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Appendix E

Mixtures and Tracer Radionuclides

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Mixtures of radionuclides at Hanford can be found in reactor facilities, former processing facilities, waste management facilities, and laboratories. The radionuclides most commonly encountered in mixtures include ^{137}Cs, ^{90}Sr, and plutonium, although others are also possible. This appendix discusses the bioassay capability for mixtures of ^{137}Cs and ^{90}Sr, ^{137}Cs and plutonium, and ^{90}Sr and plutonium.

Where the composition of a mixture can be well-characterized, (e.g., a potential intake identified at the time by field indicators), then bioassay for a tracer radionuclide may provide optimum monitoring capability, with determination of nuclides not detectable by bioassay inferred by ratio using intake characterization information, such as a representative nasal or surface smear or an air sample. Depending upon the isotope ratios in the mixture, the tracer radionuclide may be important from a bioassay perspective, but may not be a dominant contributor to internal dose.

Bioassay for a tracer radionuclide can provide a reasonable indicator of potential intake as a cost-effective alternative to multiple bioassays when the mixture is well-characterized. However, detection of the tracer radionuclide as a high routine measurement can lead to complicated assessments. For high routine bioassay measurements, there may not be any obvious specific material to which a worker was exposed. For many years an assumption of a 1:1 ^{137}Cs:^{90}Sr activity ratio was used as a fission product mixture, however, the wide range of waste management practices that have occurred at Hanford do not provide assurance that the 1:1 ratio is valid. Thus, where one nuclide is used as an indicator for others, detection of that nuclide by routine measurement is most appropriately used as a trigger for supplemental bioassay for other, potentially significant, radionuclides. Once the bioassay analyses have been completed, intakes are confirmed only for those nuclides detected or that can confidently be inferred from tracer nuclide detection and knowledge of the workplace mixture.

Bioassay capability (in terms of minimum detectable doses) has been evaluated for combinations of ^{137}Cs and ^{90}Sr, ^{137}Cs and plutonium, and ^{90}Sr and plutonium. For convenience, it is considered irrelevant as to whether the plutonium is ^{239}Pu, ^{238}Pu, Pu-alpha, or ^{241}Am, because the dose coefficients are reasonably close. The dose

coefficients and retention fractions used for these analyses are taken from the chapters of this manual that address the specific radioisotopes.

E.1 Cesium-137 and Strontium-90 Mixtures

Mixtures of ^{137}Cs and ^{90}Sr are particularly common in waste management facilities and are especially prevalent in the 200 Area tank farms. It is assumed that both nuclides are class D. Table E.1 and Figure E.1 show the minimum detectable doses associated with a preview whole body count and a ^{90}Sr urinalysis for several mixtures of ^{137}Cs and ^{90}Sr. Collectively, these show that an annual whole body count using the NaI Preview Counter meets the 100-mrem bioassay goal for minimum detectable committed effective dose equivalent for mixtures having ^{137}Cs:^{90}Sr activity ratios of up to approximately 1:20. Use of the germanium coaxial counter improves the ratio to about 1:40 for meeting the 100-mrem bioassay goal, as shown in Table E.1 and Figure E.2.

E.2 Cesium-137 and Plutonium Mixtures

Mixtures of ^{137}Cs and plutonium can be found primarily in facilities associated with spent fuel management, and in wastes associated with such buildings. Examples include the spent fuel basins, fuel processing hot cells, and waste tank sludges. By radioactivity, these mixtures are likely to be mostly ^{137}Cs, with ^{137}Cs:plutonium ratios ranging from perhaps 1000:1 to 1:1. Until the mid-1990s, little attention was given to trace amounts of plutonium in predominantly fission product contamination. However, recognition of the dosimetric importance of trace plutonium developed with the implementation of the committed dose system and as more detailed facility contamination characterization data became available. Determining whether the plutonium might be class W or Y is problematic; if the plutonium contamination resulted from leaching out of fuel or residuals from processing of fuel, then a class W assumption would be appropriate. If it resulted from corroded, unreprocessed fuel, then a class Y assumption would probably be more appropriate.

