ROSATOM

ГОСУДАРСТВЕННАЯ КОРПОРАЦИЯ ПО АТОМНОЙ ЭНЕРГИИ «РОСАТОМ»

ТОПЛИВНАЯ КОМПАНИЯ РОСАТОМА ТВЭЛ

Reprocessing of Fast Reactor Mixed Used Nuclear Fuel

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ВНИИНМ имени А.А.Бочвара
ПРЕДПРИЯТИЕ ГОСКОРПОРАЦИИ «РОСАТОМ»

ROSATOM goal in the back-and is a closed nuclear fuel cycle

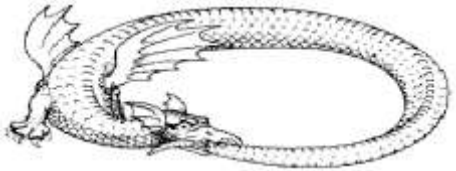
ЗСЖЦ
back-end

Очень велик
too long

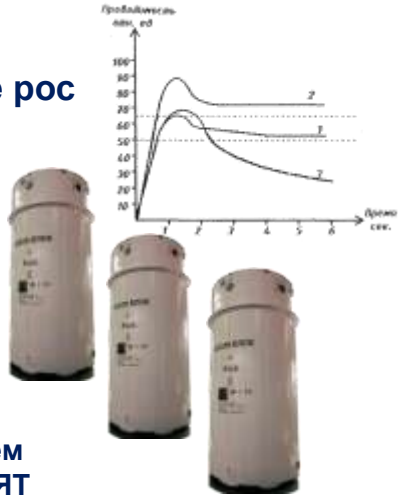
Что делать с хвостом?
what to do with the back-end?

Отбросить?
to fall off?

Замкнуть!
to close!



Сделать так, чтобы хвост не рос
to prevent SNF accumulation



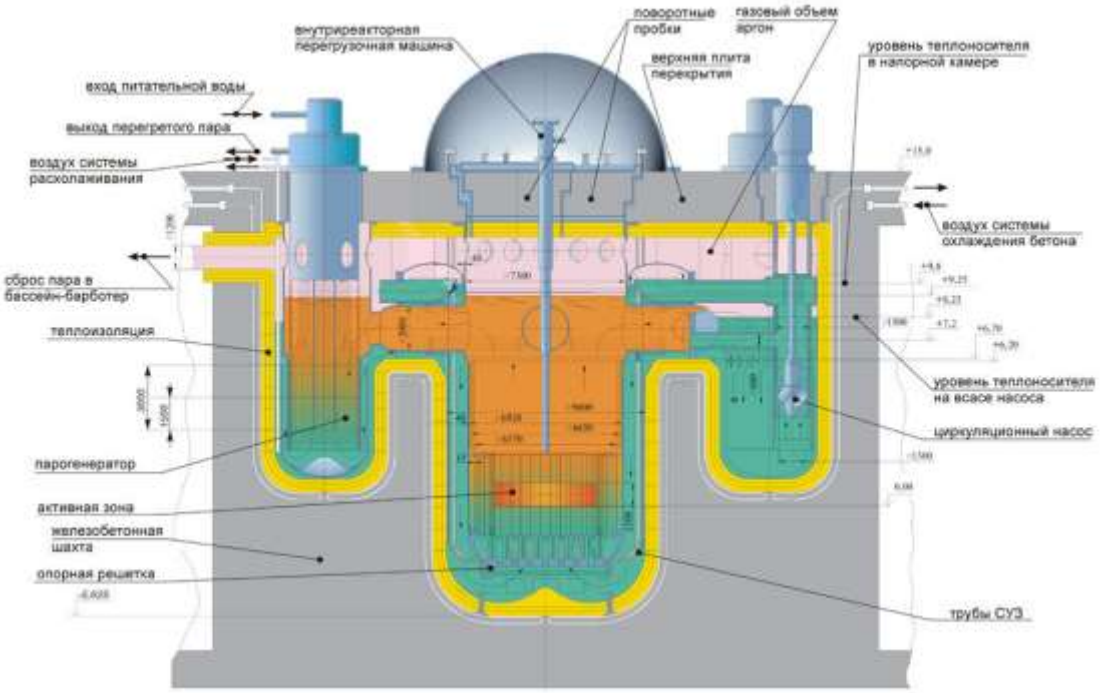
Утилизировать наследие
to utilize the nuclear heritage

Вот, собственно, зачем мы создаем ту самую систему обращения с ОЯТ
that's why we develop the system of SNF management

One of the possible ways is
a closed nuclear fuel cycle with the help of fast reactors

High capacity fast reactors

BREST-1200



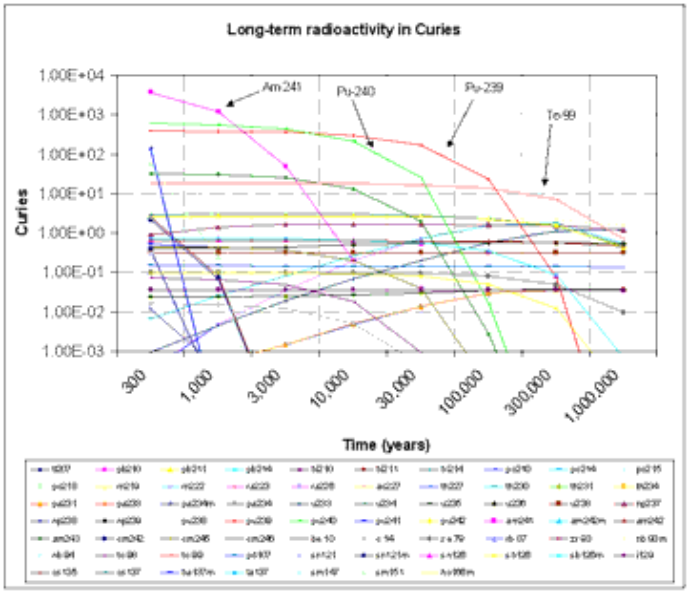
Coolant – Pb
Fuel – MNIT (U-PuN)

BN-1200

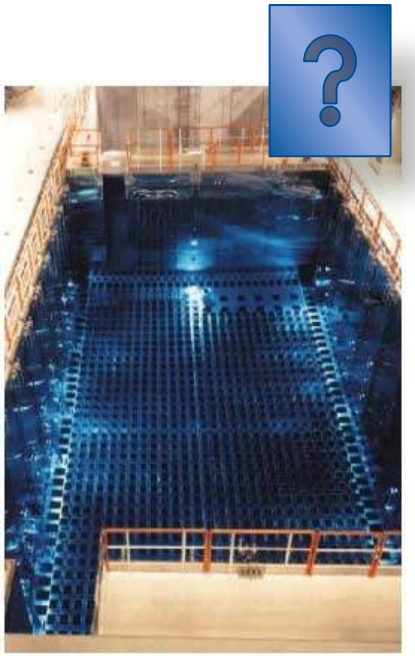
Coolant – Na
Fuel – MNIT (U-PuN)
MOX ($U\text{-}PuO_2$)

