
KIT
Karlsruhe Institute of Technology

# MYRRHA ODER LÄSST SICH DIE PROBLEMATIK DER ENDLAGERUNG ENTSCHÄRFEN

Th. Walter Tromm, Programme Nuclear Waste Management, Safety and Radiation Research

# KIT – PART OF THE HELMHOLTZ ASSOCIATION

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**Helmholtz research centers**

| | |
|---|---|
| KIT | **Karlsruhe Institute of Technology** |
| DLR | German Aerospace Center |
| FZJ | Forschungszentrum Jülich |
| DESY | Deutsches Elektronen-Synchrotron |
| DKFZ | German Cancer Research Center |
| IPP | Max-Planck-Institute for Plasma Physics |
| HMGU | Helmholtz-Zentrum München |
| GSI | Helmholtz Center for Heavy Ion Research |
| HZB | Helmholtz-Zentrum Berlin für Materialien und Energie |
| AWI | Alfred-Wegener-Institute for Polar and Marine Research |
| HZDR | Helmholtz Center Dresden Rossendorf |
| UFZ | Helmholtz Center for Environmental Research |
| GKSS | Helmholtz-Zentrum Geesthacht – Center for Materials and Coastal Research |
| GFZ | Helmholtz-Zentrum Potsdam – German Research Center for Geosciences |
| MDC | Max-Delbrück-Center for Molecular Medicine |
| GEOMAR | Helmholtz Centre for Ocean Research Kiel |
| HZI | Helmholtz Center for Infection Research |
| DZNE | German Center for Neurodegenerative Diseases |

# NUCLEAR WASTE MANAGEMENT, SAFETY AND RADIATION RESEARCH

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## PARTICIPATING HELMHOLTZ - CENTRES

Forschungszentrum Jülich GmbH (FZJ)


HZDR HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF

Helmholtz – Zentrum Dresden – Rossendorf (HZDR)

KIT Karlsruhe Institute of Technology

Karlsruher Institut für Technologie (KIT)


≈ **9,780 employees**, including
≈ **385 professors**
> 3,100 doctoral researchers
> 2,000 postdoctoral researchers and staff scientists
≈ **22,500 students**

**1.090,7 Mio. € budget** *(Status 2021)*

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**The Research University in the Helmholtz Association**

- **University of Karlsruhe (1825)**
- **Research Center Karlsruhe (1956)**

→ merger to
**Karlsruhe Institute of Technology KIT (2009)**

**→ Institutional change as part of our DNA**
→ an excellent staff-student ratio

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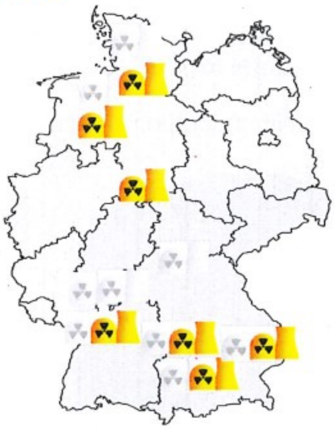
## 7TH GERMAN ENERGY RESEARCH PROGRAMME:

**Nuclear phase-out until 2022 in Germany**

- **but on an international level, nuclear energy has a long-term perspective.**
- **Political guidelines emphasize importance of nuclear competence in Germany beyond 2022**

- Preservation of the necessary national expertise also for the **participation in national and international committees** remains absolutely necessary.
- Including **sufficient personnel resources**
- It is in Germany's long-term safety interest to be able to monitor developments in neighbouring countries with regard to **existing and planned plants** from a technical point of view.
- Including **alternative disposal strategies** as well as disposal strategies pursued abroad



Federal Ministry
for Economic Affairs
and Energy

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# ABOUT MYRRHA

### THE WORLD'S 1ST LARGE SCALE ACCELERATOR DRIVEN SYSTEM

MYRRHA (**M**ulti-purpose h**Y**brid **R**esearch **R**eactor for **H**igh-tech **A**pplications) is the world's first large scale Accelerator Driven System (ADS) that consists of a subcritical nuclear reactor driven by a high power linear accelerator. With the subcritical concentration of fission material, the nuclear reaction is sustained by the particle accelerator only. Turning off the proton beam results in an immediate and safe halt of the nuclear reactions.

