Hi Tim, Collins, NRR

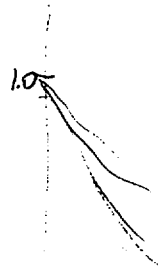
Hope this is what you were looking for.

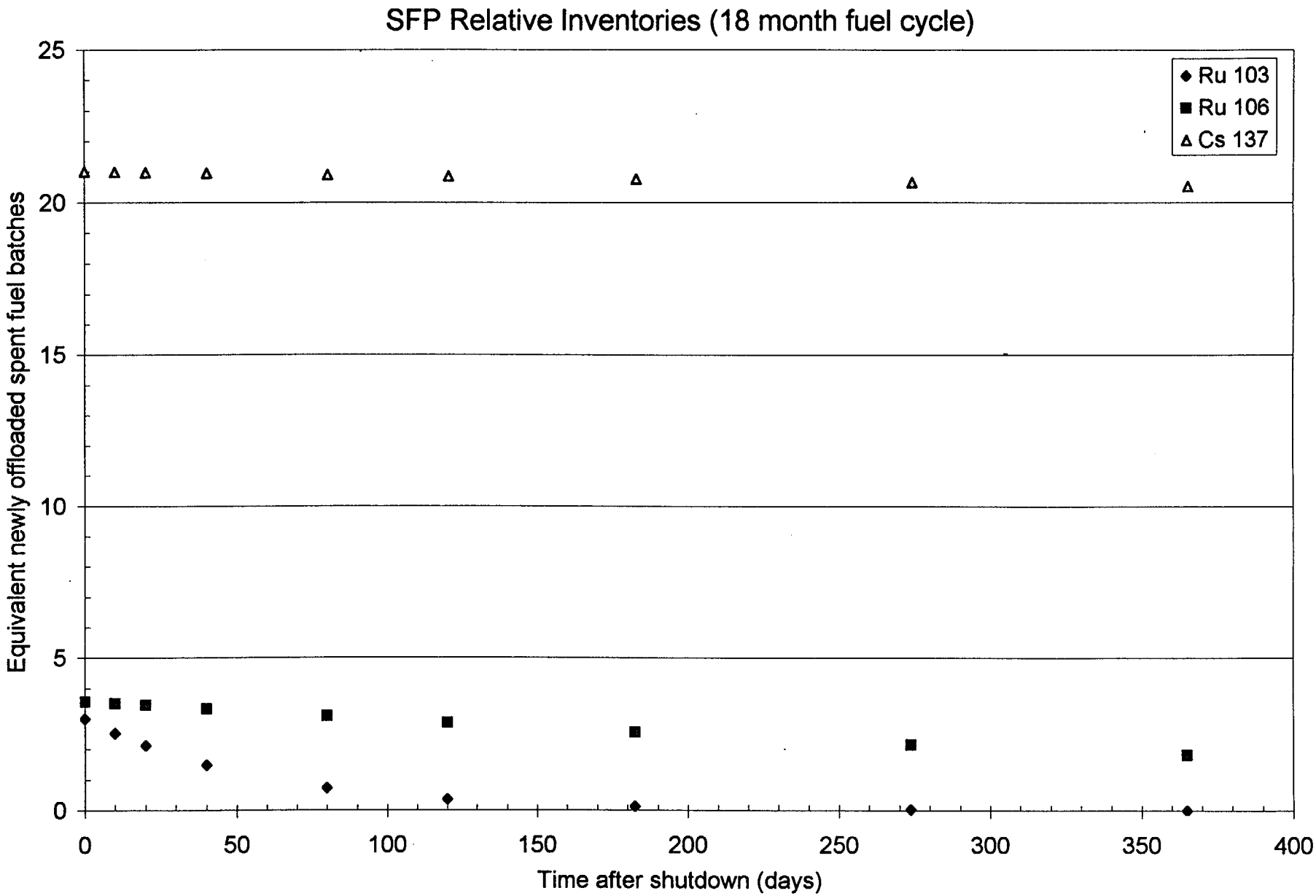
I made the relative activity scale for all three graphs the same, so that it would be meaningful to compare between them. Arbitrarily, the scale is set such that the equilibrium Ru-106 activity at one year = 1 unit of relative activity.

