

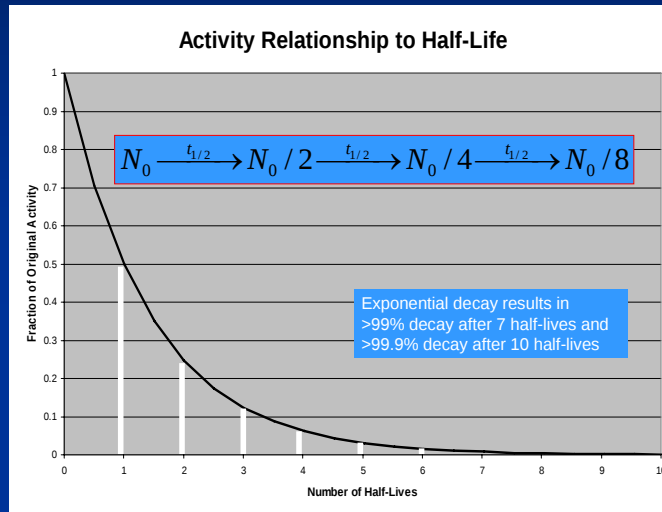
Radioactive Production and Decay of SRE Reactor Gases

Radionuclide Decay and Exposure to Gases and Gas Decay Products

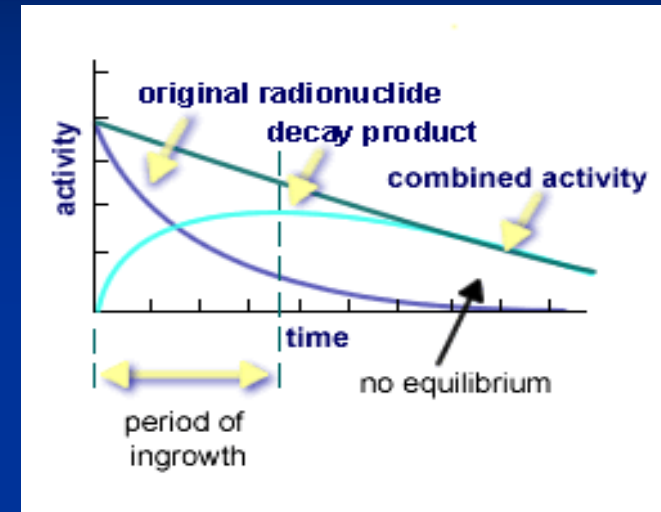
Radionuclide exposure is a function of both released amounts and radioactive decay until the time of exposure.

Some radionuclides decay to other radionuclides but eventually the decay chain ends in a stable (non-radioactive) isotope.

The rate of decay of a radionuclide is a function of its half-life ($T_{1/2}$).



**Ingrowth of daughter (D)
radionuclides from parent (P)
when $T_{1/2P} < T_{1/2D}$ and $A_{D0} = 0$**



Gases estimated to have been released after the SRE accident were primarily the isotopes of non-reactive noble gases Xenon, Krypton, and Argon identified below.

