Non-proliferation Aspects of Advanced Recycling for Fast Reactors Fuel Cycle. Overview

Alexander Bychkov - international expert
Ex-DDG-NE IAEA (2011-2015)
R&D activity on Fast Reactor Fuel Cycle – 1982 - 2011 (RIAR, Dimitrovgrad)

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Sometimes it's useful to blow dust off old books.

Content of the overview

- Brief Historical overview - not analysis
- Consideration of technological and infrastructure aspects of fast reactor fuel recycling
- Highlighting of some Specific Characteristics of Current and Advanced Approaches for FR fuel recycling
- Brief listing of International Studies related safeguard aspects for advanced approaches for FR fuel recycling

Beyond of overview:

- Pu isotopic composition subjects
- Current Rosatom's PRORYV Project and other modern national projects

Technological approaches for FR fuel recycling(1)

Current (well-established)industrial reprocessing based on PUREX-process.

This technology is applicable for FR SNF reprocessing, including irradiated MOX fuel. This has been demonstrated at existing SNF reprocessing plants for power reactors. Products - uranium and plutonium oxides with high decontamination factors from fission products (around 10^8) – are ready for MOX-pelletaizing.

Various options are possible, such as FR SNF reprocessing together with LWR fuel when mixing a fraction of FR MOX at the cutting-dissolution stage, or separate processing, which, however, requires a limit on criticality.

The results of MOX-fuel reprocessing by PUREX-based processes were published in France, Russia, Japan and other countries.

Russian reprocessing complex - MAYAK Plant - operates on a regular basis with the BN-600 reactor's uranium spent fuel

Technological approaches for FR fuel recycling(2)

Advanced aqueous-based and low-temperature methods are under development:

- Advanced processes based on aqueous extraction or precipitation, including processes without separation of U and Pu.
- Advanced methods for minor-actinide (MA) recycling
- Other low temperature methods, as example, are based on room-temperature ionic liquids or on critical CO_2 extraction.

All these methods, as a rule, have been tested only at the laboratory level.

Two projects with the introduction of improved technologies are close to industrial implementation:

- Reprocessing plant in Japan at Rokkasho-mura - incomplete separation of uranium and plutonium, and the production of their mixture.
- Experimental and Demonstration Center was commissioned in Russia in 2025 - designed to test new aqueous-based reprocessing technologies with reducing of radioactive waste generation.

Technological approaches for FR fuel recycling(3)

The second line of RD&D for FR SNF recycling is high-temperature processes.

High temperature recycling process:

- Pyro-process (electrorefining, electrowinning, precipitation etc.) in molten salts (chlorides, mainly) tested with FR SNF on pilot – low DF (100-1000)
- Fluoride volatility process is based on fluorination of SNF that also was demonstrated on limited amount of short-cooled FR irradiated fuel. Currently this method is considered as part of combined reprocessing systems.
- Other methods with limited chemical operations are based on Oxidation-Reduction methods (ex. DUPIC) or melting.

Combination of pyro-process and aqueous methods (FLUOREX, Preliminary selected process of UPuN recycling for BREST reactor and so on).

Only two labs have conducted pilot tests on real FR SNF reprocessing and recycling – INL and RIAR for EBR-II and BOR-60.

Infrastructural approaches for FR fuel recycling

Using of current industrial reprocessing approach:

- At reactor intermediate storage of FR SNF
- Transportation system for FR SNF
- Central reprocessing plant based on PUREX or some advanced aqueous (or combined) processes
- Storage facilities for Pu-contained materials
- Centralized FR fuel refabricating facilities
- Transportation system for fresh FR fuel.

On-site recycling:

- Reprocessing/refabricating facilities on Fast reactor(-s) site
- Advanced and simplified reprocessing/recycling technologies
- No transportation outside site

Specific Characteristics of Current and Advanced Approaches for FR Fuel Recycling

Current Industrial SNF reprocessing by PUREX aqueous process:

- **Continues process – technological flows control as periodic mass balance control. Complete mass balance control on last stages.**
- **Two approaches for FR SNF:**

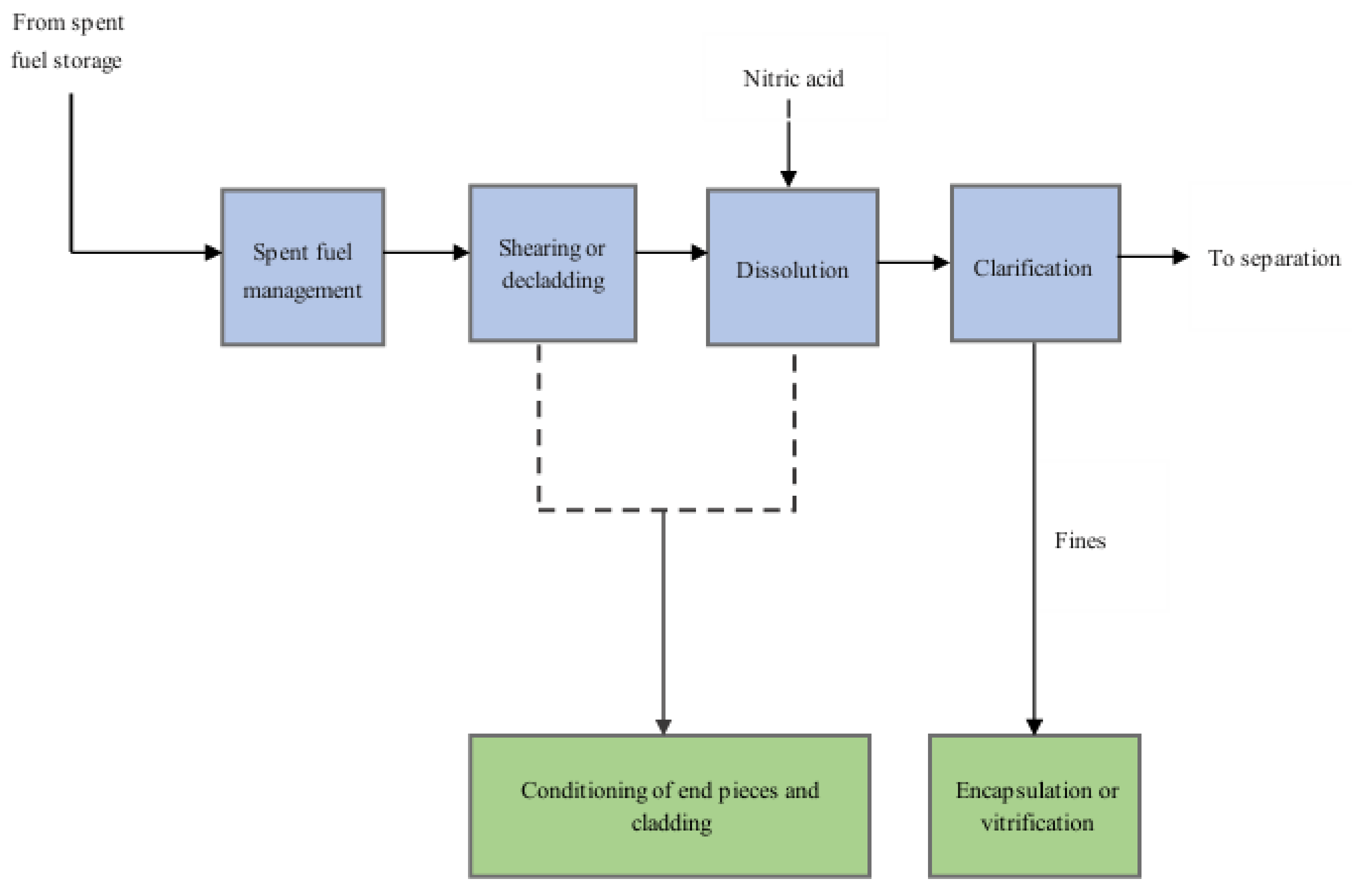
- **Reprocessing together with LWR SNF**
- **Reprocessing in separate technological line for high-enriched material**

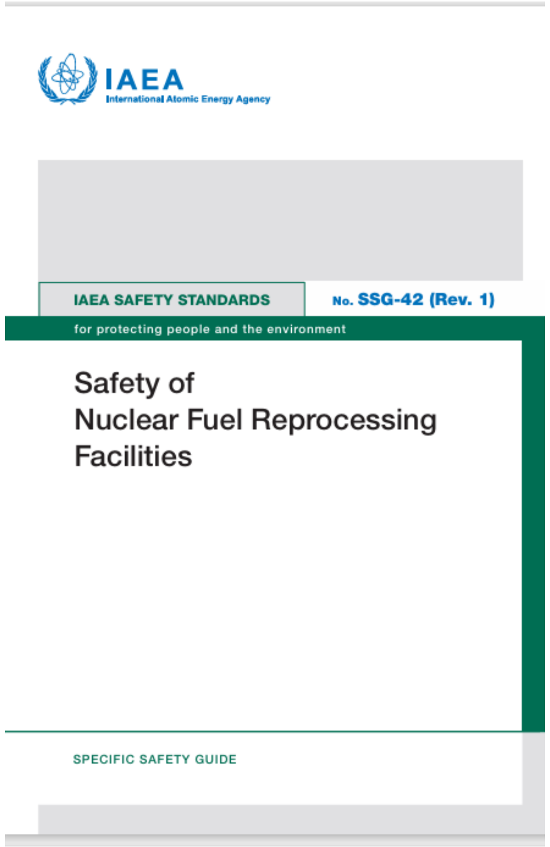
Advanced FR SNF reprocessing based on pyro-prcesses:

