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

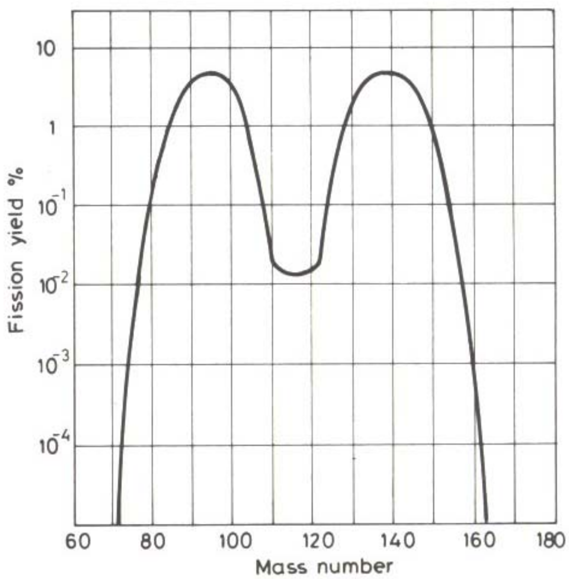


Fig. 6. Distribution of the fission products of ^{235}U as a function of the mass number

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.

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_1H) from reaction $^2_1H + ^2_1H \rightarrow ^3_1H + ^1_1H$	Depends on weapon design. Magnitude 10^4 Ci/kiloton[b] 10^{23} to 10^{24} atoms ^3_1H/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 $^{14}_7N + ^1_0n \rightarrow ^{14}_6C + ^1_1H$	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

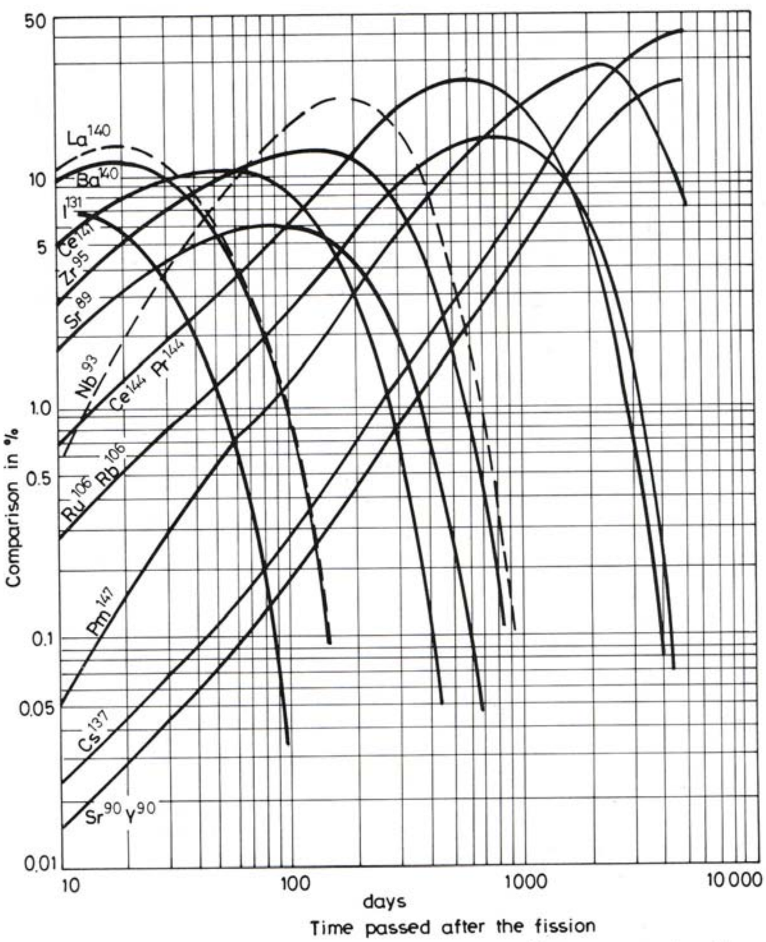


Fig. 8. Proportion of the radioactive isotopes produced in the fission of ^{235}U in the total radioactivity as a function of the time passed after the explosion