Bioassay program capabilities for ^{137}Cs and ^{239}Pu as tracer nuclides for several cesium-plutonium mixtures are shown in Table E.2 and Figures E.3 and E.4. The source material considered here is assumed to be class D ^{137}Cs and class W plutonium. This assumption provides a reasonably conservative estimate of minimum detectable dose (MDD) based on a whole body count and the assumed isotopic ratio. Doses associated with plutonium detection by urinalysis would be substantially higher if the plutonium was a class Y form.

Table E.1. Minimum Detectable Dose ($H_{E,50}$, in mrem) for Mixtures[a] of ^{137}Cs and ^{90}Sr Based on Tracer Nuclide Bioassay

Days Post Intake	1:1 Cs:Sr			1:10 Cs:Sr			1:20 Cs:Sr		
	Preview[b]	Coax[c]	Urine[d]	Preview[b]	Coax[c]	Urine[d]	Preview[b]	Coax[c]	Urine[d]
1	0.46	0.28	0.03	4.0	2.5	0.02	8.0	4.9	0.02
2	0.48	0.29	0.03	4.2	2.6	0.03	8.2	5.1	0.03
7	0.52	0.32	0.08	4.5	2.8	0.07	9.0	5.5	0.07
14	0.55	0.34	0.25	4.8	2.9	0.22	9.4	5.8	0.22
30	0.60	0.37	2.2	5.2	3.2	1.9	10	6.4	1.9
60	0.73	0.45	7.5	6.4	3.9	6.5	13	7.8	6.5
90	0.89	0.55	9.5	7.8	4.8	8.2	15	9.5	8.2
180	1.6	0.97	15	14	8.4	13	27	17	13
365	5.1	3.2	30	45	27	26	88	54	26
730	52	32	71	450	280	62	900	550	61
Days Post Intake	**1:40 Cs:Sr**			**1:100 Cs:Sr**			**1:1000 Cs:Sr**		
	Preview[b]	Coax[c]	Urine[d]	Preview[b]	Coax[c]	Urine[d]	Preview[b]	Coax[c]	Urine[d]
1	16	9.7	0.02	40	24	0.02	394	243	0.02
2	16	10	0.03	41	25	0.03	408	251	0.03
7	18	11	0.07	45	27	0.07	444	273	0.07
14	19	12	0.21	47	29	0.21	468	288	0.21
30	21	13	1.9	52	32	1.8	516	318	1.8
60	25	15	6.4	63	39	6.4	627	386	6.4
90	31	19	8.1	76	47	8.1	763	470	8.1
180	54	33	13	135	83	13	1350	831	13
365	180	110	26	439	270	26	4388	2700	26
730	1800	1100	61	4500	2700	61	44,000	27,000	61

(a) Assumes acute inhalation of class D, 5-µm-AMAD particles for both ^{137}Cs and ^{90}Sr.
(b) Preview count MDA of 1.3 nCi ^{137}Cs.
(c) Coaxial count MDA of 0.8 nCi ^{137}Cs.
(d) ^{90}Sr urinalysis MDA of 10 dpm/d.