**MYRRHA consists of 4 major components:**

- **The linear accelerator (linac)**
- **The lead-bismuth eutectic (LBE) cooled reactor**
- **The Proton Target Facility (PTF)**
- **The Full Power Facility (FPF)**

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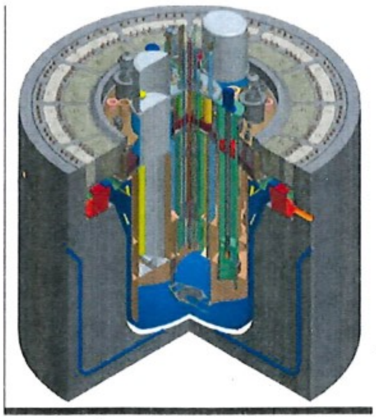
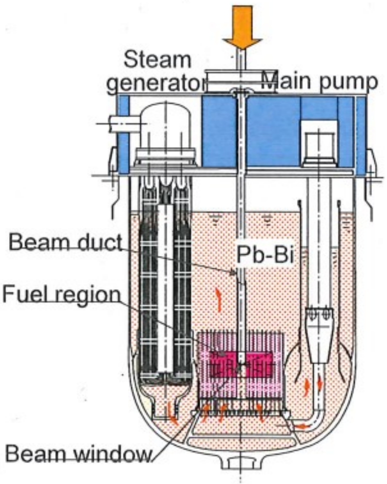
# MYRRHA: MACHINE FOR TRANSMUTATION

- Proton accelerator (**Linac** or Cyclotron)
- Spallation target for the production of high-energetic neutrons
- Sub-critical configuration (reactor core) with Pu and MA





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## FAST REACTORS / ADS IN EUROPE

ESNII

2025

- **ASTRID** SFR Prototype — Reference Technology: Design, Construction & Commissioning — Na
- **MYRRHA** Flexible Irradiation Facility — Supporting Infrastructure: Design, Construction & Commissioning — LBE
- **ALFRED** LFR Demonstrator — Short-term alternative Technology: Conceptual design, siting, & supporting R&D — Pb
- **ALLEGRO** GFR Demonstrator — Long-term alternative Technology: Conceptual design, siting, & supporting R&D — He

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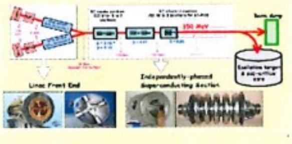
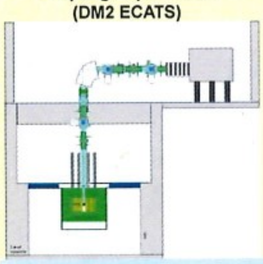
## ADS DEMONSTRATION: THE EUROTRANS PROJECT