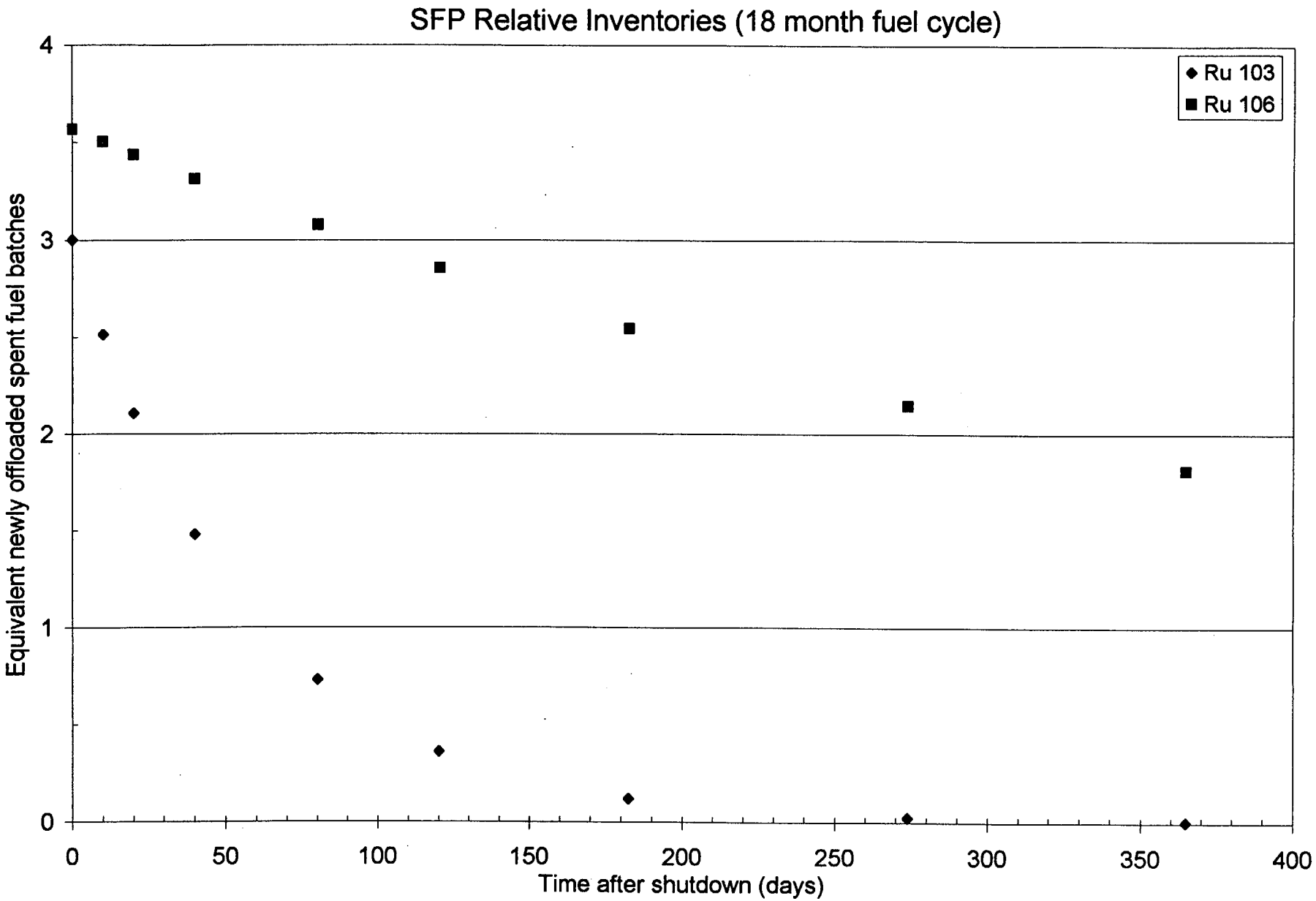
Also, I'm not sure if this is obvious or subtle, but the time scale in years means something slightly different for the Cs and Ru than it does for the decay heat power. For the Cs and the Ru, the time value on the graph spans only the period from when the spent fuel was originally taken out of the core to the time of final reactor shutdown, and not the time after shutdown indicated in the chart title. Clearly, though, the decay heat power curve would include this time after shutdown. In conclusion, there is a relatively small horizontal offset consisting of the time after final reactor shutdown (6mos, 1yr, or 2yrs depending on plot) between the decay heat power curve and the curves for the two radionuclides.

I can't tell if my explanation is clear or not, so please let me know if you have any questions or if you would like me to arrange something differently.

John Lehning, NRR
jxl4
x3285




SFP Relative Inventories (18 month fuel cycle)
Ru 103
Ru 106
Cs 137
Equivalent newly offloaded spent fuel batches
25
20
15
10
5
0
0
50
100
150
200
250
300
350
400
Time after shutdown (days)


SFP Relative Inventories (18 month fuel cycle)
Ru 103
Ru 106
Equivalent newly offloaded spent fuel batches
0
1
2
3
4
0
50
100
150
200
250
300
350
400
Time after shutdown (days)

		Activity after:	40	days	
Isotope	Half life (days)	Lambda			cycle length (months)
Cs-137	10950	6.33011E-05			18
Batch #	Batch Age (yr)	decay (days)	a/azero	Cum	% Delta from this Batch
1a	0.109589041	40	0.9975	**1.00**	
1b	0.109589041	40	0.9975	**1.99**	100%
1c	0.109589041	40	0.9975	**2.99**	50%
2	1.609589041	587.47	0.9635	**3.96**	32%
3	3.109589041	1134.94	0.9307	**4.89**	24%
4	4.609589041	1682.41	0.8990	**5.79**	18%
5	6.109589041	2229.88	0.8684	**6.65**	15%
6	7.609589041	2777.35	0.8388	**7.49**	13%
7	9.109589041	3324.82	0.8102	**8.30**	11%
8	10.60958904	3872.29	0.7826	**9.09**	9%
9	12.10958904	4419.76	0.7560	**9.84**	8%
10	13.60958904	4967.23	0.7302	**10.57**	7%
11	15.10958904	5514.7	0.7053	**11.28**	7%
12	16.60958904	6062.17	0.6813	**11.96**	6%
13	18.10958904	6609.64	0.6581	**12.62**	6%
14	19.60958904	7157.11	0.6357	**13.25**	5%
15	21.10958904	7704.58	0.6140	**13.87**	5%
16	22.60958904	8252.05	0.5931	**14.46**	4%
17	24.10958904	8799.52	0.5729	**15.03**	4%
18	25.60958904	9346.99	0.5534	**15.59**	4%
19	27.10958904	9894.46	0.5345	**16.12**	3%
20	28.60958904	10441.93	0.5163	**16.64**	3%
21	30.10958904	10989.4	0.4988	**17.14**	3%
22	31.60958904	11536.87	0.4818	**17.62**	3%
23	33.10958904	12084.34	0.4654	**18.08**	3%
24	34.60958904	12631.81	0.4495	**18.53**	2%
25	36.10958904	13179.28	0.4342	**18.97**	2%
26	37.60958904	13726.75	0.4194	**19.39**	2%
27	39.10958904	14274.22	0.4051	**19.79**	2%
28	40.60958904	14821.69	0.3913	**20.18**	2%
29	42.10958904	15369.16	0.3780	**20.56**	2%
30	43.60958904	15916.63	0.3651	**20.92**	2%

~3½

9 cores

10 cores

$$\#\ \text{of cores} = \frac{\text{Batch\#} - 1}{3} + 1$$

i.e. for Batch 28

$$\#\ \text{cores} = \frac{28-1}{3} + 1 = 10\ \text{cores}$$

			Activity after:	180	days
Isotope	Half life (days)	Lambda			cycle length (months)
Cs-137	10950	6.33011E-05			18

