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Supplement of

Assessment of Partitioning and Transmutation of High-Level Waste and Hypothetical Implementation Scenarios in Germany

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Assessment of Partitioning and Transmutation of High Level Waste - Hypothetical Implementation Scenarios in Germany

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Overview

What is Partitioning & Transmutation?

- Fuel Cycle
- Criteria for Assessment
- Technology

Simulation

- Scenarios + Assumptions
- Separated Plutonium Stockpile
- Minor Actinide Stockpiles

Conclusion

Partitioning and Transmutation (P&T)

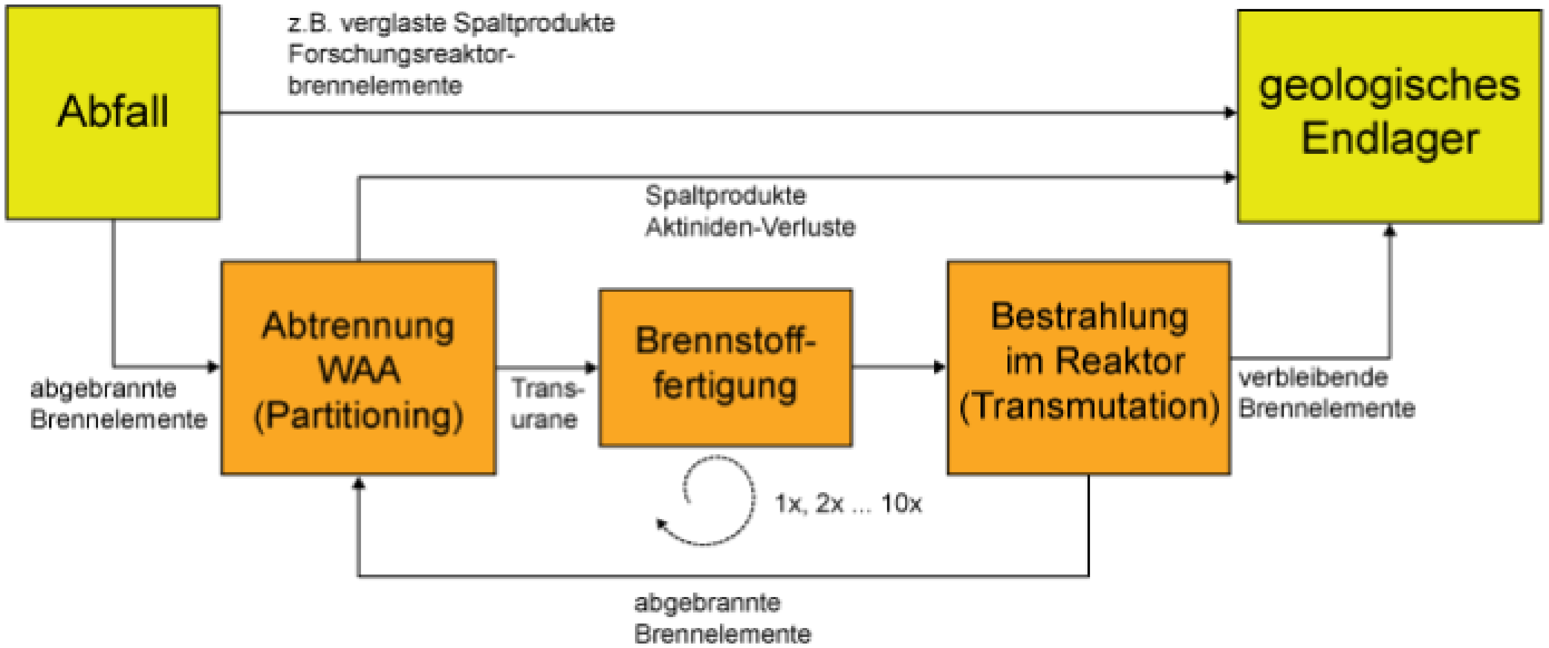
Partitioning: Separation of spent nuclear fuel into different material streams

- (short-lived) fission products
- Plutonium
- Minor Actinides (MA): Np, Am, Cm

Transmutation: Transformation of long-lived radionuclides into short-lived or stable isotopes

Goal: Significantly reduced requirements on long-term radioactive waste management

P&T Fuel Cycle



Source: Öko-Institut e.V.

Criteria for P&T Assessment

- Technology availability (needed R&D, development risks)
- Risks
  - Safety (new reactor types, various fuel compositions, regulations...)
  - Security (proliferation risks by access to weapons-usable materials)
  - Safeguards (new measures needed)
- Implementation period
- Effect on radioactive waste disposal (radiotoxicity vs. long-term safety, decay heat, volume)
- Overall energy production strategy (phase-out?)

