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FISSION TRACK ANALYSIS OF PLUTONIUM IN SMALL SPECIMENS OF BIOLOGICAL MATERIAL:
ULTRASENSITIVE ANALYSIS FOR ^{239}Pu IN 50 URINE SAMPLES FROM THE MARSHALL ISLANDS FURNISHED BY BROOKHAVEN NATIONAL LABORATORY

Final Technical Report to the DOE/NVOO
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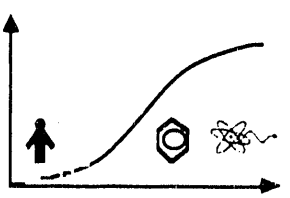

FISSION TRACK ANALYSIS OF PLUTONIUM IN SMALL SPECIMENS OF BIOLOGICAL MATERIAL: Ultrasensitive Analysis for ^{239}Pu in 50 Urine Samples from the Marshall Islands Furnished by Brookhaven National Laboratory

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University of Utah, Environmental Radiation & Toxicology Laboratory
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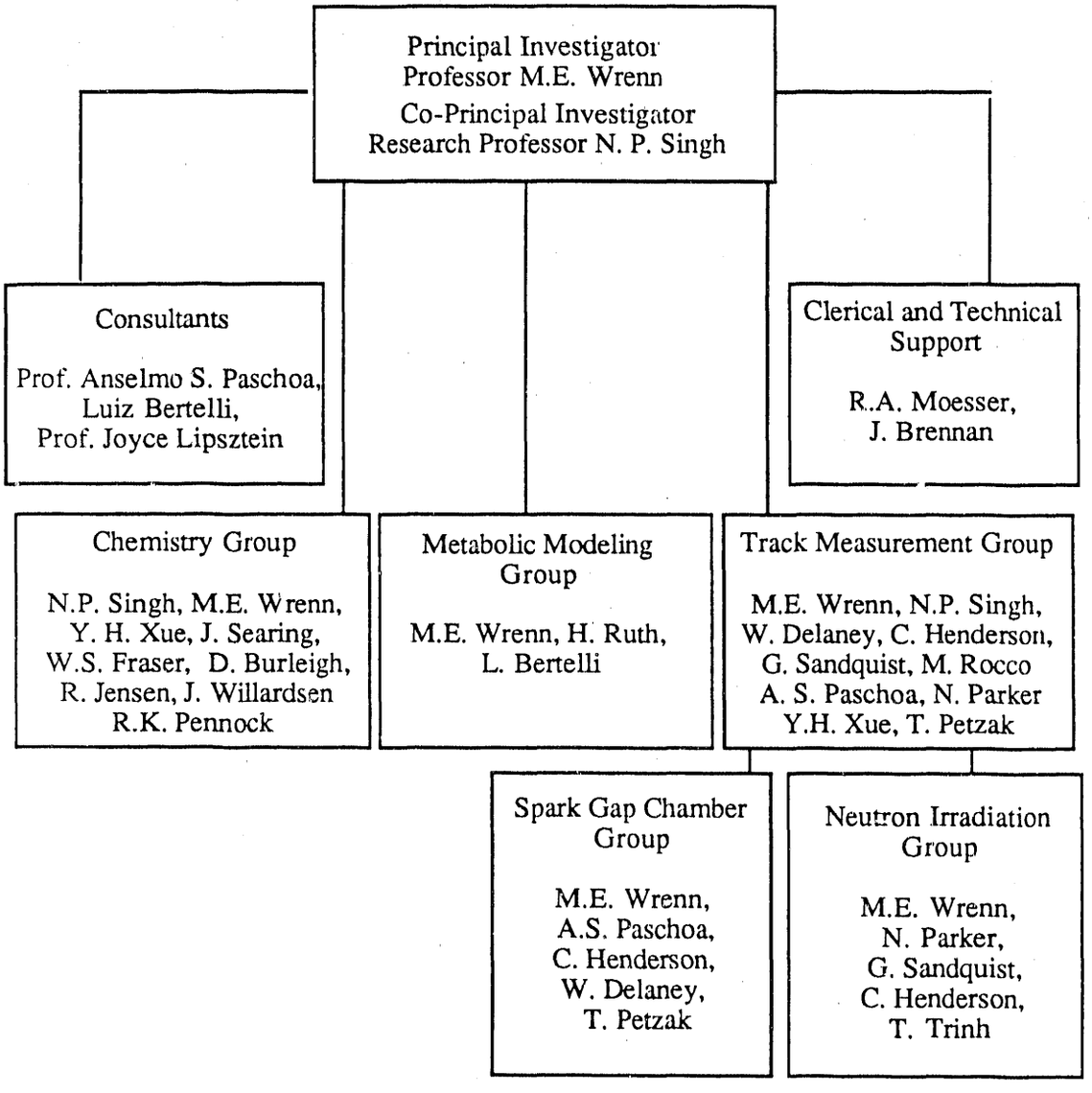
ABSTRACT