- **Batch processes – technological mass control on each stages. Constant information on mass balance.**
- **For pyro-processes – low decontamination factor – reprocessed fuel in SNF "standard":**

- **So named self-protected material**
- **Simplified control of all internal transportation due to high radioactivity**

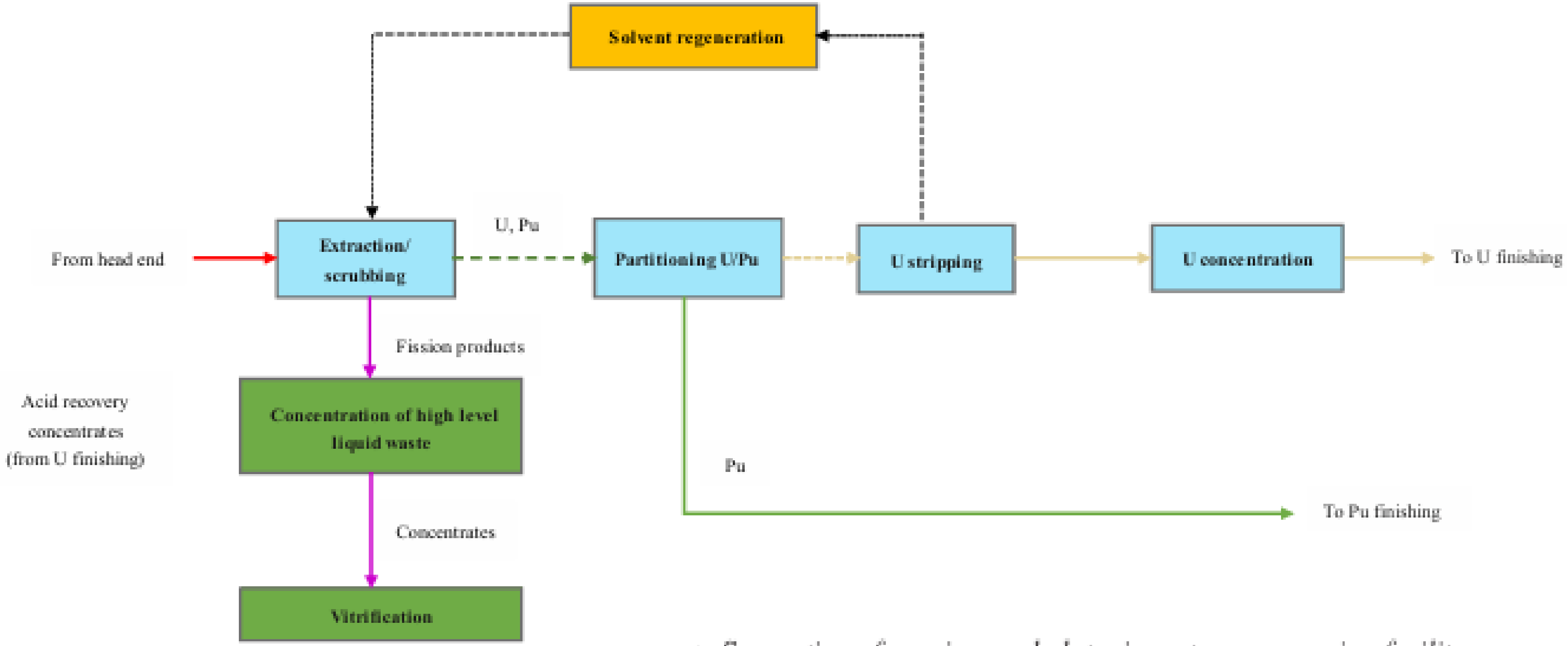
Current PUREX-based reprocessing (1):





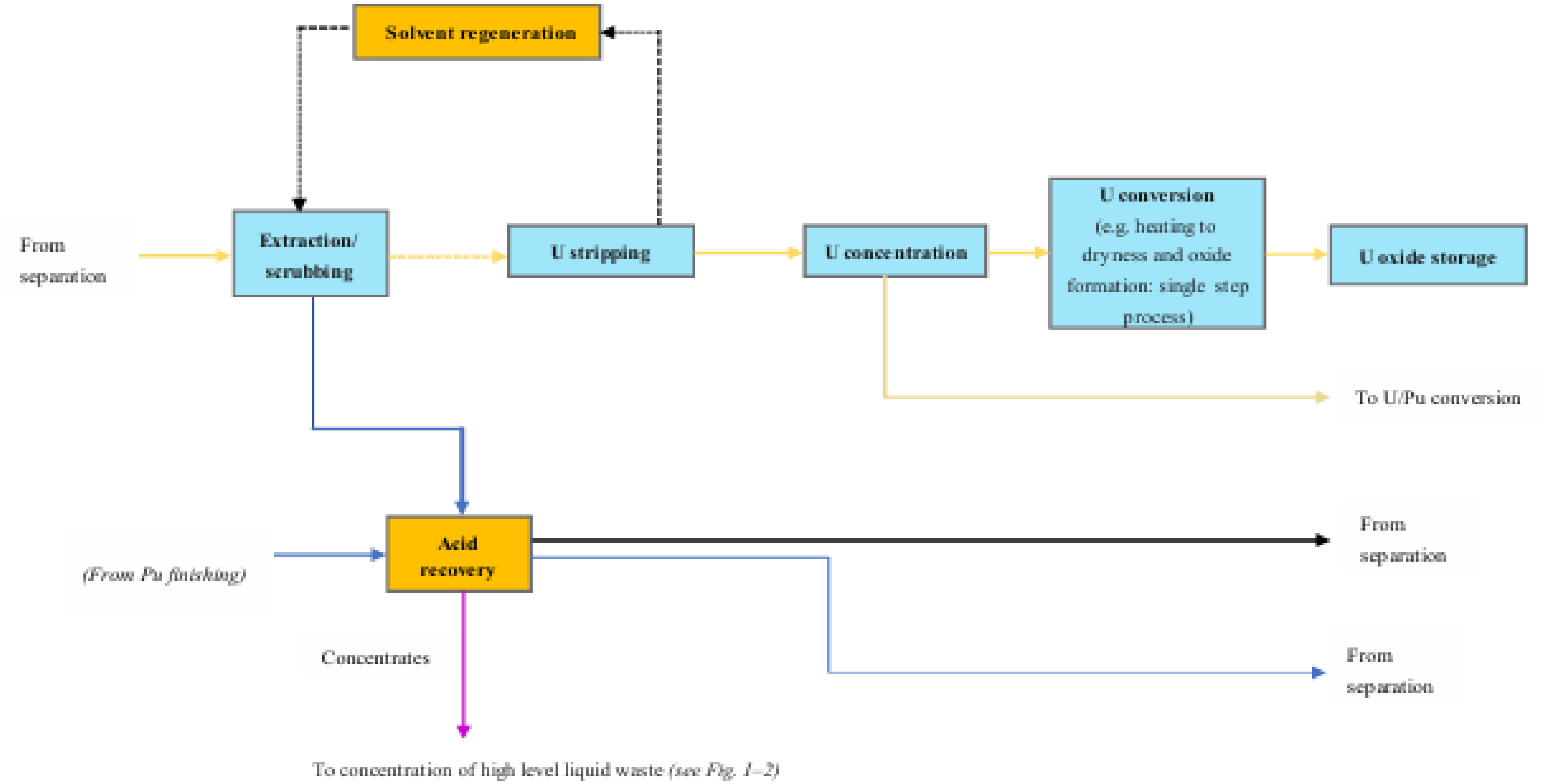
Main process routes at the head end of a reprocessing facility.

Current PUREX-based reprocessing (2):