Choices of Technology in P&T Fuel Cycles

Not available on industrial scale:

Reprocessing:

- Pyroprocessing
- Hydroprocessing (e.g. PUREX)

Fuel:

- Mixed-Oxide Fuel (MOX) with increased MA content
- Inert-Matrix fuel (IMF) - no Uranium
- Molten salt

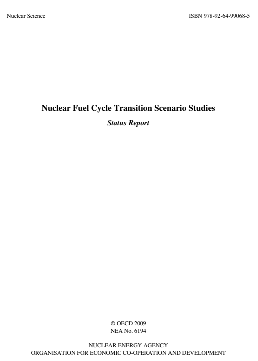
Irradiation facility:

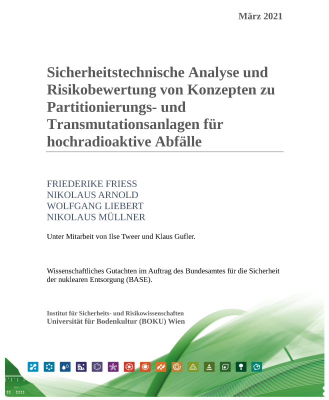
- Critical Fast Reactors (FR)
- Accelerator-driven systems (ADS)
- Molten-salt Reactors (MSR)

Modeling Goals and Challenge

P&T requires 5-10 irradiation cycles, depending on implementation path
⇒ analysis of different hypothetical scenarios

- How long would the scenario last?
- How many and what kind of facilities would be needed?
- What are the actual effects on waste streams & disposal requirements?





OECD/NEA 2009

acatech 2014

Öko-Institut e.V. / Universität Hamburg 2015

ISR 2021

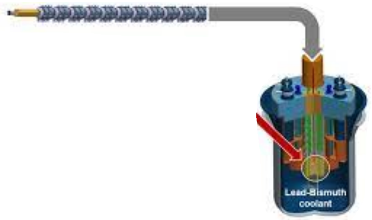
Scenarios

Scenario 1: FR (based on ASTRID)

- Hydrochemical reprocessing
- MOX fuel (MA enriched)

Scenario 2: ADS (based on EFIT)

- Inert matrix fuel (IMF)
- Pyrochemical reprocessing



Scenario 3: MSR (based on MOSART)