A neutron induced fission track method was successfully developed for assaying ^{239}Pu in human urine with a detection limit below 20 aCi (0.73 μBq) per sample, which for the 200 ml sample size analyzed is equivalent to 100 aCi/l (3.67 μ Bq/l). The technique involves means to remove potentially interfering natural uranium from the sample and reagents. The method was applied to 50 urine samples including an unknown number of spikes and controls from the Marshall Islands. 49 samples were successfully analyzed. Of the 49, one sample had activity >16,000 aCi/l (0.59 mBq/l) and a second showed 450 aCi/l (16.5 μBq/l). All others were below our detection limit. The mean activity for the 47 samples which were not positive for ^{239}Pu did not differ significantly from the mean for our control samples, which consisted of urines collected from six young adult Utah residents.

DISCLAIMER

RESEARCH MANAGEMENT ORGANIZATION



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1. OBJECTIVE:

The objective of this research was to develop an ultrasensitive fission track assay method for human urine, obtaining highly sensitive analyses capable of detecting 100 aCi/liter of ^{239}Pu in human urine.

A second objective was to measure ^{239}Pu in 50 sets of urine samples collected in the Marshall Islands and furnished to us by Brookhaven National Laboratory (BNL).

The scope of the report does not include any interpretation of the results. In fact, all analyses were performed blind so that no one in the laboratory including the analysts, knew any details about the origin or composition of any urine sample furnished, other than that they were from the Marshall Islands. Neither did we know which samples might be controls or spiked samples.

2. INTRODUCTION:

This report gives both the results and the details of the 50 urine samples analyses.

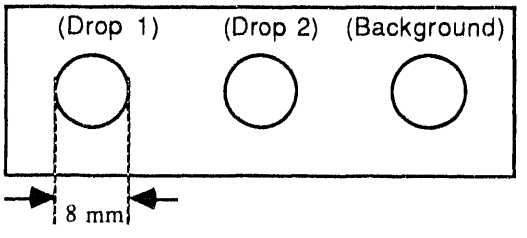
Of the 50 analyses undertaken, 49 were successfully completed. One sample was lost due to handling accidents in the laboratory. In addition, 28 urine controls were analyzed. Of these 28, 26 met our acceptance criteria. The controls consisted of urine samples from young male adult residents of Utah who were born after 1963, the year of maximum global fallout in the United States. In the period 1962 - 1964, adults living at the latitude of New York City inhaled and retained between 2 to 4 pCi of ^{239}Pu. People born after 1963 could not have inhaled as much Pu from subsequent global fallout during its passage from the atmosphere to the boundary layer of the troposphere, in the process of being deposited in the soil. We believe that subsequent transport of Pu from soil to man either in the food

chain or by inhalation of Pu resuspended from soil would be considerably less than the amount which would have been inhaled during the initial deposition of the fallout. If this is true, then young adults today should have accumulated less systemic Pu than older adults, and the urine of young adults would be among the lowest in Pu content.

3. SYNOPSIS OF METHOD:

The method was as follows. The samples furnished by BNL were homogenized by dissolving any precipitate with concentrated HCl, then returning the dissolved preciptate to the aqueous sample. A 200 ml aliquot of the urine sample was withdrawn, precipitated with rhodizonic acid, redissolved in HCl, passed through two ion exchange columns and eluted onto a Lexan slide. The Lexan slide had three equal circular areas, two to receive the first two elution drops from the elution of the second ion exchange column and the third to serve as a background for that slide. The slide was irradiated with well thermalized neutrons to a fluence of 1.1×10^{17} n/cm^2, returned to the laboratory, etched under controlled temperature conditions, and subsequently the total track count in each area was determined by optical counting by a qualified track counter under a microscope, often under semi-automated conditions. The net track count was equal to the sum of the tracks in the two elution drops less twice the track count in the background area for that slide.

