Kernspaltung in Kernkraftwerken und Kernwaffen / Spaltprodukte

- Verteilungen
- Produzierte Radionuklide: Aufbau und Zerfall in Kernbrennstoffen

  Bsp: 440MW Reaktor, Produktionsraten für 1 Jahr

Kernwaffen:

Verteilungen / wie in Reaktoren

Produzierte RN (Spaltung, Aktivierung, Fusion, Spaltbares Material

Radioaktive Kontamination

- Die am meisten dazu beitragenden Radionuklide
- Zeitliche Entwicklung
- Vergleich Kernwaffen mit Unfällen

Kernkraftwerke

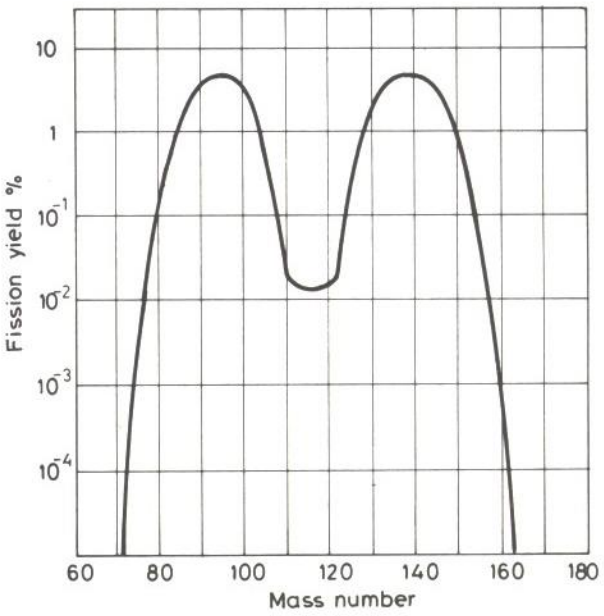


Fig. 6. Distribution of the fission products of ^{235}U as a function of the mass number

Table 1.4 Production and decay of important radionuclides produced in a reactor

Fission product		A (production)		B (decay)		
Isotope	Half-life (months)	1 year	5 years	100 days	1 year	5 years
^{89}Sr	1.7	4200	4300	1100	36	—
^{90}Sr	350	160	740	160	150	110
^{91}Y	1.9	5400	5500	1600	64	—
^{95}Zr	2.2	5500	5600	1900	110	—
$^{95}Nb^b$	1.2	5400	5600	3200	240	—
^{103}Ru	1.3	3400	3400	660	8.2	—
^{106}Ru	12	240	470	200	120	7.80
^{115}Cd	1.4	0.66	0.066	0.13	—	—
$^{125}Te^b$	1.9	3.8	15	4.3	4.0	1.40
^{127}Sb	0.13	87	87	—	—	—
^{131}I	0.27	2800	2800	0.44	—	—
$^{131}Xe^b$	0.40	28	28	0.16	—	—
^{132}Te	0.11	4100	4100	—	—	—
$^{132}I^b$	0.003	4100	4100	—	—	—
$^{133}I^b$	0.029	720	720	—	—	—
^{133}Xe	0.18	6100	6100	—	—	—
^{136}Cs	0.44	5.8	5.8	0.033	—	—
^{137}Cs	360	120	570	120	120	110
^{140}Ba	0.43	5700	5700	26	—	—
$^{140}La^b$	0.056	5700	5700	29	—	—
^{141}Ce	1.1	5300	5300	530	1.10	—
^{144}Ce	9.4	3000	4900	2300	1200	30
$^{147}Pm^b$	31	540	1800	530	440	150

Columns marked A represent the activity PBq (10^{15}dps)[a] after selected periods of continuous operation of a reactor at a power level of 3,000 megawatts thermal. Columns marked B represent the activity at specific times after shutdown or removal from a reactor that had been operating for 1 year

[a] Calculated using fission product yields.

[b] Daughter product.

IAEA, 1974; reproduced by permission of IAEA, Vienna.

Table 6.2 Common types of nuclear power reactor.