Problems

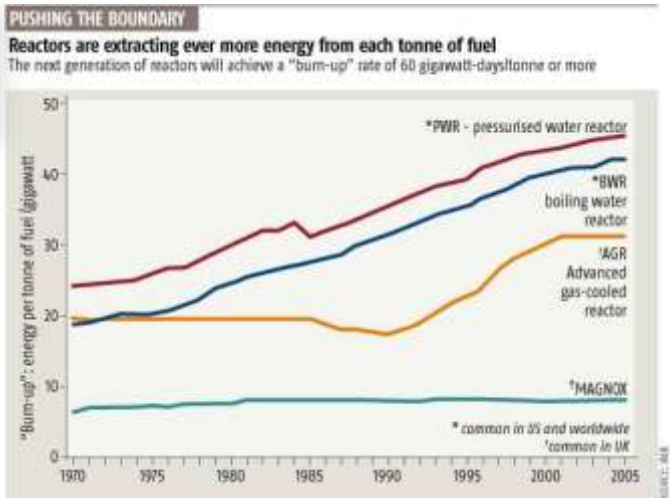
- Nuclear fuel burn-up increase (up to 100 GW*d/t)
- The increase of high-level waste reprocessing and storage costs
- Cooling time reduction
  (less than 1 year in order to withdraw from storages)
- Actinides reprocessing



http://www.whatisnuclear.com/articles/waste.html



http://www.atomic-energy.ru/news/2011/10/26/27948



http://www.robedwards.com/2008/04/nuclear-super-f.html

Closed fuel cycle with fast reactors

Advantages

- Using ^{238}U as an energy source
- No UNF accumulation
- Utilization of Pu
- Minor actinides utilization

Difficulties

- Necessity to handle (very) highly radioactive materials with high content of nuclear materials

Basic requirements for FR UNF reprocessing technologies

Imperative

1. Safety

2. Ecological acceptability

3. Economic efficiency

The more precise the measurement of position, the more imprecise the measurement of momentum, and vice versa.
Werner Heisenberg, 1927

Technical

1. Ability to reprocess UNF with low cooling time and high burnup

2. Satisfying Non-Proliferation Treaty provisions

3. Pu loss less than 0,1 %

4. Final products suitable for fuel fabrication of "fresh" fuel

5. Low volume of radioactive waste

6. Partitioning

Very similar requirements (India version)

Challenges in reprocessing technologies

P.R.Vasudeva Rao

Indira Gandhi Centre for Atomic ResearchKalpakkam-603 102

Economy: Addressing cost of fuel cycle & reduction in waste volumes per unit energy production

1.Processing after high burn-up and short cooling time – for reducing annual inventory to be processed, and reducing out-of-reactor inventory

2.This also results in production of less volume of HLLW per unit energy production

3.“Simple” (CHON based) extractants and diluents that do not result in deleterious degradation products

Safety:

Extractants that will avoid third phase formation and red oil formation
Materials that will resist corrosion over extended period of time
Instrumentation, automation: key to dose reduction

Existing experience

ORNL (ANS Annual Meeting, Las Vegas, Nevada, June 18-22, 1972)

15% PuO_2—85% $U0_2$, 20,000 Mwd/t, cooling – 65 days

COGEMA, CEA, AREVA (Global-2011)

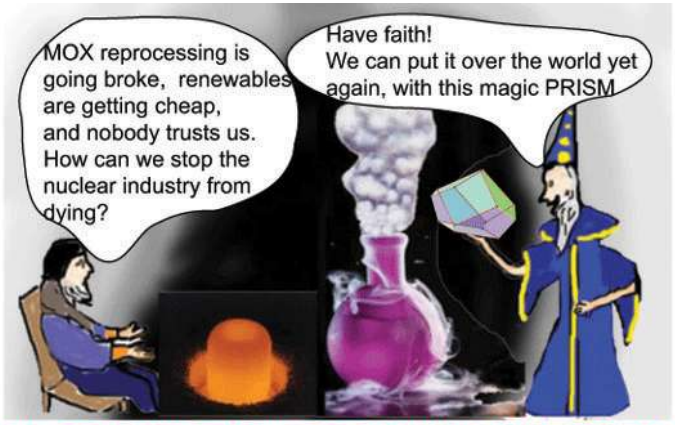
about 70MtHM of used LWR MOX have been recycled in AREVA plants.
Pu content ranging from 4% to 7% on average and burn-up from 30 to 53 GWd/MtHM. Largest quantity was treated in 2007, with 31.4 MtHM within one campaign.

IGCAR (ATOMEXPO-2010)

150 GWd/t has been reprocessed in CORAL Demonstration Facility

PO «Mayak»

Several MOX fuel assemblies from BN-600 were reprocessed in 2012



NUCLEAR LOBBY PROMISES TO TURN PLUTONIUM INTO GOLD

High burn-up and low cooling time

Burn-up and cooling time	Heat, kWt	Activity, MCi
WWER-1000, 50 GWt*day/t, 2 years	4,7	1,3
BN-1200 active core, 100 GWt*day/t, 2 years	13,8	3,4

But would it be economically acceptable?

Estimated contents of extraction feed solution in different reactors SNF reprocessing

Reprocessing scheme	Extraction feed contents, g/l					Waste
	U	Pu	ΣFM	Np+TPE	ΣFP	Glass volume, m3/tSNF
RBMK-1000	300	1,5	2,7	0,097	4,8	0,07/0,05
VVER-1000	300	3,0	6,6	0,37	10,8	0,15/0,15
BN-1000	300	55,0	55,0	1,8	24,6	0,34/0,54
RBMK-1000 + 10% BN-1000	300	6,9	7,9	0,25	6,8	0,10/0,10
RBMK-1000 + 7% BN-1000	300	5,2	6,4	0,20	6,2	0,09/0,09

Data for combined FR and TR SNF reprocessing (Conference, Radiochemistry-2009)

MOX or dense fuel?

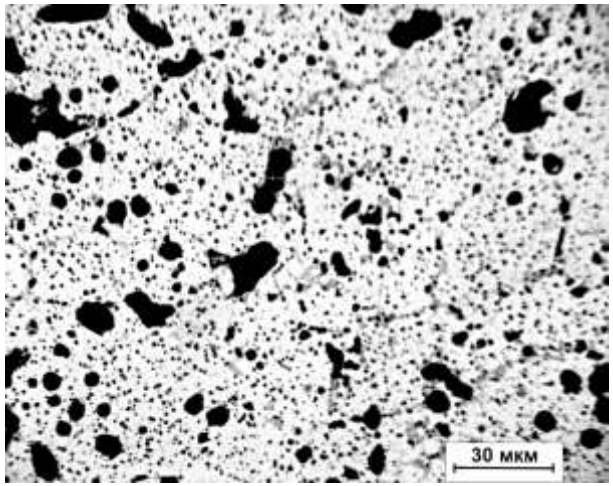
- **Main questions**
  - **Safety level**
  - **Pu reproduction in active core**

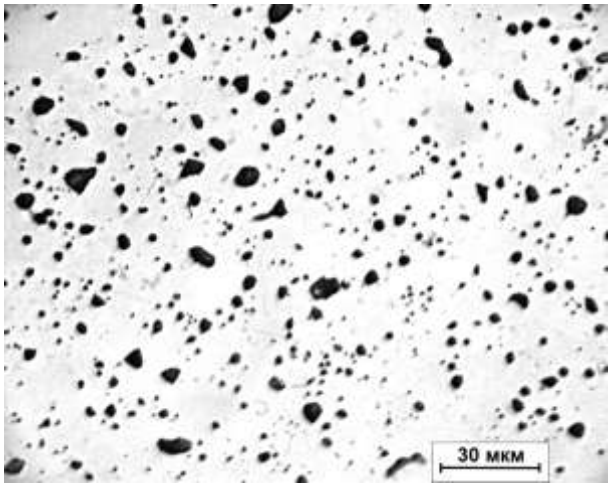
- **Answer – dense fuel (metal, carbide, nitride) is better compared to MOX.**

- **However – MOX fabrication and MOX UNF reprocessing are realized on industrial scale**

Why mixed U-Pu nitride (MNIT)?