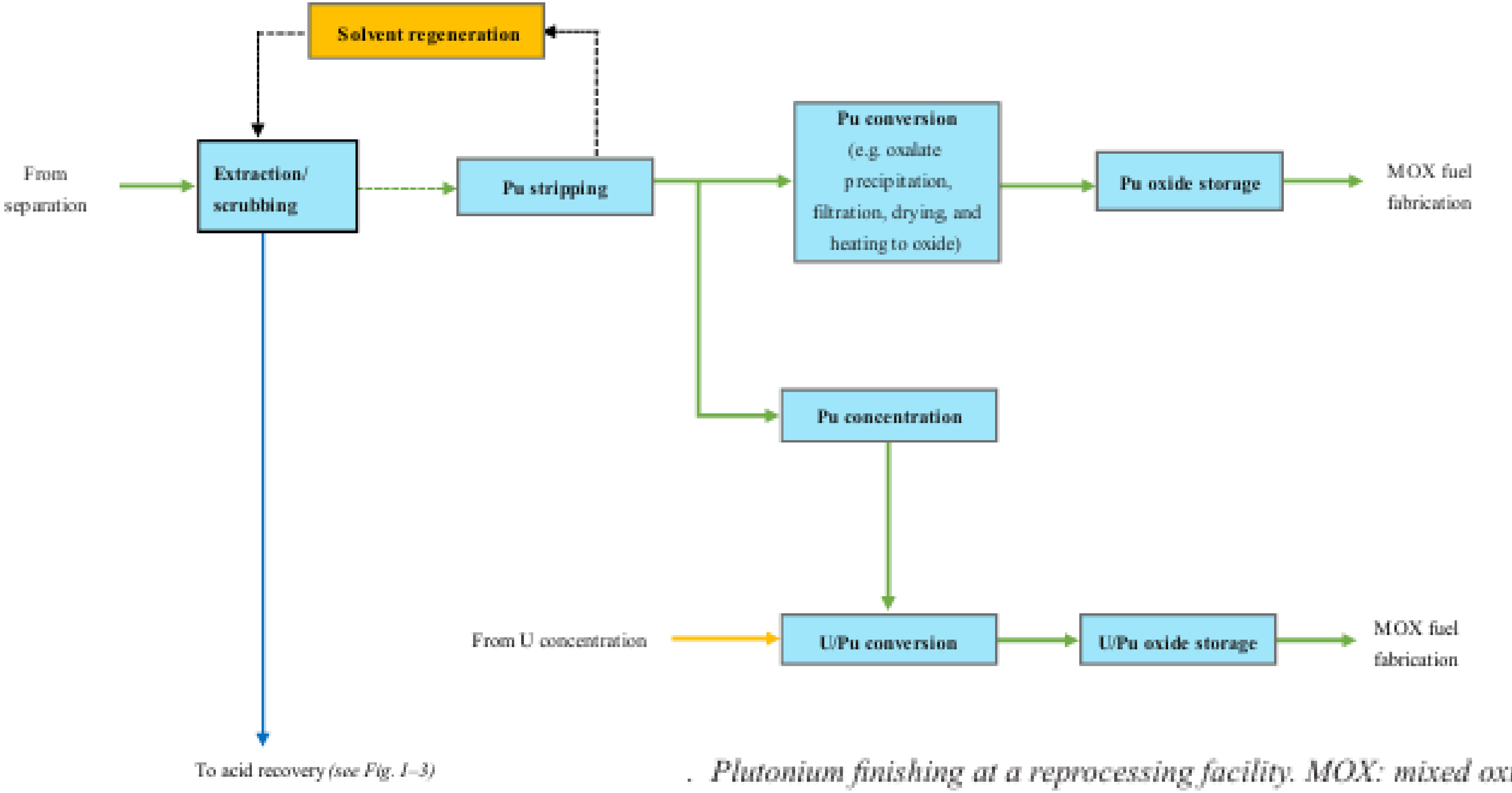
. *Separation of uranium and plutonium at a reprocessing facility.*

Current PUREX-based reprocessing (3):



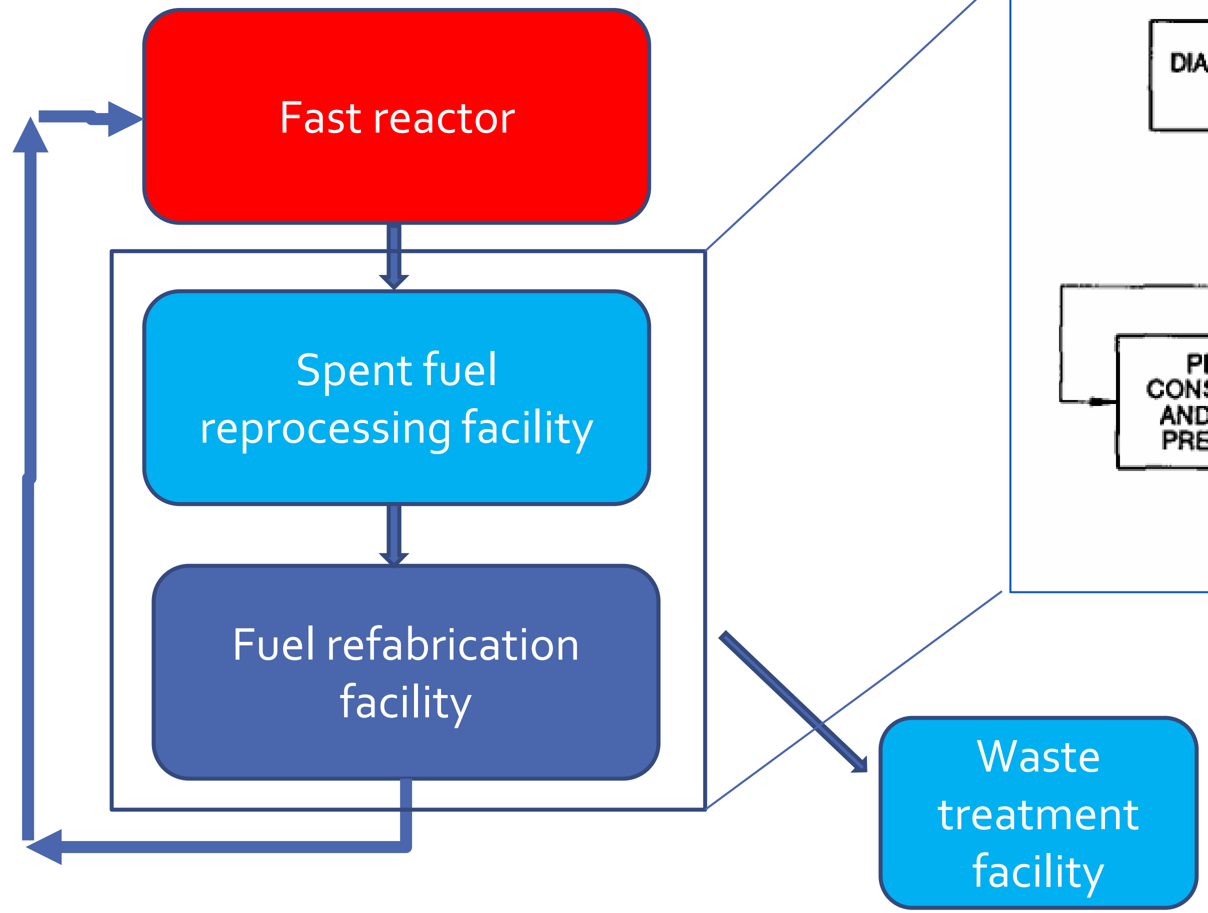
Uranium finishing at a reprocessing facility.

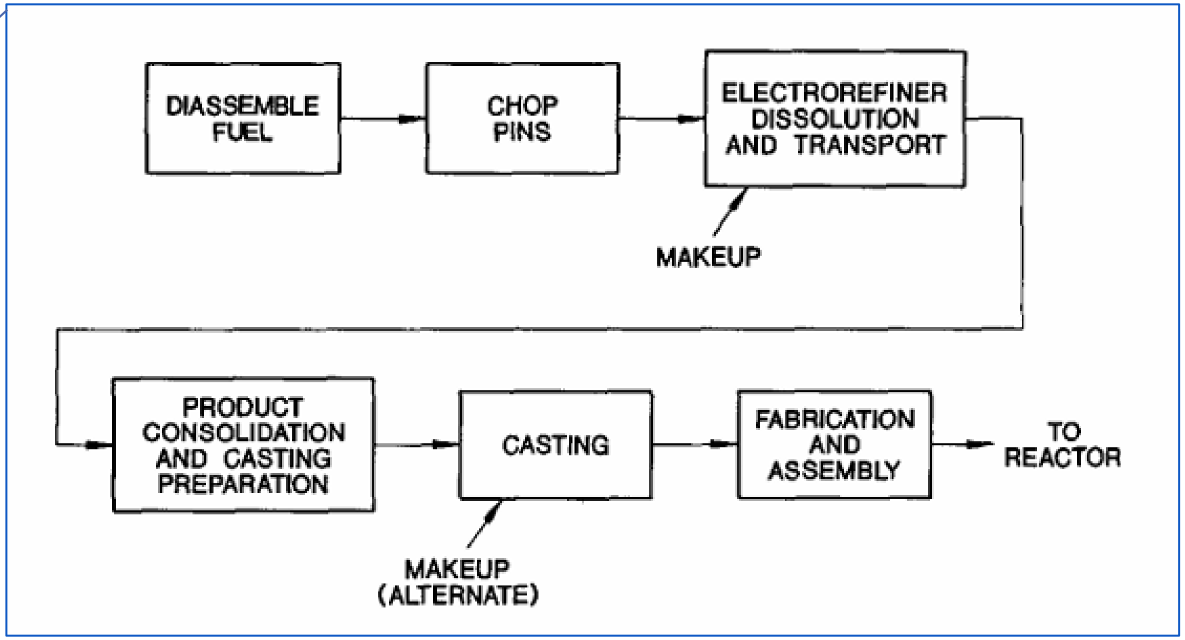
Current PUREX-based reprocessing (4):