Lexan Slide



4. CRITERIA FOR ACCEPTANCE OF RESULTS AS POSITIVE:

Three criteria were established in order to consider a sample positive for Pu in excess of that found in the controls. (1) First, the elution pattern should not be inconsistent with that obtained for urine spiked with ^{239}Pu, namely tracks measured in the first drop had to significantly exceed the tracks measured in the second drop. The elution pattern for the mean and individual samples of three spiked urines is shown in Figures 1 and 2. Because the characteristic elution pattern of Pu under the conditions of our analysis differs from that of uranium, we only consider a result positive if the elution pattern identifies the tracks as being due to plutonium; (2) second, the total number of tracks should exceed the detection limit. In our case, the detection limit was taken as two standard deviations above the mean track number among the control urines, a criterion which would lead to a false positive for a single analysis of a sample in approximately 2.3% of the analyses. (3) A replicate analysis must satisfy criteria 1 and 2.

5. SUMMARY OF POSITIVE RESULTS:

The results from 2 of the 50 samples showing a positive indication of ^{239}Pu are shown in Table 1. Only two samples met our criteria for definite positives; a third sample, (#27) was listed as a near positive because the single analysis completed (71 tracks) was above our detection limit of 70 tracks and also the elution pattern was consistent with ^{239}Pu being the source. However, since we were not able to process a second aliquot of sample #27 (due to unavailability) we cannot identify it with high probability as being positive for ^{239}Pu. Similarly sample #49 did not meet our criteria for acceptance, but is also near positive. (See footnote to Table 1).

6. YIELD AND TRACK REGISTRATION EFFICIENCY:

The net effect of track registration efficiency and yield was determined in two different ways. First, the measurement of the radiochemical yield from the first column,

(determined by gross alpha measurements from 8 radiochemical tracer experiments in which ^{238}Pu and ^{242}Pu were added to urine), (82 ± 16%), was multiplied by the combined yield and track registration efficiency, (2.15 tracks/aCi) (determined when plutonium was eluted onto Lexan through the second column). This resulted in an expected yield and registration efficiency of 1.76 tracks/aCi. The second method was by direct radiochemical yield determination from three spiked urine samples, which gave a net yield and registration efficiency of 1.42 tracks/aCi with a range between 1.12 and 1.67 tracks/aCi. (See Table 2 and 9) We have used the mean 1.60 tracks/aCi as our best estimate of yield and registration efficiency.

7. RESULTS FOR CONTROL URINES:

Acceptable analyses were obtained in 26 of 28 control urines analyzed. The means and standard deviations of net tracks in 26 control urine samples (or subgroups of the 26) taken from 4 young volunteers born on or after 1963 are shown in Table 3, and individual results are shown in Table 8. Table 11 shows the detailed of results in 28 analyses of controls, of which 2 were rejected as statistical outliers. Our hypothesis is that such young people have very little ^{239}Pu in their bodies (and consequently little in urine) since they were born after most deposition of global ^{239}Pu had already occurred and consequently they could not have accumulated much by direct inhalation. It is assumed that accumulation from inhalation of resuspended dust and ingestion in food is also negligible. Although these assumptions appear reasonable, we are not certain they are correct.

The mean number of tracks found in the control urines was 40 tracks with a standard deviation of 14 tracks. We have tested the results on these 26 controls from 5 irradiations for normality using the Kolmorogov-Smirnov test for normality and normality was not rejected ($p=0.23$). In Table 3 we have listed the net track number plus two standard deviations for 5 irradiations, and also for the cumulative samples irradiated. We call this

the track detection limit. For a single tailed test the detection limit for the R26-31 group corresponds to a probability of finding a track count exceeding 68 tracks 2.3% of the time when a sample is drawn from a population identical to that of the controls (ie, there is a 2.3% chance of a false positive).

Because our procedure was to make a second analysis whenever the track count in a sample exceeded the track detection limit, and to accept a positive as true only if the results from both analyses exceeded the detection limit, the chance of falsely finding a positive should be 0.023 x 0.023 = 0.0005, or about 1 in 2000. We note that two of the 28 control samples analyzed were clear outliers and these two have been excluded from the statistical analysis here.

8. ACTIVITY DETECTION LIMITS:

In Table 4 we show the calculation of the detection limit expressed as both aCi/liter and aCi/sample. Our best estimate of the detection limit is 17 aCi/sample or, since we analyzed 0.2 litre samples, the detection limit per unit volume was 5 times that or 86 aCi/liter. Note that the probabilistic interpretation for this detection limit adopted here depends upon the distribution of control values being adequately described or fit by a normal distribution. We tested the 26 control urine results for a normality using the Komorogov-Smirnov test of normality. Normality was not rejected (p = 0.23).