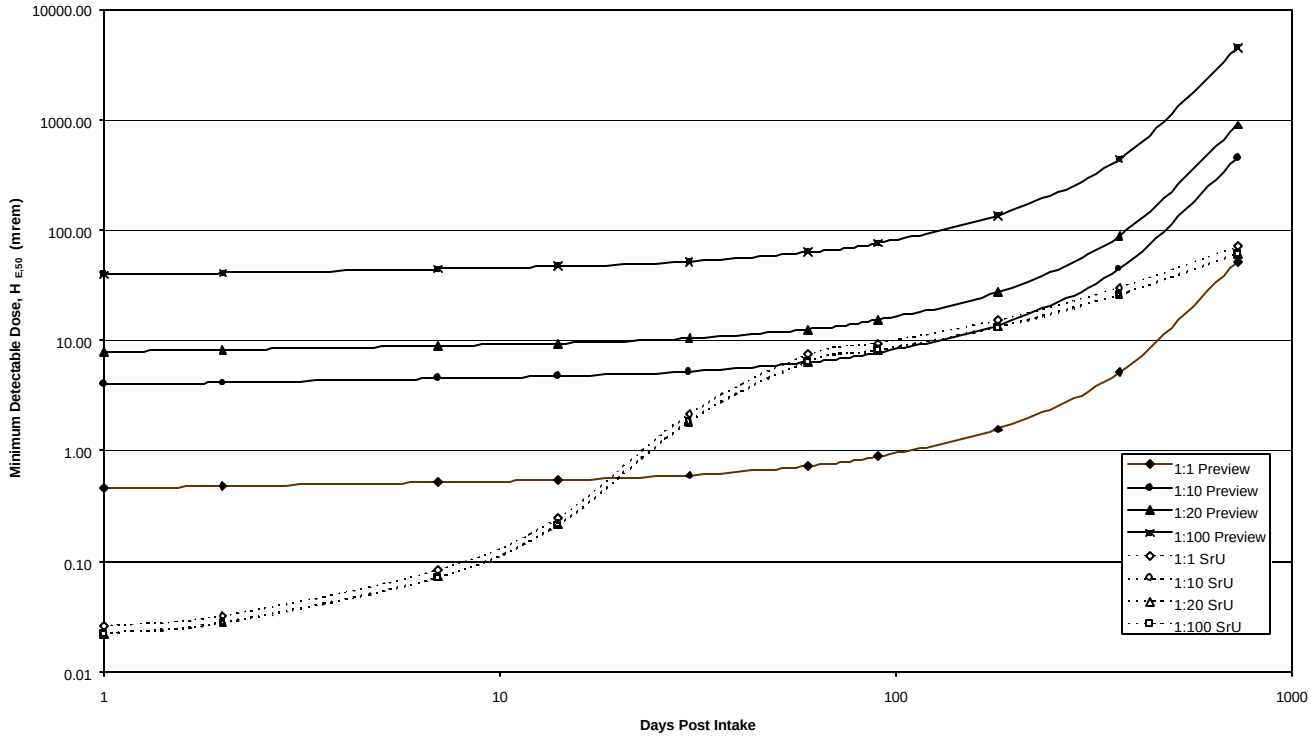

Figure E.1. Bioassay Capability Comparison for ^{137}Cs:^{90}Sr Mixtures Based on Preview Whole Body Count (WBC) and ^{90}Sr Urinalysis (SrU)

