The International Symposium on Present Status and Future Perspective for Reducing Radioactive Wastes
– Aiming for Zero-Release-
October 9, 2014

# Reduction of the Radioactive Wastes by SCNES


**The Japan Atomic Power Company**

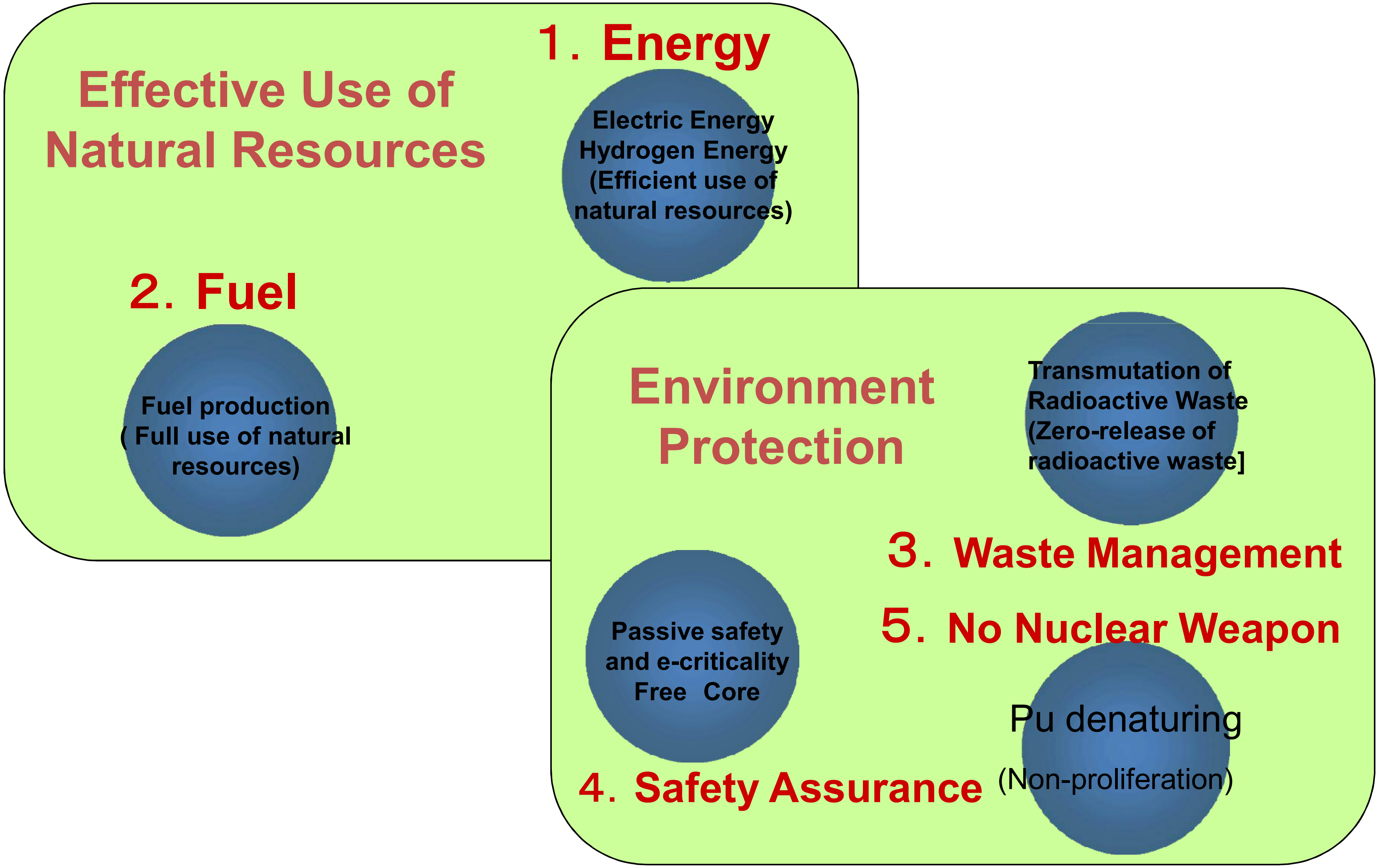
Executive Officer, in charge of
Projects Development Department