Name	Acronym	Fuel	Enrichment (%U-235)	Coolant	Moderator	Comments
Pressurized-water reactor	PWR	Uranium oxide	Yes (2–3%)	Light water	Light water	The same light water acts as moderator and coolant. It is under pressure to prevent boiling and takes heat away from the reactor core to heat exchangers
Boiling-water reactor	BWR	Uranium oxide	Yes (2–3%)	Light water	Light water	The same light water acts as moderator and coolant. It is allowed to boil and generates steam directly to power electricity- generating turbines
Canadian deuterium reactor	CANDU	Uranium metal	No (0.7%)	Heavy water	Heavy water	Separate heavy water is used for moderator and coolant. The heavy water moderator is cooled separately
Magnox	—	Uranium metal	No (0.7%)	Carbon dioxide gas	Graphite	An early type of reactor used mainly in the UK. Carbon dioxide gas takes heat away to heat exchangers
Advanced gas cooled	AGR	Uranium oxide	Yes (2–3%)	Carbon dioxide gas	Graphite	A development of the Magnox reactor, used solely in the UK. Operates at higher temperatures and is more efficient
RBMK	—	Uranium oxide	Yes (~ 2%)	Light water	Graphite	A hybrid reactor type used solely in the former Eastern Bloc countries

Table 6.3 Reactor types and net electrical power in 2000 (from Nuclear Engineering International, 2001).

Reactor type	Operating commercial reactors			Commercial reactors under construction	
	Number of units	Total MW(e)[a]	% of Total MW(e)	Number of units	MW(e)
PWR	258	241 055	65	24	22 811
BWR	91	82 002	22	4	4663
GCR[b]	18	3288	0.9	—	—
AGR	14	9164	2.5	—	—
CANDU	34	17 957	4.8	5	3145
RBMK	13	13 600	3.7	1	1000
FBR[c]	4	1280	0.3	—	—
Other	5	213	0.05	—	—
Total	437	368 559	—	34	31 619

[a]Total installed capacity. The electricity delivered to the grid will be lower. The thermal energy generated is normally about three times the electricity capacity and depends upon the efficiency of the reactor type.
[b]GCR, Graphite-moderated, gas-cooled reactors – mainly UK Magnox.
[c]FBR, Fast breeder reactor.

Kernwaffen

Table 1.2 Sources of radioactivity in nuclear explosions

Source	Isotope of interest	Strength of source
1. Fission fragments	Mass numbers 70–160	2.9×10^{23} fragments per kiloton of fission. Activity at 1 hour $= 1.5 \times 10^{10}$Bq[a]
2. Fusion reaction products	Principally tritium ($^{3}_{1}$H) from reaction $^{2}_{1}H + {}^{2}_{1}H \rightarrow {}^{3}_{1}H + {}^{1}_{1}H$	Depends on weapon design. Magnitude 10^4 Ci/kiloton[b] 10^{23} to 10^{24} atoms $^{3}_{1}$H/kiloton. Fusion energy release can vary from 0% to 99% of total
3. Neutron activation	Depends on explosion location and bomb case material. A principal isotope is carbon-14 from atmospheric nitrogen $^{14}_{7}N + {}^{1}_{0}n \rightarrow {}^{14}_{6}C + {}^{1}_{1}H$	2×10^{23} neutrons liberated in fission and fusion per kiloton
4. Fissile materials	Plutonium-239	Depends on weapon design. Comes from non-fissioned weapons material plus neutron activation of uranium

a) Distribution and evolution of radioelements after nuclear explosion, Dupuis, M.J. (1970) *Bulletin of Information, Science and Technology*, **149**, 41–52.
b) Ericksson, E., *Tellus*, **17**, 118–130 (1965).

Table 3 Distribution of fission products from a nuclear explosion as a function of their half-life

Half-life	Number of radioactive isotopes
Shorter than 1 day	131
1 – 10 days	17
10 – 30 days	9
30 days – 1 year	12
1 – 10 years	7
10 – 100 years	3
Longer than 100 years	10

Radioaktive Kontamination

Table 4 The most significant isotopes responsible for radioactive contamination

Isotope	Physical half-life	Most probable energy of radiation (MeV)		
		β_{max}	γ	α
^{1}H	12.3 years	0.02		
^{14}C	5570 years	0.16		
^{85}Kr	10.8 years	0.67	0.52	
^{89}Sr	50.4 days	1.46		
^{90}Sr	28 years	0.54		
^{90}Y	64.2 hours	2.26		
^{91}Y	58 days	1.53	1.21	
^{95}Zr	65 days	0.40	0.73	
^{95}Nb	35 days	0.16	0.76	
^{106}Ru	1.0 year	0.04		
^{106}Rh	30 seconds	3.60	0.51	
^{129}I	$1.72 \cdot 10^{7}$ years	0.15	0.04	
^{131}I	8.1 days	0.61	0.36	
^{134}Cs	2.3 years	0.66	0.80	
^{137}Cs	30 years	0.51	0.66	
^{140}Ba	12.8 days	1.02	0.03	
^{140}La	40.2 hours	1.36	1.60	
^{144}Ce	285 days	0.32	0.13	
^{144}Pr	17.5 minutes	2.98	0.69	
^{147}Pm	2.6 years	0.22		
^{147}Nd	11.1 days	0.81	0.09	
^{239}Pu	$2.44 \cdot 10^{4}$ years		0.05	5.15
^{240}Pu	6580 years		0.04	5.16