. *Plutonium finishing at a reprocessing facility. MOX: mixed oxide.*

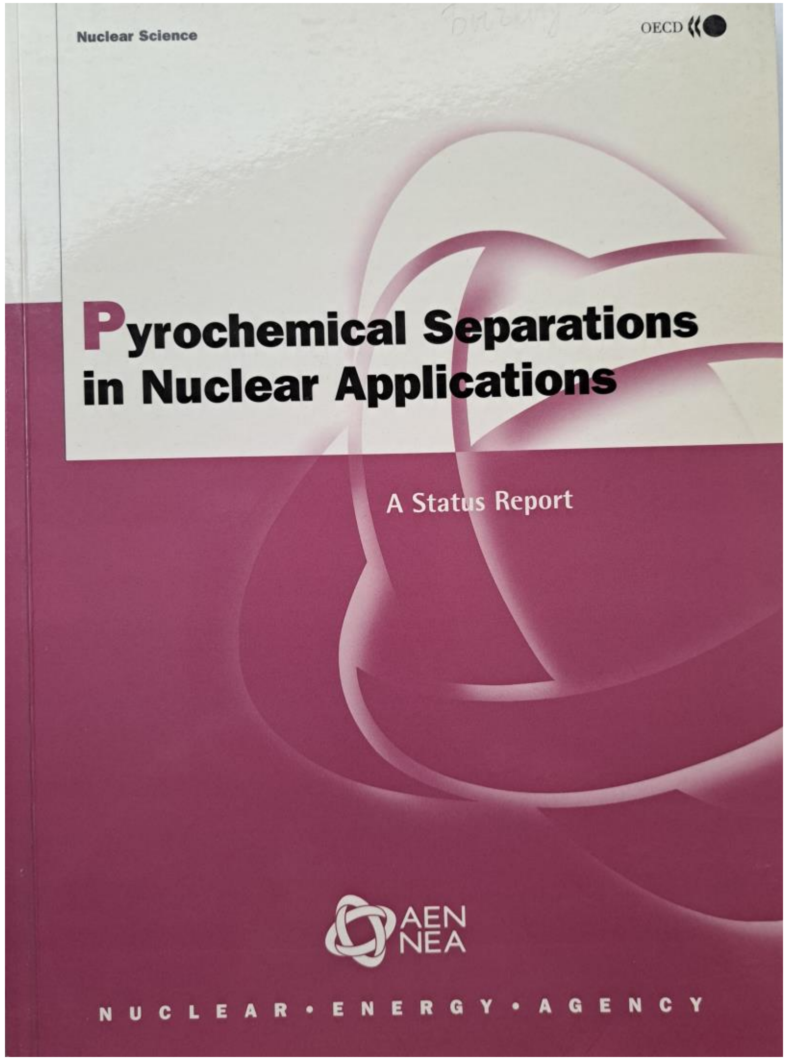
Fuel recycling steps in case of on-site location





For U-Pu-Zr fuel recycling

Pyro-process options as basic advanced recycling



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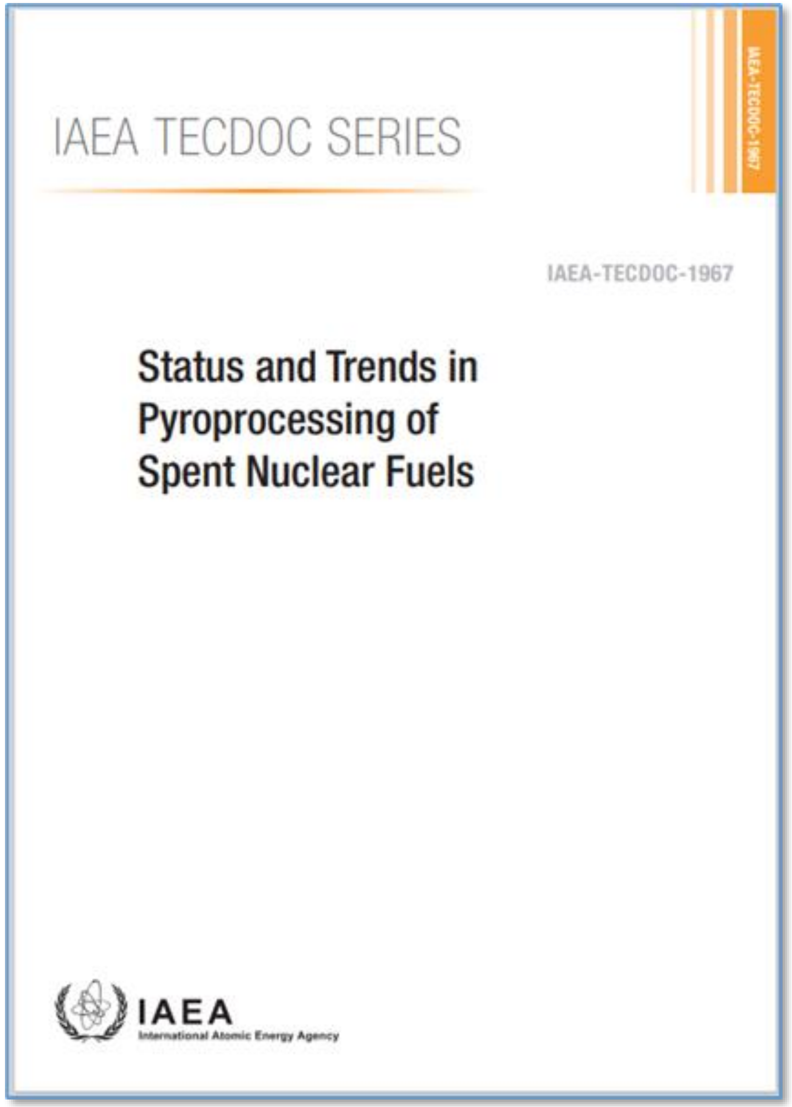

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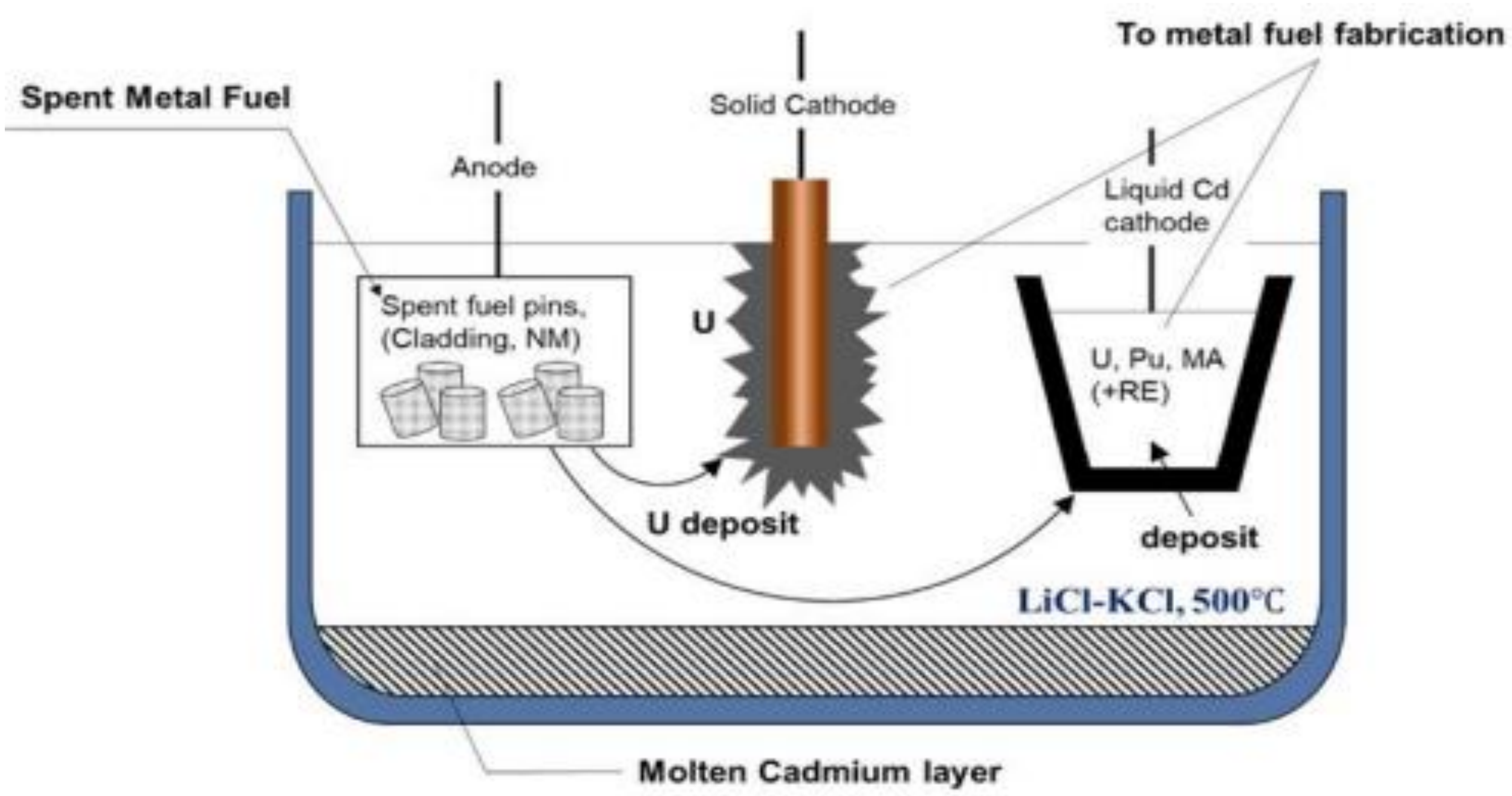
Pyro-process option for metallic (and nitride) FR fuel