**Shoji KOTAKE**

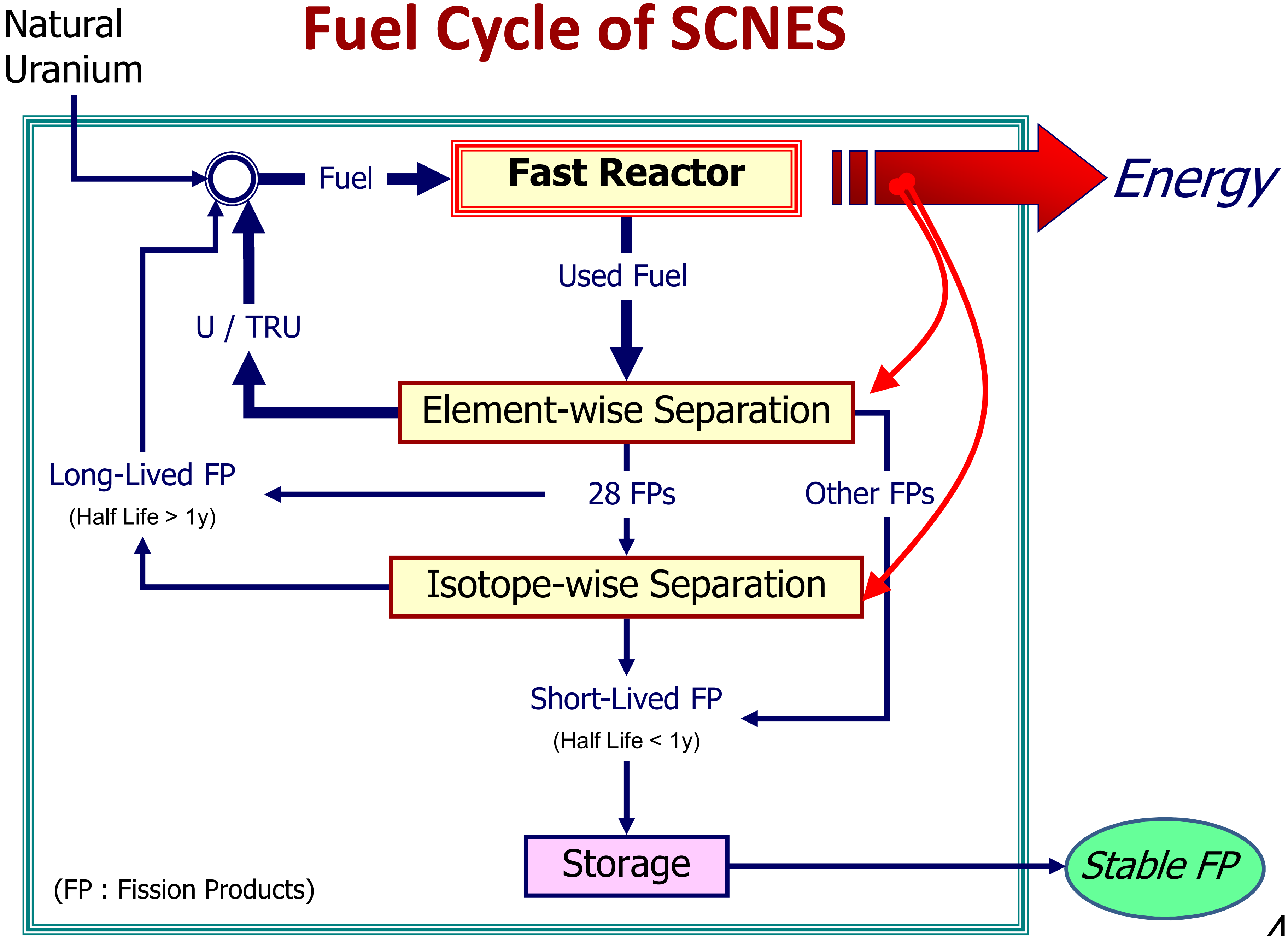
# Self-Consistent Nuclear Energy System
# - SCNES -

- The concept of SCNES is originally proposed by Prof. Fujii-e/ Tokyo Institute of Technology in 1991.
- SCNES is the ultimate nuclear energy system which achieve both **the effective use of natural resources** such as energy generation and fuel production and **the environmental protection** such as safety assurance, waste management and non-proliferation, simultaneously.
- Full usage of TRU fission by the fast neutron, such as the generated energy of 200Mev and generated neutron of 2.9.
- The scientific feasibility of SCNES has been confirmed based on the neutron and energy balance.

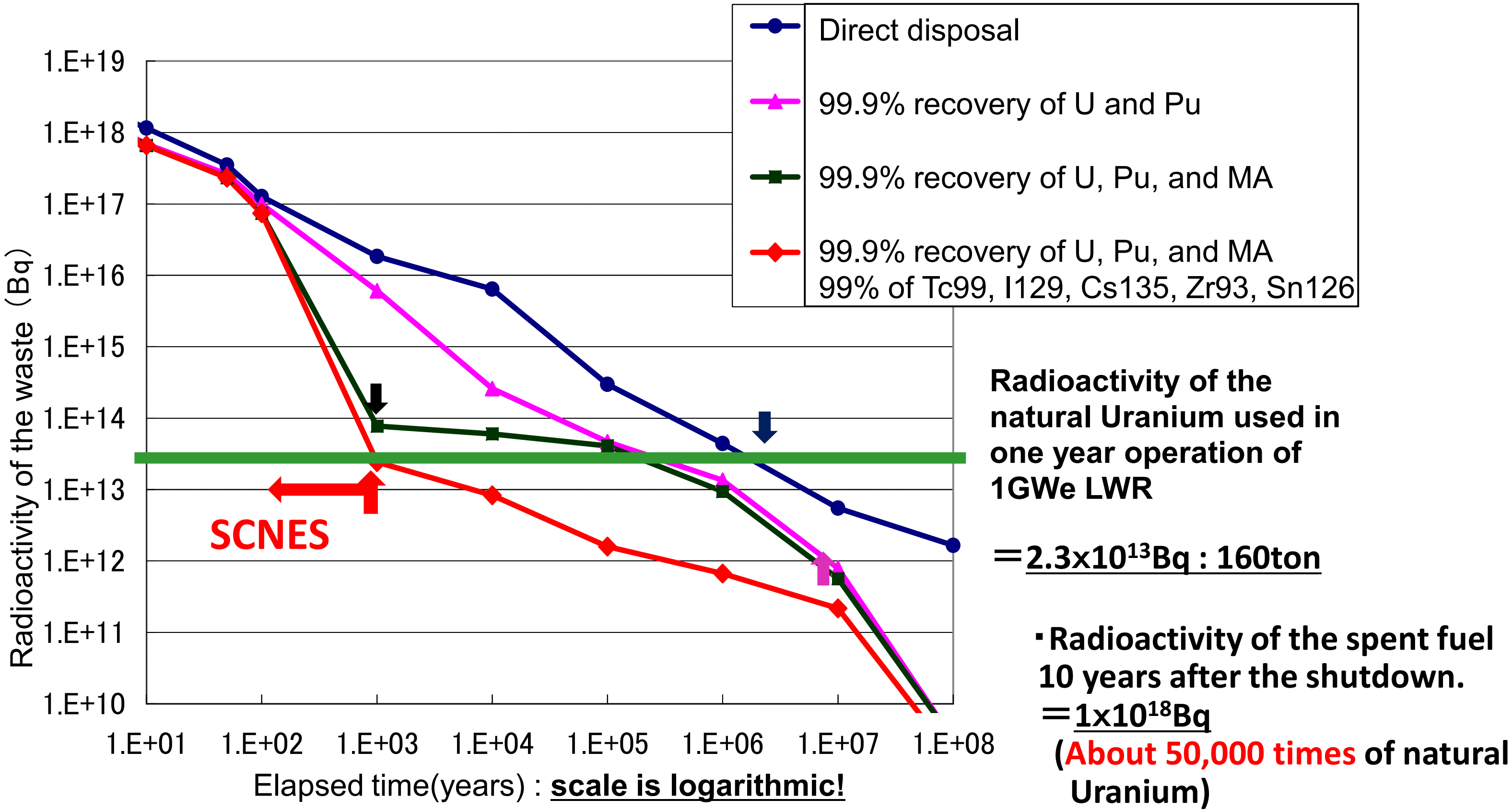
# SCNES: Nuclear Energy System which satisfies Five Objectives simultaneously