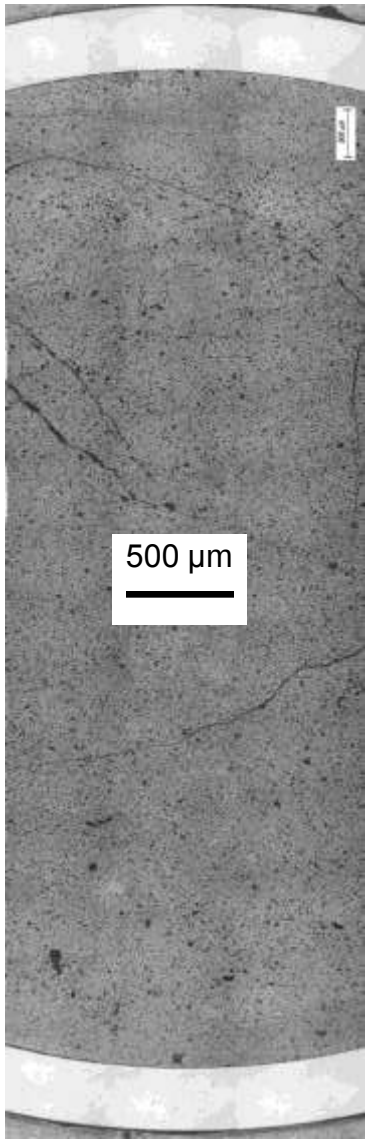
1. Pu reproduction coefficient ~1.05 without blanket
2. 0.5% ΔK/K during the whole campaign
3. Compatibility of MNIT with shells material
4. Compatibility of MNIT with Na and Pb coolant
5. Experience of U nitride fuel use





a *b*

Microstructure of (U,Pu)N fuel with burn-up 5 % h.a. (*a*) and 4 % h.a. (*b*)



Mixed U-Pu nitride UNF composition

Insoluble fission products	Volatile fission products	Gaseous fission products
Mo – solubility in UN < 0.1 % wt. Probably metal or intermetallide **Noble metals** (Ru, Rh, Pd) Probably intermetallide phases, such as $(U,Pu)Pd_3$ or $(U,Pu)(Pd,Rh,Ru)_3$ possibly, including Mo and Tc. **Alkali-earth elements.** expected fall out in the form of nitride phases Sr_3N_2 and Ba_3N_2	**Alkaline metals**: caesium and rubidium; **halogens**: iodine and bromine, and also **tellurium, cadmium, stannum, selenium** and **stibium**. tendency to migrate into cold zones of a fuel element observed in the zone of interaction between the core and shell.	Gaseous fission products include **inert gases** (Kr, Xe) Nitride fuel may be operated at low temperature with a liquid-metal sublayer in a fuel element, at the same time gas remains in the nitride matrix in clusters and fine pores.

MINT stability at high temperature

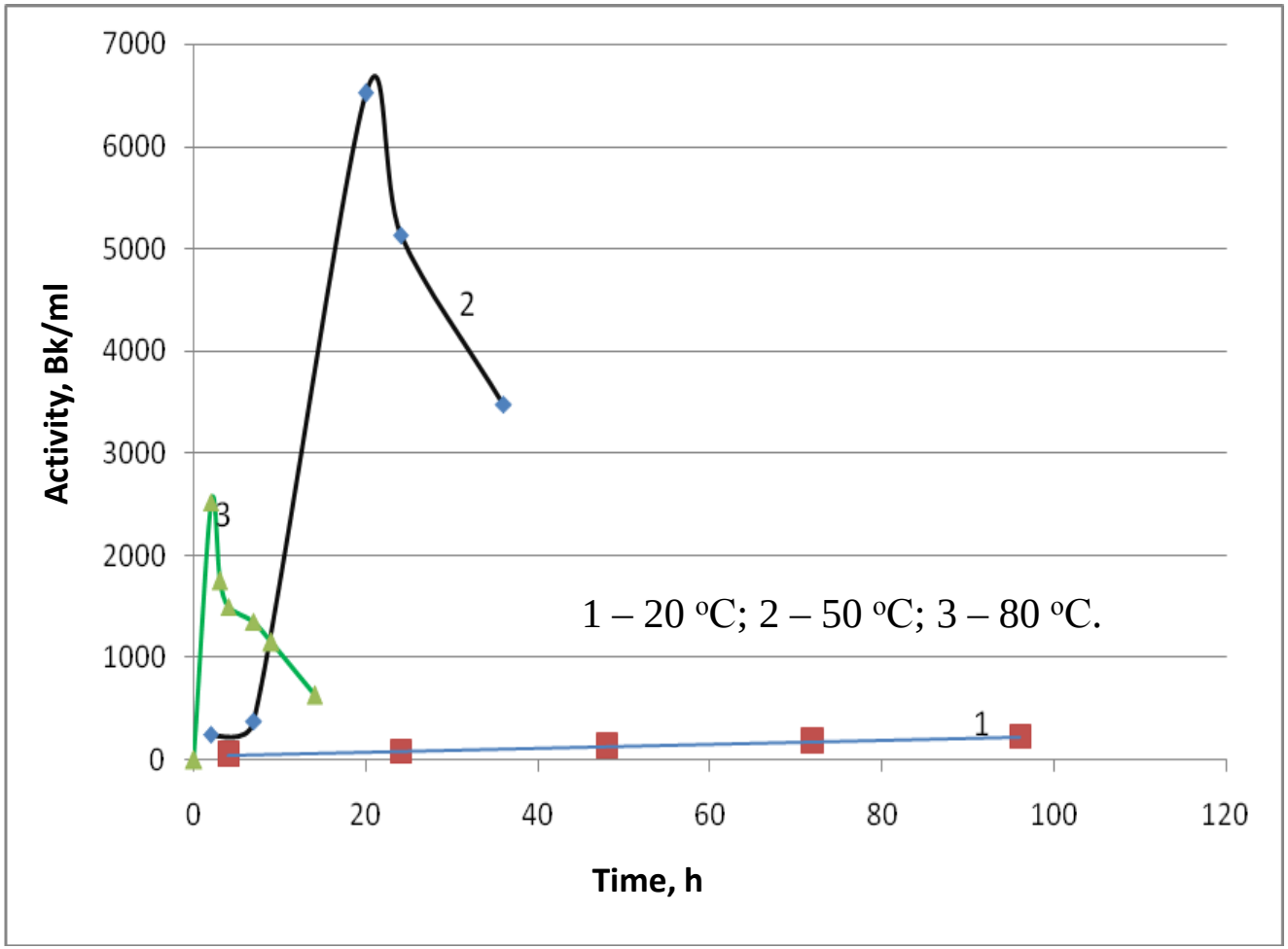
Start tempetature and min oxygen concentration for oxidation of simulated spent mixed U-Pu nitride nuclear fuel

Size	Oxidation start temperature		Oxidation start O_2 content
	O_2 2 % vol.	Air	
-25 μm	300 °C	250 °C	1,5 % vol.
+70 -100 μm	315 °C	255 °C	1,6 % vol.
+800 -1000 μm	410 °C	355 °C	1,8 % vol.

For the particle >100 μm exothermal effect of the reaction is apparent even in presence of 3 % vol. O_2.

Experiments with MNF showed no oxidation of mixed U and Pu nitrides below 260°C.