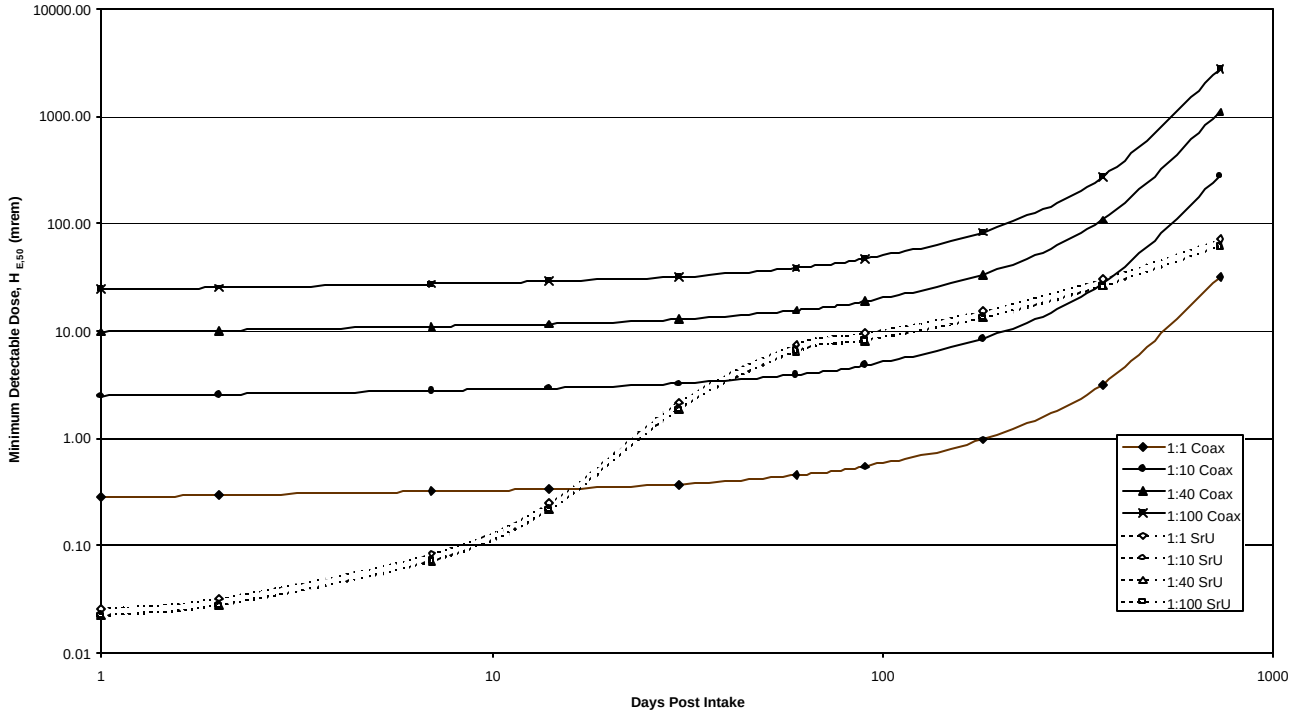

Figure E.2. Bioassay Capability Comparison for ^{137}Cs:^{90}Sr Mixtures Based on Coaxial Whole Body Count (WBC) and ^{90}Sr Urinalysis (SrU)

Table E.2. Minimum Detectable Dose ($H_{E,50}$, in mrem) for Mixtures[(a)] of ^{137}Cs and ^{239}Pu Based on Tracer Nuclide Bioassay

Days Post Intake	1000:1 Cs:Pu			100:1 Cs:Pu			80:1 Cs:Pu		
	Preview[(b)]	Coax[(c)]	Urine[(d)]	Preview[(b)]	Coax[(c)]	Urine[(d)]	Preview[(b)]	Coax[(c)]	Urine[(d)]
1	0.77	0.47	14	7.1	4.4	12	8.8	5.4	12
2	0.80	0.49	22	7.3	4.5	20	9.1	5.6	20
7	0.87	0.53	69	8.0	4.9	63	9.9	6.1	63
14	0.91	0.56	108	8.4	5.2	99	10	6.4	99
30	1.0	0.62	169	9.3	5.7	160	12	7.1	160
60	1.2	0.75	237	11	6.9	220	14	8.6	220
90	1.5	0.91	338	14	8.4	310	17	11	310
180	2.6	1.6	431	24	15	400	30	19	400
365	8.5	5.3	585	79	48	540	98	60	540
730	87	53	970	800	490	890	1000	610	890
Days Post Intake	**40:1 Cs:Pu**			**10:1 Cs:Pu**			**1:1 Cs:Pu**		
	Preview[(b)]	Coax[(c)]	Urine[(d)]	Preview[(b)]	Coax[(c)]	Urine[(d)]	Preview[(b)]	Coax[(c)]	Urine[(d)]
1	18	10.8	12	70	43	12	701	430	12
2	18	11	20	73	45	20	730	450	20
7	20	12	63	79	49	63	790	490	63
14	21	13	99	83	51	98	830	510	98
30	23	14	160	92	57	160	920	570	150
60	28	17	220	110	69	220	1100	690	220
90	34	21	310	140	84	310	1400	840	310
180	60	37	400	240	150	390	2400	1500	390
365	200	120	540	780	480	530	7800	4800	530
730	20,000	1200	890	7900	4900	880	79,000	49,000	880

(a) Assumes acute inhalation of class D, 5-µm-AMAD particles for ^{137}Cs and class W, 5-µm-AMAD particles for ^{239}Pu.
(b) Preview count MDA of 1.3 nCi ^{137}Cs.
(c) Coaxial count MDA of 0.8 nCi ^{137}Cs.
(d) ^{239}Pu urinalysis MDA of 0.02 dpm/d.