Z	74	75	76	77	78	79	80	81	82	N
56	Major Fission Product Gases									
Barium	131Ba 11.50 D 100.00%	132Ba >3.0E+21 Y 0.101% 24	133Ba 8841 D 100.00%	134Ba STABLE 2.417%	135Ba STABLE 6.592%	136Ba STABLE 7.654%	137Ba STABLE 11.222%	138Ba STABLE 71.689%	139Ba 63.06% 100.00%	
	130Cs 29.21 M 98.46%	131Cs 9.689 D 100.00%	132Cs 6.480 D 96.13% 1.87%	133Cs STABLE 100%	134Cs 2.0652 Y 100.00% 3.0E-4%	135Cs 2.3E+6 Y 100.00%	136Cs 13.94 D 100.00%	137Cs 30.08 Y 100.00%	138Cs 33.41 M 100.00%	
Cesium	129Xe STABLE 26.40%	130Xe STABLE 0.071%	131Xe STABLE 21.222%	132Xe STABLE 26.909%	133Xe 5.243 D 100.00%	134Xe 2.3E+22 Y 10.43% 28-80.00%	135Xe 9.14 H 100.00%	136Xe >2.4E+21 Y 6.857% 38-	137Xe 3.818 M 100.00%	
Xenon	126I 24.90 M 95.10%	127I 1.57E+7 Y 100.00%	130I 12.96 H 100.00%	131I 8.0252 D 100.00%	132I 2.295 H 100.00%	133I 20.8 H 100.00%	134I 52.5 M 100.00%	135I 6.58 H 100.00%	136I 83.4 s 100.00%	
Iodine	127Te 9.37 H 12.35 Te 100.00%	128Te 6.8E+14 Y 31.7% 100.00%	129Te 69.6 M 100.00%	130Te >5E+23 Y 34.0% 100.00%	131Te 25.0 M 100.00%	132Te 3.204 D 100.00%	133Te 13.5 M 100.00%	134Te 41.8 M 100.00%	135Te 19.0 s 100.00%	
Iodine isotopes with significant yields and half-lives and their xenon gas daughters										
51	126Sb 12.35 D 100.00%	127Sb 3.65 D 100.00%	128Sb 9.01 H 100.00%	129Sb 4.40 H 100.00%	130Sb 39.5 M 100.00%	131Sb 23.03 M 100.00%	132Sb 2.79 M 100.00%	133Sb 2.5 M 100.00%	134Sb 0.76 s 100.00%	

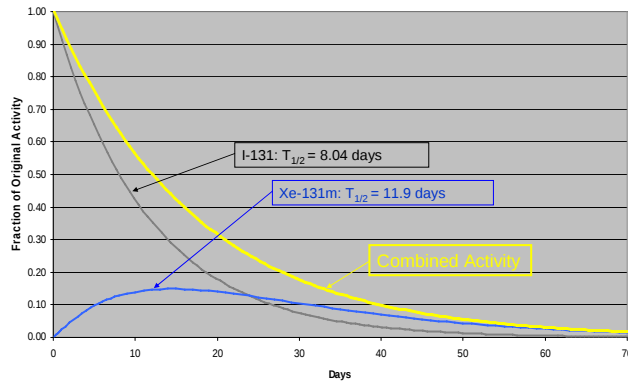
	46	47	48	49	50	51	52	53	54
2	86Kr STABLE 100.00%	87Kr STABLE 100.00%	88Kr STABLE 100.00%	89Kr STABLE 100.00%	90Kr STABLE 100.00%	91Kr STABLE 11.22%	92Kr STABLE 17.15%	93Kr STABLE 10.00%	94Kr STABLE 17.38%
	Major Long Lived Fission Product Gas								
39	86Y 2.68 h 100.00%	87Y 14.74 h 100.00%	88Y 79.8 h 100.00%	89Y 106.626 d 100.00%	90Y STABLE 100%	91Y 64.053 h 100.00%	92Y 58.51 d 100.00%	93Y 3.54 h 100.00%	94Y 10.18 h 100.00%
38	84Sr STABLE 0.56%	85Sr 64.84 d 100.00%	86Sr STABLE 9.86%	87Sr STABLE 7.00%	88Sr STABLE 82.58%	89Sr 50.53 d 100.00%	90Sr 28.90 y 100.00%	91Sr 9.63 h 100.00%	92Sr 2.66 h 100.00%
37	83Rb 56.2 d 100.00%	84Rb 33.1 d 100.00%	85Rb STABLE 72.17%	86Rb 16.642 d 99.99% 5.2E-3%	87Rb 4.88E+10 y 27.83% 100.00%	88Rb 50.53 d 100.00%	89Rb 15.15 m 100.00%	90Rb 158 s 100.00%	91Rb 58.4 s 100.00%
36	82Kr STABLE 11.58%	83Kr STABLE 11.49%	84Kr STABLE 57.00%	85Kr 39.168 d 100.00%	86Kr STABLE 17.30%	87Kr 76.3 m 100.00%	88Kr 2.84 h 100.00%	89Kr 3.15 m 100.00%	90Kr 32.32 s 100.00%
	Krypton								
35	81Br STABLE 49.51%	82Br 35.282 h 100.00%	83Br 2.40 h 100.00%	84Br 31.80 m 100.00%	85Br 2.90 m 100.00%	86Br 55.1 s 100.00%	87Br 55.65 s 100.00%	88Br 16.29 s 100.00%	89Br 4.40 s 100.00%
	Krypton gas isotope with significant yield and half-life								
34	80Se STABLE 49.61% 29-	81Se 19.45 m 100.00%	82Se STABLE 8.73%	83Se 22.3 m 100.00%	84Se 3.10 m 100.00%	85Se 31.7 s 100.00%	86Se 15.3 s 100.00%	87Se 5.50 s 100.00%	88Se 1.53 s 100.00%
	46	47	48	49	50	51	52	53	54