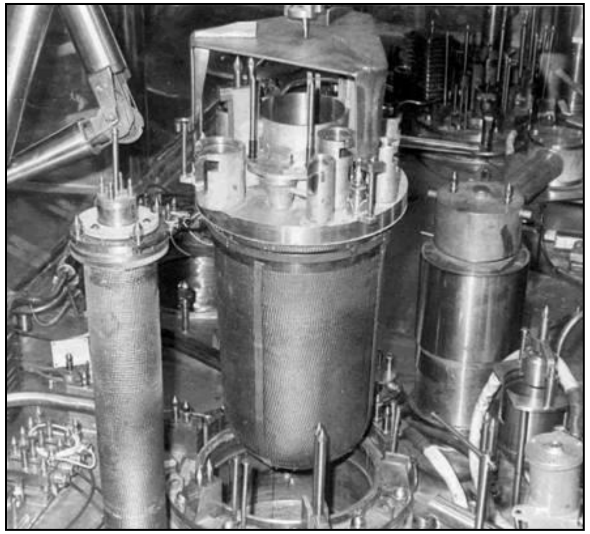


U deposit

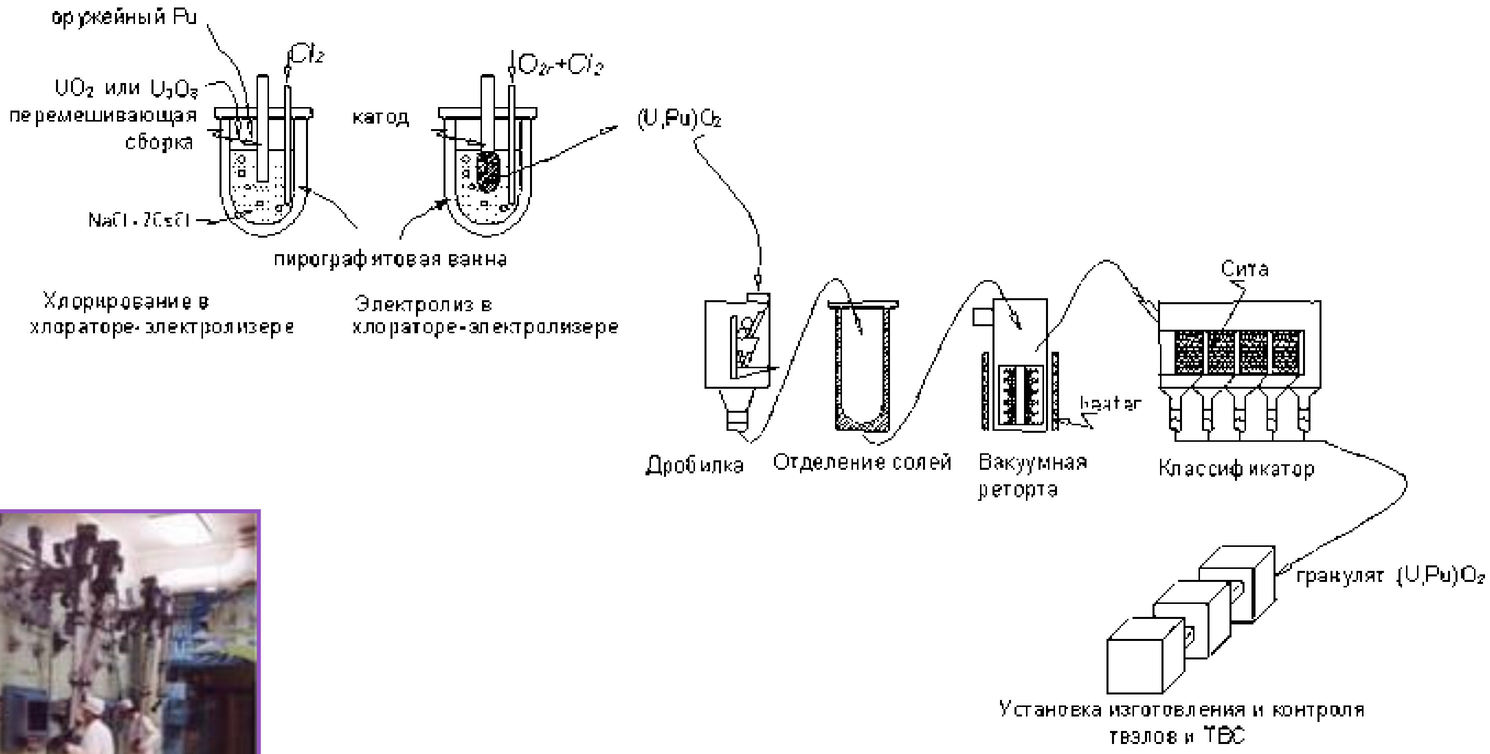
The process for metallic U-Pu-Zr and nitride (U,Pu)N fuel

U, MA and Pu in a liquid Cd cathode

Production and recycling of FR MOX fuel by pyro-process and vibropacking

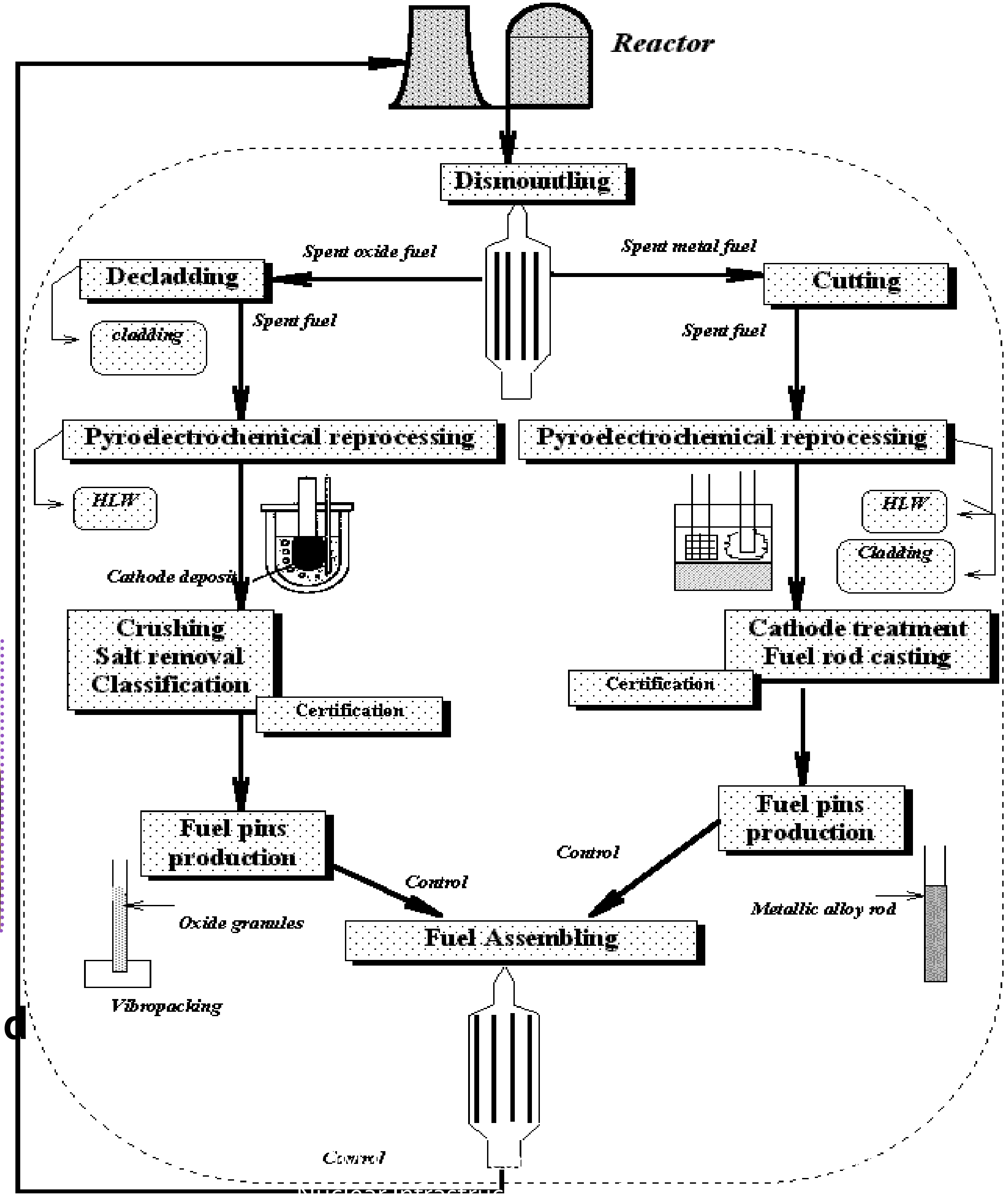


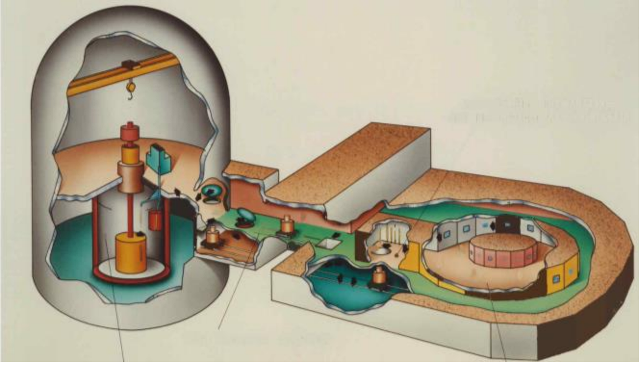
This option was developed and tested in RIAR (Dimitrovgrad, Russia) on pilot manufacturing and recycling of MOX fuel - 1970 -2010-s. Remote controlled equipment lines were tested.



