Nuclear Fue Cylce

Einzelne Stufen des „Cycles“

- **Aktivitätbilanz**

- **Zeitbilanz**

- **Massenbilanz**

Nuclear – Fuel Cylce: Von der Urangewinnung bis zur Endlagerung

NUCLEAR FUEL CYCLE

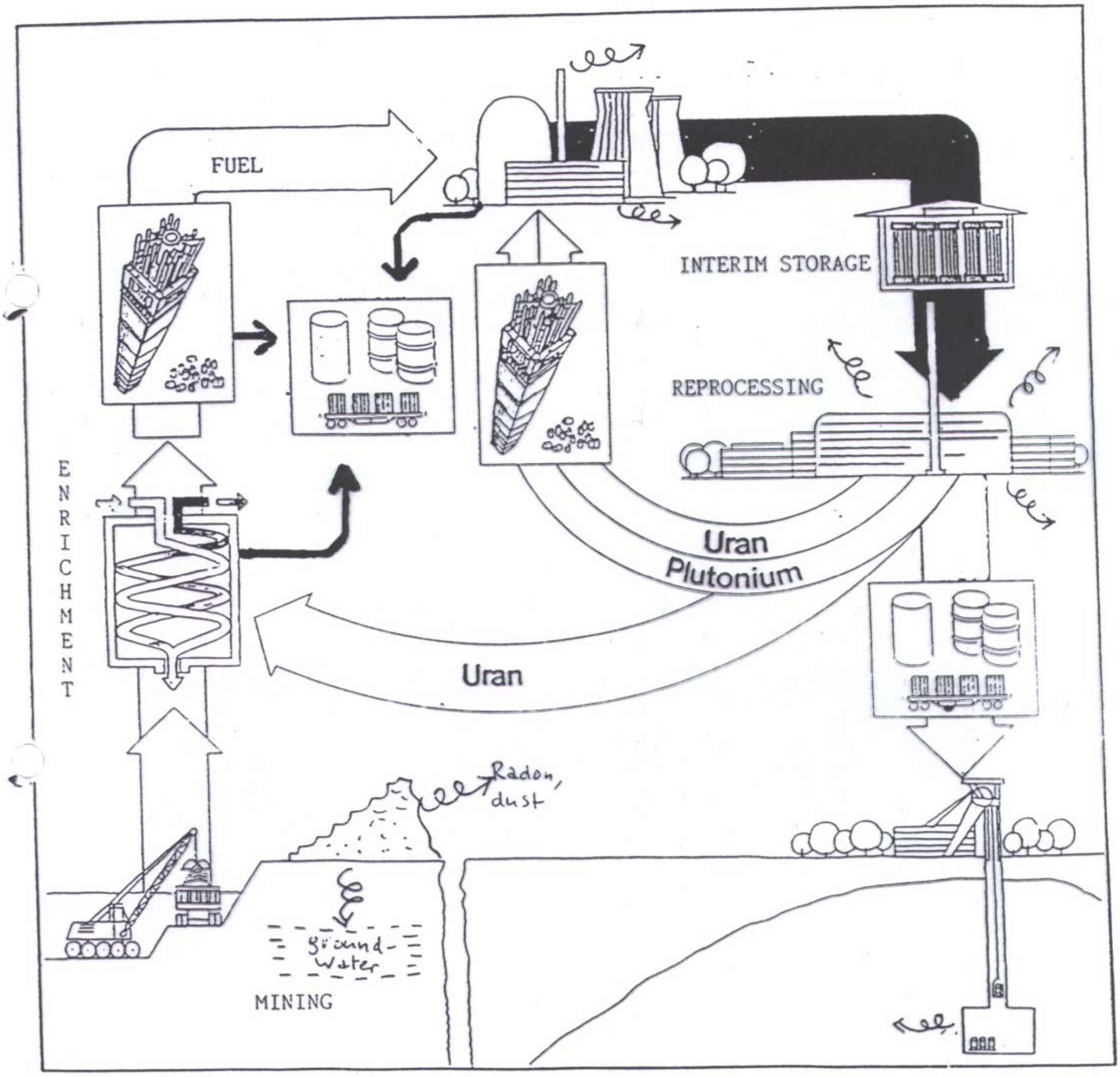
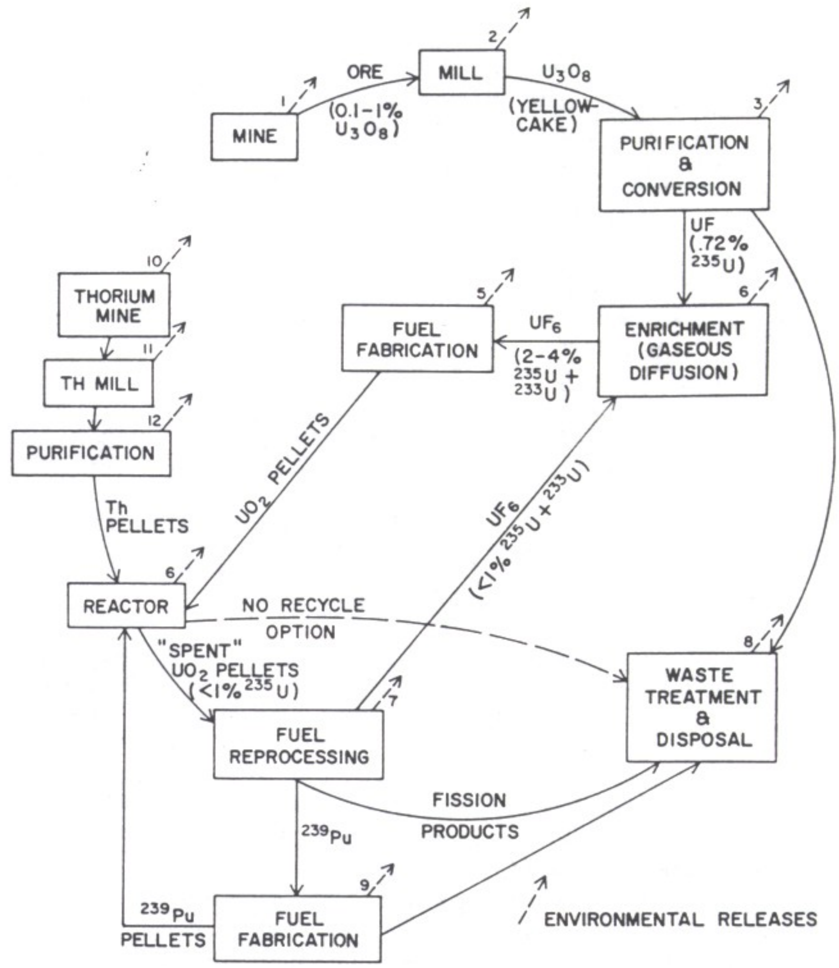