	Potential Activation Product Gas											
Z	38Ca 440 MS ≤ 100.00%	39Ca 859.6 MS ≤ 100.00%	40Ca > 3.0E+21 Y 96.94% 2+	41Ca 1.02E+5 Y ≤ 100.00%	42Ca STABLE 0.647%	43Ca STABLE 0.135%	44Ca STABLE 2.09%	45Ca 162.61 D p-: 100.00%	46Ca 0.28E+16 Y 0.004% 2p-			
19	37K 1.22E S 100.00%	38K 7.6396 M 100.00%	39K STABLE 99.2601%	40K 1.248E+9 Y 0.0117% p-: 89.28% e-: 10.72%	41K STABLE 6.7302%	42K 12.321 H p-: 100.00%	43K 22.9 H p-: 100.00%	44K 22.13 M p-: 100.00%	45K 17.81 M p-: 100.00%			
Potassium	36Ar STABLE 0.3365%	37Ar 34.95 D ≤ 100.00%	38Ar STABLE 0.0632%	39Ar 269 Y p-: 100.00%	40Ar STABLE 99.6003%	41Ar 109.61 M p-: 100.00%	42Ar 32.9 Y p-: 100.00%	43Ar 5.37 M p-: 100.00%	44Ar 11.87 M p-: 100.00%			
Argon	35Cl STABLE 75.77%	36Cl 3.01E+5 Y p-: 90.10% e-: 1.90%	37Cl STABLE 24.23%	38Cl 37.24 M p-: 100.00%	39Cl 56.2 M p-: 100.00%	40Cl 1.35 M p-: 100.00%	41Cl 38.4 S p-: 100.00%	42Cl 6.2 S p-: 100.00%	43Cl 4.83 S p-: 100.00%			
17	34S STABLE 4.21%	35S 87.51 D p-: 100.00%	36S STABLE 0.02%	37S 5.05 M p-: 100.00%	38S 170.3 M p-: 100.00%	39S 8.8 S p-: 100.00%	40S 11.5 S p-: 100.00%	41S 403 S p-: 100.00%	42S 1.26 S p-: 100.00%	43S 1.013 S p-: 100.00%	44S 425 S p-: 100.00%	45S 1.013 S p-: 100.00%
16	Potential activation gas from argon in helium purge gas											
18	19	20	21	22	23	24	25	N				

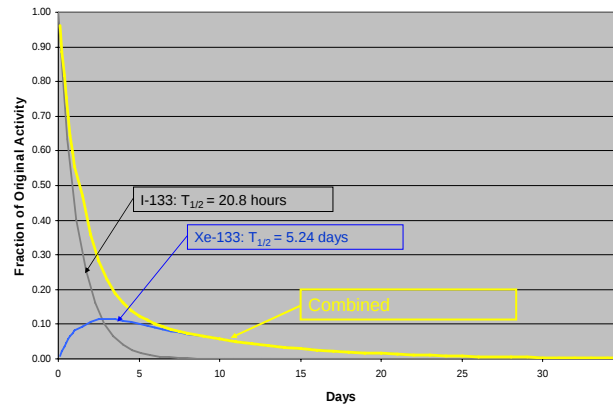
Source for Table Data : National Nuclear Data Center, Brookhaven National Laboratory,
http://www.nndc.bnl.gov/nudat2/