# Fuel Cycle of SCNES



# Reduction of radioactivity




**Necessary period for reducing radioactivity to the same level of natural Uranium**

Direct disposal ; 1 million years
FBR cycle ; 0.3 million years
FBR cycle with MA burning ; Oder of 1,000 years
SCNES: MA burning + LLFP nuclide transmutation; 1,000 to several hundred years

# What are long-term rad. waste? (1/2)

・**Actinide nuclides, created by neutron absorption into Uranium 238, have a long-term activity**

Pu-239： $2.41 \times 10^4$ y

（Total Pu is approx. **10kg** containing Pu238,Pu241)

**Minor actinides(MA);**

**Np-237**：$2.14 \times 10^6$ y(**0.6kg**),

**Am-241**：432y(**0.4kg**),

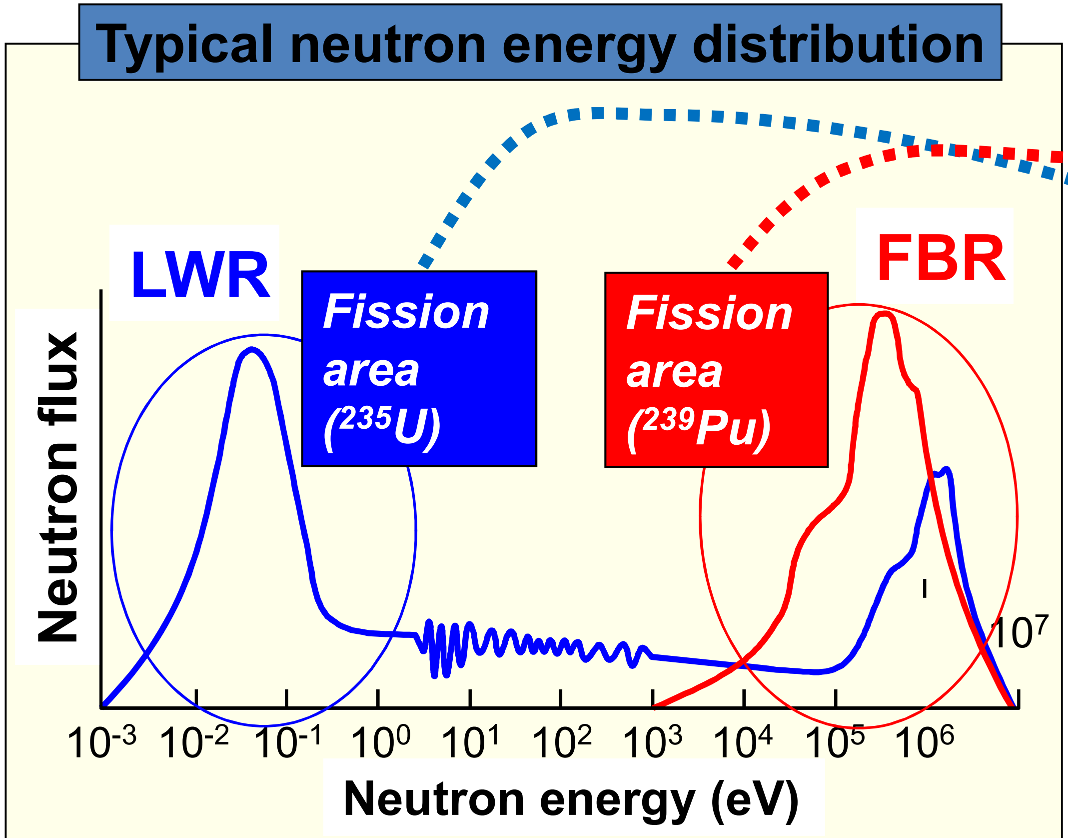
**Am-243**：7370y(**0.2kg**),

**Cm-244**：18y(**0.06kg**)

→**Pu and MA(Np, Am, Cm) are burnable and transmutable as fuel in fast reactors**

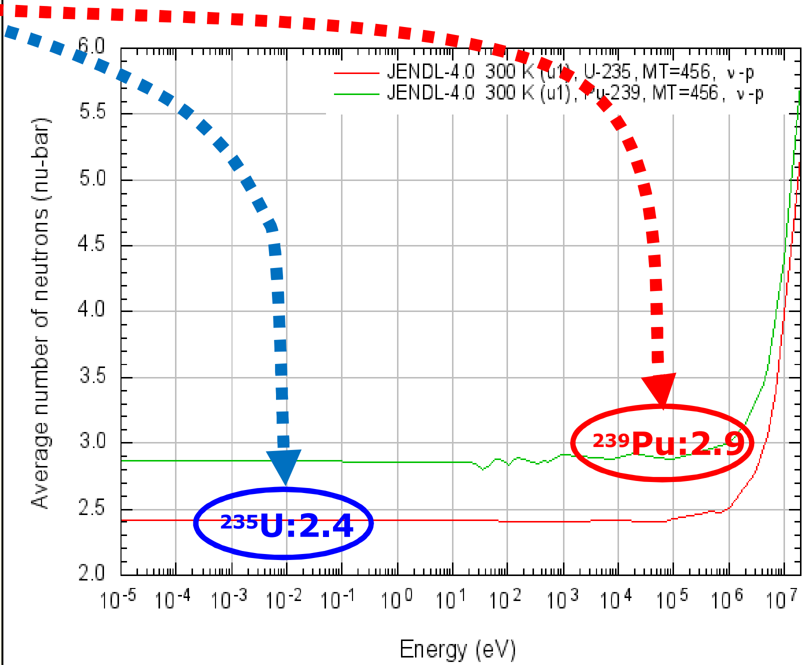
**Numbers in round brackets indicate approximate contents per 1ton of spent fuel of 45GWd/t burn-up**

# Characteristics of Fast Reactor Core: More neutrons are generated by Pu fission




*Area above ~$10^5$eV for LWR :*
*Quite less fission due to smaller fission cross section by ca. two orders than fission area*

**ν : Number of neutrons per fission**




- More neutrons are produced by Pu fissions by fast neutrons.
- More neutrons are used for keeping the criticality and fuel productions or LLFP transmutations.