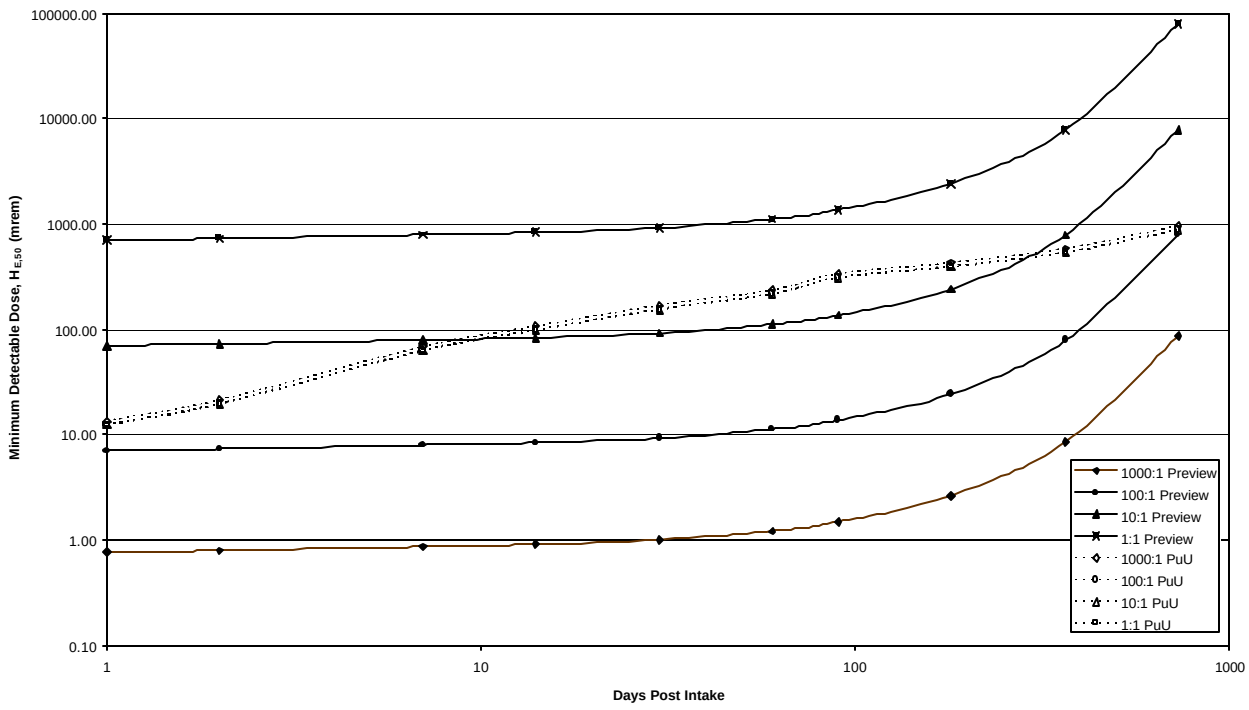

Figure E.3. Bioassay Capability Comparison for ^{137}Cs:^{239}Pu Mixtures Based on Preview Whole Body Count (WBC) and ^{239}Pu Urinalysis (PuU)