Radioactive Decay of SRE Reactor Inventory and Estimated Releases

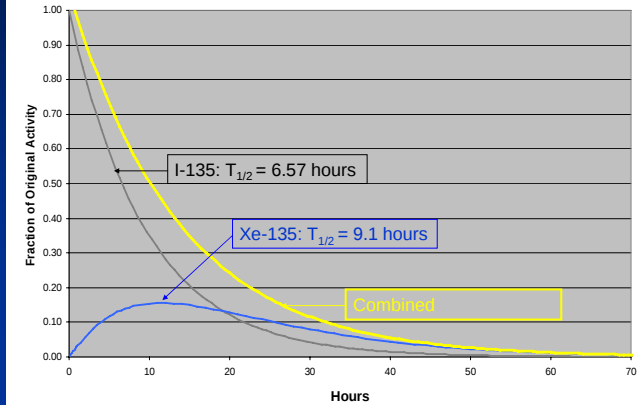
I-131/Xe-131m Ingrowth and Decay Activity Units



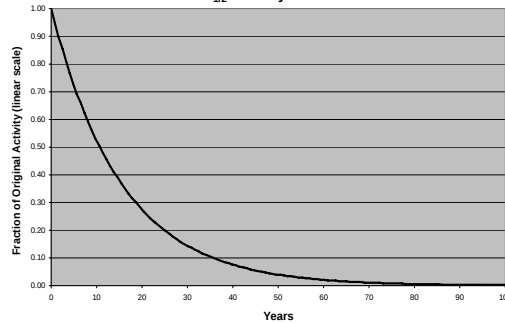
I-133/Xe-133 Ingrowth and Decay (Activity)



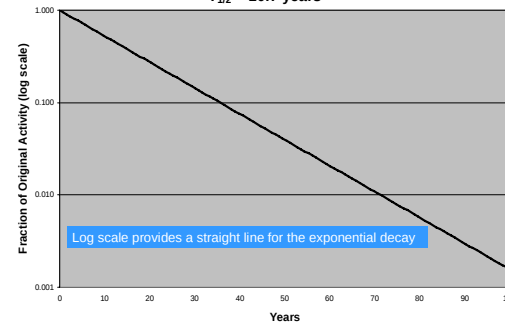
I-135/Xe-135 Ingrowth and Decay (Activity)