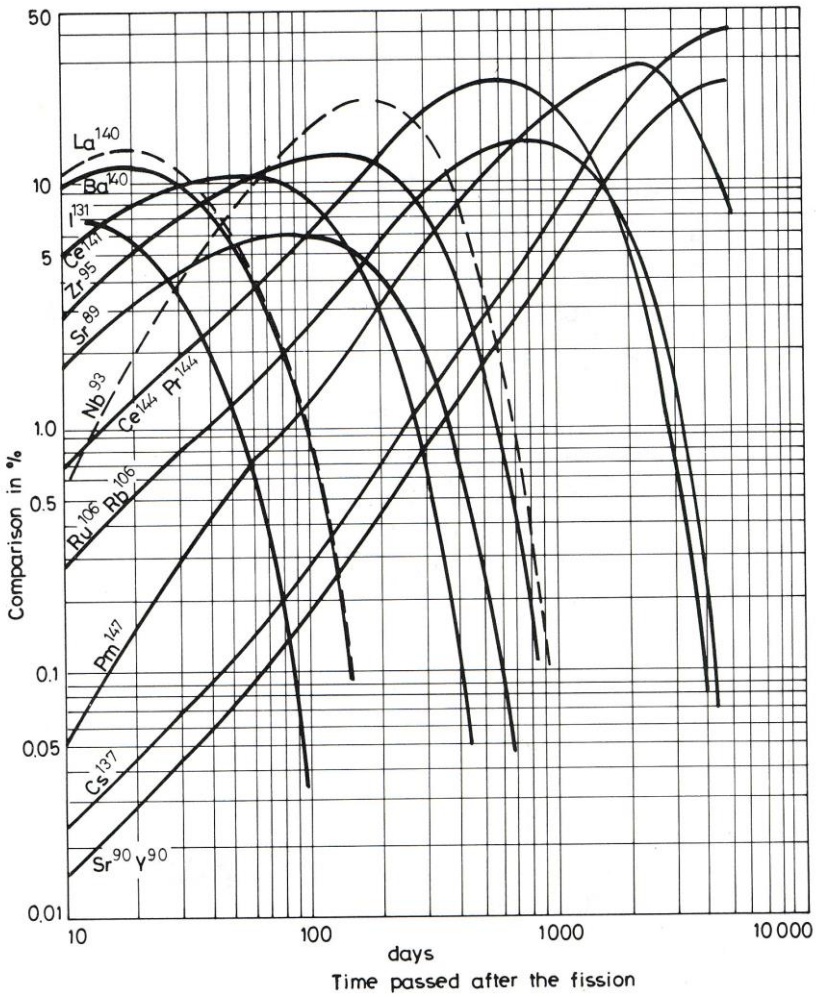


Fig. 8. Proportion of the radioactive isotopes produced in the fission of ^{235}U in the total radioactivity as a function of the time passed after the explosion