MINT STABILITY IN WATER



Influence of treating time on water activity at different temperature

At high temperature the speed of leaching is not a constant

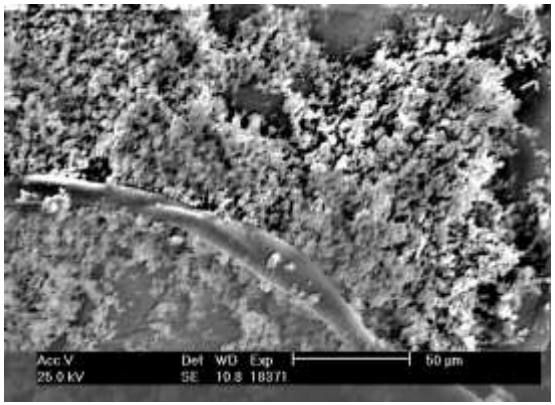
Plutonium leaching from simulated used MINT fuel with ≈ 0.0064 μgPu/(mm²·hr) at 80°C.

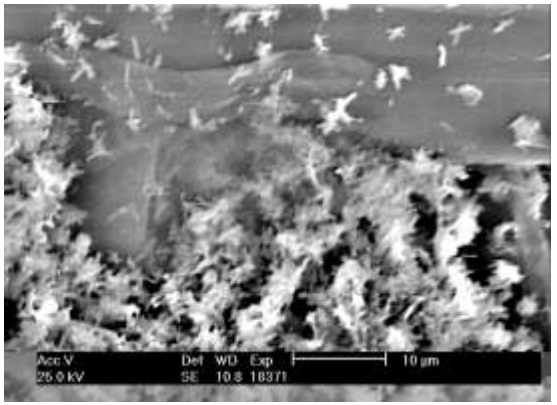
Dissolution of simulated used MINT in nitric acid

Composition of solution and residue after dilution of model nitride fuel

Index	Elements								
	U	Pu	La	Pd***	Ru	Rh***	Zr	Mo	Ag
Concentrations in solution, g/l	376	52.0	8.0	1.46	1.16	0.094	2.64	1.22	0.46
FP content in solution*, %	99.9	101	85.4	62.3	38.8	9.79	71.3	30.3	91.1
FP content in insoluble phase*, %	0.035	1.26	n.d.**	8.88	51.7	65.3	30.9	74.9	n.d.

* Relative to content in source pellet
** Not found
*** – Currently there is no explanation on imbalance of palladium and rhodium.





Microstructure of insoluble residue in secondary electrons under various magnification

Particularities of MINT UNF

1. In case of clad damage of used MINT UNF the U, Pu will be going in basin water

2. Damaged MINT UNF elements should be stored in additional penal.

3. The cutting of MINT UNF should be done under < 200 ^{o}C and in inert medium with O_2 < 3% vol.

1. The dissolution of used MINT UNF can be easily realized in radiochemical plant.

2. The recovery of Pu from insoluble residue can be necessary

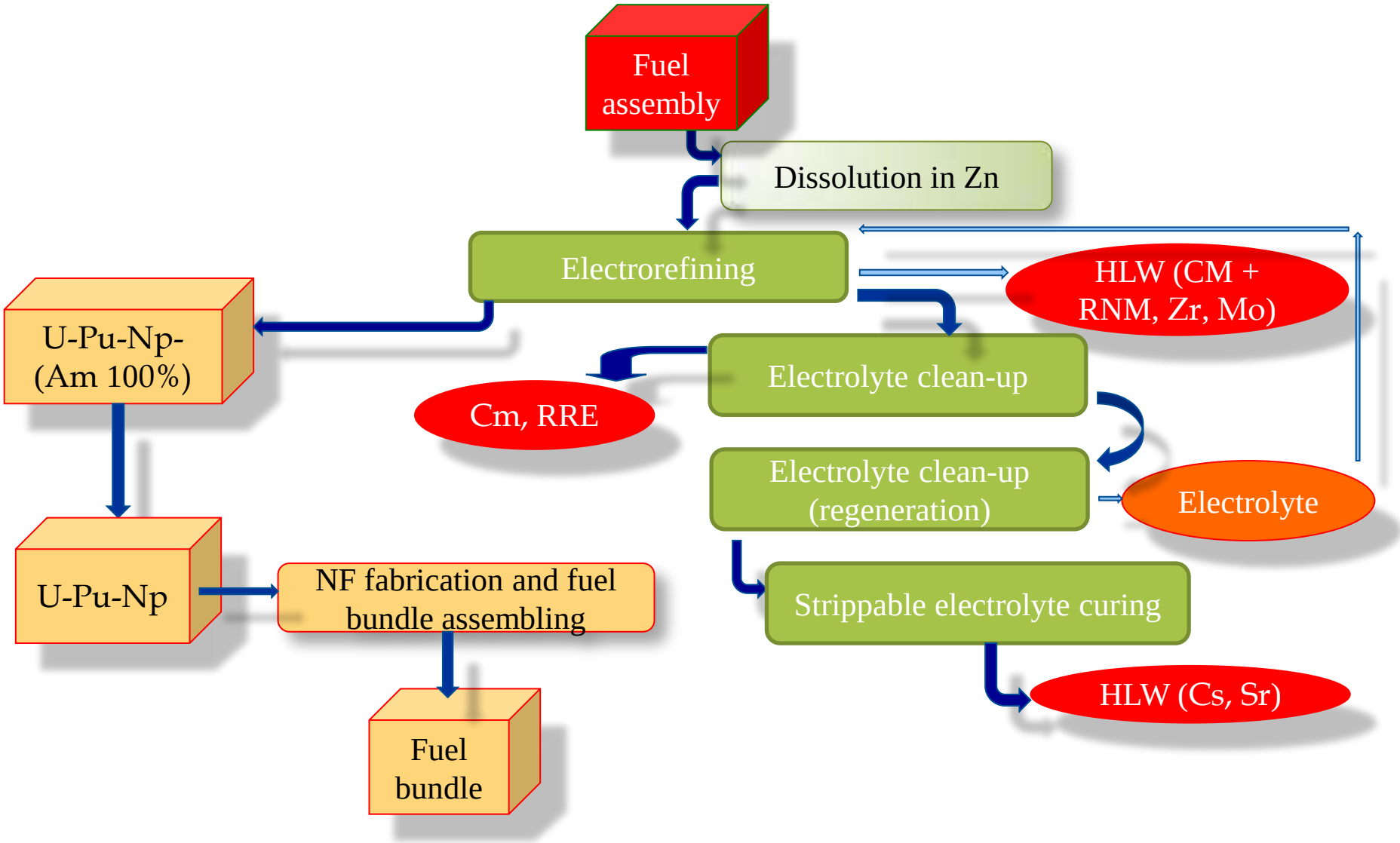
On-site reprocessing

Cooling time	1 year
Recycle of fissible materials	99,9 %
Type of UNF	Mixed U-Pu nitride or MOX
Separation U, Pu, Np	Not provided
U-Pu-Np purification coefficient	Up to 10^6 from 10^3
Transmutation of minor actinides	Homogeneously or heterogeniously