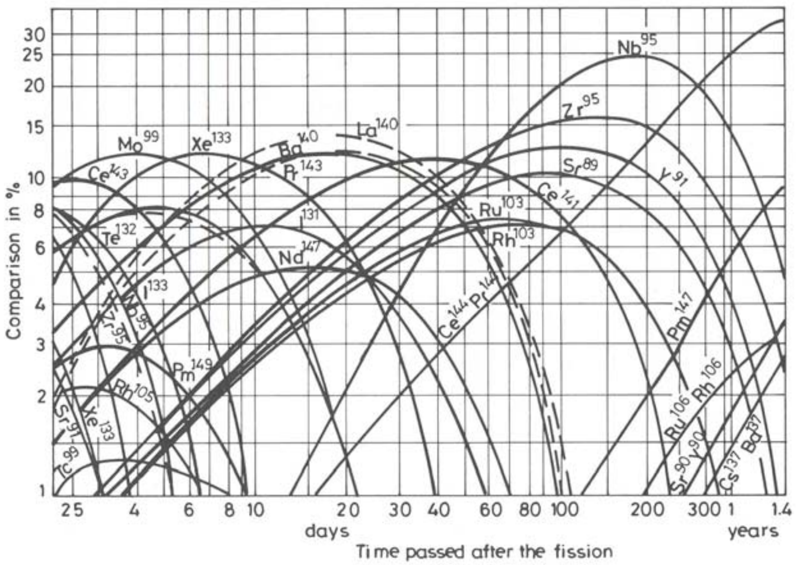


Fig. 7. Proportion of the radioactive isotopes produced in the fission of ^{235}U in the total radioactivity as a function of the time passed after the explosion

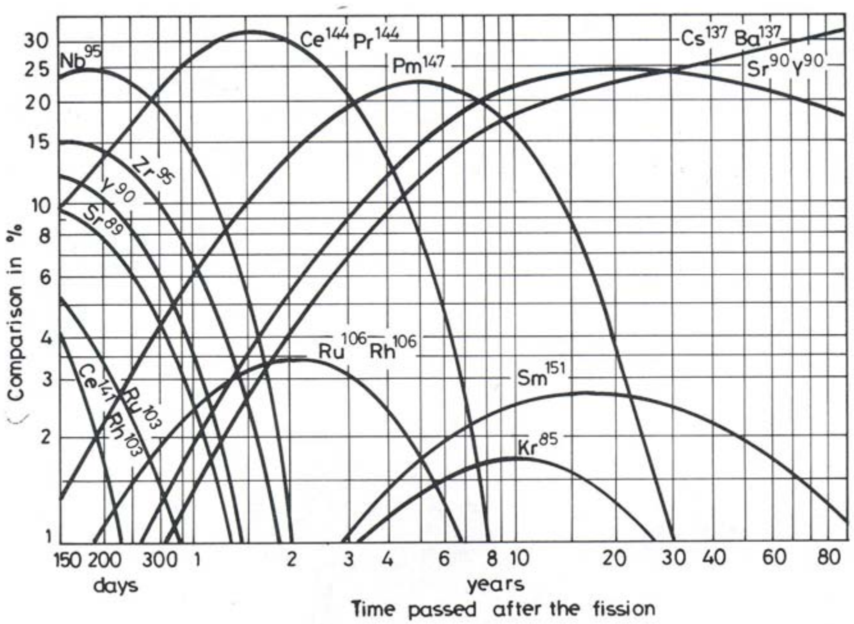


Fig. 9. Proportion of the radioactive isotopes produced in the fission of ^{235}U in the total radioactivity as a function of the time passed after the explosion

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

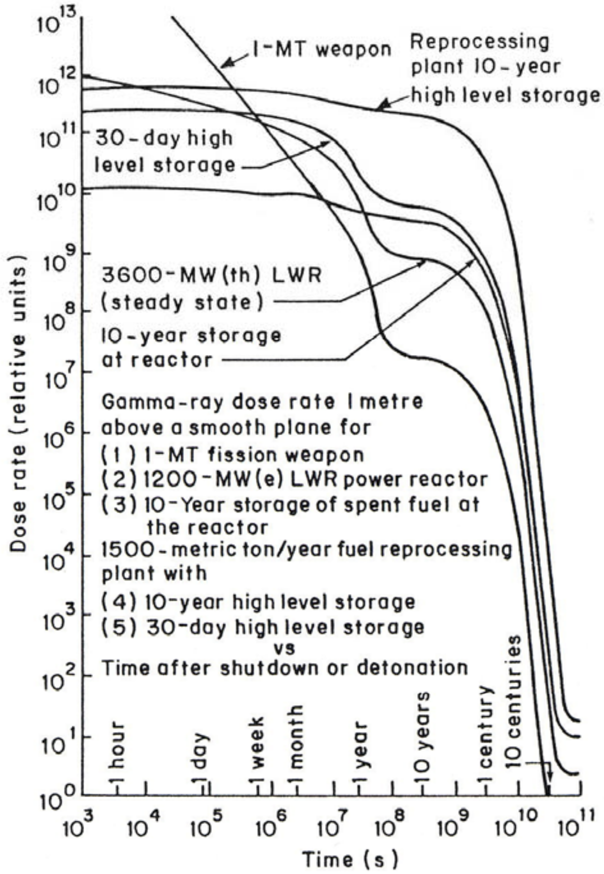


Figure 1.2 Gamma-ray dose rate area integral versus time after shutdown or detonation (Chester and Chester, 1976). The dose rate area integral is a measure of the radioactive inventory. (From Chester and Chester 1976; copyright 1976 by the American Nuclear Society, La Grange Park, Illinois).