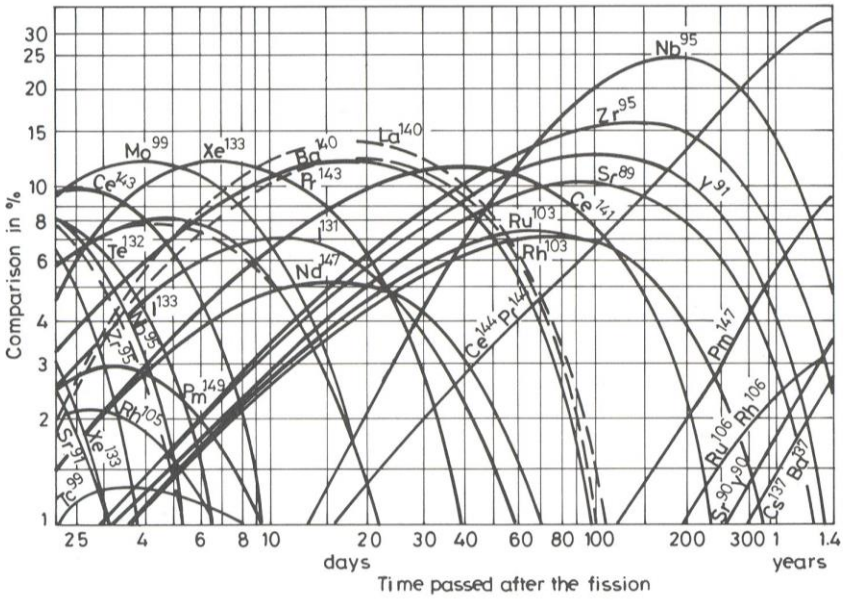


Fig. 7. Proportion of the radioactive isotopes produced in the fission of ^{235}U in the total radioactivity as a function of the time passed after the explosion

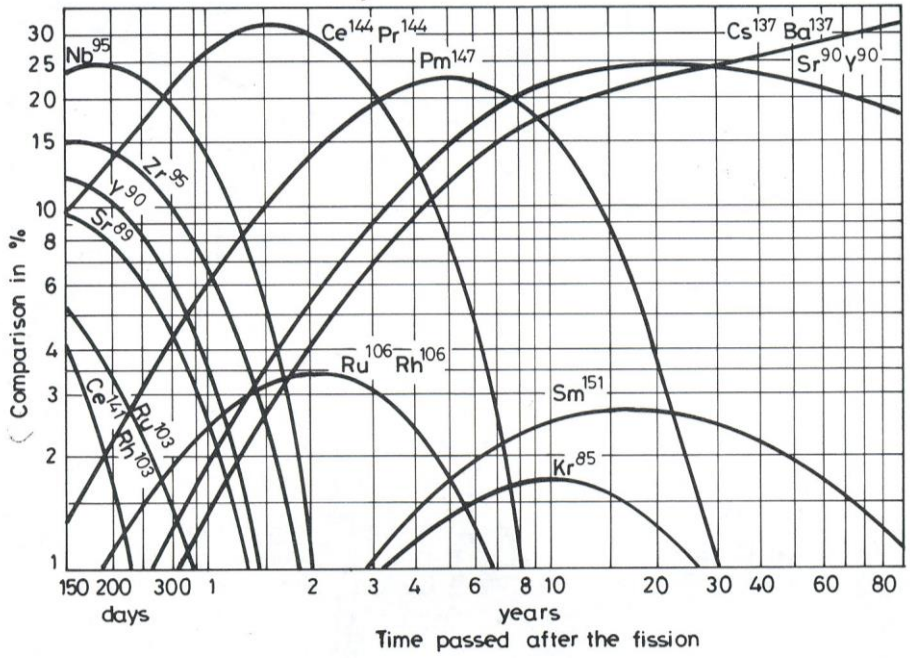


Fig. 9. Proportion of the radioactive isotopes produced in the fission of ^{235}U in the total radioactivity as a function of the time passed after the explosion

Table 1.10 Estimated fractional release of radionuclides available for long-range transport from Chernobyl (Gudiksen *et al.*, 1989) compared with the USAEC reactor safety study (WASH-1400, 1975) and the Windscale reactor accident (Clarke, 1974)

WASH–1400 (%) Chemical group	Chernobyl estimate	Range estimate	Best estimate	Windscale estimate
Noble gases				
Xe, Kr	100	50–100	90	100
Halogens				
I, Br	80	50–100	90	20
Alkali metals				
Cs, Rb	40	40–90	80	20
Tellerium group				
Te, Se, Sb	10	5–25	15	20
Alkaline earths				
Ba, Sr	1.2	2–20	10	0.2
Noble metals includes Ru, Rh, Pd, Mo, Tc	0.9	1–10	3	2.0
Rare earths and actinides includes Y, La, Ce, Pr, Nd, Pm, Sm, Eu, Np, Pu, Cm	0.2	0.01–1	0.3	0.2
Refractory oxides				
Zr, Nb	0.2	0.01	0.3	0.2