Provided by Mr. N. Uto/JAEA

# *Characteristic of Fast Reactor core: Minor Actinides are burnt as fuel*

- $\sigma_f/\sigma_c$ of MA nuclides in the Fast reactor are higher values compared with the light water reactor

  $\sigma_f$：Fission cross section (Probability that a neutron causes a nuclide to be fission）

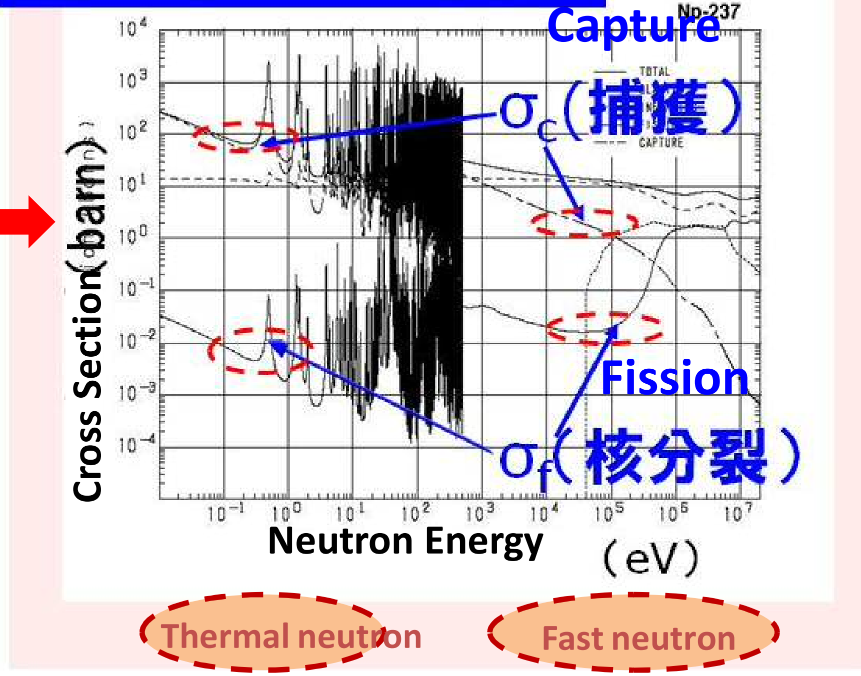
  $\sigma_c$：Capture cross section（probability that a neutron is captured into a nuclide ）

$\sigma_f/\sigma_c$ of MA nuclides

| | LWR (PWR) | Fast reactor |
|---|---|---|
| Np-237 | 0.02 | 0.19 |
| Am-241 | 0.01 | 0.14 |
| Am-243 | 0.01 | 0.12 |
| Cm-244 | 0.06 | 0.70 |

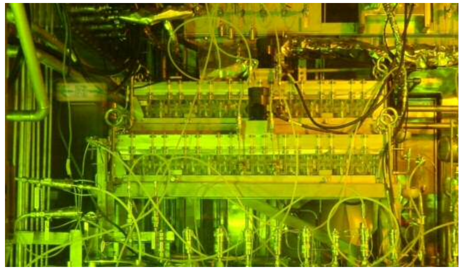
Source：Actinide and Fission Product Partitioning and Transmutation --- Status and Assessment report, OECD/NEA, 1999