- Molten salt
- Pyroprocessing

Sources:GIF; www.bellona.org; www.duboichemicals.com

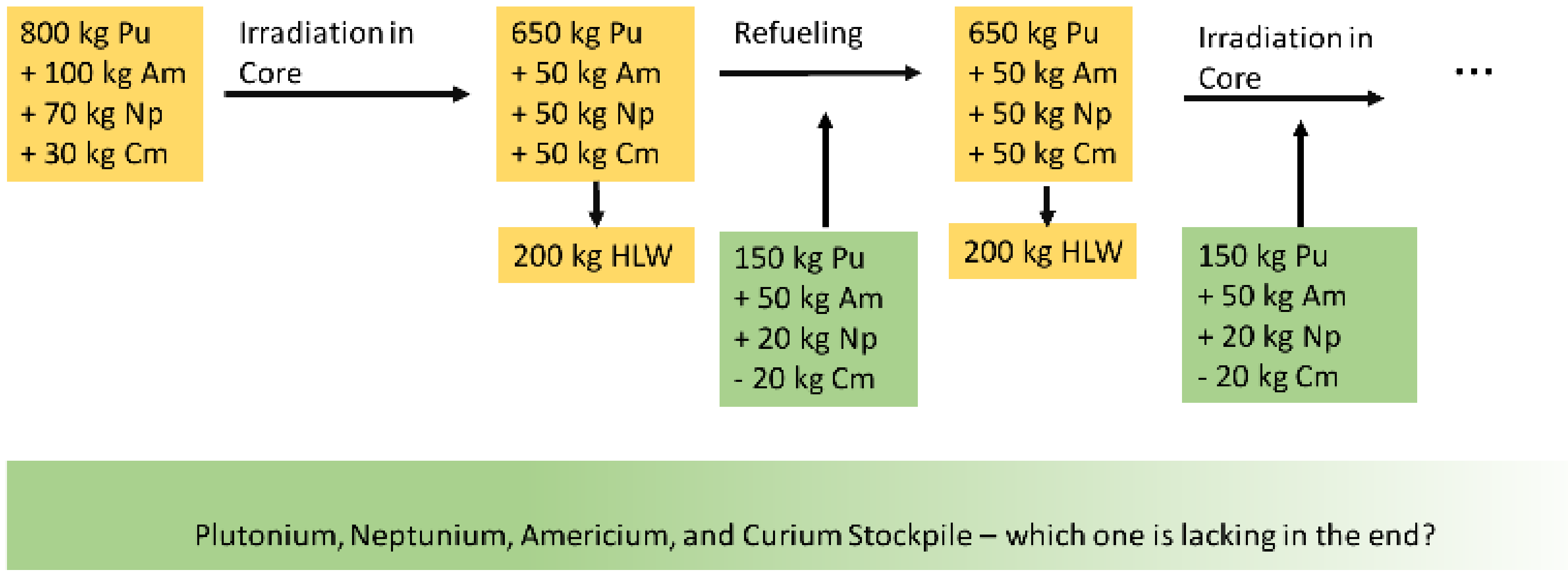
Fuel Composition in P&T Fuel Cycle

(U), Pu, MA fractions change with each irradiation cycle

$\Rightarrow$ Influence on reactor dynamics?

$\Rightarrow$ Adaption of reactor design?

Our assumption: element fraction constant - no adaption needed



Model Assumptions

- All necessary technology available on industrial scale
- P&T only suitable for spent fuel elements, not for vitrified waste
- Transmutation efficiencies per element, not per isotope
- No detailed modeling of fission products (estimate based on cross sections)
- Facilities are operated total lifetime