Table 4 shows that we can infer a detection limit of 78 or 99 aCi/l depending on whether we use the calibration factor from the radiochemical tracer or the direct yield experiments. In this report we have used the mean of the mean calibration coefficients determined from both the three direct yield results and the tracer yield determinations using alpha counting, which leads to a detection limit of 86 aCi/l.

9. RESULTS FOR 50 SAMPLES:

The results for net tracks and aCi/l are shown in Table 5 for all BNL samples analyzed. Detailed data on the tracks measured in the 3 areas for each slide (one sample per slide) are given in Tables 6 and 7 which show the data necessary to judge whether an elution pattern typical of Pu was obtained. Table 1 summarizes the results for two samples for which positive results were obtained and two other samples for which near positive results were obtained.

10. COMPARISON OF THE MEAN OF THE NON-POSITIVE RESULTS WITH THE CONTROLS:

Of the 49 samples successfully analyzed, only two were found to be positive according to our criteria. The mean track number of the 47 non-positive results was 43.9 with a standard error of the mean of 2.4. The distribution of values was tested for normality and found to be adequately fit by a normal distribution ($p=0.26$, Kolmogorov-Smirnov test of normality). The 26 acceptable control results were also not rejected for normality ($p=0.23$) and had a mean of 40.4 with a standard error of the mean of 2.7. The two means did not differ significantly using an unpaired t-test to compare the BNL samples against the controls ($p=0.37$). Therefore, there was no significant difference between the mean net tracks found in the control urines and the mean of the non-positive results from the urine samples from the Marshall Islands.

When, however, we subtracted the mean track number of the 26 control urines from each analysis in order to express the results in aCi/liter of urine we found that a pattern of positives was found in the first 30 samples and negatives in the next 20 samples. This led us to believe that our results for control urines had been decreasing with time (and our experience with the technique). Accordingly, we separated the samples and controls into two groups, as shown in Table 12. For the first 30 samples (BNL 1-30) there were 16 control urines measured with means and standard errors of the means of 49.2 ± 2.6 and 43.4 ± 3.3 respectively. The

difference in the means was equal to 5.8 tracks, which is not significantly different from 0 (p=0.18). However, the mean of the net track number for all individual samples in the groups (converted to aCi/l) was equivalent to 18.3 ± 8.1 aCi/l, which assuming normality was statistically significantly different from zero (p=0.01). For the last 20 samples (BNL 31-50) the difference between the means of the samples and control urines was 1 track which is equivalent to 3.1 ± 13 aCi/l, which assuming normality is not significantly different from zero (p=0.59). Again normality was not rejected. Interestingly, there was no significant difference between the means of the two groups of samples from the Marshall Islands using a t-test (p=0.29).

11. COMPARISON OF CONTROLS WITH REAGENT BLANKS:

The net results of 18 reagent blank determinations are listed in Table 8 with detailed results for each sample in Table 10. The reagent blanks sometimes consisted of processing reagents through both columns and sometimes through column 2 only, since we found in a subset of samples that there was no significant difference between the results for processing through 2 columns and the second column only. The mean of 18 reagent blank determinations was 31.8 tracks with a standard error of the mean of 2.4. Normality was not rejected (p=0.33) and comparison by a t-test with the mean from the 26 control samples (see Table 12) showed a statistically significant difference (p=0.029) of 9 tracks. We cannot yet say whether these 9 tracks were due to uranium or plutonium, but if they were due to plutonium in the control urine samples they would be equivalent to 6 aCi of ^{239}Pu or about 30 aCi/liter.

12. CONCLUSIONS:

1. We successfully developed a technique to measure ^{239}Pu content in human urine with a detection limit below 20 aCi/sample which for a 200 ml urine sample is equivalent to 100 aCi/l.

2. We successfully analyzed 49 of the 50 urine samples furnished us by BNL. Two of the 49 samples were positive for ^{239}Pu.

TABLE 1

Results Testing Positive or Near Positive for Pu-239

BNL #	Tracks		Avg.	Tracks Minus Controls	** Net aCi/ Sample	aCi/l
16	247	166	207	167	110	550
29	5040*	>1,900*	5040	5000	≥3130	≥15,600
Near Positive						
49††	61	108	84.5	44.1	31	153
27†	71	--	71	27.6	17	86

* Track density was too high to be quantitative.