Technology we have got

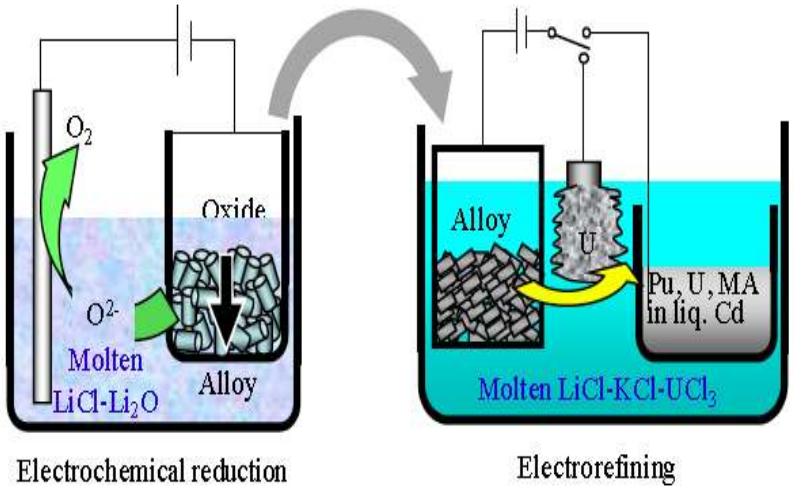
	Purification coefficient, U-Pu (Np) from FP		Actinides recovery Pu (Am)		Cooling time	
	Achieved	Potential	Achieved	Potential	Achieved	Potential
Pyro	10^3	10^6	98 %	99,9%	1 year	6 months
Fluorine	10^{4-6}	10^7	-	99,9%	-	6 months
Hydro	10^7	10^7	99,9 %	99,9%	4 years	3 years
Pyro + Hydro	-	10^7	-	99,9%	-	6 months