- Radioactive decay / Uranium inventory is not considered

Starting Situation - German Inventory

Element (group)	Fraction	Inventory 2022
Total	100.00%	10,113.0 t
Uranium	94.27%	9,534.0 t
Plutonium	1.27%	128.6 t
Minor Actinides (Np, Am, Cm)	0.21%	21.1 t
Fission Products	4.04%	408.1 t

Inventory 2022 estimated based on data from 2020.

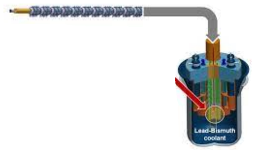
Scenarios & Facilities

Scenario 1: FR (based on ASTRID, 1200 MWth)

- max 8 facilities, 23 in total
- cycle length 11 years (hydroprocessing)
- total scenario length $\approx$ 300 years

Scenario 2: ADS (based on EFIT, 400 MWth)

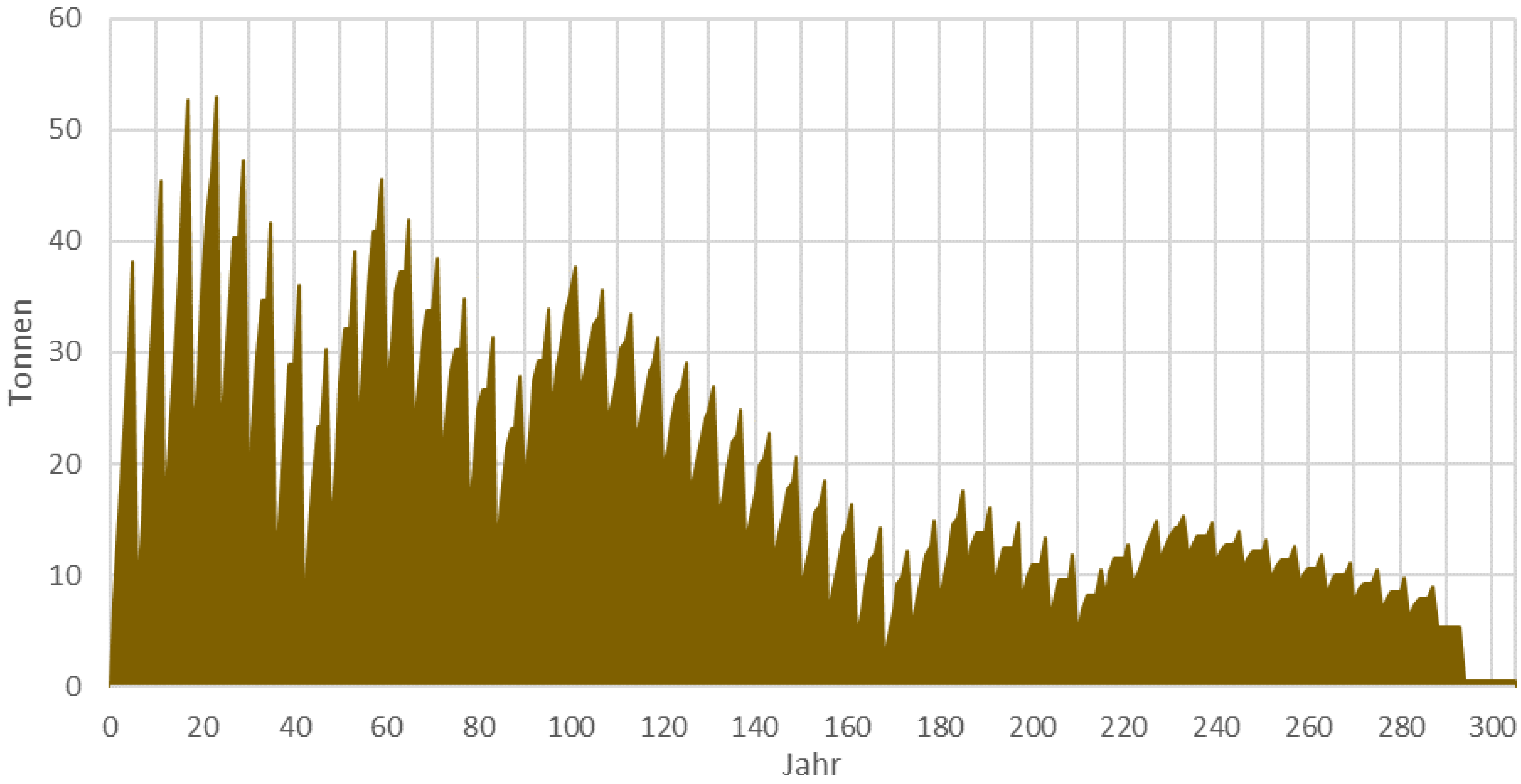
- 2 facilities, consecutively
- cycle length 7 years
- total scenario length $\approx$ 90 years