Batch #	Batch Age (yr)	decay (days)	a/azero	Cum	% Delta from this Batch
1a	0.493150685	180	0.9887	**0.99**	
1b	0.493150685	180	0.9887	**1.98**	100%
1c	0.493150685	180	0.9887	**2.97**	50%
2	1.993150685	727.47	0.9550	**3.92**	32%
3	3.493150685	1274.94	0.9225	**4.84**	24%
4	4.993150685	1822.41	0.8910	**5.73**	18%
5	6.493150685	2369.88	0.8607	**6.60**	15%
6	7.993150685	2917.35	0.8314	**7.43**	13%
7	9.493150685	3464.82	0.8031	**8.23**	11%
8	10.99315068	4012.29	0.7757	**9.01**	9%
9	12.49315068	4559.76	0.7493	**9.75**	8%
10	13.99315068	5107.23	0.7238	**10.48**	7%
11	15.49315068	5654.7	0.6991	**11.18**	7%
12	16.99315068	6202.17	0.6753	**11.85**	6%
13	18.49315068	6749.64	0.6523	**12.51**	6%
14	19.99315068	7297.11	0.6301	**13.14**	5%
15	21.49315068	7844.58	0.6086	**13.74**	5%
16	22.99315068	8392.05	0.5879	**14.33**	4%
17	24.49315068	8939.52	0.5679	**14.90**	4%
18	25.99315068	9486.99	0.5485	**15.45**	4%
19	27.49315068	10034.46	0.5298	**15.98**	3%
20	28.99315068	10581.93	0.5118	**16.49**	3%
21	30.49315068	11129.4	0.4944	**16.98**	3%
22	31.99315068	11676.87	0.4775	**17.46**	3%
23	33.49315068	12224.34	0.4613	**17.92**	3%
24	34.99315068	12771.81	0.4455	**18.37**	2%
25	36.49315068	13319.28	0.4304	**18.80**	2%
26	37.99315068	13866.75	0.4157	**19.21**	2%
27	39.49315068	14414.22	0.4015	**19.62**	2%
28	40.99315068	14961.69	0.3879	**20.00**	2%
29	42.49315068	15509.16	0.3747	**20.38**	2%
30	43.99315068	16056.63	0.3619	**20.74**	2%

			Activity after:	40	days
Isotope	Half life (days)	Lambda			cycle length (months)
Rh-106	365	0.001899033			18

Batch #	Batch Age (yr)	decay (days)	a/azero	Cum	% Delta from this Batch
1a	0.109589041	40	0.9269	**0.93**	
1b	0.109589041	40	0.9269	**1.85**	100%
1c	0.109589041	40	0.9269	**2.78**	50%
2	1.609589041	587.47	0.3277	**3.11**	12%
3	3.109589041	1134.94	0.1159	**3.22**	4%
4	4.609589041	1682.41	0.0410	**3.27**	1%
5	6.109589041	2229.88	0.0145	**3.28**	0%
6	7.609589041	2777.35	0.0051	**3.28**	0%
7	9.109589041	3324.82	0.0018	**3.29**	0%

		Activity after:	180	days
Isotope	**Half life (days)**	**Lambda**		**cycle length (months)**
Rh-106	**365**	0.001899033		**18**

Batch #	Batch Age (yr)	decay (days)	a/azero	Cum	% Delta from this Batch
1a	0.493150685	180	0.7105	**0.71**	
1b	0.493150685	180	0.7105	**1.42**	100%
1c	0.493150685	180	0.7105	**2.13**	50%
2	1.993150685	727.47	0.2512	**2.38**	12%
3	3.493150685	1274.94	0.0888	**2.47**	4%
4	4.993150685	1822.41	0.0314	**2.50**	1%
5	6.493150685	2369.88	0.0111	**2.51**	0%
6	7.993150685	2917.35	0.0039	**2.52**	0%
7	9.493150685	3464.82	0.0014	**2.52**	0%

Iodine-131 DECAY

Isotope	Half life Days	Lambda
Iodine-131	8	0.086643398

	Days	a/azero	
	8	0.5	
	16	0.25	
	24	0.125	
1 month	32	0.0625	Less than 7% remains after 1 month
	40	0.03125	
	48	0.015625	
	56	0.0078125	
2 months	64	0.00390625	Less than 1% remains after 2 months
	72	0.001953125	
	80	0.000976563	
	88	0.000488281	
3 months	96	0.000244141	
	104	0.00012207	
	112	6.10352E-05	
4 months	120	3.05176E-05	
	128	1.52588E-05	
	136	7.62939E-06	
	144	3.8147E-06	
5 months	152	1.90735E-06	
	160	9.53674E-07	
	168	4.76837E-07	
	176	2.38419E-07	
6 months	184	1.19209E-07	
	192	5.96046E-08	
	200	2.98023E-08	
	208	1.49012E-08	
7 months	216	7.45058E-09	
	224	3.72529E-09	
	232	1.86265E-09	
8 months	240	9.31323E-10	