Pyroelecrochemical reprocessing



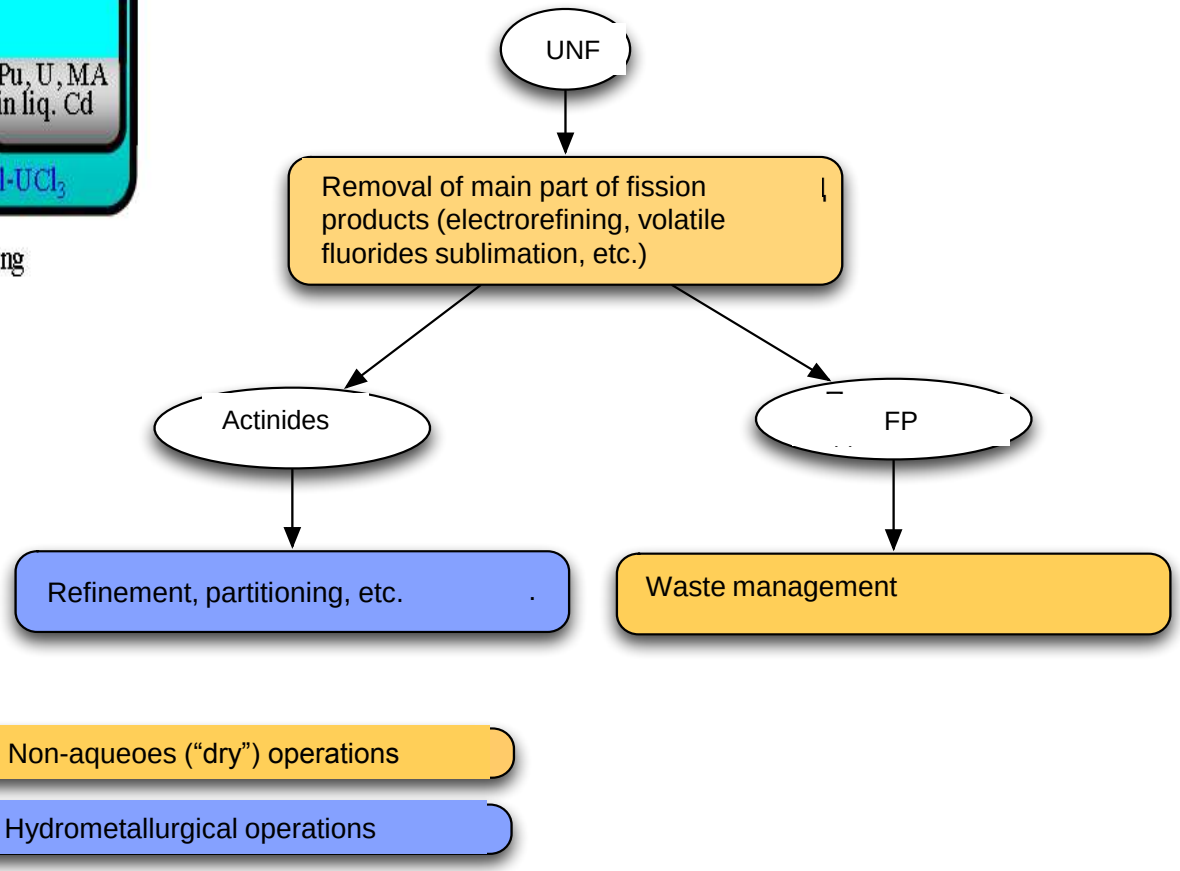
High burn-up and low cooling time

Pyroelectrochemical and other “dry” processes

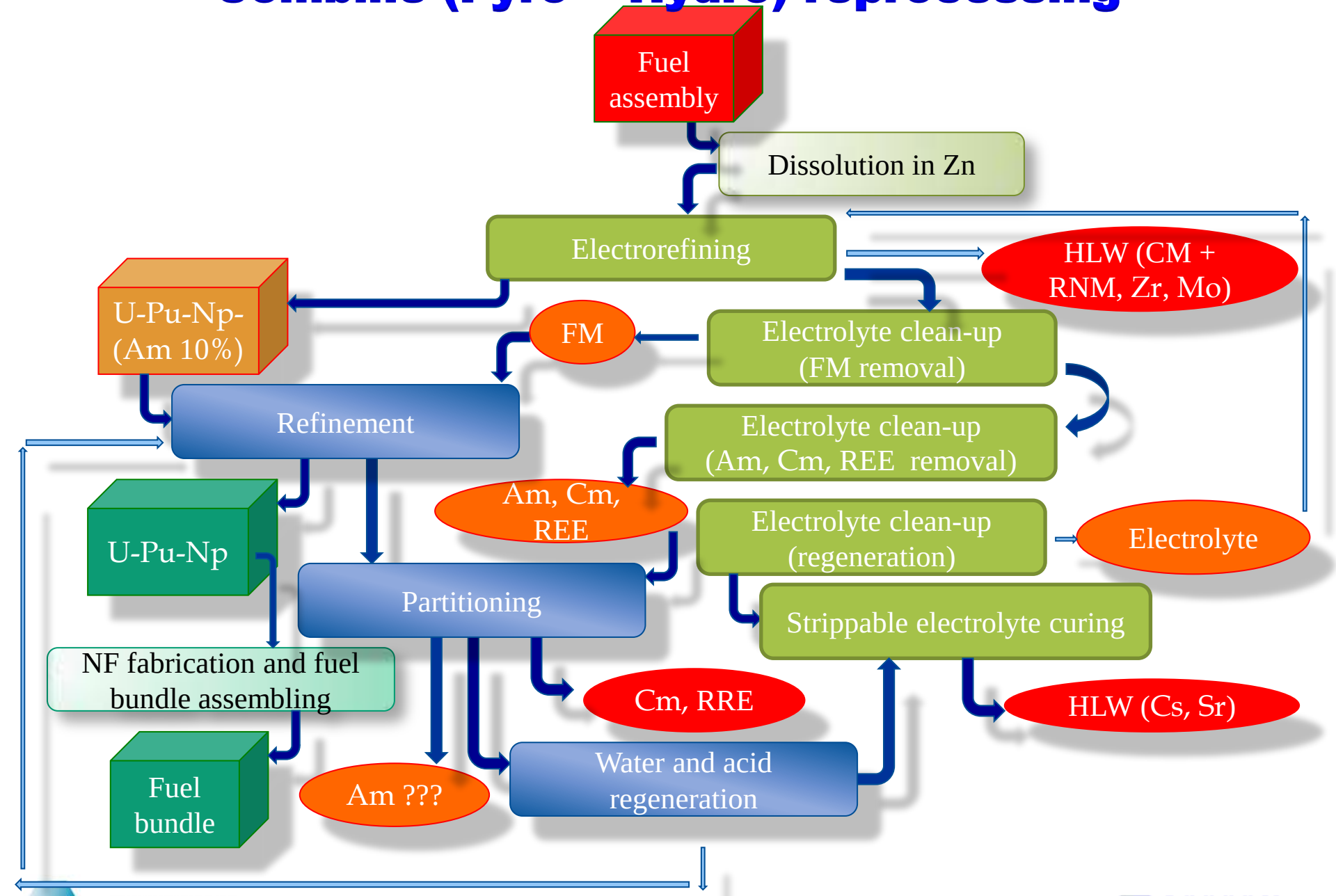


KATO, T. , et al., “Actinides Recovery from Irradiated MOX fuel by Pyrochemical Reprocessing”, Global 2011 (Proc. Int. Conf., Makuhari, Japan, 2011), paper # 391320

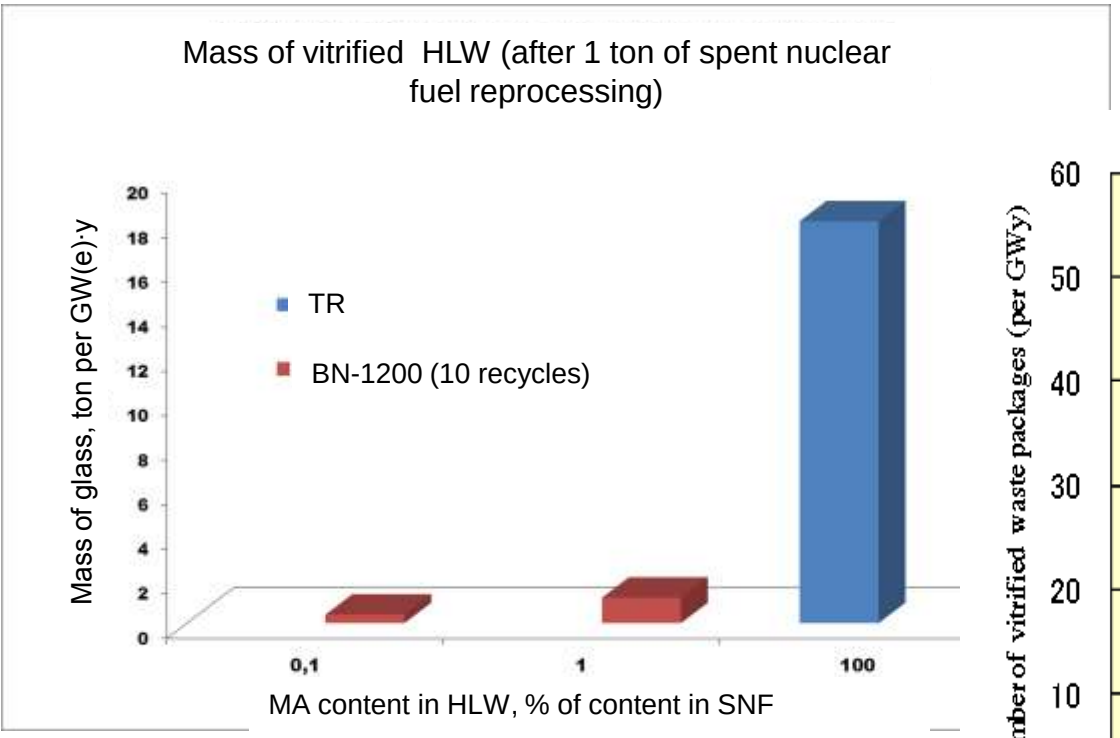
Low cooling time and high burnup are forcing to use non-aqueous operations at the head of SNF reprocessing

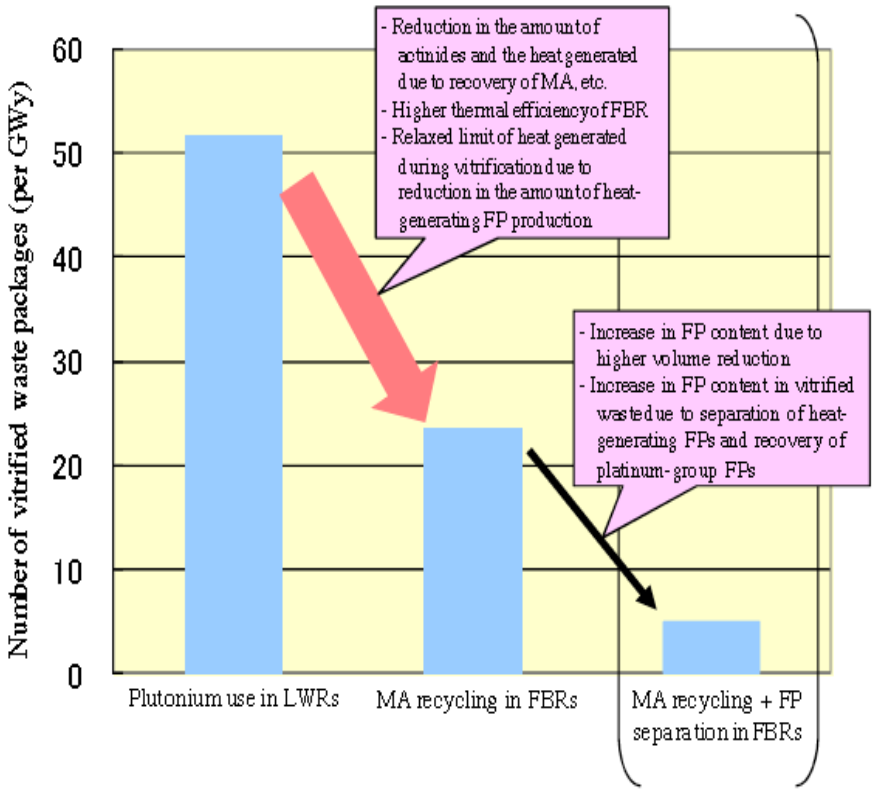


Combine (Pyro + Hydro) reprocessing



Volume of wastes containing MA for recycling in BN-1200 is negligibly small compared to that from TR SNF reprocessing

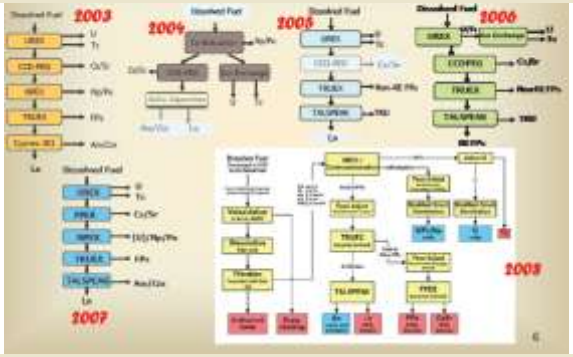




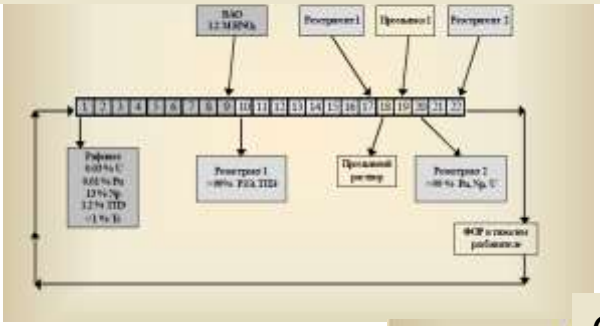
IKEDA, Yo., et al., "Overview of Fast Reactor Cycle System Technology Development Project (Fact) Phase 1 and Future Direction" , Global 2011 (Proc. Int. Conf., Makuhari, Japan, 2011), paper # 451660.