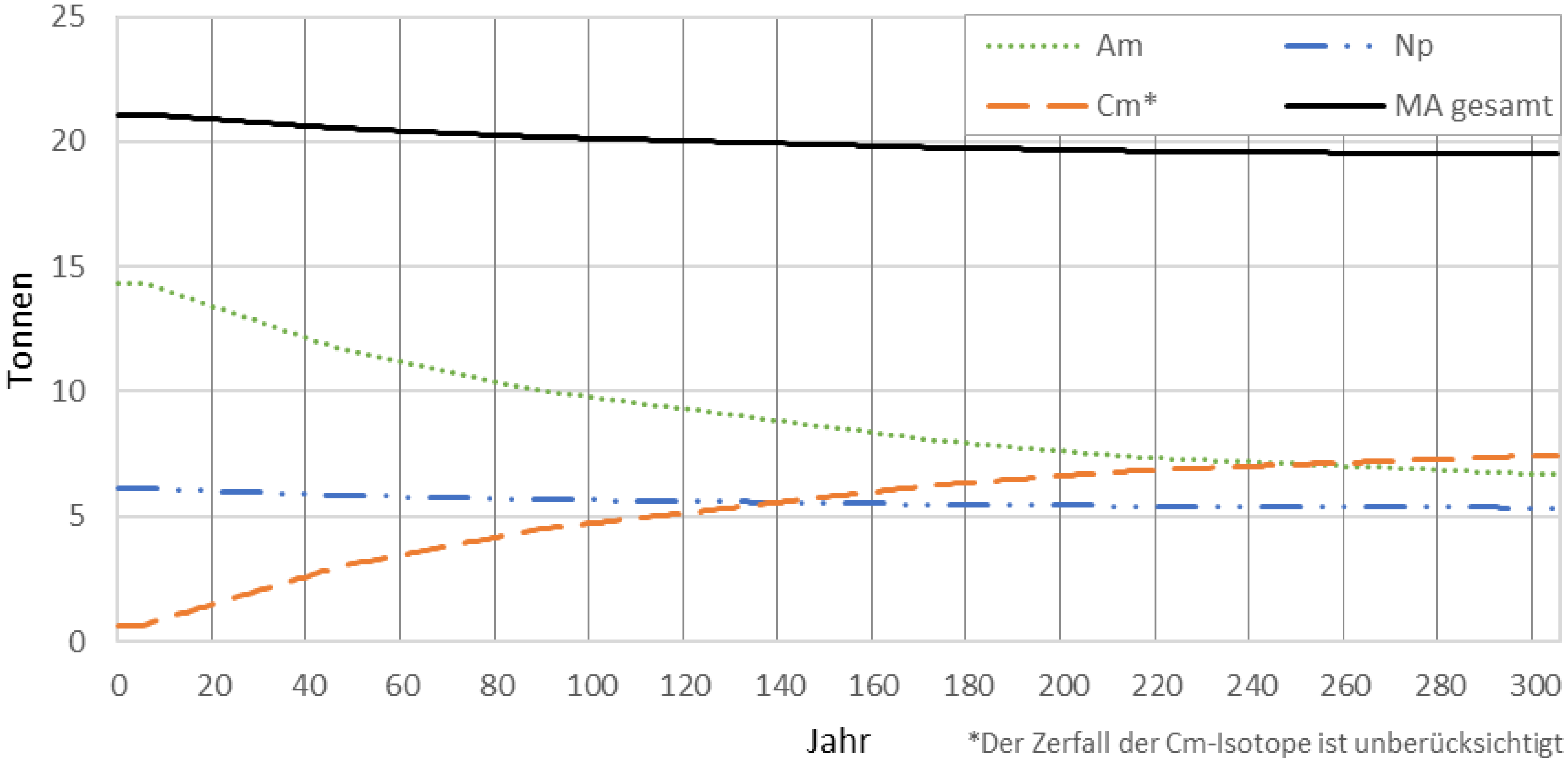
Scenario 3: MSR (based on MOSART, 2400 MWth)