Kr-85 Decay
 $T_{1/2} = 10.7$ years



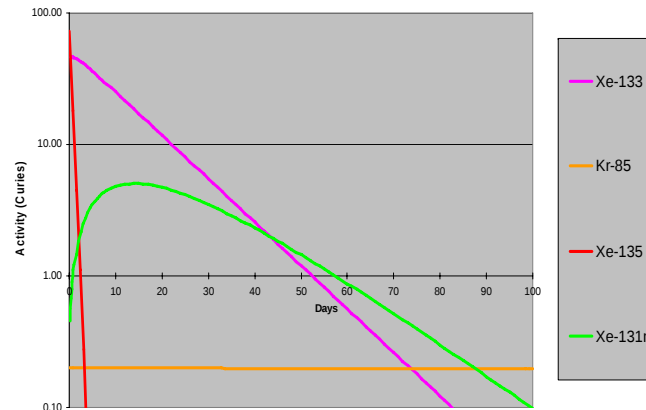
Kr-85 Decay
 $T_{1/2} = 10.7$ years



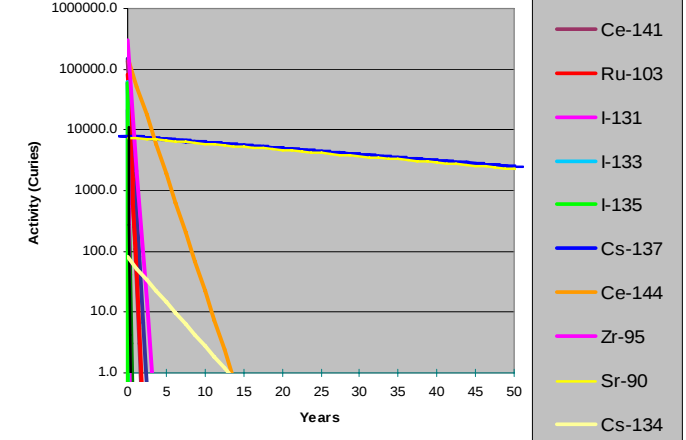
When the exponential decay is plotted on a log scale the plot is linear.

The plots below show the amounts of noble gases estimated to have been released after the SRE accident, the total reactor inventory of other fission products at the time of the accident, and their decay over time.

Activities of Gases After Shut Down of the SRE Reactor
(Estimated Inventory Released to the Environment)



Activities of Other Significant Fission Products
After Shut Down of the SRE Reactor
(Total Reactor Core Inventory)



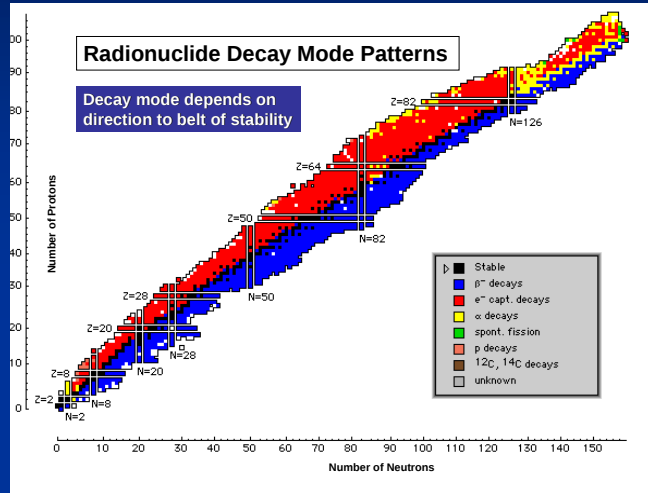
Radioactive Decay and Equilibrium of SRE Reactor Fuels

Radioactive Decay

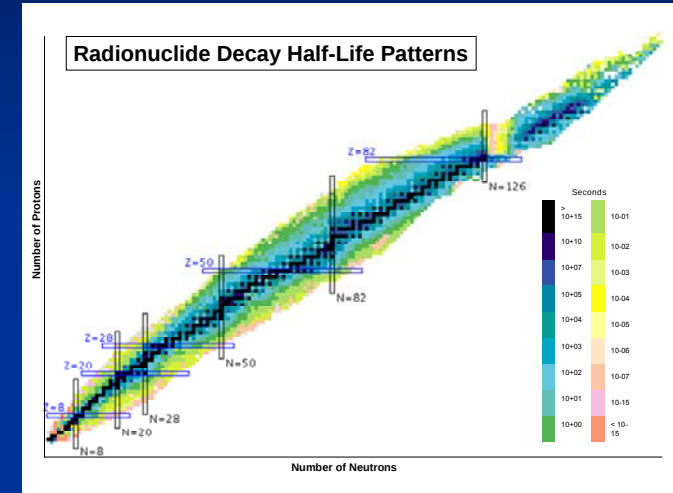
- Due to nuclear instability
- Mode depends on direction to belt of stability. Possible Modes:

- Alpha decay (α)
- Beta decay (β^-)
- Positron Decay (β^+)
- Electron capture (EC)
- Spontaneous Fission

