish. Standard addition was used as a check on accuracy.

RESULTS FROM LABORATORY UU09

Date and time samples received: 16.10.85 at 11.30 a.m.
Condition of samples on receipt: good, still intact and no leaks

Concentrations of uranium are in μg/L

	Sample						
Test	A 24.10.85	B 24.10.85	C 25.10.85	D 25.10.85	E 28.10.85	F 28.10.85	G 28.10.85
1	93.7	<5.0	17.1	17.1	5.0	56.4	13.0
2	98.2	<5.0	18.0	18.4	5.1	49.2	15.8
3	98.3	<5.0	18.4	17.0	5.0	46.9	16.1
4	101.1	<5.0	17.2	17.2	6.9	47.9	13.7
5	97.4	<5.0	14.9	15.3	4.3	48.0	14.8
6	101.2	<5.0	16.1	17.7	3.9	49.4	15.9
7	-	-	18.8	17.3	-	-	-
8	-	-	17.3	16.0	-	-	-
No.	6	6	8	8	6	6	6
Mean	98.3	-	17.2	17.0	5.0	49.6	14.9
SD	± 2.8	-	± 1.4	± 1.0	± 0.9	± 3.4	± 1.3

Brief description of method: The method utilises the fusion/fluorescence technique. Our fusion burner will fuse 12 samples simultaneously and we prepare a standard curve with each fusion run. We use a lower detection limit of 5 μg/L and results below this are quoted as < 5.0 μg/L. Samples A-G were kept frozen until 24.10.85.

RESULTS FROM LABORATORY UU10

Date and time samples received: 16.10.85 at 3.00 p.m.
Condition of samples on receipt: chilled

	Total uranium (μg/L)		Error estimate (± %)		Date of test	
Sample	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2
A	97	94	9	9	18.10.85	18.10.85
B	< 3	< 3	10	10	"	"
C	19	21	11	10	"	"
D	29	28	12	11	"	"
E	< 3	< 3	14	12	"	"
F	83	86	9	8	"	"
G	42	44	5	7	"	"

Brief description of method: Fluorimetric determination using Jarrell-Ash fluorimeter after fusion on ribbon burner of NiF/LiF pellets containing evaporated urine.

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RESEARCH PUBLICATIONS

Alligator Rivers Region Research Institute Research Report 1983-84
Alligator Rivers Region Research Institute Annual Research Summary 1984-85
Alligator Rivers Region Research Institute Annual Research Summary 1985-86
Alligator Rivers Region Research Institute Annual Research Summary 1986-87

Research Reports (RR) and Technical Memoranda (TM)

RR 1	The macroinvertebrates of Magela Creek, Northern Territory. April 1982 (pb, mf - 46 pp)	R. Marchant
RR 2	Water quality characteristics of eight billabongs in the Magela Creek catchment. December 1982 (pb, mf - 60 pp)	B.T. Hart & R.J. McGregor
RR 3	A limnological survey of the Alligator Rivers Region. I. Diatoms (Bacillariophyceae) of the Region. August 1983 (pb, mf - 160 pp)	D.P. Thomas
	*A limnological survey of the Alligator Rivers Region. II. Freshwater algae, exclusive of diatoms. 1986 (pb, mf - 176 pp)	H.U. Ling & P.A. Tyler
RR 4	*Ecological studies on the freshwater fishes of the Alligator Rivers Region, Northern Territory. Volume I. Outline of the study, summary, conclusions and recommendations. 1986 (pb, mf - 63 pp)	K.A. Bishop, S.A. Allen, D.A. Pollard & M.G. Cook
	Ecological studies on the freshwater fishes of the Alligator Rivers Region, Northern Territory. Volume II. (in press)	K.A. Bishop, S.A. Allen, D.A. Pollard & M.G. Cook
	Ecological studies on the freshwater fishes of the Alligator Rivers Region, Northern Territory. Volume III. (in press)	K.A. Bishop, S.A. Allen, D.A. Pollard & M.G. Cook
TM 1	Transport of trace metals in the Magela Creek system, Northern Territory. I. Concentrations and loads of iron, manganese, cadmium, copper, lead and zinc during flood periods in the 1978-1979 Wet season. December 1981 (pb, mf - 27 pp)	B.T. Hart, S.H.R. Davies & P.A. Thomas
TM 2	Transport of trace metals in the Magela Creek system, Northern Territory. II. Trace metals in the Magela Creek billabongs at the end of the 1978 Dry season. December 1981 (pb, mf - 23 pp)	S.H.R. Davies & B.T. Hart
TM 3	Transport of trace metals in the Magela Creek system, Northern Territory. III. Billabong sediments. December 1981 (pb, mf - 24 pp)	P.A. Thomas, S.H.R. Davies & B.T. Hart
TM 4	The foraging behaviour of herons and egrets on the Magela Creek flood plain, Northern Territory. March 1982 (pb, mf - 20 pp)	H.R. Recher & R.T. Holmes
TM 5	Flocculation of retention pond water. May 1982 (pb, mf - 8 pp)	B.T. Hart & R.J. McGregor
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