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.

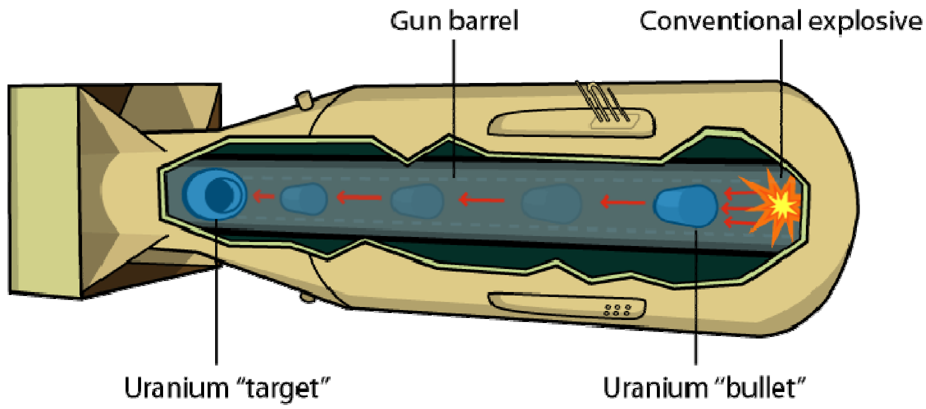
Aktivierungsprodukte

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

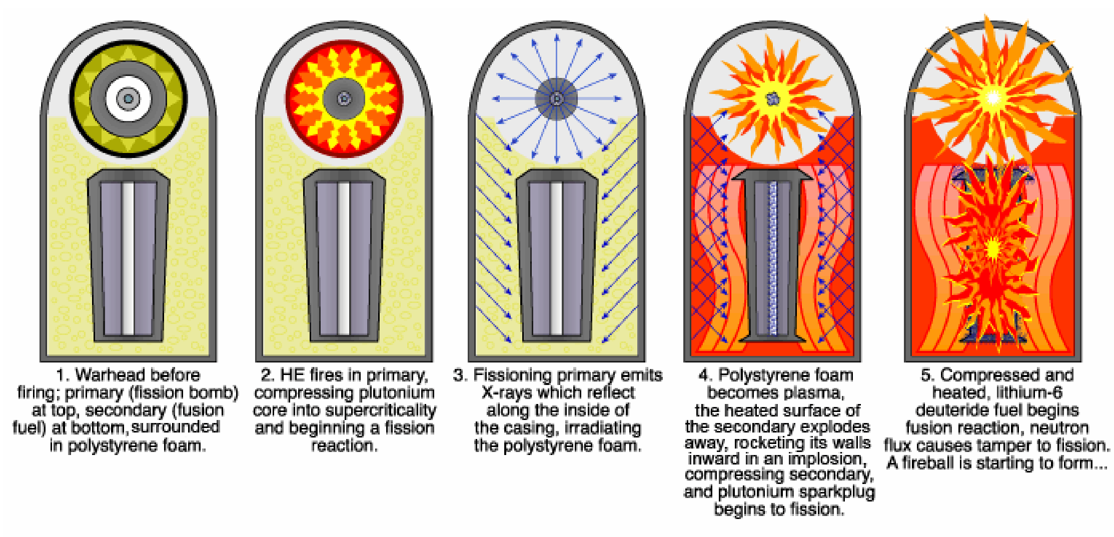
Radionuclide	Radiation	Half-life	Important element analogs
^{3}H	β	12.3 year	H
^{14}C	β	5568 year	C
^{24}Na	β,γ	15 hr	Na
^{32}P	β	14 day	P
^{35}S	β	87 day	S
^{41}A	β,γ	110 min	—
^{45}Ca	β	164 day	Ca
^{54}Mn	γ	291 day	Mn
^{55}Fe	χ (EC)[a]	2.6 year	Fe
^{59}Fe	β,γ	45 day	Fe
^{57}Co	γ	270 day	Co
^{58}Co	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