FIG. 1

Source: after DWK 1985

... effluents

Nuclear – Fuel Cylce



1 – U, Th, Ra, Rn, RnD
2 – Th, Ra, Rn, RnD, (U) + PROCESSING CHEMICALS
3 – NO_2, HF, CaF, (UF_6), (^{234}Th)
4 – HEAT, COAL FIRED EMISSIONS, (UF_6)
5 – CHEMICALS, F_2, HNO_3
6 – ^3H, ^{85}Kr, ^{133}Xe, ^{37}Ar, ^{131}I, OTHER FISSION PROD. (FP), HEAT
7 – ^{85}Kr, ^3H, ^{131}I, ^{129}I, OTHER FP, TRANSURANICS, MANY CHEM.
8 – LONG-LIVED FP, TRANSURANICS
9 – CHEMICALS, (Pu)
10 – Th, Ra, Rn, RnD
11 – Ra, Rn, RnD, (Th) + PROCESSING CHEMICALS
12 – CHEMICALS, Th

FIGURE 6. Basic elements and options within the nuclear fuel cycle, showing the kinds of materials that can be released to the environment.

Table 2
PRIMARY DECAY SCHEMES OF ^{238}U and ^{232}Th

Uranium-238			Thorium-232		
Radionuclide	Half-life	Radiation	Radionuclide	Half-life	Radiation
^{238}U	4.5×10^9 year	α,γ	^{232}Th	1.4×10^{10} year	α,γ
^{234}Th	24 day	β,γ	^{228}Ra	6.7 year	β,γ
^{234}Pa	1.2 min	β,γ	^{228}Ac	6.1 hr	β,γ
^{234}U	2.5×10^5 year	α,γ	^{228}Th	1.9 year	α,γ
^{230}Th	8×10^4 year	α,γ	^{224}Ra	3.6 day	α,γ
^{226}Ra	1620 year	α,γ	^{220}Rn	55 sec	α,γ
^{222}Rn	3.8 day	α,γ	$^{216}Po^*$	0.16 sec	α,β
$^{218}Po^*$	3.1 min	α,β	^{212}Pb	11 hr	β,γ
^{214}Pb	27 min	β,γ	$^{212}Bi^*$	61 min	α,β,γ
$^{214}Bi^*$	20 min	α,β,γ	^{212}Po	3×10^{-7} sec	α
^{214}Po	1.6×10^{-4} sec	α	^{208}Pb	Stable	None
^{210}Pb	19 year	β,γ			
$^{210}Bi^*$	5.0 day	α,β,γ			
^{210}Po	138 day	α,γ			
^{206}Pb	Stable	None			

MATERIAL AND RADIOLOGICAL BALANCES OF THE NUCLEAR FUEL CYCLE

The figures in the following *mass balance* are taken from (3). They are normalized to the annual consumption of a 1 GWe-NPP and reflect average industrial practice as concerns ore grade and tail assay.