**Example: Cross section of Np-237**

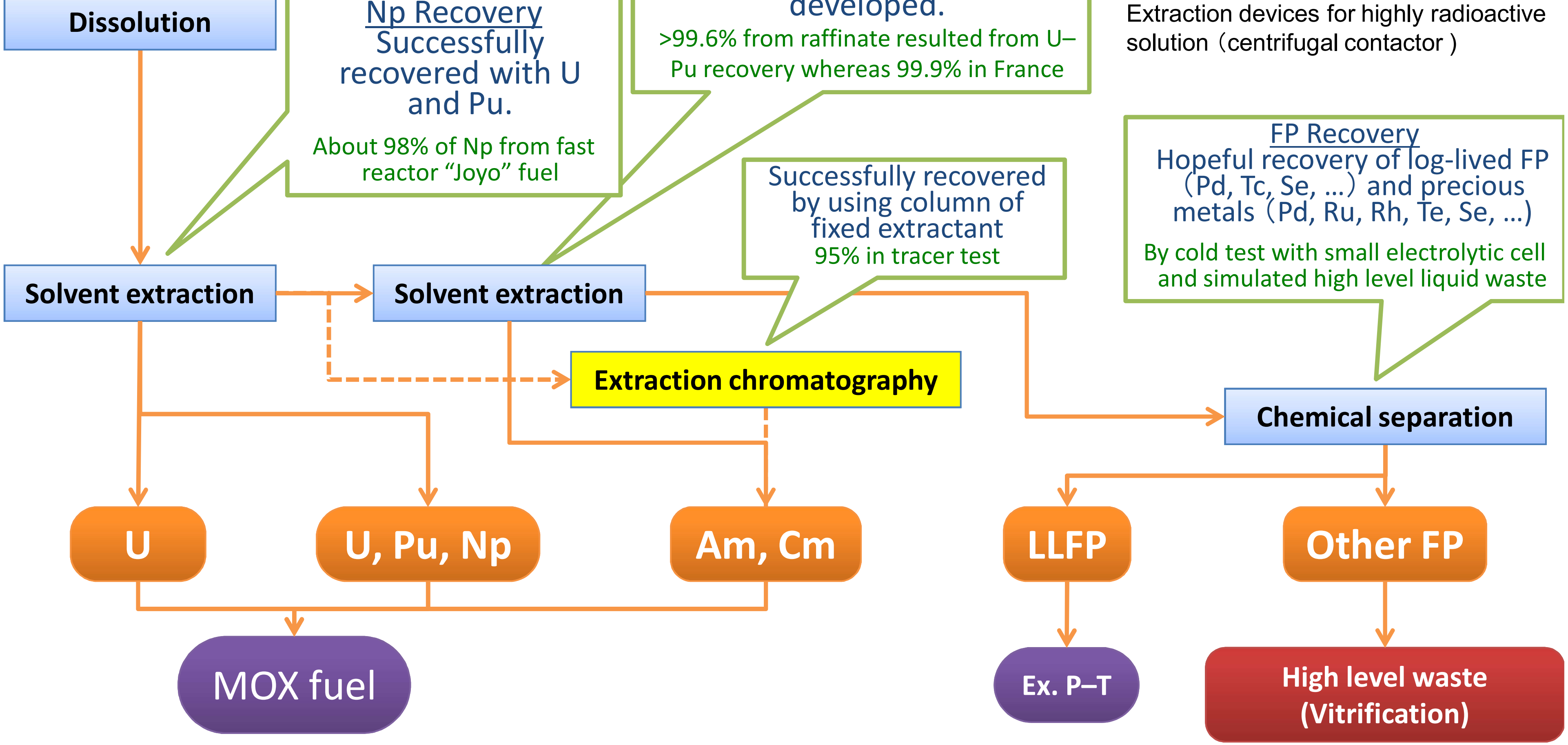



Provided by Mr. N. Uto/JAEA

# Current Status of MA/FP separation Technologies



Extraction devices for highly radioactive solution（centrifugal contactor ）

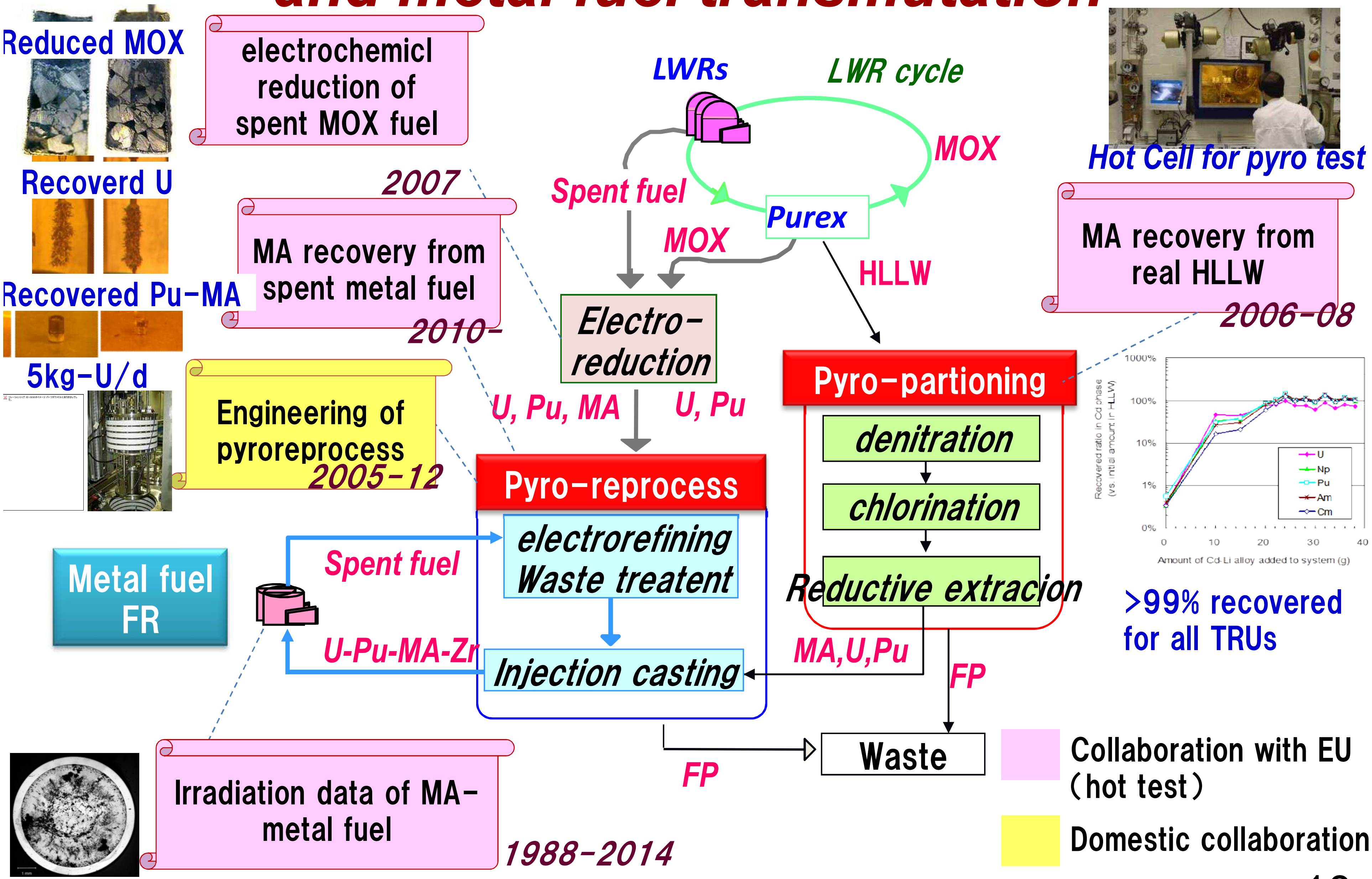




Journal of Nuclear Science and Technology, Vol. 44, No. 3, p. 373–381 (2007).
M. Miguirditchian et al., Global 2009, France, Paris, 1036 (2009).
JAEA-Evaluation 2011-003 (2011).