Old author's diagrams (early 1990-s) for comparison of MOX recycling by pyro/vibro (RIAR, Russia) and U-Pu-Zr fuel recycling by pyro/injection casting (ANL, USA)

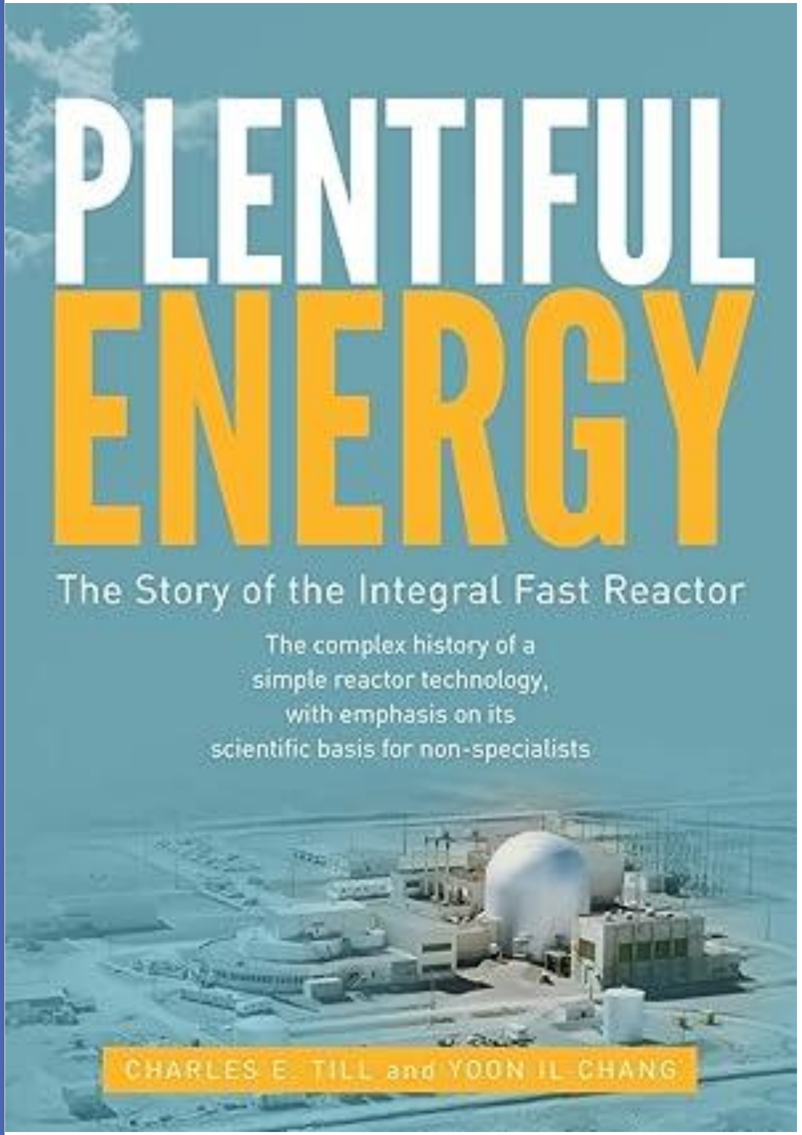
MOX fuel recycling for Fast reactor (Dimitrovgrad Dry Process)

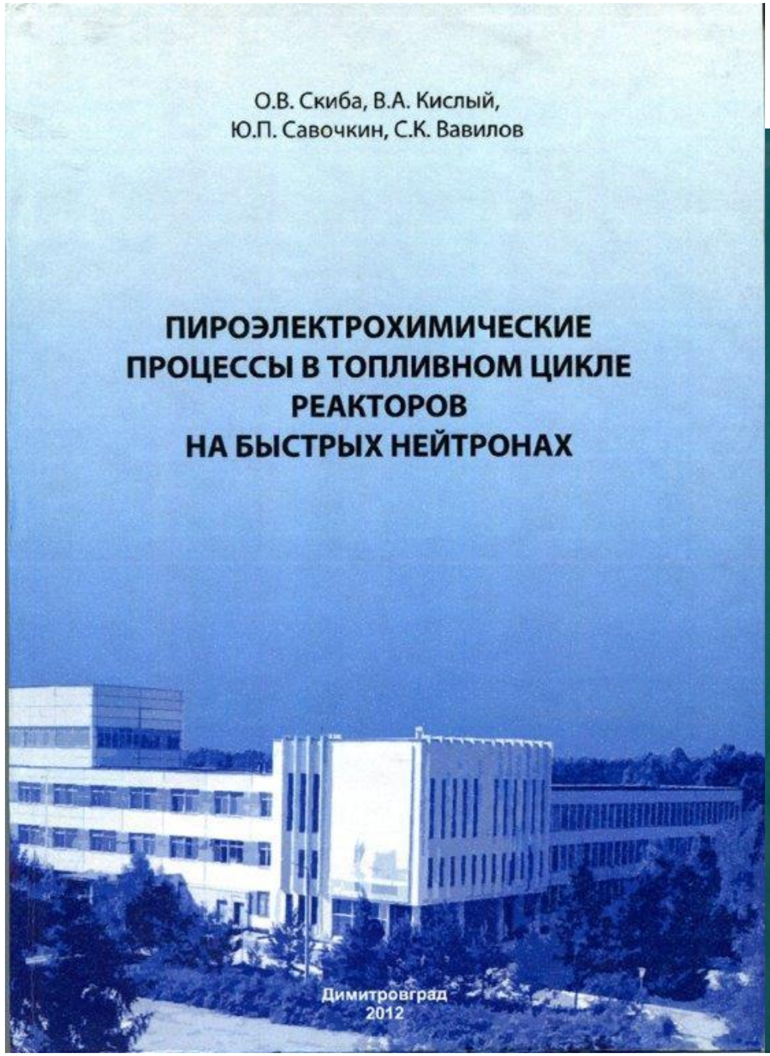




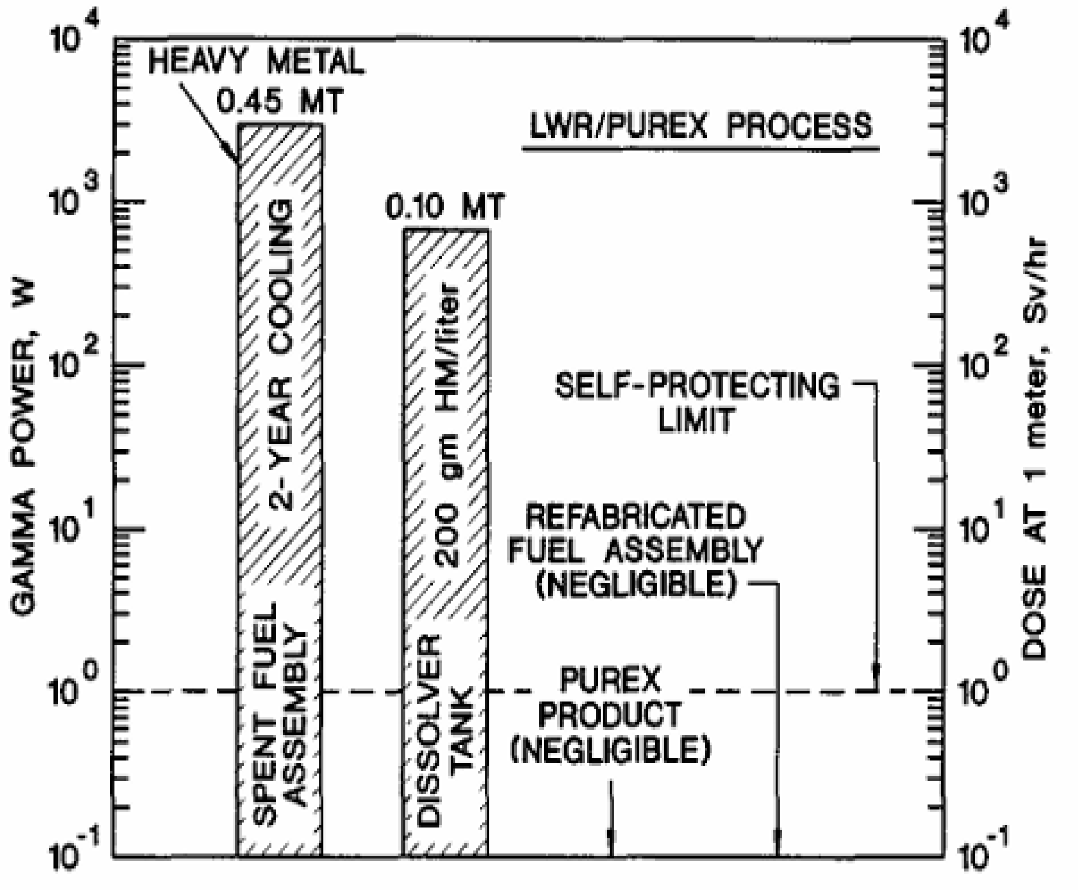
UPuZr fuel pyro-recycling for the Integral Fast Reactor Concept developed by ANL/INL, USA

Some books related on-site recycling





Decontamination factor for PUREX reprocessing



Purification of uranium and plutonium very high. DF ~ 10^8
Recovered materials are ready for production of any type of fresh fuel for any types of nuclear reactors – LWR, FR etc.