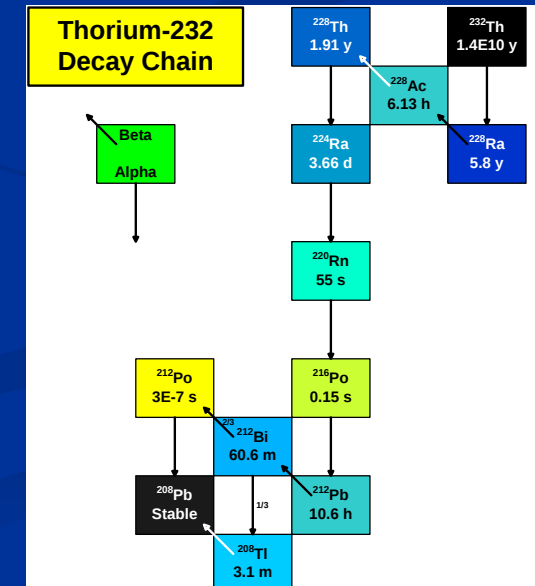
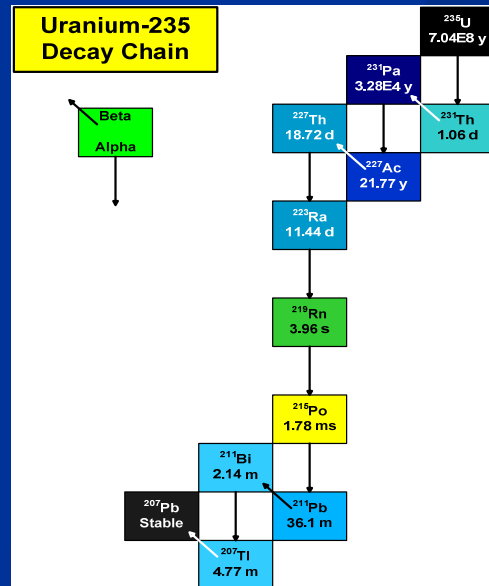
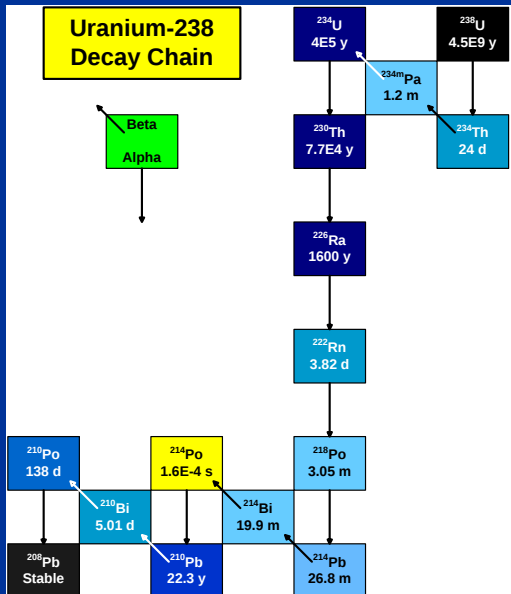
Decay mode depends on direction to belt of stability



Half-lives are longer as decay moves closer to belt of stability

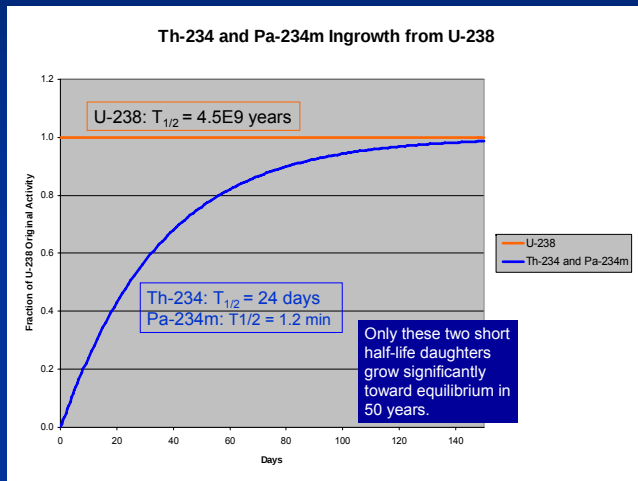


Decay Chains Associated with SRE Reactor Fuel Elements (Thorium-232 only used in SRE Core II)