** Using a yield and registration efficiency of 1.60 tracks/aCi. Multiply the aCi/sample by 5 to express results in aCi/l

† Although not meeting our criteria for accepting as a positive, we have listed it because we were unable to analyze a second aliquot, and because the elution pattern is consistent with that expected for ^{239}Pu.

†† This sample did not meet our criteria for acceptance as positive since the first aliquot tested did not exceed the detection limit of 68 tracks. However, we analyzed a replicate to gain further experience with replications and also because the track number was not far below the detection limit. Our replicate analysis met our criteria for acceptance as a single sample. Had we analyzed the second aliquot first, this set of analyses still would have failed our acceptance criteria for a positive.

TABLE 2

Yield of Pu from Urine,1st Column
(Tracer Pu-238, 242)

86.0

97.8

99.7

74.1

87.1

78.4

54.0

mean = 82.4% ± 16 (1 σ)
yield and registration efficiency
(column 2 only) = 2.15 tracks/aCi
product = 1.77 tracks/aCi

Track Yield (tracks/aCi) from Urines Spiked with 250 aCi Pu-239

1.67

1.12

1.46

mean = 1.42 tracks/aCi

The mean of the two techniques is 1.60 tracks/aCi

TABLE 3

Control Urines** (Net tracks)

# of irradiation	n	mean±1s	DL(mean+2s)
R24	none		
R26	10*	49±11	71
R28	6	35±11	57
R29	4	45±14	73
R30	4	33±13	59
R31	2*	24	
R26-28	**16**	**43.4±13.3**	**70**
R29+30	8	39±14	67
R29+30+31	**10**	**35.7±13.8**	**63**
R26-31	26	40±14	68

* One result was dropped as a clear outlier (R26: 56, 64, 54, 139), (R31: 202, 23, 25).
** Controls were born in 1963 or later.

TABLE 4

Detection Limit (DL) for Pu-239 in Urine† by Neutron Induced Fission Track Analysis

$$DL = \frac{2\,\sigma}{Y_1 Y_2\,\varepsilon\,F\,V}$$

ε = Tracks/aCi on plastic

Y_i= Yield Chemical on column i

F= fraction of sample placed on substrate

V= volume of sample analyzed (liters)

σ = standard deviation of controls

n	Y_1	ε	$Y_1Y_2\varepsilon$	F	V	$Y_1Y_2\varepsilon FV$	σ	DL (aCi/l)	DL x V aCi/sample
26	.82	2.15**	1.77	1.0	0.2	0.35	13.8	78	16
26	--	--	1.60	1.0	0.2	0.30	13.8	99	20
26			1.60	1.0	0.2	0.32	13.8	**86**	**17**

**Tracks/aCi (2 fractions)

† Current Utah residents born in 1962 or later

Probability of a false positive from a single analysis: 0.023

Probability of 2 false positives on replicate analyses is: 0.0005

TABLE 5

Results for BNL Samples

BNL Sample #ID	Net* Number of Tracks per 200 ml Urine Sample: Net tracks	Replicate Analysis	^{239}Pu aCi/l ± 1σ
#1	41		-7.5 ± 52.1
#2	52		26.9 ± 50.5
#3	46		8.1 ± 51.4
#4	43		-1.3 ± 49.6
#5	19		-76.3 ± 50.4
#6	63		61.3 ± 51.1
#7	67		73.8 ± 55.5
#8	36	72	33.1 ± 53.5
#9	40	49	3.4 ± 50.3
#10	51		23.8 ± 49.6
#11	62		58.1 ± 52.9
#12	65		67.5 ± 51.0
#13	63		61.3 ± 52.7
#14	65		67.5 ± 53.2
#15	58		45.6 ± 51.8
#16	**[126]**	**[247]**	**447.2 ± 65.2**
#17	56		39.4 ± 52.7
#18	37		-20.0 ± 47.4
#19	43		-1.3 ± 48.4
#20	21		-70.0 ± 48.6
#21	61		55.0 ± 53.2
#22	32		-35.6 ± 48.9
#23	45		5.0 ± 51.3
#24	Lost**		
#25	43		-1.3 ± 51.1
#26	46		8.1 ± 48.3
#27	[71]		86.3 ± 53.0
#28	37		-20.0 ± 55.0
#29	**>1900**	**≥[5040]**	**≥15,600.0 ± 228**
#30	44		1.9 ± 52.0
#31	65	4	-3.8 ± 49.7
#32	43		22.8 ± 51.7
#33	[70]	25	36.9 ± 52.7
#34	33		-8.4 ± 52.2
#35	58		69.7 ± 53.1
#36	60	26	22.8 ± 50.3
#37	30		-17.8 ± 49.7
#38	19		-52.2 ± 48.2
#39	14		-67.8 ± 48.1
#40	14		-67.8 ± 49.3
#41	40		13.4 ± 49.1
#42	71	42	65.0 ± 52.8
#43	**95**	10	52.5 ± 51.2
#44	18		-55.3 ± 50.0
#45	18		-55.3 ± 50.0
#46	[77]	10	24.4 ± 52.3
#47	24		-36.6 ± 47.4
#48	40	18	-20.9 ± 50.7
#49	[61]	[108]	152.5 ± 53.7
#50	32		-11.6 ± 51.8