High-level waste partitioning

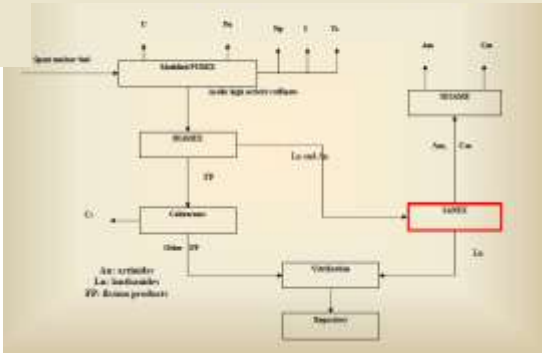
Reprocessing technologies (USA)



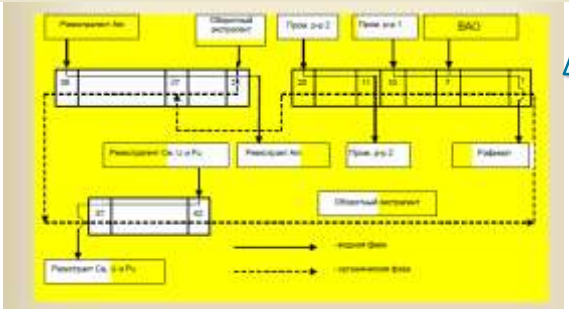
FOR reprocessing technology
China, Russia



Reprocessing technologies (EU)



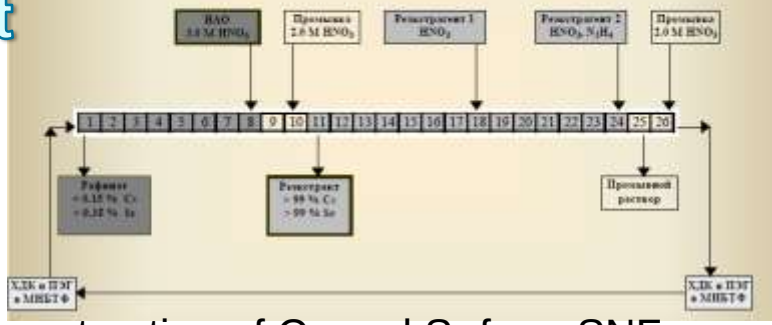
SETFICS-process
Japan, Russia



And these are not all the existing options

Cs and Sr extraction

CCD-process

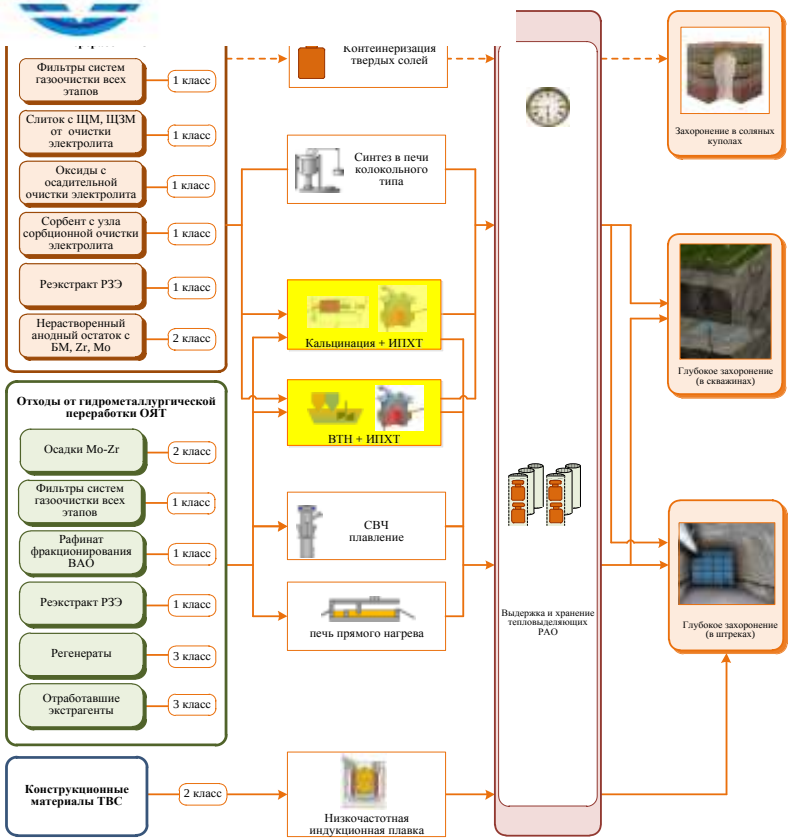


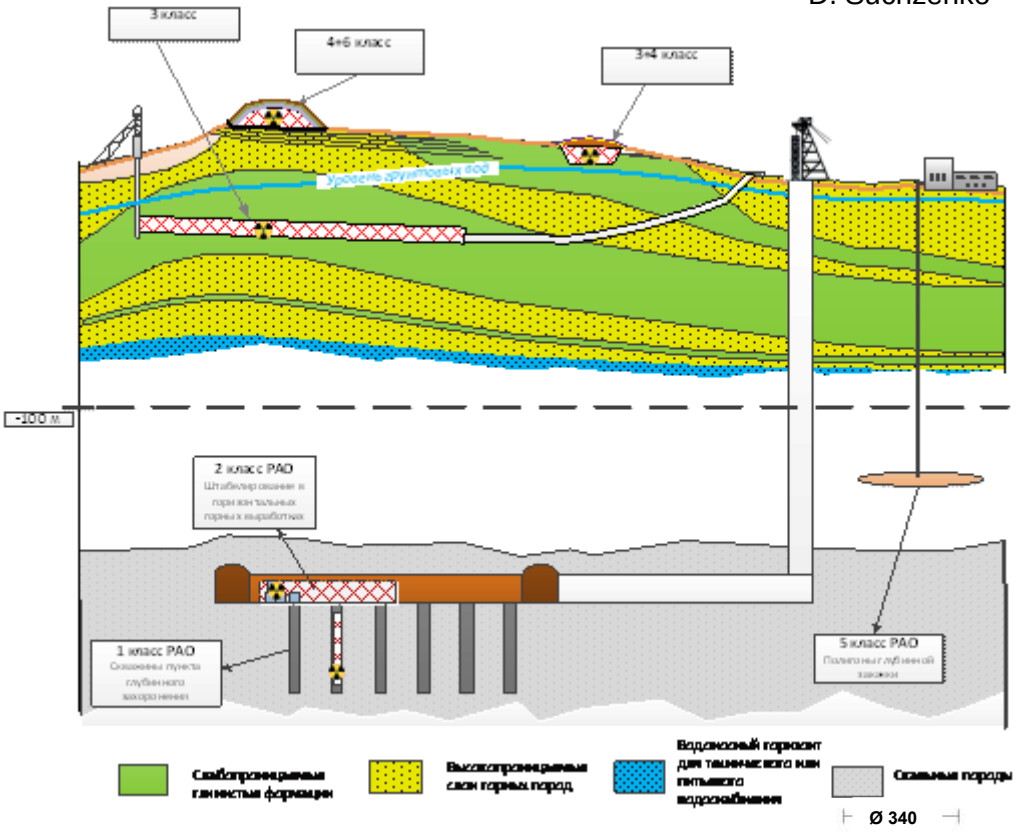
- The only scheme performed on the industrial scale is the extraction of Cs and Sr from SNF reprocessing waste using DCC (DCC-process).
- Processes allowing Tc extraction as well as extraction of TPE and REM are FOR-processes and TRUEX-process. But they do not solve the problem of purification from Mo and Zr.
- At the time UNEX-process is the only technological scheme for extraction of all long-lived nuclides, proven on real wastes accumulated recently.