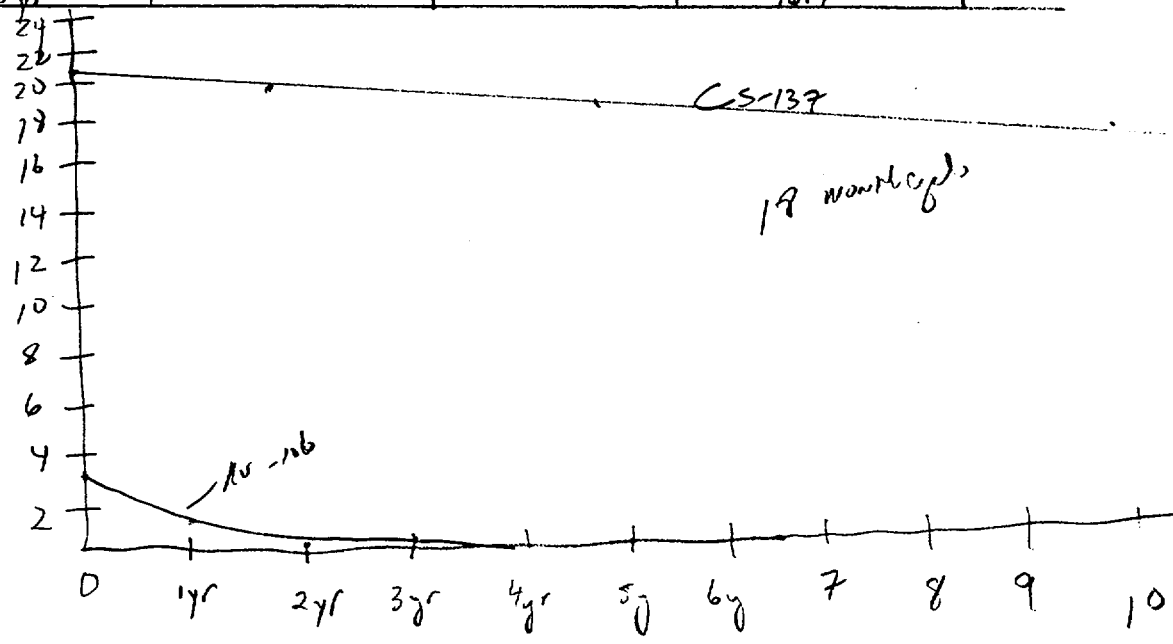
106

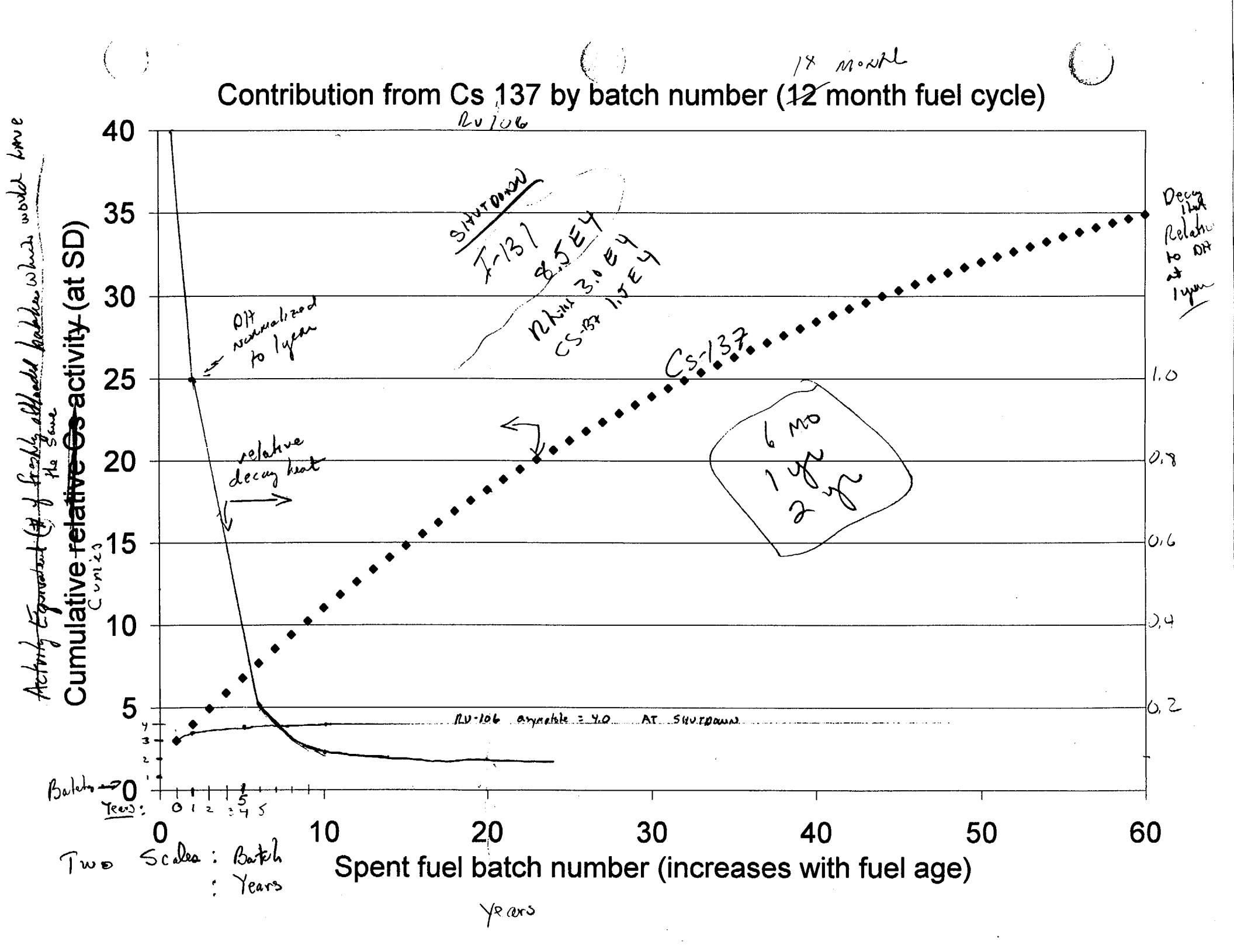
RHUTHENIUM AFTER ONE YEAR DECAY						
Isotope	Half life (yrs)	Lambda				18 month cycle
Rh-106	1	0.693147181				
	Batch #	decay (yr)		a/azero	Cum	% Delta from this Batch
	1a		1	0.5	0.5	
	1b		1	0.5	1	100%
	1c		1	0.5	1.5	50%
		2	2.5	0.176776695	1.676777	12%
		3	4	0.0625	1.739277	4%
		4	5.5	0.022097087	1.761374	1%
		5	7	0.0078125	1.769186	0%

accounts for Pu contribution

12 month fuel cycle			
Time after SD (days)	Ru 103 (equivalent newly offloaded spent fuel batches)	Ru 106	Cs 137
0	3.002	4.033	23.913
10	2.516	3.959	23.898
20	2.109	3.886	23.883
40	1.481	3.744	23.853
80	0.731	3.476	23.792
120	0.361	3.228	23.733
182.5	0.120	2.874	23.639
273.75	0.024	2.427	23.503
365	0.005	2.049	23.369
2yr		1.0	
5yr		.12	
10yr		—	