* "Net" means total tracks in the first two elution drops minus 2 x the track background on the same lexan slide. No control urine backgrounds have been subtracted.

** "Lost" refers to a sample processing accident such as a broken beaker or sample slide dropped on the floor.

"Bold" numbers refer to net track counts >68 (mean + 2s of 26 controls).

["Boxed"] numbers mean the elution pattern is consistent with that from Pu.

TABLE 6

Results for BNL Samples in Detail (BNL 1-30)

CODE	1st drop	2nd drop	Blank	2 drops (Total)	2 drops (Net)
R24					
BNL#5	30	21	16	51	19
BNL#8	31	31	13	62	36
BNL#9	38	20	9	58	40
BNL#10	50	13	6	63	51
BNL#15	58	20	10	78	58
BNL#16	128	38	20	166	126
BNL#17	50	32	13	82	56
BNL#18	30	15	4	45	37
BNL#19	24	29	5	53	43
BNL#20	26	17	11	43	21
BNL#26	19	35	4	54	46
BNL#29	>858	>998		>1900	
R28					
BNL#1	40	31	15	71	41
BNL#2	48	20	8	68	52
BNL#3	31	37	13	68	46
BNL#4	33	26	8	59	43
BNL#6	47	30	7	77	63
BNL#7	63	40	18	103	67
BNL#8	59	49	18	108	72
BNL#9	38	31	10	69	49
BNL#11	36	50	12	86	62
BNL#12	44	33	6	7	65
BNL#13	46	39	11	85	63
BNL#14	47	42	12	89	65
BNL#16	217	62	16	279	247
BNL#21	56	31	13	87	61
BNL#22	23	27	9	50	32
BNL#23	41	28	12	69	45
BNL#25	39	28	12	67	43
BNL#27	57	34	10	91	71
BNL#28	52	33	24	85	37
BNL#29	3800	1286	23	5286	5240
BNL#30	43	29	14	72	44

TABLE 7

Results for BNL Samples in Detail (BNL 31-50)

	R29				R31			
Code	1st drop	2nd drop	Blank	Net tracks	1st drop	2nd drop	Blank	Net tracks
BNL#31	46	29	5	65	13	9	9	4
BNL#33	64	32	13	70	31	14	10	25
BNL#35	43	35	10	58				
BNL#37	25	21	8	30				
BNL#39	10	20	8	14				
BNL#41	21	27	4	40				
BNL#43	58	39	1	95	19	12	11	10
BNL#45	21	21	12	18				
BNL#47	18	14	4	24				
BNL#49	49	26	7	61	72	42	3	108

	R30				R31			
Code	1st drop	2nd drop	Blank	Net tracks	1st drop	2nd drop	Blank	Net tracks
BNL#32	45	18	10	43				
BNL#34	40	21	14	33				
BNL#36	51	27	9	60	16	18	4	26
BNL#38	16	17	7	19				
BNL#40	20	16	11	14				
BNL#42	46	37	6	71	41	27	13	42
BNL#44	16	26	12	18				
BNL#46	78	29	15	77	11	15	8	10
BNL#48	43	29	16	40	16	14	6	18
BNL#50	34	24	13	32				

TABLE 8

Results for Control Urines* (200 ml) and Reagent Blanks**

Net Number of Tracks:

ID#	R24	R26	R28	R29	R30	R31
RB#1	29	31	34	24	35	
RB#2	46	46	26	42	22	
RB#3	37	41	45	16		
RB#4	12	Lost	26	23		
RB#5		a/n ††				
RB#6		37				
FUB#1		35				
FUB#2		61				
FUB#3		35				
FUB#4		49				
FUB#13			41			
FUB#14			23			
FUB#15			33			
FUB#16				57		
FUB#17					43	
FUB#18						205†
BUB#1				55		
BUB#2					20	
BUB#3						25
STUB#1				26		
STUB#3					24	
KUB#11			26			
KUB#12			27			
KUB#13			59			
KUB#14				40		
KUB#15					44	
KUB#16						23
JUB#1		56				
JUB#2		64				
JUB#3		54				
JUB#4		159†				
WUB#1		47				
WUB#2		Lost				
WUB#3		34				
WUB#4		50				