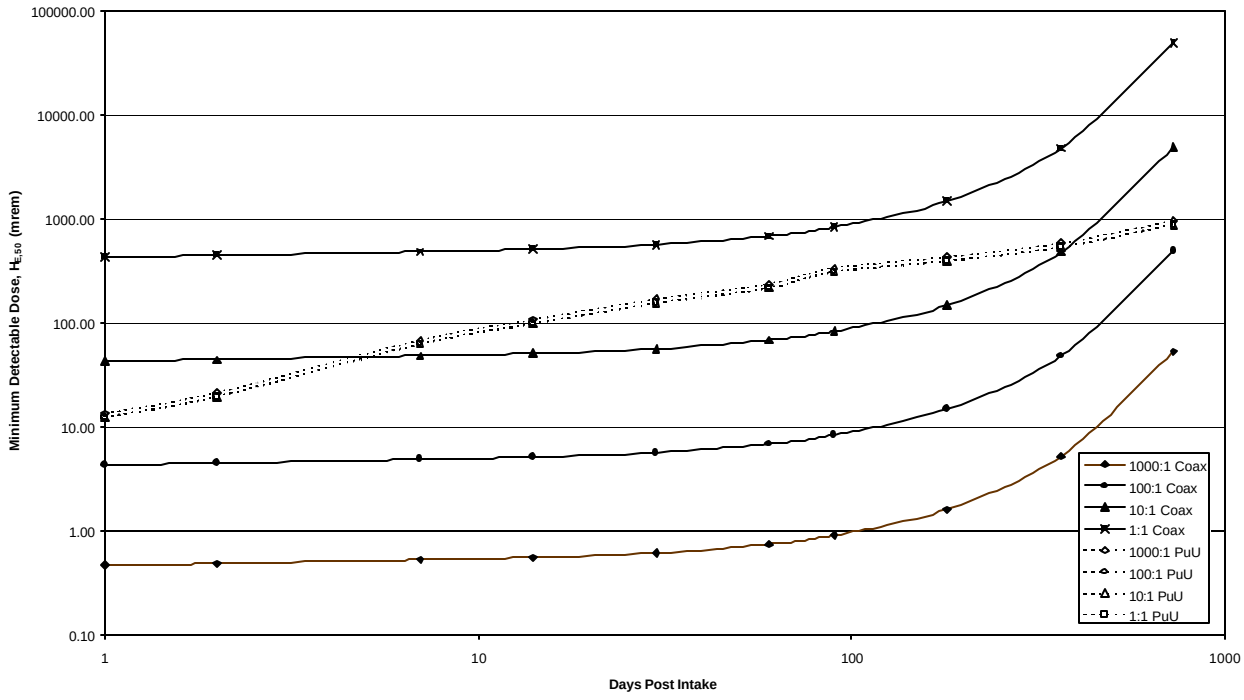

Figure E.4. Bioassay Capability Comparison for ^{137}Cs:^{239}Pu Mixtures Based on Coaxial Whole Body Count (WBC) and ^{239}Pu Urinalysis (PuU)

Based on the data presented, an annual whole body count using the preview counter is capable of meeting the 100-mrem bioassay goal for mixtures down to about an 80:1 ratio of ^{137}Cs:plutonium. Using the coax counter allows reduction to approximately 40:1. If the potential exists for exposure to material with ^{137}Cs:plutonium ratios lower than these, then the worker should be considered for routine plutonium bioassay as might be performed for a pure plutonium source.

E.3 Strontium-90 and Plutonium Mixtures

Mixtures of ^{90}Sr and plutonium are considered most likely to occur in tank farm facilities, probably associated with contamination originating from waste tank sludges. The ^{90}Sr is assumed to be a class D material and the plutonium a class W material, consistent with the nitrate nature of most waste tank contents. It is possible that dry plutonium contamination exposed to dry air and a normal building/outdoor temperature environment could undergo gradual oxidation over long time periods and approach a class Y material. However, the use of class W dose coefficients for plutonium provides a conservative approach to the estimations of MDD based on ^{90}Sr as a tracer radionuclide.

Bioassay program capabilities for ^{90}Sr and ^{239}Pu as tracer nuclides for several strontium-plutonium mixtures are shown in Table E.3 and Figures E.5. The source material considered here is assumed to be class D ^{90}Sr and class W plutonium. This assumption provides a reasonably conservative estimate of MDD based on radiostronitum urinalysis and the assumed isotopic ratio. Doses associated with plutonium detection by urinalysis would be substantially higher if the plutonium was a class Y form. Based on the data presented, an annual ^{90}Sr urinalysis is capable of meeting the 100-mrem bioassay goal for mixtures down to about a 600:1 ratio of ^{90}Sr:plutonium. The mixture for which a ^{90}Sr urinalysis would provide essentially equal MDD capability with a plutonium urinalysis for class W material was calculated to be 86:1, and the MDD was calculated to be 560 mrem. If the potential exists for exposure to material with ^{90}Sr:plutonium ratios lower than these, then the worker should be considered for routine plutonium bioassay as might be performed for a pure plutonium source.

Table E.3. Minimum Detectable Dose ($H_{E,50}$, in mrem) for Mixtures[(a)] of ^{90}Sr and ^{239}Pu Based on Tracer Nuclide Bioassay

Days Post Intake	1000:1 ^{90}Sr:Pu		600:1 ^{90}Sr:Pu		100:1 ^{90}Sr:Pu		10:1 ^{90}Sr:Pu	
	^{90}Sr Urine[(b)]	^{239}Pu Urine[(c)]	^{90}Sr Urine[(b)]	^{239}Pu Urine[(c)]	^{90}Sr Urine[(b)]	^{239}Pu Urine[(c)]	^{90}Sr Urine[(b)]	^{239}Pu Urine[(c)]
1	0.06	19	0.1	17	0.4	13	4.0	12
2	0.08	31	0.1	26	0.5	21	4.9	20
7	0.20	98	0.3	84	1.3	66	13	63
14	0.59	150	0.8	130	4	104	38	99
30	5.1	240	7.3	210	35	160	330	160
60	18	340	25	290	120	230	1100	220
90	23	480	32	410	150	330	1500	310
180	36	610	52	530	250	420	2300	400
365	72	830	100	710	490	560	4600	540
730	170	1400	240	1200	1100	930	11,000	890