**Accelerator development (DM1 DESIGN)**

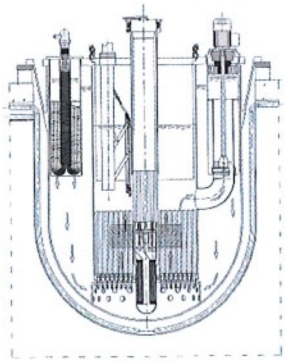


**Coupling Experiments (DM2 ECATS)**



GUINEVERE Experiment at SCK-CEN

**Design of an experimental (XT-ADS) and an industrial (EFIT) system (DM1 DESIGN)**



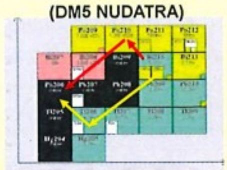
EFIT

**U-free MA Fuel Development (DM3 AFTRA)**

| CERCER MgO | CERMET Mo |
|---|---|

**Liquid metal technology, thermal-hydraulics and materials studies (DM4 DEMETRA)**

**Nuclear Data (DM5 NUDATRA)**



## KIT CONTRIBUTIONS TO TRANSMUTATION PROJECTS, I.E. MYRRHA

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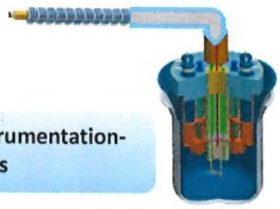
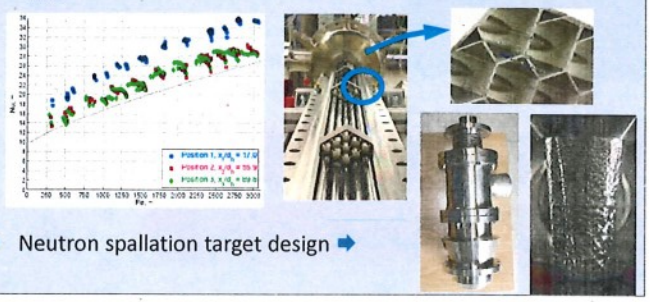


- Key technologies and physics
- Design and performance
- Competence preservation and development

**thermal-hydraulics-instrumentation-components**

**Heat transfer in HLM-cooled rod bundles:**

- $T_{max}$, T', Nu-correlations, validation data for CFD, ...



- Neutron spallation target design ➡

THINS
SEARCH
MAXSIMA
**MARISA**

## KIT CONTRIBUTIONS TO TRANSMUTATION PROJECTS, I.E. MYRRHA

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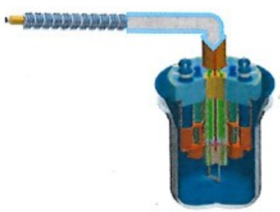
- Key technologies and physics
- Design and performance
- Competence preservation and development

**tailored materials**
**coolant chemistry control**



*Corrosion - corrosion protection*
In-situ oxidation against dissolution attack

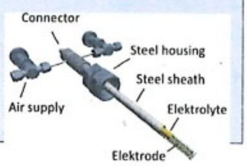
- Advanced surface alloys – GESA
- New advanced materials (ODS, SiCSiC)
- Mechanical properties (LM degradation)
  - fretting, erosion, creep
- Model development – Simulation

*Coolant chemistry*

Experiments &Simulation

- New oxygen sensors
- Oxygen transport
- Impurity control

Liquid metal




GETMAT LEADER MATTER SEARCH ESNII+ MatISSE

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## EU-PROJECT PATRICIA: FUEL ROD BUNDLE EXPERIMENTS WITH LIQUID METAL LBE

PATRICIA

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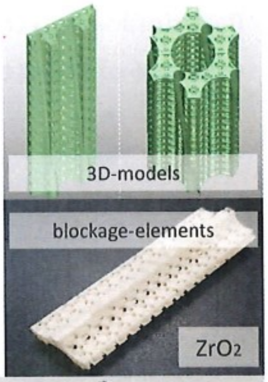
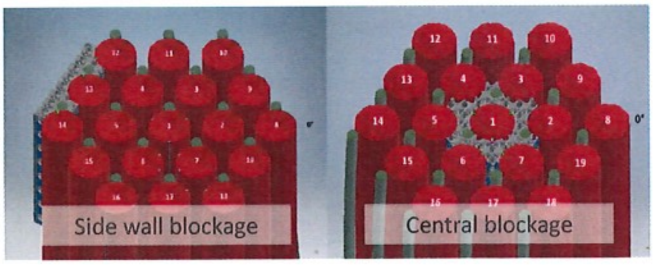
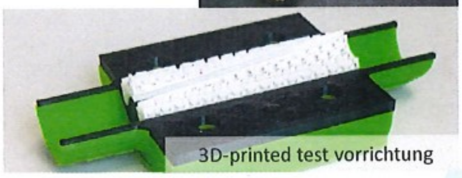
- Successful development of 3D(LCM)-printed porous structured ceramic blockage elements ($ZrO_2$ , l=3 W/mK)
  - → pressure losses (test structure by ITES-3D-printer)
  - → built in existing rod bundle (MAXSIMA)
    2022 – experiments in THEADES loop