Published by ANL

Decontamination factor for IFR recycled fuel after pyro electrorefining – “self protected materials”

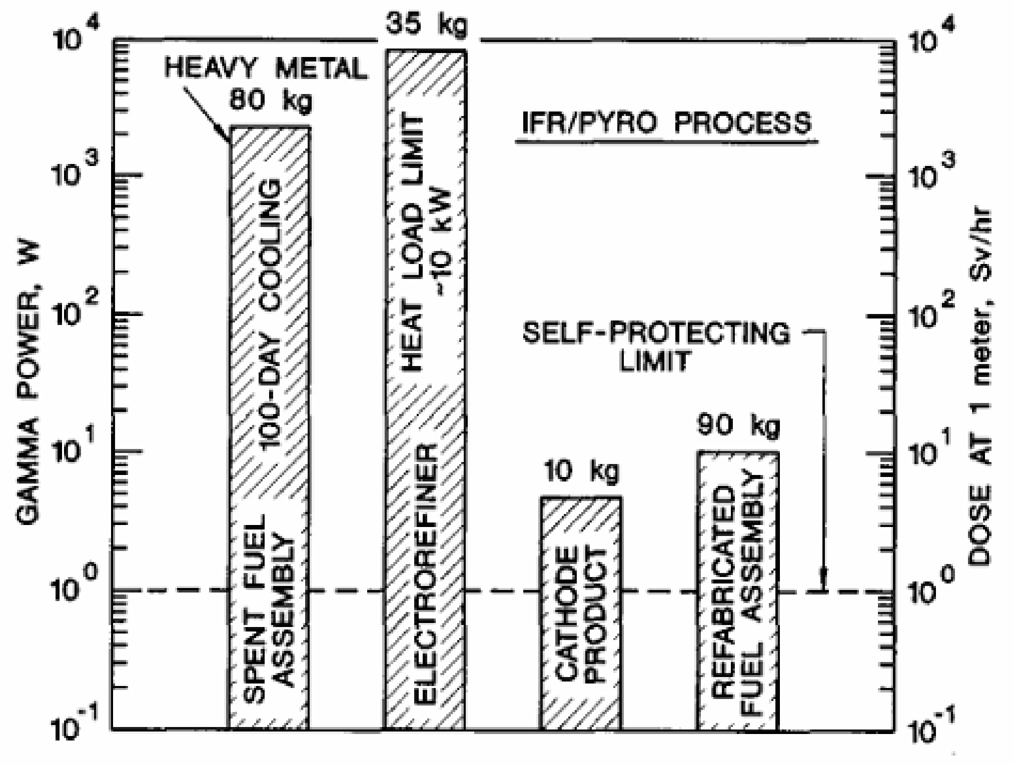
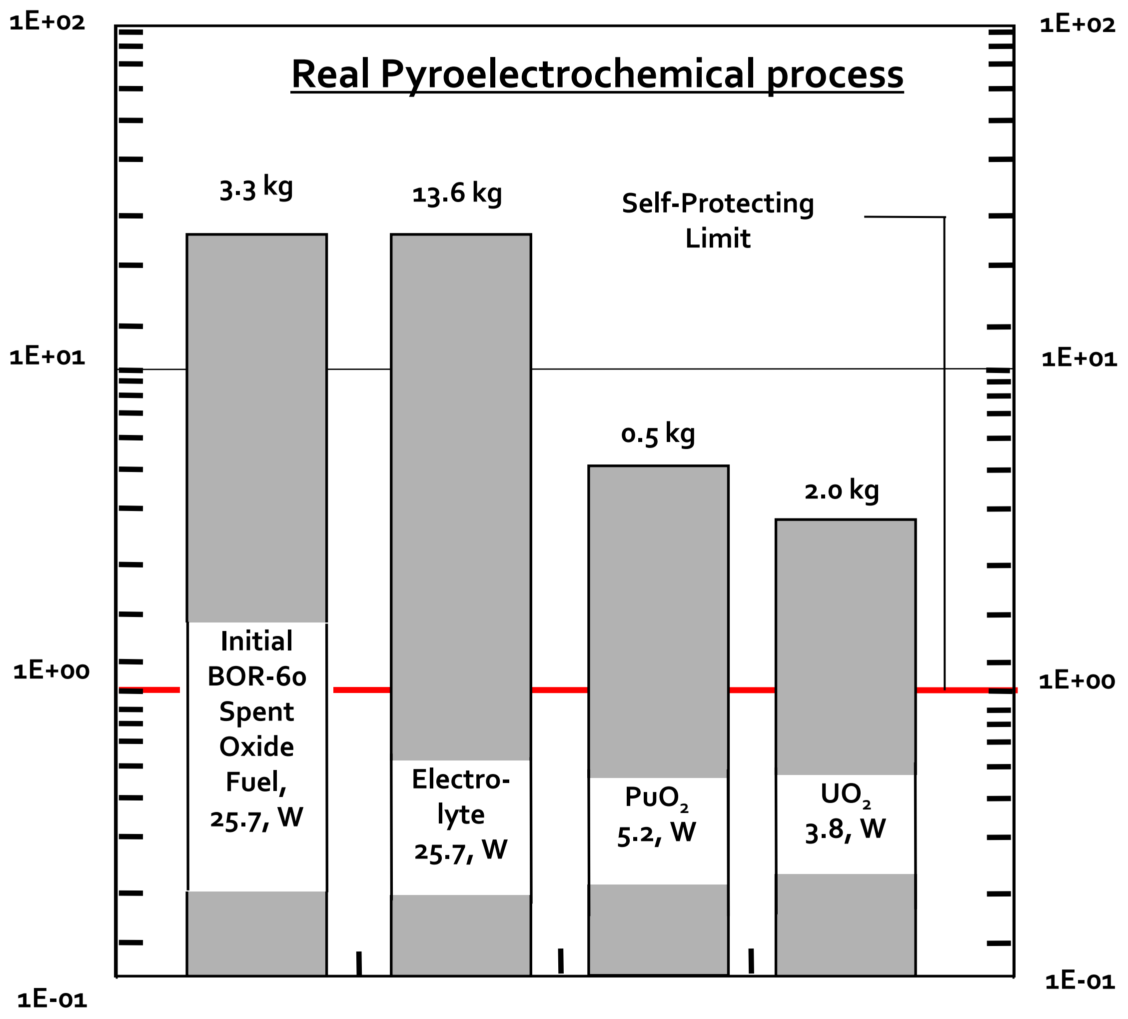


Fig. 3. Self-Protection of IFR Materials by Gamma Radiation.

Published by ANL

- Molten salt electrochemical processes resulted low DF -10^2-10^3.
- The recovered materials have gamma-activity compared with Spent Fuel.
- As result recovered materials are “low attractive”
- And easily controlled through facility by gamma-radioactivity :



Self-Protection of BOR-60 spent Fuel Reprocessing by Gamma Radiation .

Published by RIAR

Decontamination factor for BOR-60 recycled fuel after pyroprocessing

- DFs on some FPs
  - Ru-Rh - 30-50
  - Ce-Pr -20-200
  - Cs – 3000-10000
  - Eu – 40-200
- Recovered MOX and PuO2 had the physical characteristic required for vibropacking recycled fuel

International Studies of safeguard aspects for advanced approaches for fast reactor fuel recycling

R&D on advanced recycling with pyro-processes are carried out in USA, Japan, Rep.Korea, India etc.

Detailed considerations of subjects related safeguardability and physical protection were published by ANL/INL.

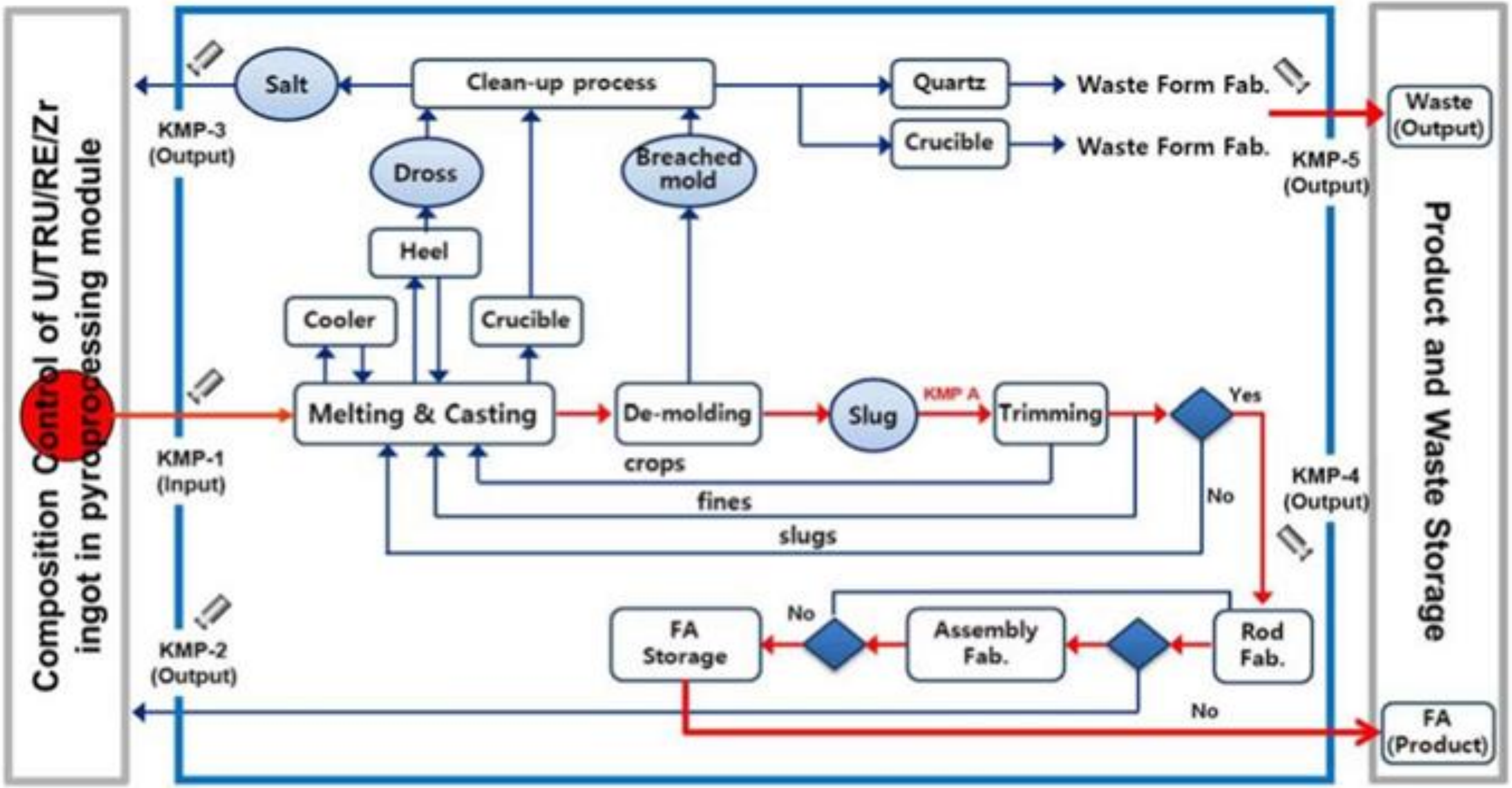
Other labs (including RIAR) followed ANL approaches