(a) Assumes acute inhalation of class D, 5-µm-AMAD particles for ^{90}Sr and class W, 5-µm particles for plutonium.
(b) ^{90}Sr urinalysis MDA of 10 dpm/d.
(c) ^{239}Pu urinalysis MDA of 0.02 dpm/d.

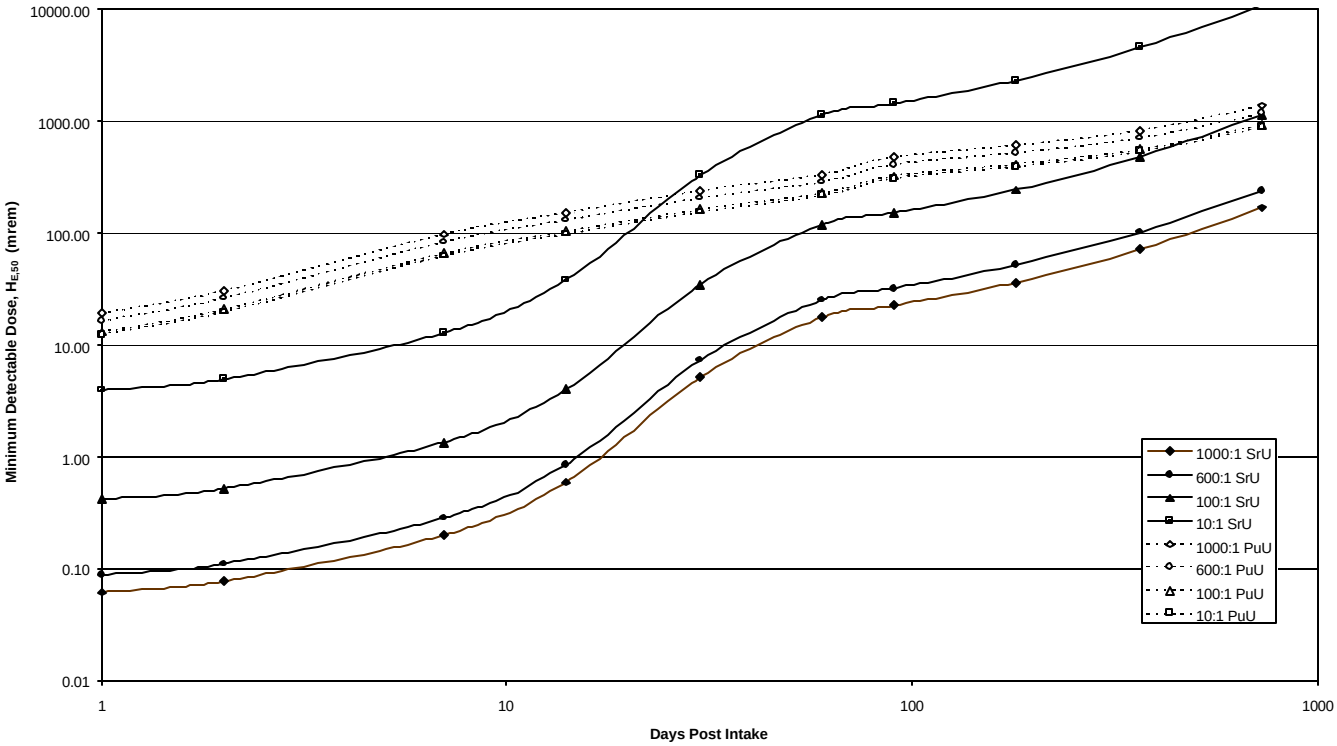

Figure E.5. Bioassay Capability Comparison for ^{90}Sr:^{239}Pu Mixtures Based on ^{90}S Urinalysis (SrU)r and ^{239}Pu Urinalysis (PuU)