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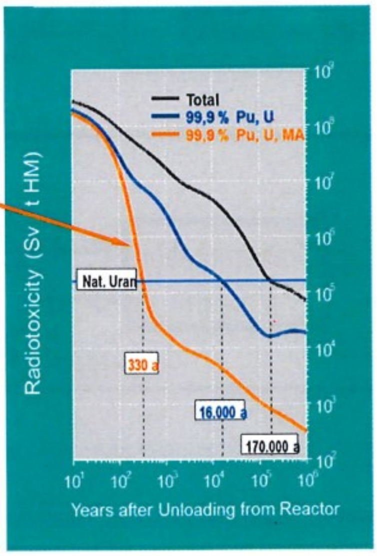
## REDUCTION OF RADIOTOXICITY

- **Partitioning and transmutation of 99.9% of Pu, U and MA**

**Achievement**

**Disposal times are shifted from geological to historical time scales.**



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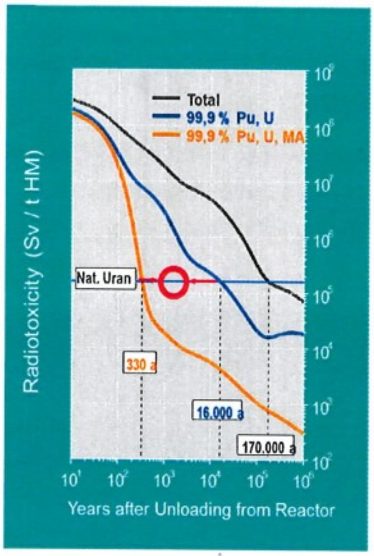
## REDUCTION OF RADIOTOXICITY

- **Partitioning and transmutation of 99.9% of Pu, U and MA**

$$\varepsilon_{PT} = \frac{\varepsilon_P \varepsilon_T}{1-(1-\varepsilon_T)\varepsilon_P}$$




Point of operation, considering losses and efficiencies

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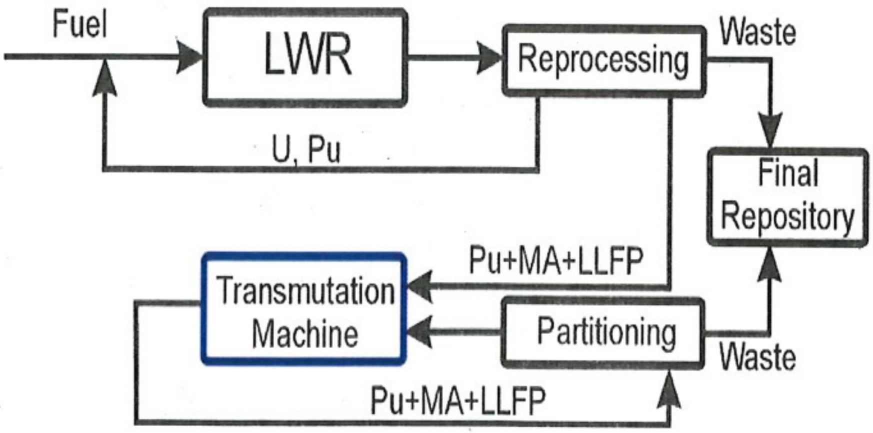
## FUEL CYCLE WITH P&T




- **Strategy: Separation and destruction of plutonium and minor actinides in a transmutation machine.**
- **Advantage: Reduction of radiotoxicity, volume and heat quantity of the waste to be placed in a repository.**