Provided by JAEA

# Recent Achievements on pyro-partitioning and metal fuel transmutation




Transmutation was confirmed through isotope analyses

Provided by CRIEPI

# *The demonstration test plan of the fuel assembly with MA in cooperation Japan, USA and France*

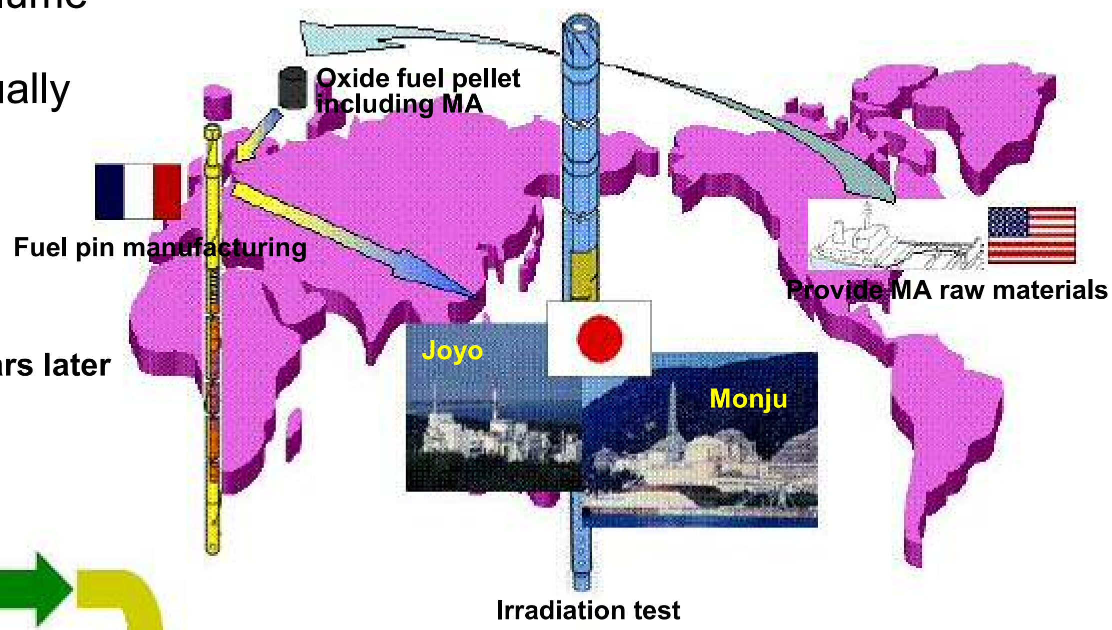
GACID (Global Actinide Cycle International Demonstration)

Objective：Demonstration to burn up a fuel including minor actinide (MA) (to be also called TRU fuel) in “Joyo” and “Monju” as a potential fuel for the commercial FBR.

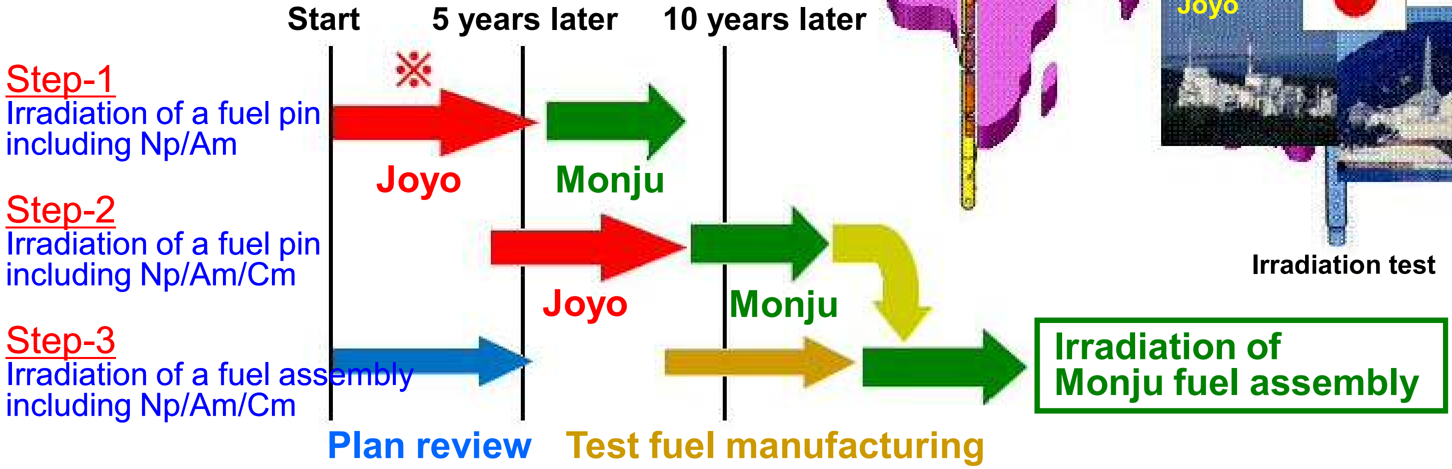
Demonstration to recycle total volume of MA by burning up in FBR