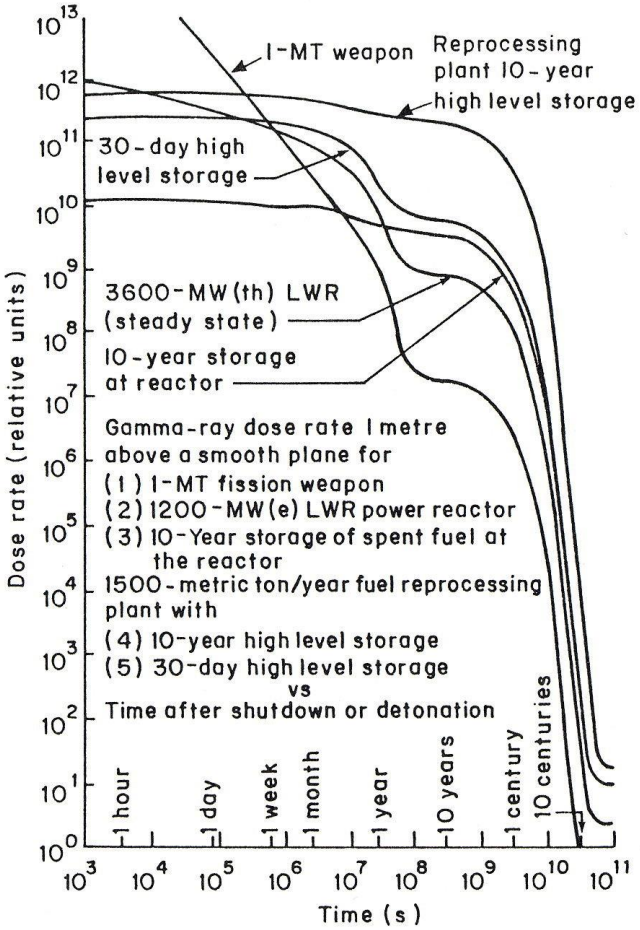


Figure 1.2 Gamma-ray dose rate area integral versus time after shutdown or detonation (Chester and Chester, 1976). The dose rate area integral is a measure of the radioactive inventory. (From Chester and Chester 1976; copyright 1976 by the American Nuclear Society, La Grange Park, Illinois).

Table 1.3 A comparison of radioactive releases from nuclear detonations and nuclear reactor accidents

	Radioactivity released (PBq)[a]			
Nuclide	Hiroshima	Weapon tests	Chernobyl	Windscale
^{137}Cs	0.1	1500	89	0.044
^{134}Cs[b]	—	—	48	0.0011
^{90}Sr	0.085	1300	7.4	0.00022
^{133}Xe	140	210 0000	4400	14
^{131}I	52	780 000	1300	0.59

[a] Decay corrected to 3 days after shutdown or detonation.
[b] ^{134}Cs is produced in reactors by neutron activation.
Gudiksen *et al.*, 1989; reproduced by permission of the Health Physics Society.

Table 6- I - Estimates, made in 2011 by IRSN (during and after the accident) and various Japanese agencies and scientific teams, of the activities (× 10^{15} Bq) of the main categories of radionuclides released during the Fukushima accident. Releases from the Chernobyl accident are also provided for comparison.

		Noble gases	Xe-133	Iodines (incl. ^{131}I	^{131}I	Cesiums (incl. ^{137}Cs	^{137}Cs
IRSN ERS -	**Total**	**2,080**	**2,000**	**182**	**90**	**26**	**10**
IRSN - 2011 research	Reactor 1	1,920	1,530	42	13	3	1
	Reactor 2	2,270	2,180	114	57	17	6
	Reactor 3	2,350	2,240	253	126	38	14
	Total	**6,550**	**5,950**	**408**	**197**	**58**	**21**
NISA (June 2011)	Reactor 1	-	3,400	-	12	-	0.6
	Reactor 2	-	3,500	-	140	-	14
	Reactor 3	-	4,400	-	7	-	0.7
	Total	-	**11,000**	-	**160**	-	**15**
NSC (April 2011)	**Total**	-	-	**630**	**150**	-	**12**
Chino et al. (2011), JAEA, NERH report	**Total**	-	-	-	**150**	-	**13**
Stohl (*Stohl et al. (2011)*)	**Total**	-	**16,700 (13,400-20,000)**	-	-	-	**35.8 (23.3-50.1)**
Morino et al. (2011)	**Total**	-	-	-	**142**	-	**9.94**
Chernobyl *(IAEA 2005)*	**Total**	**6,533**	**6,500**	**4,260**	**1760**	**168**	**85**