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# PARTITIONING

# AND

# TRANSMUTATION

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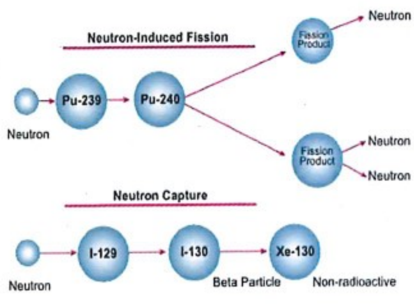
# PARTITIONING & TRANSMUTATION




**Procedure:**

- Separation of long-lived, highly radioactive radionuclides (Pu, MA, LLSP) of the high-level waste
- Transmutation of the highly radioactive elements into short-lived and/or stable elements by neutron-induced fission or by neutron capture reactions.

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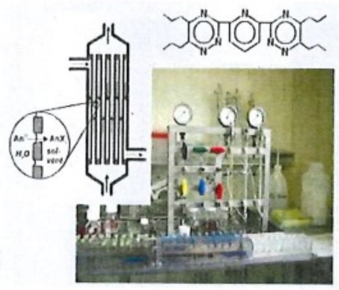
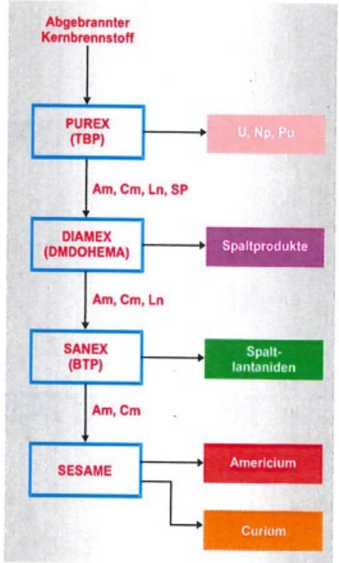
# PARTITIONING

- Basic investigations
- Process-design

⇨ Feasible in lab-scale



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# SCENARIOS DEVELOPED BY OECD/NEA AND EU

| | Scenario | Characteristics | Remarks | HM Loss Waste kg/TWhe |
|---|---|---|---|---|
| Near Term Scenarios | A1 (dir. disp.) | Once through fuel cycle in Gen II & III reactors | 50 GWd/THM @ 4.2% $^{235}U$ cooling 50 years | 1920.0 |
| | A2 | Mono-recycling of Pu in Gen III reactors | 2020 | 10.7 |
| | A3 | Multi recycling of Pu in Sodium Fast reactors | 2040 | 1.4 |
| Evolutionary Scenarios | B1 | Multi recycling of U, Pu and MA in Gen IV reactors | 2040 | 1.9 |
| | B2 | Mono recycling of Pu in Gen III reactor + Burning of Pu and MA in ADS | 2040 | 0.8 |
| | B3 | Mono-recycling of Pu in Gen III reactor + Multi-recycling of Pu in Gen IV Reactor + Burning of MA in ADS | | 0.8 |

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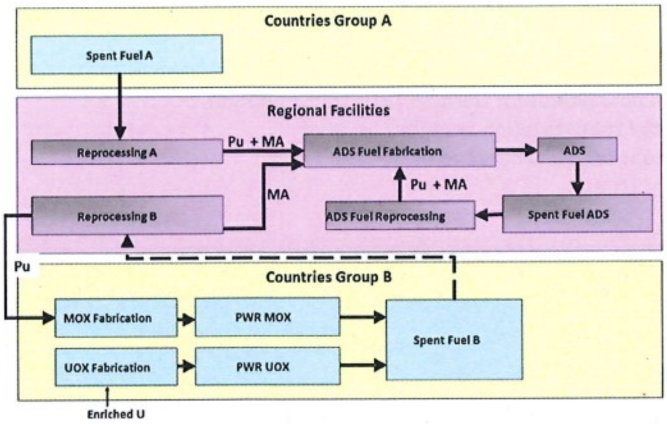
# „DOUBLE STRATA“ SCENARIO LAYOUT AS AN EXAMPLE




Salvatores et al. (KIT and CEA)

- Actual data (e.g. spent fuel inventories) are provided from e.g. *France and Germany, ..., in the framework of a European project.*
- Results obtained have confirmed P&T potential to meet objectives.