Three steps are carried out gradually

One of the SFR projects in GIF



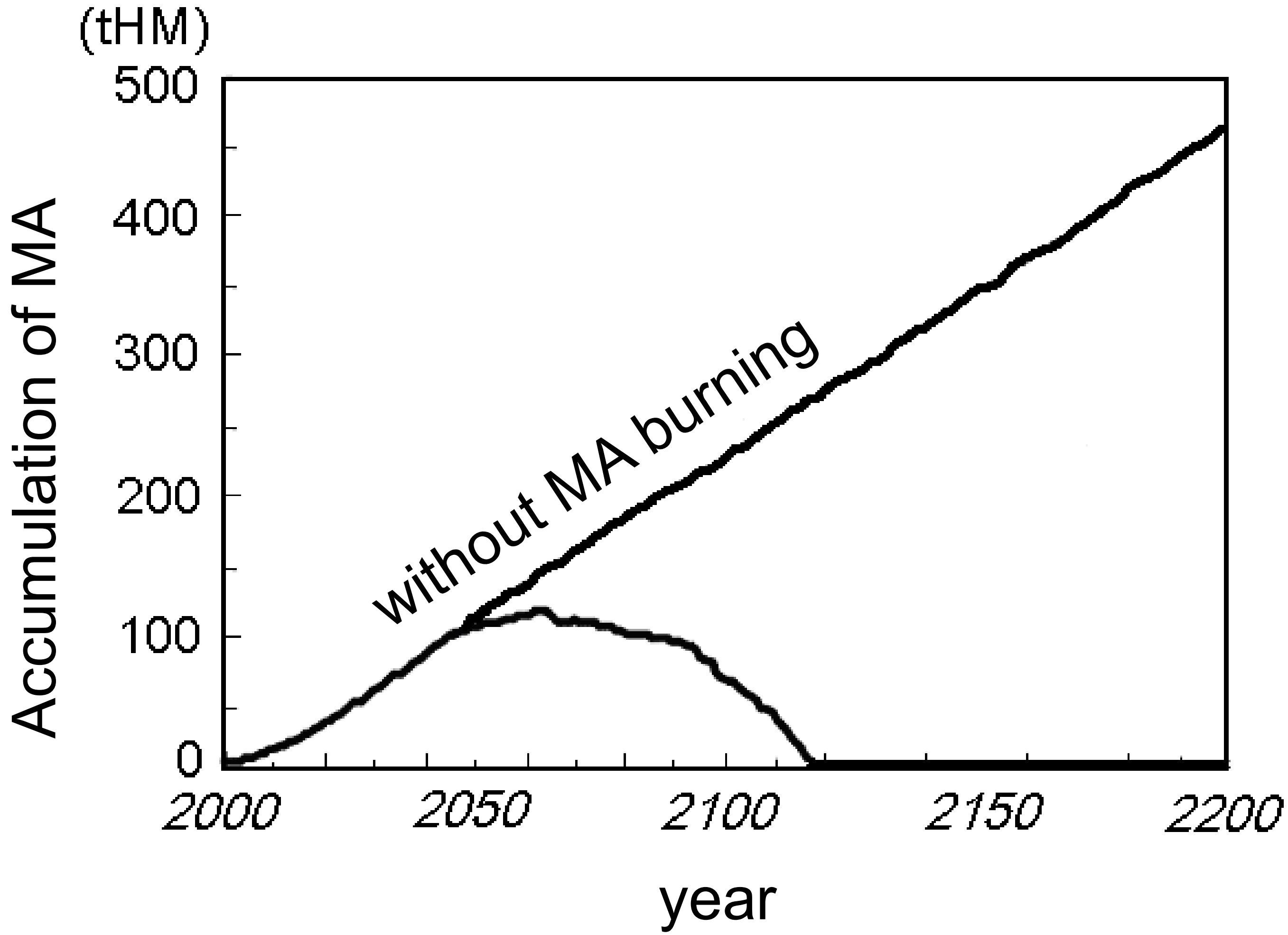

GACID schedule




Provided by JAEA

※Twice short-term irradiation test were finished.
(In the future, long-term irradiation test will be carried out)

# The ability of FR MOX fuels to burn MA




**FRs, with MA bearing fuels(ca. 3.5%) from LWRs, have capability to burn all amount of MA when in 2050 year**

Reference:「Evaluation about characteristics of FBR Cycle」the report by JNC No.12 supplement *2001.9*

# What are long-term rad. waste? (2/2)

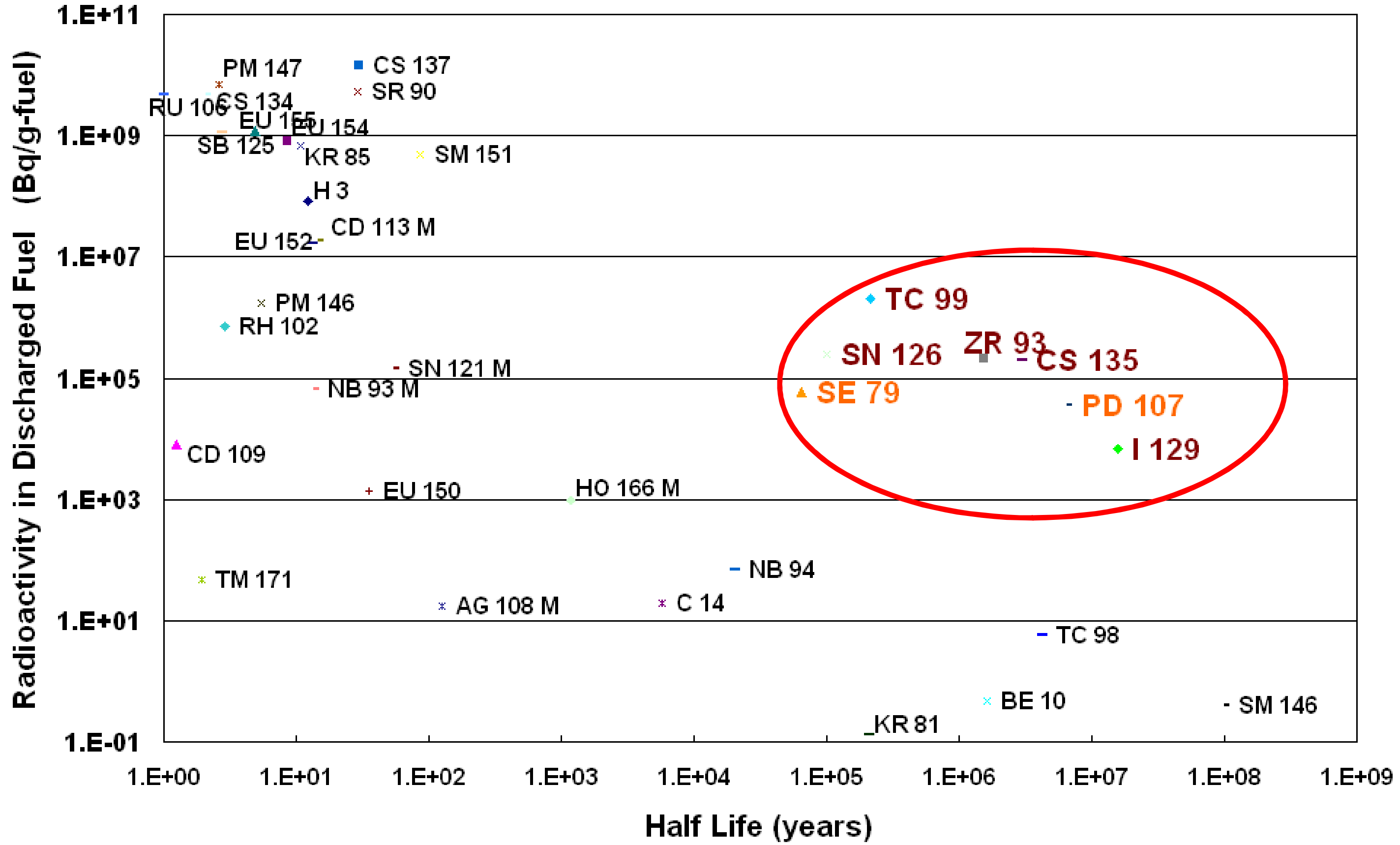
**・Long-lived Fission Products（FP）;**
**Major nuclides and its half-lives:**