Management with Radwaste

T. Gupalo
V. Chistyakov
D. Suchzenko

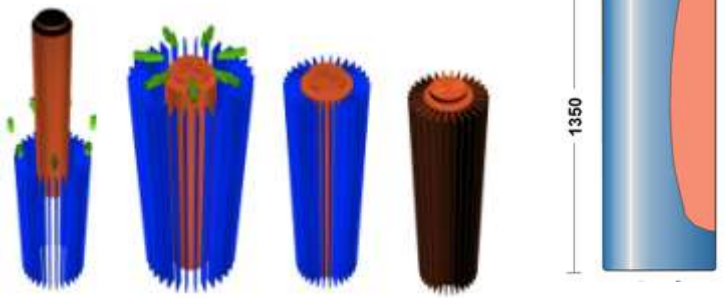
ВНИПИ ПРОМТЕХНОЛОГИИ





Different radwaste require different final form and disposal. And different radwaste management cost.

We need an optimum



Several techniques tested on laboratory and pilot scale must be upgraded to industrial-scale processes:

- decladding;
- light fission products handling (^{14}C, Kr, Xe and so on);
- ^{14}C handling;
- TPE extraction and Am - Cm separation;
- solidifying waste into forms, suitable for final isolation;
- environment regeneration technologies (electrolyte, water, argon)

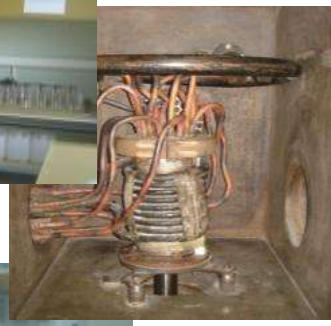
Main problems that need solutions

1. Removal of shells
2. Necessary purification coefficient of U (Pu) from FP
3. Recovery and separation of Am and Cm
4. Used salt purification and recycle
5. Mixed U-Pu-Np product
6. Management of radio

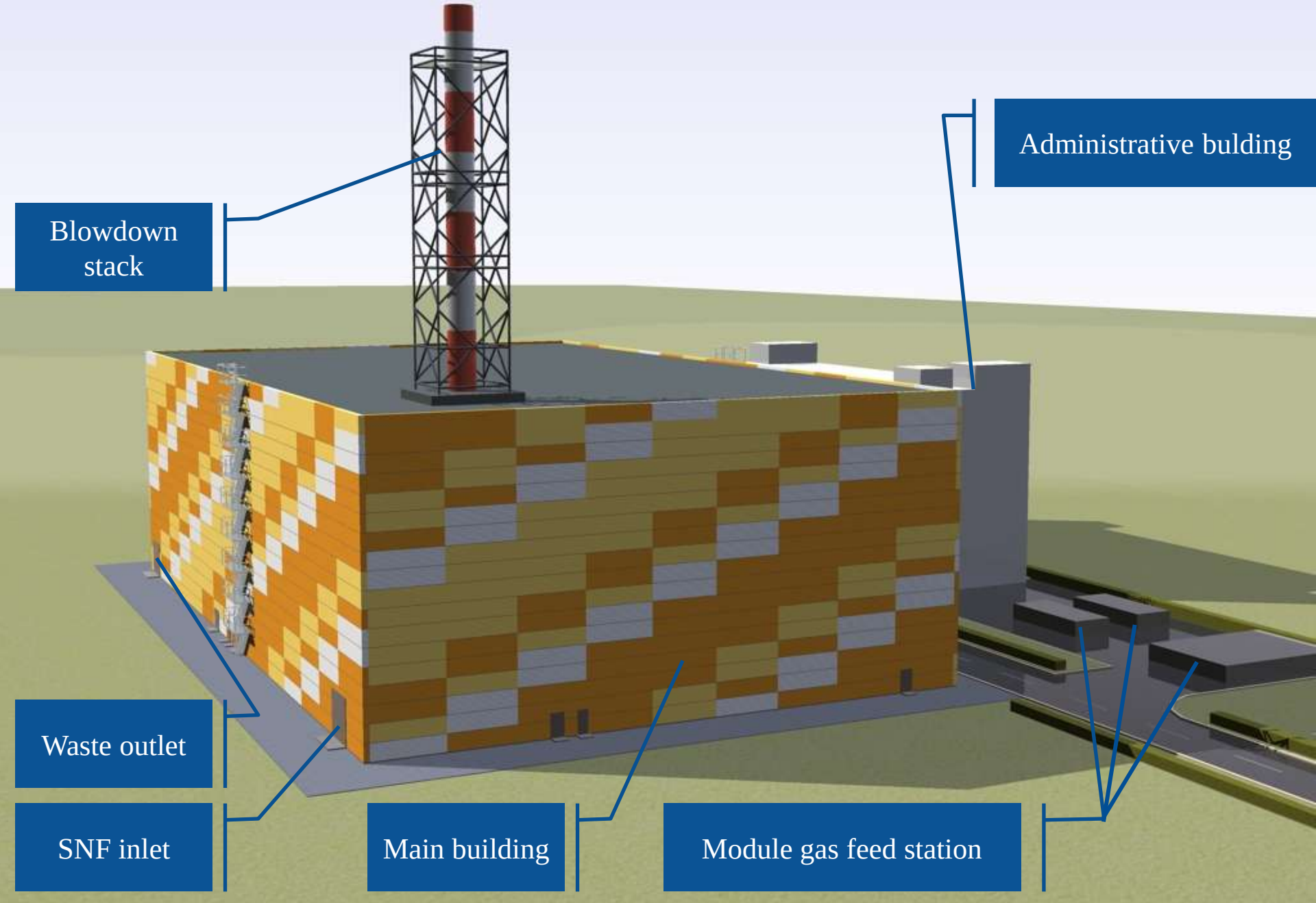







Polyfunctional Radiochemical Complex



Closed nuclear fuel cycle with fast reactors advantages:

- Use of ^{238}U and ^{239}Pu
- Controlling necessary breeding ratio
- No accumulation of UNF
- Use Pu from light water reactors UNF
- Transmutation of MA

The nuclear physicists have solved indetermination problem. Who is next?

1927

The more precise the measurement of position, the more imprecise the measurement of momentum, and vice versa.
Werner Heisenberg, 1927

2003

The properties of particles can be determined without changing the other parameters or with negligible changes

- Masanao Ozawa, 2003

2012

Confirmed – the changes are lower than Heisenberg indetermination limit

- Dilan Maler, Li Rozema, 2012