18 month fuel cycle			
Time after SD (days)	Ru 103 (equivalent newly offloaded spent fuel batches)	Ru 106	Cs 137
0	3.000	3.568	21.004
10	2.515	3.502	20.990
20	2.108	3.438	20.977
40	1.481	3.312	20.951
80	0.731	3.076	20.898
120	0.361	2.856	20.845
182.5	0.120	2.543	20.763
273.75	0.024	2.147	20.644
365	0.005	1.812	20.526
2yr		0.9	20.0
5yr		0.11	18.7
10yr		—	16.7

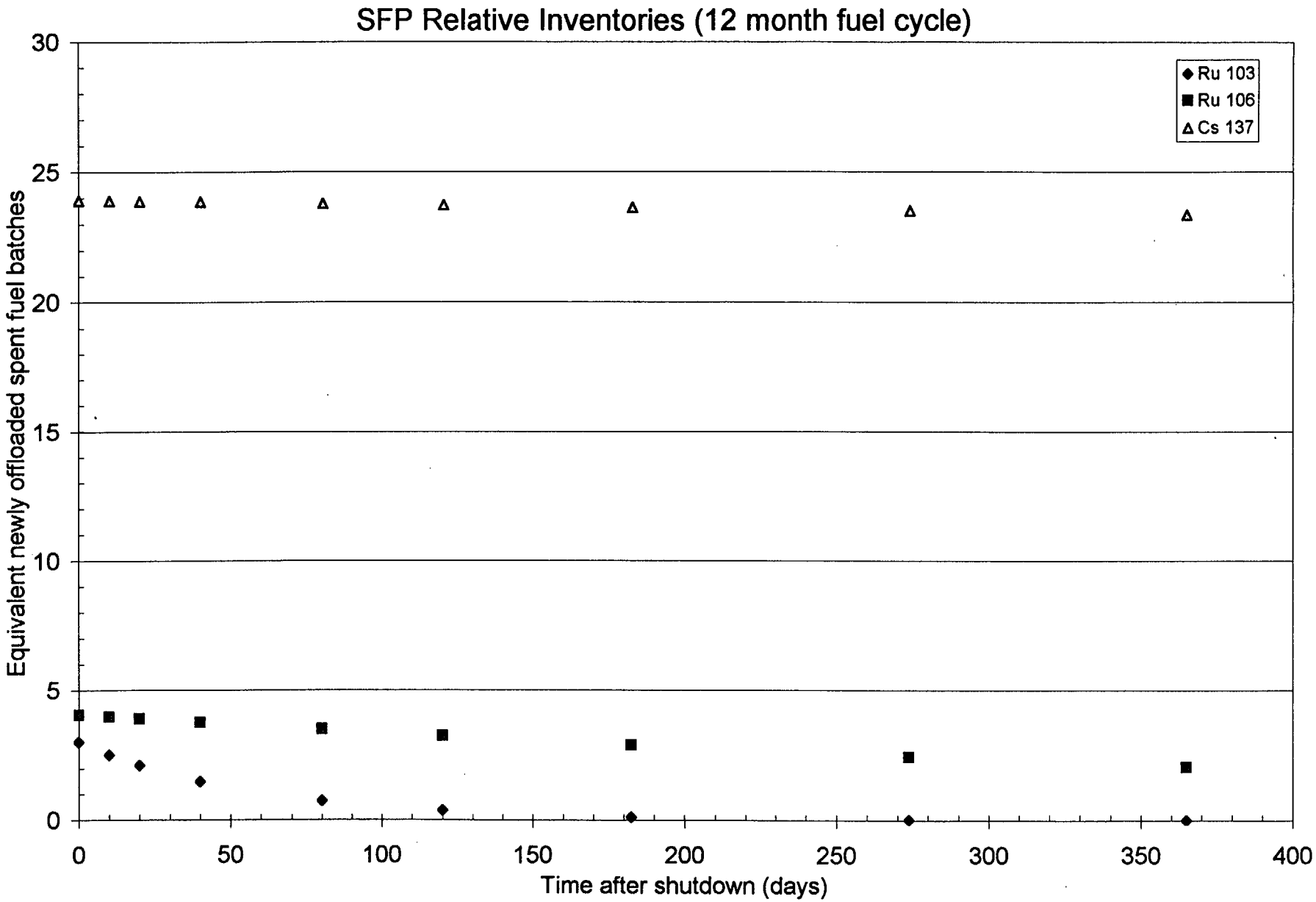


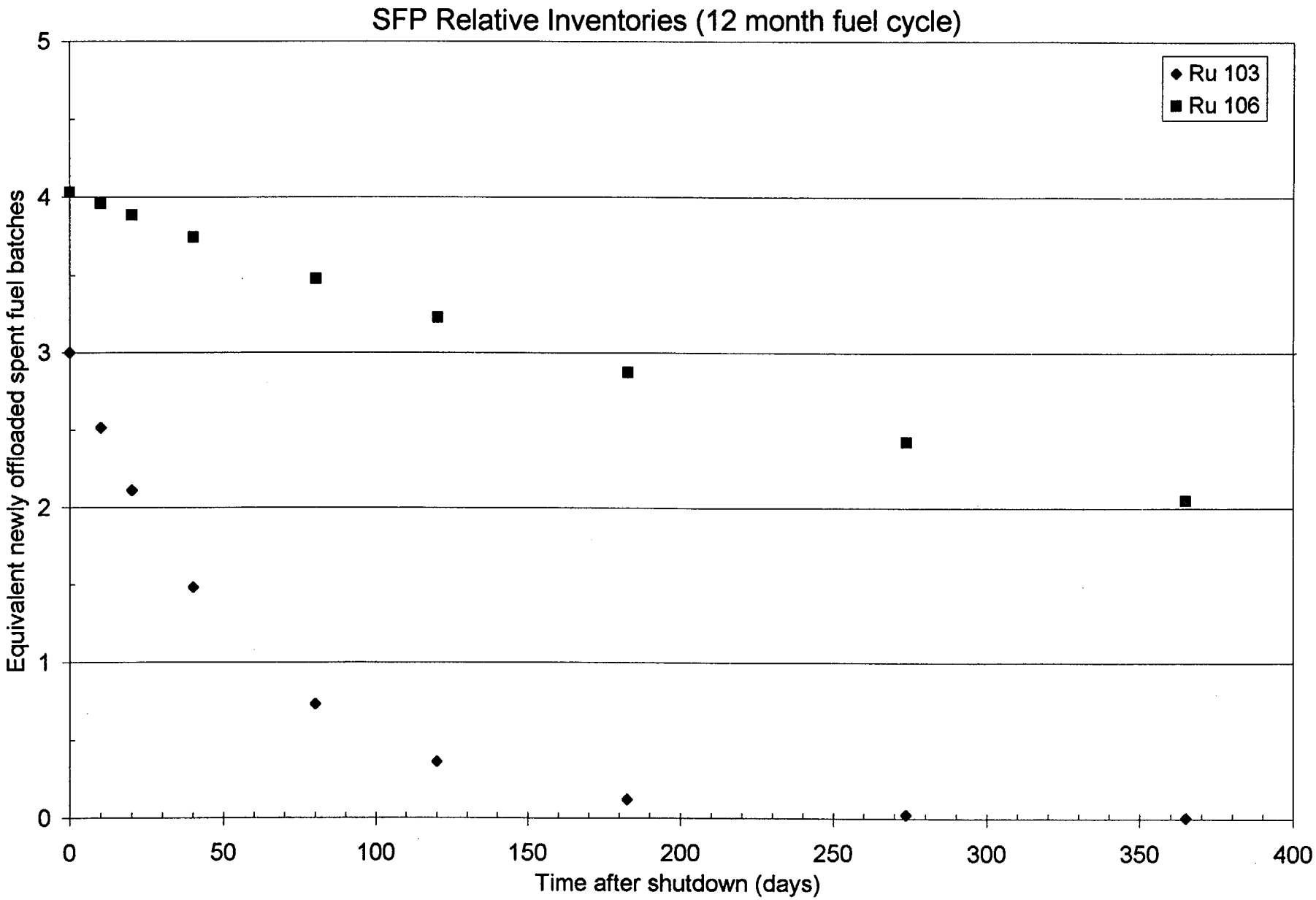

Contribution from Cs 137 by batch number (12 month fuel cycle)
18 month
RV106
SHUTDOWN
I-131
8.5E4
RV106 3.0E4
CS-137 1.7E4
Cs-137
6 mo
1 yr
2 yr
RV-106 enrichment = 4.0 AT SHUTDOWN
Cumulative relative Cs activity (at SD)
Curies
Decay heat Relative to DH at 1 year
relative decay heat
DH normalized to 1 year
Batch
Years:
0 1 2 3 4 5
0 10 20 30 40 50 60
Spent fuel batch number (increases with fuel age)
Years
Two Scales: Batch : Years

USER INPUTS				
Isotope	t 1/2 (d)	dk const (/d)	Days after SD	Months for fuel cycle
Ru 103	39.26	0.017655303	0	12
Ru 106	373.59	0.001855369	Days per Month	
Cs 137	10986.5	6.30908E-05	30.41666667	

OUTPUT SUMMARY (total spent fuel batches)		
Ru 103	Ru 106	Cs 137
3.00159227	4.03265521	23.9128837

			Ru 103			Ru 106			Cs 137		
Batch	Years after SD	Days after SD	A/Ao	Cumulative A/Ao	% addition	A/Ao	Cumulative A/Ao	% addition	A/Ao	Cumulative A/Ao	% addition
1a	0	0	1	1	-	1	1	-	1	1	-
1b	0	0	1	2	100.00%	1	2	100.00%	1	2	100.00%
1c	0	0	1	3	50.00%	1	3	50.00%	1	3	50.00%
2	1	365	0.001589739	3.001589739	0.05%	0.508033	3.5080326	16.93%	0.97723498	3.97723498	32.57%
3	2	730	2.52727E-06	3.001592266	0.00%	0.258097	3.7661298	7.36%	0.9549882	4.93222318	24.01%
4	3	1095	4.0177E-09	3.00159227	0.00%	0.131122	3.8972516	3.48%	0.93324788	5.86547106	18.92%
5	4	1460	6.38709E-12	3.00159227	0.00%	0.066614	3.9638658	1.71%	0.91200247	6.77747353	15.55%
6	5	1825	1.01538E-14	3.00159227	0.00%	0.033842	3.9977079	0.85%	0.89124071	7.66871424	13.15%
7	6	2190	1.61419E-17	3.00159227	0.00%	0.017193	4.0149008	0.43%	0.8709516	8.53966584	11.36%
8	7	2555	2.56614E-20	3.00159227	0.00%	0.008735	4.0236354	0.22%	0.85112437	9.39079021	9.97%