- 3 facilities at the same time
- cycle length 1 year
- total scenario length $\approx$ 55 years

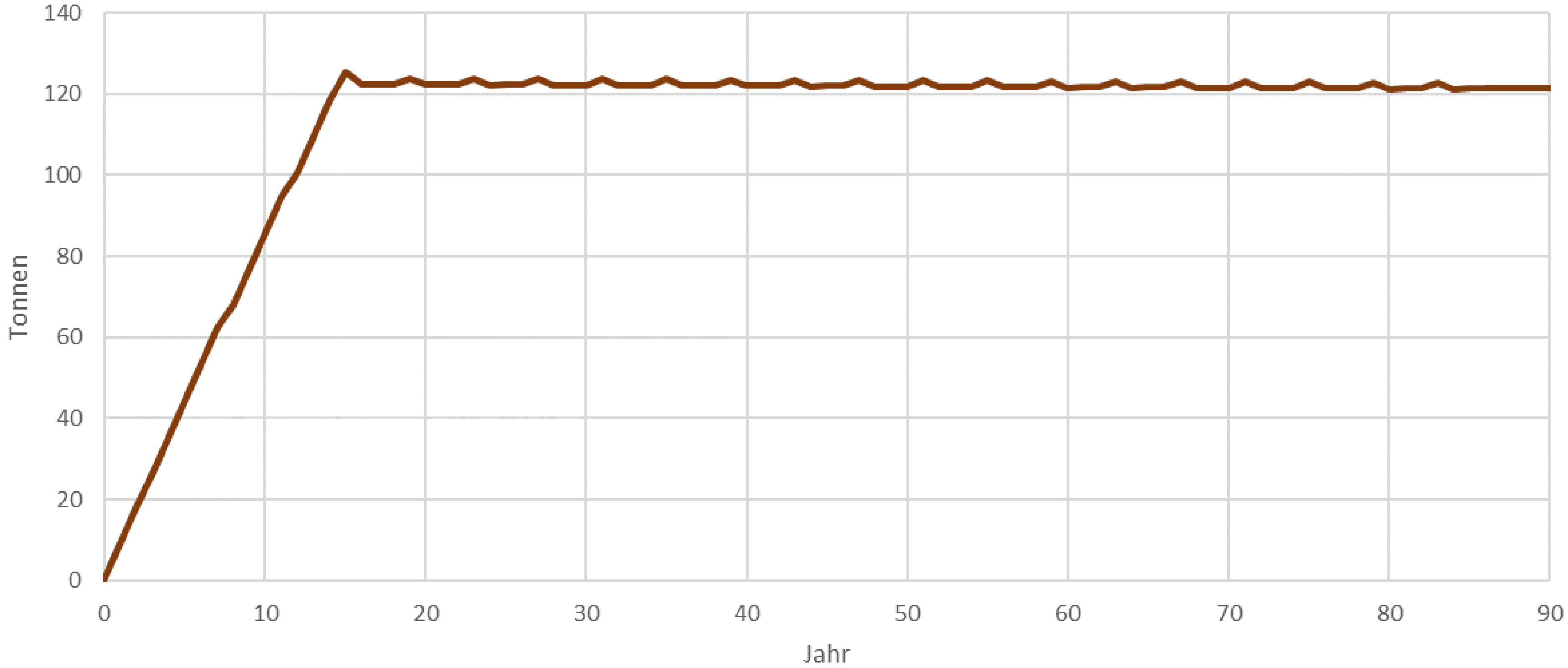
Separated Plutonium Stockpile - FR



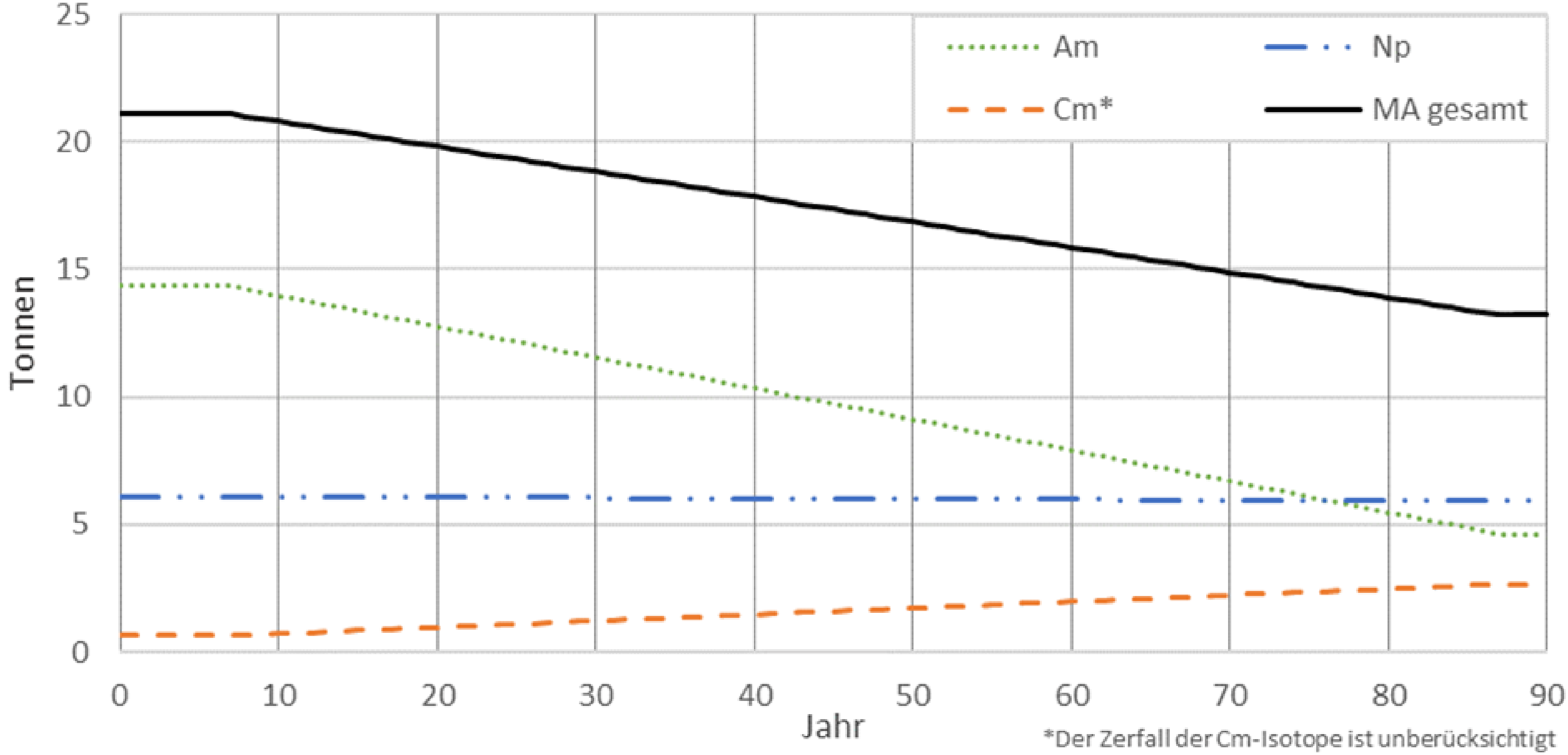
Stockpile of Transuranium Elements - FR



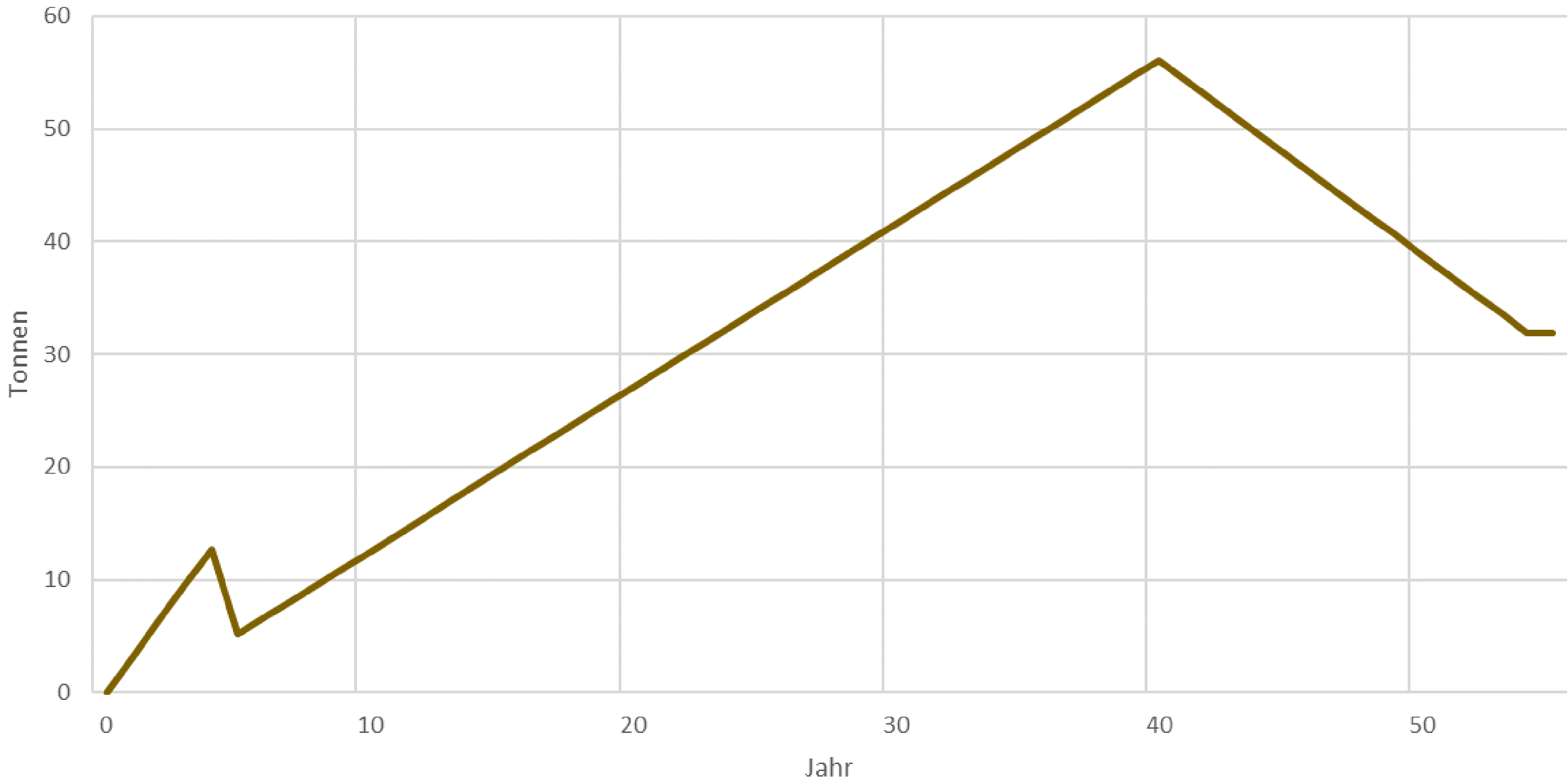
Separated Plutonium Stockpile - ADS



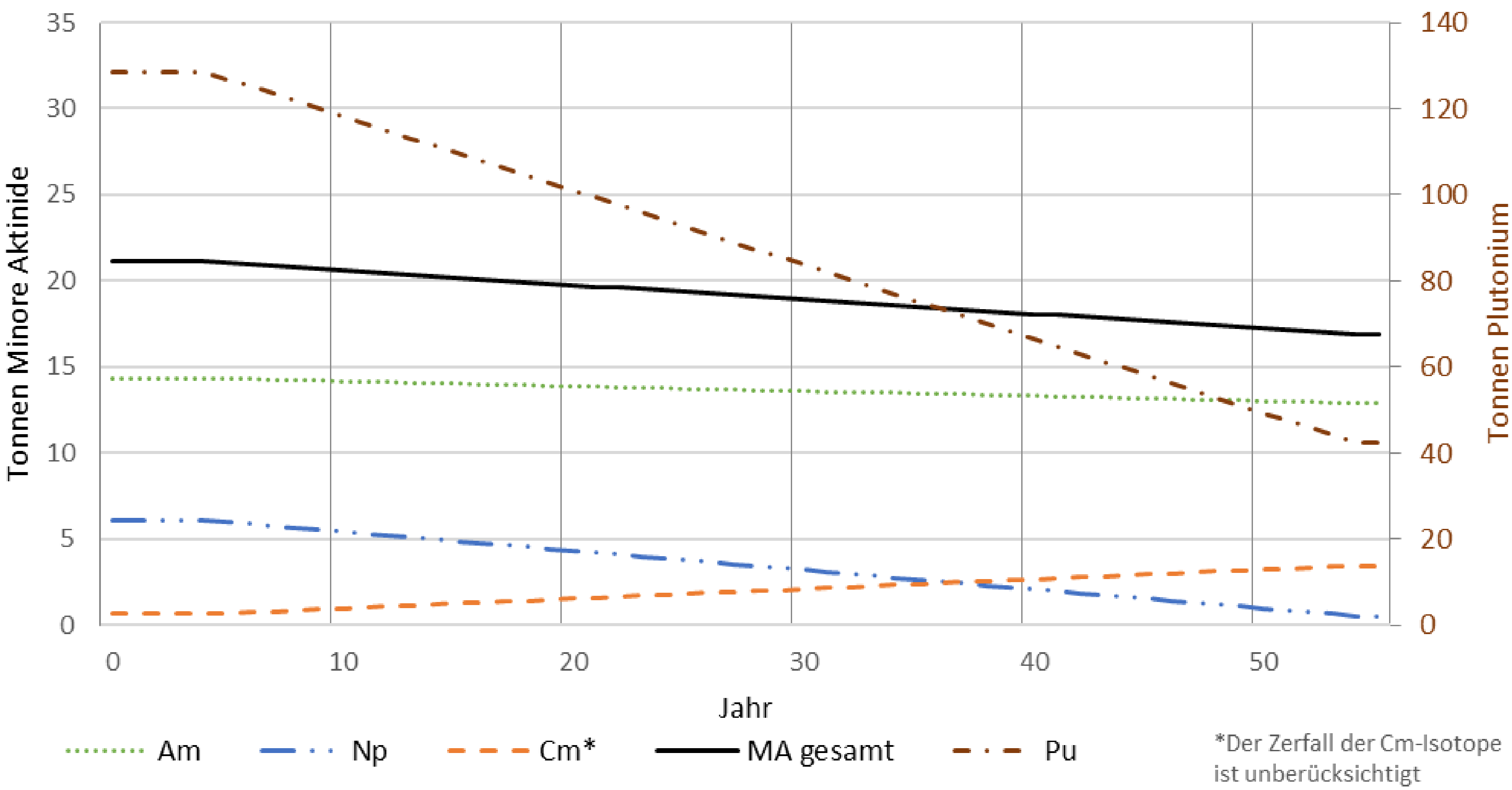
Stockpile of Transuranium Elements - ADS



Separated Plutonium Stockpile - MSR



Stockpile of Transuranium Elements - MSR



Additional Waste Streams

	FR	ADS	MSR
LLFP - Tc-99	+48%	+3%	+23%
LLFP - I-129	+63%	+3%	+27%
LLFP - Cs-135	+71%	+9%	+76%
HLW	2,300 m^3	7,400 m^3	7,350 m^3
Long-lived Waste	84,000 m^3	23,000 m^3	23,000 m^3