Non-proliferation aspects of FR recycling were considered in international studies focused on Internationalization of Nuclear fuel Cycle.

INPRO/IAEA fulfilled some collaborative projects with consideration of FR Fuel Cycle from non-proliferation point of view

GIF PRPP WG completed study for Sodium Cooled FR and its integrated Fuel recycling facility.

Some INPRO studies related Closed Fuel Cycle of FRs and non-proliferation aspects



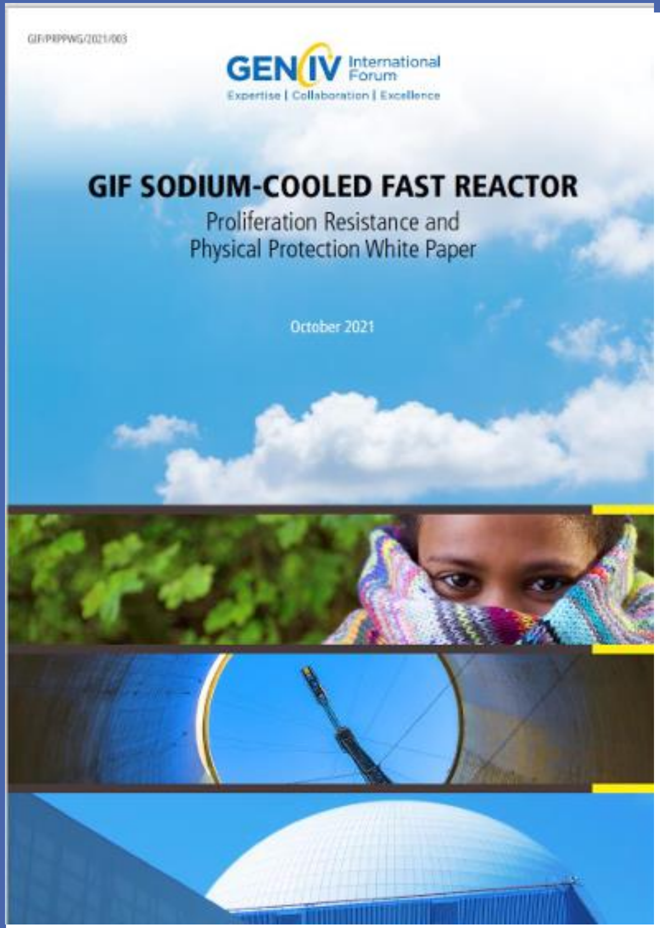
Conceptual design of MBA and KMPs of the SFMF (from PROSA collaborative Study)

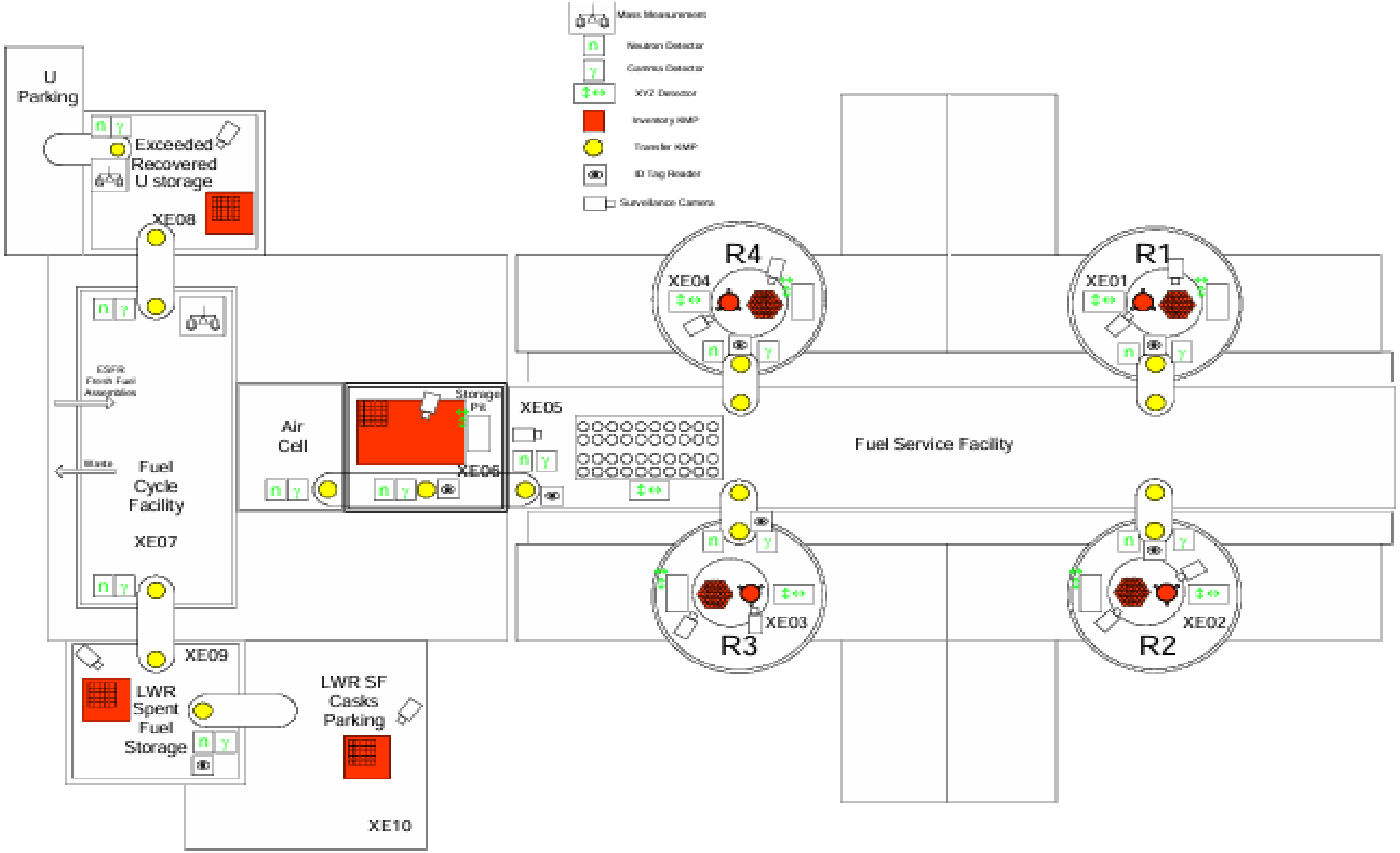
IAEA TECDOC SERIES

IAEA-TECDOC-1966

INPRO Collaborative Project: Proliferation Resistance and Safeguardability Assessment Tools (PROSA)

IAEA International Atomic Energy Agency





Safeguards system developed for the Example Sodium Fast Reactor (ESFR), object of the GIF PRPP case Study.

Conclusions

- The potential of advanced recycling technologies is high, however, in order to implement safeguards verification measures, it will be necessary to develop special procedures simultaneously combined with Non-proliferation aspects of Fast Reactor's Spent Fuel Management.
- Safeguardability of current technologies for SNF reprocessing to apply for FR fuel could be adopted as for Pu-contaned fuel.
- Safeguardability and Self-protection aspects of advanced technology and infrastructural approaches for FR fuel recycling could be taken into consideration for new constructions of FR and CFC facilities.
- FR CFC is a one of important elements of Nuclear Energy Systems Sustainability and non-proliferation aspects will be a key for this system, as it was fixed by INPRO and GIF studies.

Thank you for attention!

Alexander Bychkov

bav.vienna@yandex.com

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