9	8	2920	4.0795E-23	3.00159227	0.00%	0.004437	4.0280729	0.11%	0.8317485	10.2225387	8.86%
10	9	3285	6.48533E-26	3.00159227	0.00%	0.002254	4.0303272	0.06%	0.81281373	11.0353524	7.95%
11	10	3650	1.031E-28	3.00159227	0.00%	0.001145	4.0314725	0.03%	0.79431001	11.8296624	7.20%
12	11	4015	1.63902E-31	3.00159227	0.00%	0.000582	4.0320544	0.01%	0.77622752	12.60589	6.56%
13	12	4380	2.60561E-34	3.00159227	0.00%	0.000296	4.03235	0.01%	0.75855669	13.3644467	6.02%
14	13	4745	4.14224E-37	3.00159227	0.00%	0.00015	4.0325001	0.00%	0.74128813	14.1057348	5.55%
15	14	5110	6.58509E-40	3.00159227	0.00%	7.63E-05	4.0325764	0.00%	0.72441269	14.8301475	5.14%
16	15	5475	1.04686E-42	3.00159227	0.00%	3.88E-05	4.0326152	0.00%	0.70792142	15.5380689	4.77%
17	16	5840	1.66423E-45	3.00159227	0.00%	1.97E-05	4.0326349	0.00%	0.69180557	16.2298745	4.45%
18	17	6205	2.64569E-48	3.00159227	0.00%	1E-05	4.0326449	0.00%	0.6760566	16.9059311	4.17%
19	18	6570	4.20596E-51	3.00159227	0.00%	5.08E-06	4.03265	0.00%	0.66066616	17.5665972	3.91%
20	19	6935	6.68637E-54	3.00159227	0.00%	2.58E-06	4.0326525	0.00%	0.64562608	18.2122233	3.68%
21	20	7300	1.06296E-56	3.00159227	0.00%	1.31E-06	4.0326539	0.00%	0.63092839	18.8431517	3.46%
22	21	7665	1.68983E-59	3.00159227	0.00%	6.66E-07	4.0326545	0.00%	0.61656529	19.459717	3.27%
23	22	8030	2.68638E-62	3.00159227	0.00%	3.39E-07	4.0326549	0.00%	0.60252917	20.0622462	3.10%
24	23	8395	4.27065E-65	3.00159227	0.00%	1.72E-07	4.032655	0.00%	0.58881258	20.6510587	2.93%
25	24	8760	6.78922E-68	3.00159227	0.00%	8.74E-08	4.0326551	0.00%	0.57540825	21.226467	2.79%
26	25	9125	1.07931E-70	3.00159227	0.00%	4.44E-08	4.0326552	0.00%	0.56230907	21.7887761	2.65%
27	26	9490	1.71582E-73	3.00159227	0.00%	2.26E-08	4.0326552	0.00%	0.54950809	22.3382841	2.52%
28	27	9855	2.7277E-76	3.00159227	0.00%	1.15E-08	4.0326552	0.00%	0.53699853	22.8752827	2.40%
29	28	10220	4.33634E-79	3.00159227	0.00%	5.82E-09	4.0326552	0.00%	0.52477374	23.4000564	2.29%
30	29	10585	6.89364E-82	3.00159227	0.00%	2.96E-09	4.0326552	0.00%	0.51282726	23.9128837	2.19%