Dismantling	323,000 m^3	unknown	unkown

LLFP: Long-lived Fission Products
HLW: High Level Waste
Konrad Repository: 300,000 m^3

Conclusion I - Simulation Results

- P&T requires long-term operation of several advanced nuclear facilities
- Amount of low and intermediate level waste (LILW) increases significantly
- Stockpiles of long-lived fission products increase substantially
- high level waste (HLW) repository is needed in any case
- Separated fissile material, especially Plutonium is present / left
- Unresolved safety issues (changing fuel composition)

Conclusion II

- Technology not ready (decades of R&D)
- Reactor models fit to German situation are lacking
- Model assumptions of uttermost importance
  $\Rightarrow$ Significant impact on results
  $\Rightarrow$ more data needed
- P&T scenarios postpone final disposal of HLW / closing of deep geological repository

Following a P&T path would be a nuclear program for many decades (or even centuries).

Thank you

Frieß, F., Arnold, N., Liebert, W., and Müllner, N.: Sicherheitstechnische Analyse und Risikobewertung von Konzepten zu Partitionierungs- und Transmutationsanlagen für hochradioaktive Abfälle, Wissenschaftliches Gutachten im Auftrag des Bundesamtes für die Sicherheit der nuklearen Entsorgung (BASE), Berlin, 280 pp.,urn:nbn:de:0221-2021030826033, März 2021.

The report includes an English summary.

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