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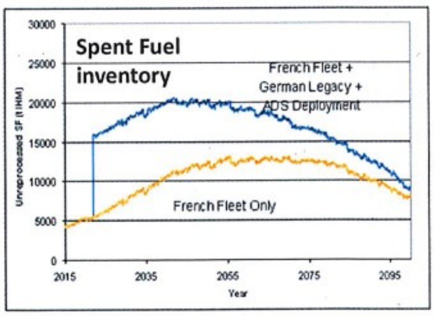
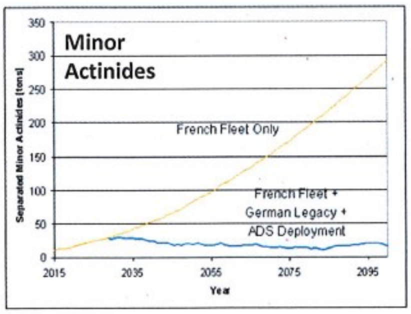
# „DOUBLE STRATA“ SCENARIO LAYOUT: E.G. FRANCE AND GERMANY




Schwenk-Ferrero et al., KIT

- Combination of ‘wastes’ from D and F in 2022.
- German Pu is used as fuel in France until 2100.
- Minor Actinides (MA) will be burnt in Accelerator Driven Systems (ADS) starting from 2030.
- Calculated with COSI Code (Dynamic Modular Fuel Cycle Analysis Tool).

## ACATECH STUDY ON PARTITIONING AND TRANSMUTATION, 2014

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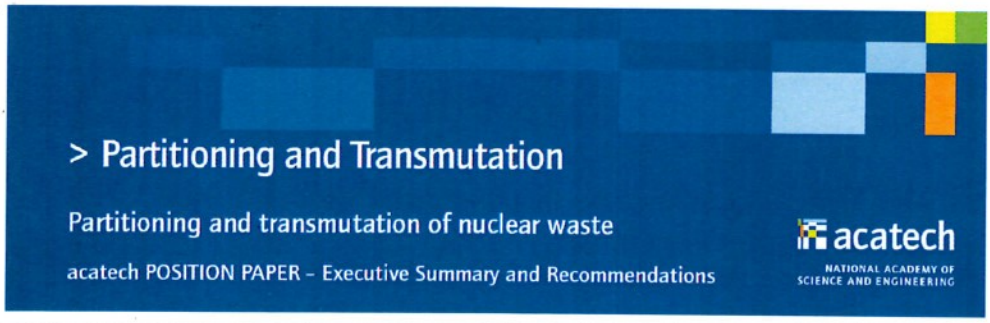
Helmholtz has been deeply involved in this interdisciplinary ACATECH study:

- P&T for **German nuclear waste management options.**

**Objective: Definition and assessment of the possible scenarios for P&T implementation.**

In particular:

- **Nuclear waste characterization** (+ evolution after planned NPP shutdown in 2022),
- Definition of **principal possibilities for German TRUs transmutation,**
- Assessment of **potential transmutation benefits,**
- **Scenario/system options for transmutation of German TRUs,**
- Technology and safety issues.