SFP Relative Inventories (12 month fuel cycle)
Ru 103
Ru 106
Cs 137
Equivalent newly offloaded spent fuel batches
Time after shutdown (days)
0
5
10
15
20
25
30
0
50
100
150
200
250
300
350
400


SFP Relative Inventories (12 month fuel cycle)
Ru 103
Ru 106
Equivalent newly offloaded spent fuel batches
0
1
2
3
4
5
0
50
100
150
200
250
300
350
400
Time after shutdown (days)

			Activity after:	40	days
Isotope	Half life (days)	Lambda			cycle length (months)
Cs-137	10950	6.33011E-05			12
Batch #	Batch Age (yr)	decay (days)	a/azero	Cum	% Delta from this Batch
1a	0.109589041	40	0.9975	**1.00**	
1b	0.109589041	40	0.9975	**1.99**	100%
1c	0.109589041	40	0.9975	**2.99**	50%
2	1.109589041	404.98	0.9747	**3.97**	33%
3	2.109589041	769.96	0.9524	**4.92**	24%
4	3.109589041	1134.94	0.9307	**5.85**	19%
5	4.109589041	1499.92	0.9094	**6.76**	16%
6	5.109589041	1864.9	0.8887	**7.65**	13%
7	6.109589041	2229.88	0.8684	**8.52**	11%
8	7.109589041	2594.86	0.8485	**9.37**	10%

-106

			RHUTHENIUM AFTER 40 days DECAY		
Isotope	Half life (days)	Lambda			12 month cycle
Rh-106	365	0.001899033			
	Batch #	decay (days)	a/azero	Cum	% Delta from this Batch
1 core	1a	40	0.926852043	0.926852	
	1b	40	0.926852043	1.853704	100%
	1c	40	0.926852043	2.780556	50%
2nd core	2	405	0.463426021	3.243982	17%
	3	770	0.231713011	3.475695	7%
	4	1135	0.115856505	3.591552	3%
3rd core	5	1500	0.057928253	3.64948	2%
	6	1865	0.028964126	3.678444	1%
	7	2230	0.014482063	3.692926	0%
	8	2595	0.007241032	3.700167	0%

⇒ After 40 days you still have slightly more than 3 cores with Rh remaining and the total amt of Rh is equal to about 1.2 cores of freshly offloaded fuel.

			RHUTHENIUM -106 AFTER 6 months DECAY		
Isotope	Half life (days)	Lambda			12 month cycle
Rh-106	365	0.001899033			
	Batch #	decay (days)	a/azero	Cum	% Delta from this Batch
	1a	180	0.710471811	0.710472	
	1b	180	0.710471811	1.420944	100%
	1c	180	0.710471811	2.131415	50%
	2	545	0.355235906	2.486651	17%
	3	910	0.177617953	2.664269	7%
	4	1275	0.088808976	2.753078	3%
	5	1640	0.044404488	2.797483	2%
	6	2005	0.022202244	2.819685	1%
	7	2370	0.011101122	2.830786	0%