* UB = Control urine
** RB = Reagent Blank
† Omitted in Analysis
†† Analysis did not meet acceptance criteria

TABLE 9

Detailed Results for Urines Spiked with 250 aCi Pu-239

Code	1st drop	2nd drop	Blank drop	Control	Net tracks	Tracks/aCi
SUF#5	362	99	8	28	417	1.67
SUK#5	228	98	9	28	280	1.12
SUB#5	282	132	11	28	364	1.46

TABLE 10

Reagent Blanks (all 18 samples)

	ID#	1st drop	2nd drop	Blank	Net tracks
R24					
	RB1	19	26	8	29
	RB2	20	40	7	46
	RB3	19	32	7	37
	RB4	15	17	10	12
R26					
	RB1	35	28	16	31
	RB2	42	36	16	46
	RB3	29	28	8	41
	RB6	24	31	9	37
R28					
	RB1	21	33	10	34
	RB2	16	44	12	26
	RB3	31	36	11	45
	RB4	35	38	24	26
R29					
	RB1	17	19	6	24
	RB2	33	29	10	42
	RB3	16	16	8	16
	RB4	20	17	7	23
R30					
	RB1	20	25	5	35
	RB2	25	19	11	22

TABLE 11

Controls (all 28 samples)

ID #	1st drop	2nd drop	Blank	Net tracks
R26				
FUB1	30	29	12	35
FUB2	54	25	9	61
FUB3	21	24	9	35
FUB4	26	35	6	49
JUB1	34	28	3	56
JUB2	46	26	4	64
JUB3	31	31	4	54
JUB4*	125	40	3	159
WUB1	30	33	8	47
WUB3	28	24	9	34
WUB4	23	39	6	50
R28				
KUB11	30	16	10	26
KUB12	30	17	10	27
KUB13	50	41	16	59
FUB13	33	28	10	41
FUB14	30	19	13	23
FUB15	21	24	6	33
R29				
FUB16	44	21	4	57
BUB1	53	20	9	55
STUB1	22	20	8	26
KUB14	36	34	15	40
R30				
FUB17	43	20	10	43
KUB15	31	35	11	44
STUB3	31	25	16	24
BUB2	19	17	8	20
R31				
FUB18*	114	110	11	205
KUB16	24	23	12	23
BUB3	32	21	14	25

* result was dropped as a clear outlier.

TABLE 12

Mean Tracks and Pu-239 (aCi/l) in Non-Positive Sample and Control Groups

	BNL 1-30*	BNL 31-50	BNL 1-50*	Control Urines (R 26-28)	Control Urines (R 29-31)	Control Urines (R 26-31)	Reagent Blanks
Mean ± SE**	49.2 ± 2.6	36.7 ± 4.0	43.9 ± 2.4	43.4 ± 3.3	35.7 ± 4.4	40.4 ± 2.7	31.8 ± 2.4
aCi/l ± SE	18.3 ± 8.1	3.1 ± 12.4	11.8 ± 7.0	–	–	–	–
n	27	20	47	16	10	26	18

* Not including samples 16, 24 and 29
** SE means standard error of the mean.