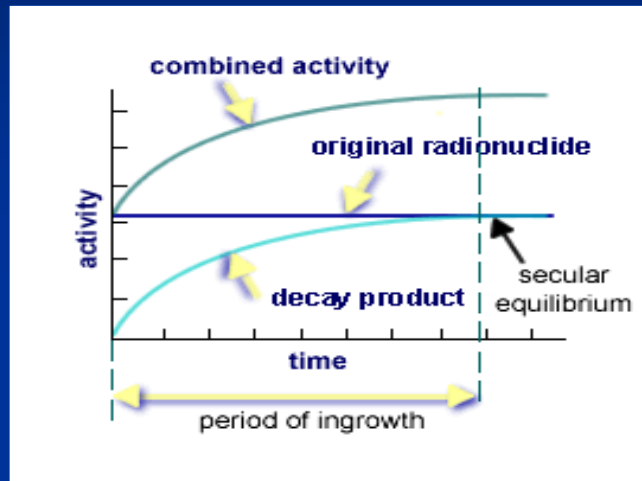


Radioactive Decay and Equilibrium of SRE Reactor Fuels

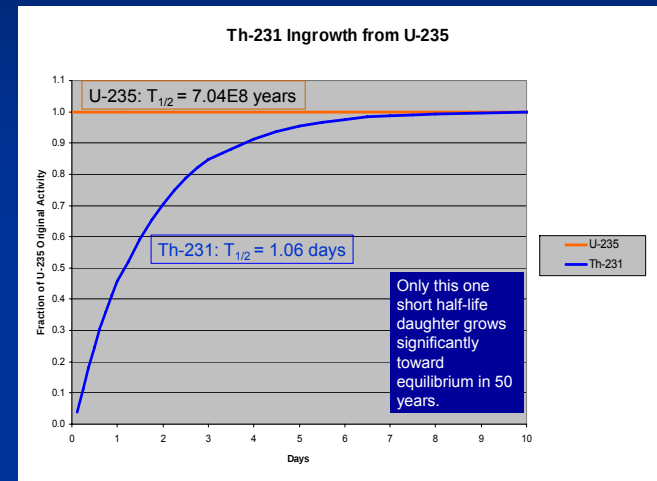
Ingrowth of early decay chain short half-life daughters from U-238



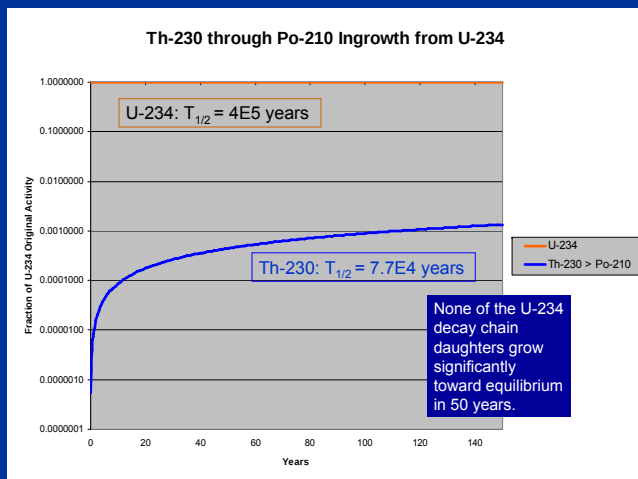
Ingrowth of daughter (D) radionuclides from parent (P) when $T_{1/2P} \gg T_{1/2D}$ and $A_{D0} = 0$



Ingrowth of early decay chain short half-life daughters from U-235



Ingrowth of long half-life daughters from U-234



The time it takes for the daughter to reach equilibrium with the parent depends on the half-life of the daughter.

Because of the long half-life of intermediate members in the U-238 and U-235 decay chains, equilibrium is only established for early short half-life daughters. All members of the Th-232 decay chain approach early equilibrium.

Ingrowth of decay chain short half-life daughters from Th-232