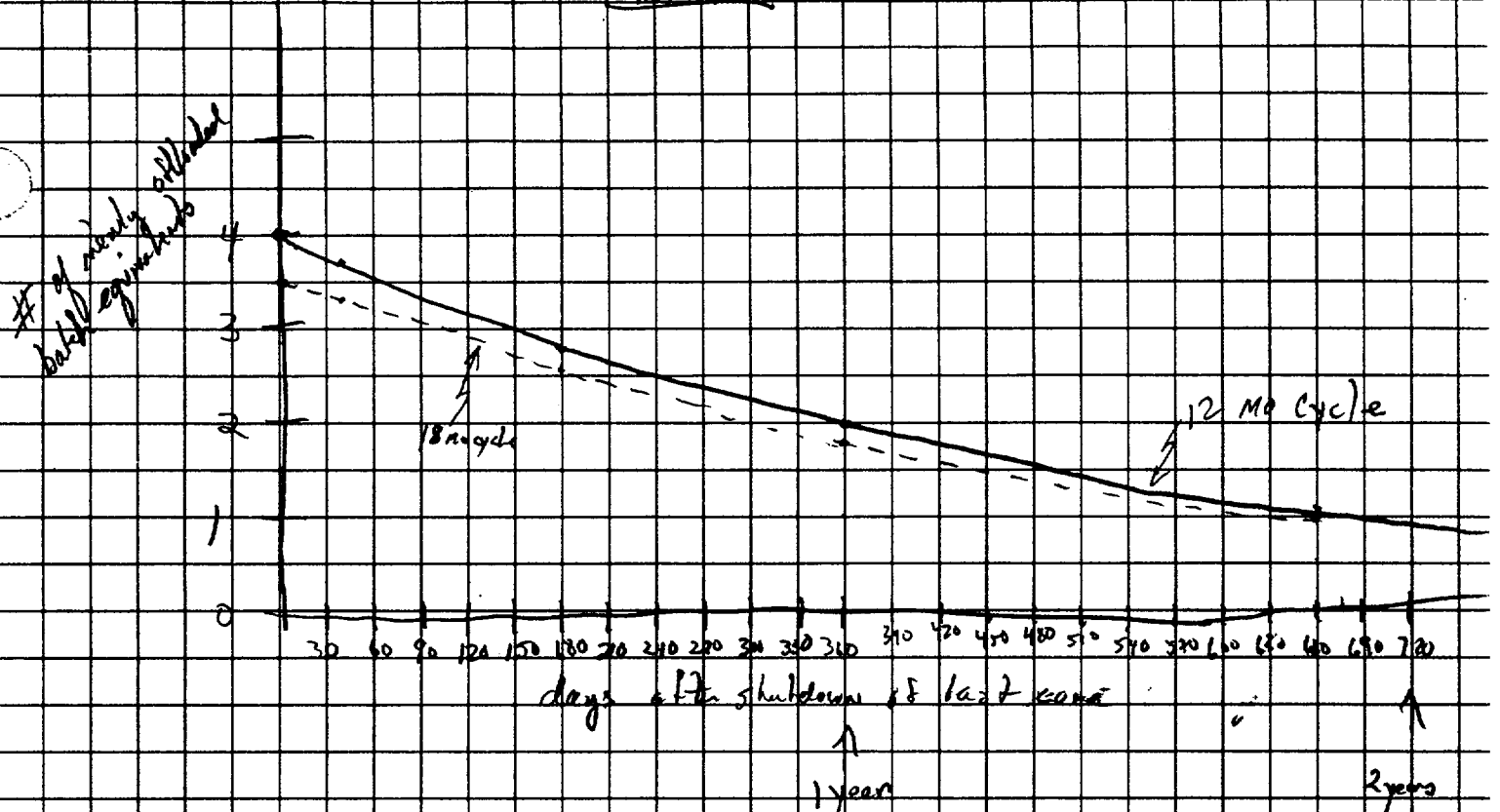
106

RHUTHENIUM AFTER ONE YEAR DECAY					
Isotope	Half life (yrs)	Lambda			12 month cycle
Rh- 106	1	0.693147181			
	Batch #	decay (yr)	a/azero	Cum	% Delta from this Batch
	1a	1	0.5	0.5	
	1b	1	0.5	1	100%
	1c	1	0.5	1.5	50%
	2	2	0.25	1.75	17%
	3	3	0.125	1.875	7%
	4	4	0.0625	1.9375	3%
	5	5	0.03125	1.96875	2%
	6	6	0.015625	1.984375	1%
	7	7	0.0078125	1.992188	0%

$$\frac{\text{Batch \#} - 1}{3} + 1 = \#\text{ of cuts}$$

			RHUTHENIUM -103 AFTER 40 days DECAY		
Isotope	Half life (days)	Lambda			12 month cycle
Rh-103	37.3	0.018583034			
	Batch #	decay (days)	a/azero	Cum	% Delta from this Batch
	1a	40	0.475531871	0.475532	
	1b	40	0.475531871	0.951064	100%
	1c	40	0.475531871	1.426596	50%
	2	405	0.00053882	1.427134	0%
	3	770	6.10531E-07	1.427135	0%

Rch-10e



⇒ You have the equivalent of 1 full core at 150 days and 1 batch at ~2 years (1 core = 3 batches)

RHUTHENIUM AFTER ONE YEAR DECAY

12 mo cycle

Isotope	Half life (yrs)	Lambda
Rh-	1	0.693147
CS-137	30	0.023105

Time	Batch #	a/azero	Cum	% Delta from this Batch
25	1	0.5	0.5	100%
= CH.	2	0.25	0.75	50%
= 13	3	0.125	0.875	17%
	4	0.0625	0.9375	7%
	5	0.03125	0.96875	3%
	6	0.015625	0.984375	2%
	7	0.0078125	0.992188	1%
	8	0.00390625	0.996094	0%
	9	0.001953125	0.998047	0%
	10	0.000976563	0.999023	0%
2.5 cores →	11	0.000488281	0.999512	0%
	12	0.000244141	0.999756	0%
	13	0.00012207	0.999878	0%
	14	6.10352E-05	0.999939	0%
	15	3.05176E-05	0.999969	0%
	16	1.52588E-05	0.999985	0%
	17	7.62939E-06	0.999992	0%
	18	3.8147E-06	0.999996	0%
	19	1.90735E-06	0.999998	0%
	20	9.53674E-07	0.999999	0%

← multiply by 3 for full core

Azero = Activity of 1 Batch at shutdown
assumes 1 year between each batch

% Delta = % increase in Activity relative to the previous cumulative value, i.e. For Batch 4

$$\text{the \% Delta} = \frac{\text{Batch 4 Activity}}{\sum_{i=1}^{3} \text{Batch } i} \times 100 = \frac{.0625 \times 100}{.875} = 7.1\%$$

$$= \frac{.0625}{.875} \times 100 = 7.1\%$$

⇒ Rh consequences are same after 6 batches so # of cores beyond 2.0 doesn't matter