FIGURE 1

Average Elution Pattern for 3 Urines Spiked with Pu-239

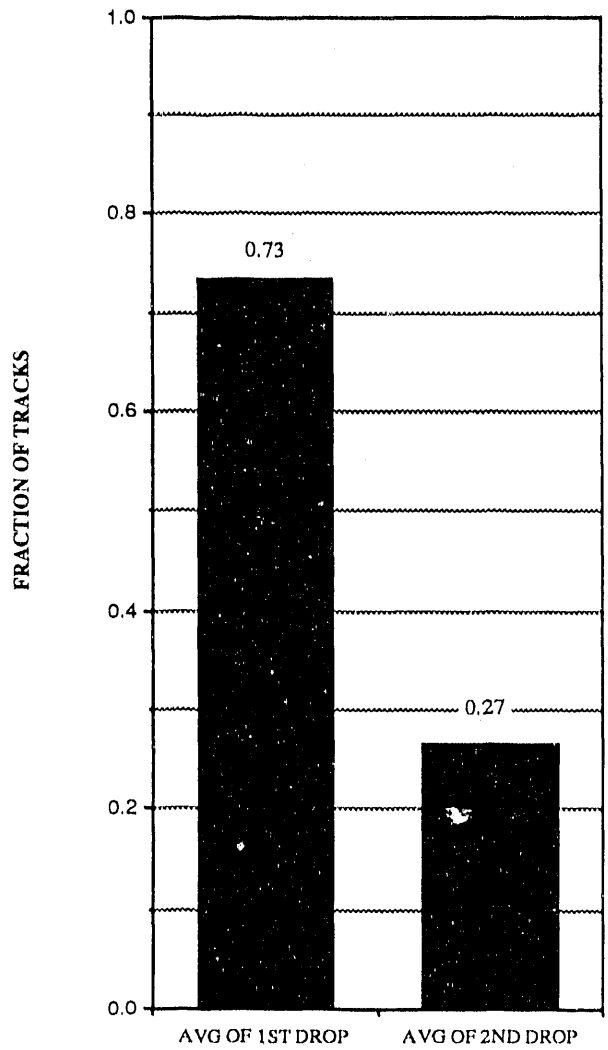
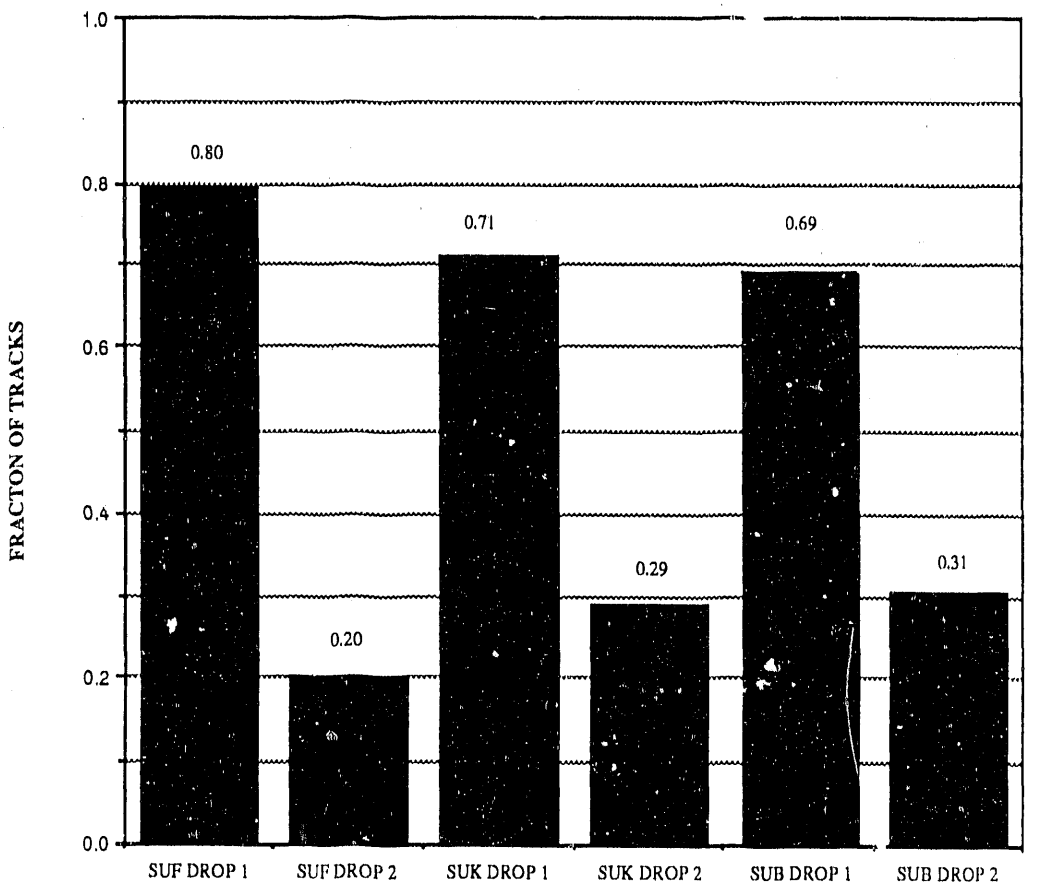


FIGURE 2

Elution Pattern for 3 Individual Urine Samples, SUF, SUK, SUB Spiked with Pu-239



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