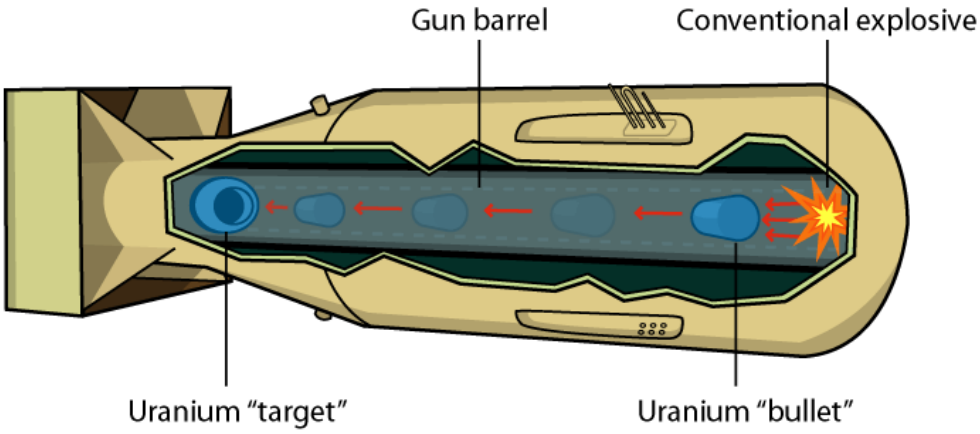
Aktivierungsprodukte

Table 9
SOME RADIONUCLIDES PRODUCED BY NEUTRON ACTIVATION IN NUCLEAR REACTORS WHICH ARE OF POTENTIAL BIOLOGICAL SIGNIFICANCE

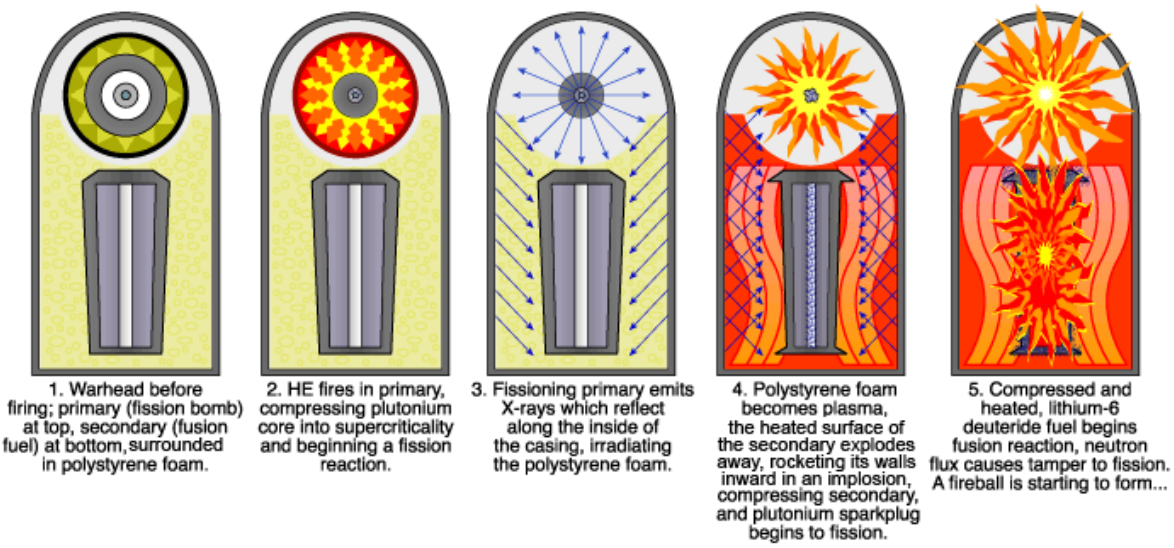
Radionuclide	Radiation	Half-life	Important element analogs
^{3}H	β	12.3 year	H
^{14}C	β	5568 year	C
^{24}Na	β,γ	15 hr	Na
^{32}P	β	14 day	P
^{35}S	β	87 day	S
^{41}A	β,γ	110 min	—
^{45}Ca	β	164 day	Ca
^{54}Mn	γ	291 day	Mn
^{55}Fe	χ (EC)[a]	2.6 year	Fe
^{59}Fe	β,γ	45 day	Fe
^{57}Co	γ	270 day	Co
^{58}Co	β^{+},γ	71 day	Co
^{60}Co	β,γ	5.2 year	Co
^{65}Zn	β^{+},γ	245 day	Zn
^{239}Pu	α,γ	24,360 year	—
^{239}Np	β,γ	2.3 day	—
^{241}Am	α,γ	470 year	—
^{242}Cm	α,γ	163 day	—

Kernwaffen-Design

Kernspaltung



Kernfusion



Kernwaffenentwicklung