MASS BALANCE

Mining	**440.000 t of rock → 40.000 t usable ore + 400.000 t discarded low grade ore.**
Milling	**40.000 t ore → 400 t yellow cake + 39.600 t tailings**
Conversion	**400 t yellow cake – 220 t UF6 + 180 t waste**
Enrichment	**220 t UF6 → 33 t enriched uranium + 187 t depleted uranium.**
Fuel fabrication:	**33 t enriched uranium → 33 t fuel + some LLW**
Reactor	**33 t fuel → 33 t spent fuel + low- and intermediate-level waste. According to the IAEA (4), a NPP produces 6.000 - 40.000 m³ of LILW in 25 years. The decommissioning waste is estimated to 7.000 - 17.000 m^3 ("230 truckloads a year for 6 years").**
Reprocessing	**33 t spent fuel -> 31.5 t uranium+0.3 t plutonium +1.2 t fission products and actinides (5) + effluents + LILW**

Currently a major problem is storage capacity for all sorts of wastes since disposal is not available at all for HLW and not available in necessary quantity for LILW. During 1990 alone, 10.000 t of spent fuel have been produced. The cumulated total was 115.000 t but the reprocessing capacity was only 4100 t uranium/year (for LWR fuel: 1800) in 1990. Thus the so far cumulated amount of spent fuel equals 20 years of reprocessing (6).

(3) J. Stellpflug: Der weltweite Atomtransport. Greenpeace report 2, rororo aktuell Hamburg 1987
(4) IAEA News feature N.6, 1990
(5) DWK 1985. A burn-up of 33 GWd/t is anticipated.
(6) IAEA yearbook 1991 part C

440.000 t ore → 33 t fuel

The *activity balance* looks quite different. During fission in the reactor, large quantities of radioactive fission and activation products are generated, some of which are very long-lived. The activities are the ones corresponding to the above quoted masses.

ACTIVITY BALANCE **(Activities produced per 1 GWe-NPP)**

Mining:	**10 PBq uranium (+ same activity of each progeny) in rock → 5.2 PBq ore + 5 PBq discarded low grade ore**
Milling:	**5.2 PBq uranium (+ same act. in each progeny) in ore → 5.2 PBq uranium in yellow cake + 5.2 PBq in tailings (in each Th-230, Ra-226 an so on).**
Conversion:	**5.2 PBq uranium in yellow cake → 2.9 PBq in UF6 + 2.3 PBq in waste**
Enrichment:	**2.9 PBq UF6 → 0.48 PBq enriched UF6 + 2.4 PBq depleted UF6**
Fuel fabrication:	**0.48 PBq enriched UF6 → 0.48 PBq fuel elements.**
Reactor:	**0.48 PBq → 2.2 10^8 PBq fission products and actinides (7) + LILW + effluents (very different)**
Interim storage of spent fuel, 7 years:	**in spent fuel 2.2 10^8 PBq → 3.7 10^5 PBq**
Reprocessing	**3.7 10^5 PBq in spent fuel → around 10^5 PBq in plutonium + 2.7 10^5 PBq in fission products and actinides + LILW + effluents (very different)**

10 PBq Uranium → 2.2 10^8 PBq in waste

Reactor operation increases the radioactivity by a factor almost half a billion. After 7 years of radioactive decay the radioactivity is still almost I million times higher than in the initial uranium ore. In the so-called *fuel cycle* a huge and costly amount of radioactive waste is produced

TIME BALANCE (roughly)

Reactor construction: **10 years**

Reactor Operation: **30 years**

Period between shut-down and decommissioning: **> 5 years**

Decommissioning: **5 – 10 years**

Interim storage of spent fuel before reprocessing: **> 5 years**

Interim storage of spent fuel before direct disposal: **?**

Interim storage of reprocessing waste before disposal: **?**

Isolation time of high-level waste: **some 100.000 years**

Isolation time of uranium mill tailings: **some 100.000 years**

An Isolation period of some 100.000 years is needed for the wastes produced during a lifetime of reactor operation.

(7) Inventory after 29.7 GWd/t burn-up according to: NG350 Marburg, Gruppe Ökologie Hannover: Bericht Wiederaufarbeitung 1, 1982