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## ACATECH STUDY ON PARTITIONING AND TRANSMUTATION, 2014

### P&T OPPORTUNITIES (FOR GERMANY)

- If rolled out successfully on an industrial scale, P&T could significantly reduce the volume of heat-generating waste destined for permanent disposal by as much as a third (from 28,000 to 9,500 cubic metres).
- By deploying P&T, it is possible to reduce the total radioactivity level in the repository for heat-generating waste just a few centuries after the waste is stored, thus also reducing its hazard potential. The level of radioactivity (or weighted radiotoxicity value) in the repository for highly radioactive heat-generating waste is roughly the same after 1,000 years as it would be after 1,000,000 years if P&T had not been deployed.
- The risk of plutonium being stolen from the repository and used for illicit purposes is reduced. Since the separated plutonium is transformed into other isotopes at transmutation facilities, only negligible quantities of it make their way into the permanent repository. This becomes particularly important once the automatic protection provided by the high local radiation dose rate has diminished.
- After partitioning, the mobile fission and activation products that were separated from the spent fuel and now require permanent disposal can be more effectively conditioned (e.g. by immobilising the waste in a matrix). This lowers the risk of them leaking from the spent fuel, thereby reducing the long-term risk of them contaminating the biosphere.

## ACATECH STUDY ON PARTITIONING AND TRANSMUTATION, 2014

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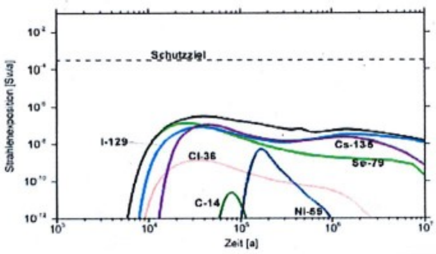
**P&T RISKS**

- The P&T facilities that would have to be built could pose a threat to both human beings and the environment. The risk is similar to that of operating plants for reprocessing or conditioning spent fuel rods or Gen IV nuclear reactors.
- The volume of waste with negligible heat generation would increase by around a third (from approx. 300,000 to approx. 400,000 cubic metres).
- During the 150 or so years during which P&T would be deployed, there would be an increased risk of radioactive materials being misused by third parties. Depending on the process employed, partitioning produces both plutonium and minor actinides either in pure or compound form.
- According to currently available safety analyses it has a negligible impact on the risk of radiation leaking from the repository.

- Salz

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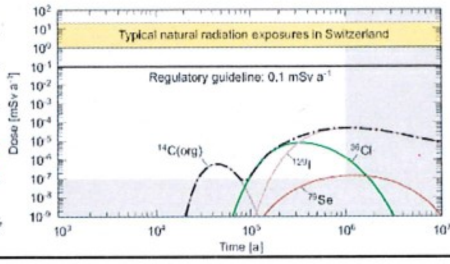


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## CONCLUSIONS

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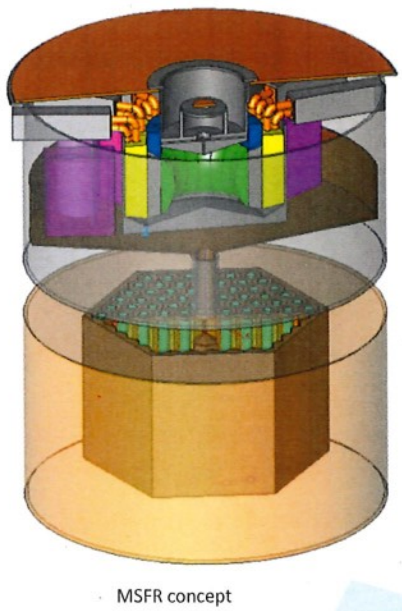
- **Wastes from nuclear power plants can be treated by P&T to reduce their radiotoxicity, volume and heat load, but all losses have to be disposed of in a final repository.**
- **P&T is an international endeavour, possibly to be implemented in a regional approach.**
- **Considerable R&D is still required to realise this technology.**
- **Future European infrastructures such as MYRRHA or MSFR concepts will be able to demonstrate the availability and capability of transmutation**
- **The Helmholtz Association, FZJ, HZDR and KIT, contributes with scientific expertise for partitioning and transmutation.**



MSFR concept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Thank you for your attention
Th. Walter Tromm
Karlsruhe Institute of Technology
KIT Energy Center