**I-129**: $15.7 \times 10^6$ y(**0.2kg**)
**Tc-99**: $0.21 \times 10^6$ y(**1kg**)
**Zr-93**: $1.5 \times 10^6$ y(**1kg**)
**Cs-135**: $2.3 \times 10^6$ y(**0.5kg**)
**Sn-126**: $0.1 \times 10^6$ y(**0.03kg**)

→**Zr, Cs and Sn needs isotope separation and transmutation in fast reactors as the target fuel**

**Numbers in round brackets indicate approximate contents per 1ton of spent fuel of 45GWd/t burn-up**

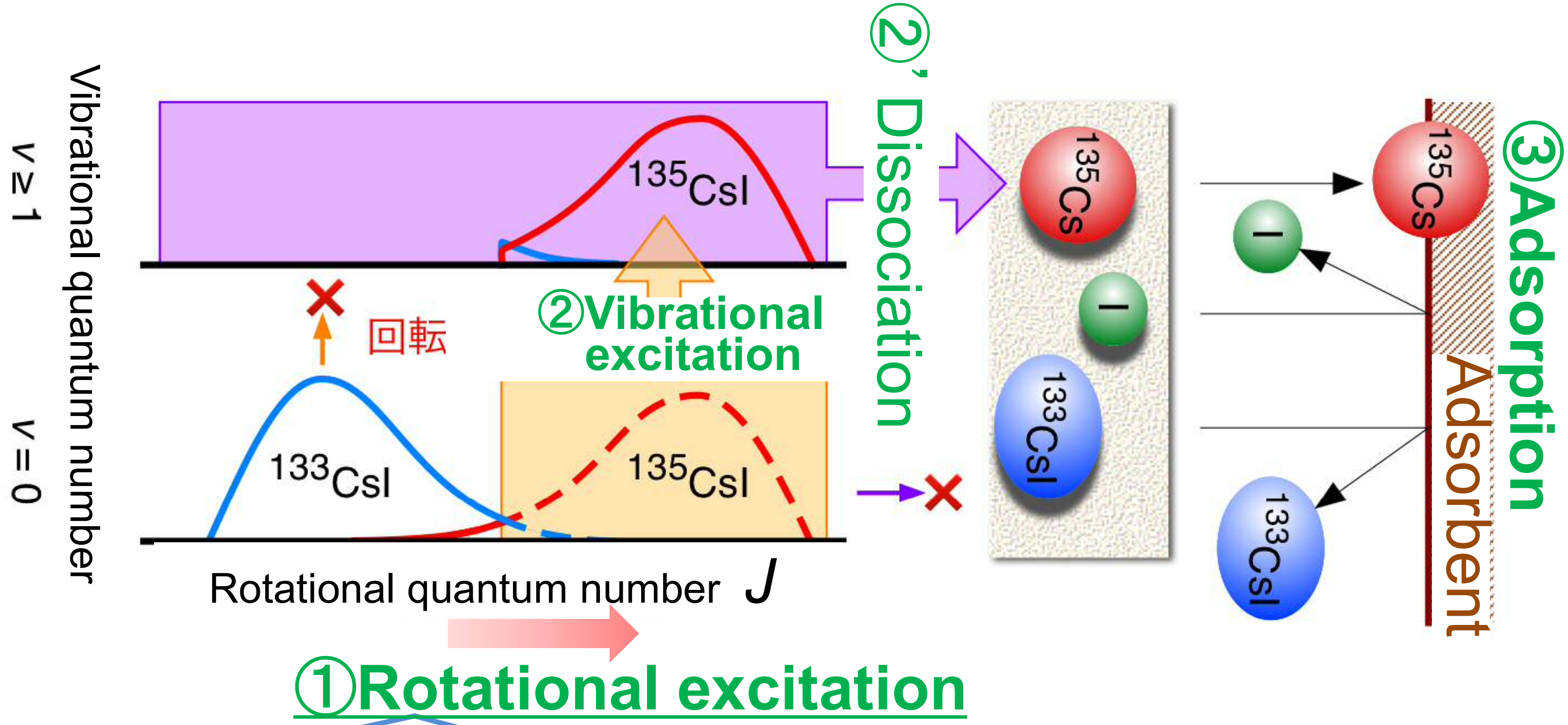
# Long-Lived Fission Products（LLFP)




Among the major long-lived FPs(I-129, Tc-99, Pd-107, Zr93, Cs-135, Sn-126, Se-79), Pd-107 is generated a little (0.3kg*) and has lower solubility into water and Se-79 has the lowest for generation (0.006kg*) *Content per 1 ton of spent fuel

→ I-129, Tc-99, Zr93, Cs-135, Sn-126 can be objects for transmutation

# The innovative technology for Cs isotope separation




【Isotope-selective displacement of distribution】

Using " an optical frequency comb" with high-power terahertz-wave pulse

Provided by JAEA/Dr. Yokoyama

# The ability of fast reactors on radioactive waste treatment

◎Monju(300MWe) class FR with MA bearing fuel(ca. 5%) can load all MA generated in <u>24units of 1GWe LWRs</u> during one year operation

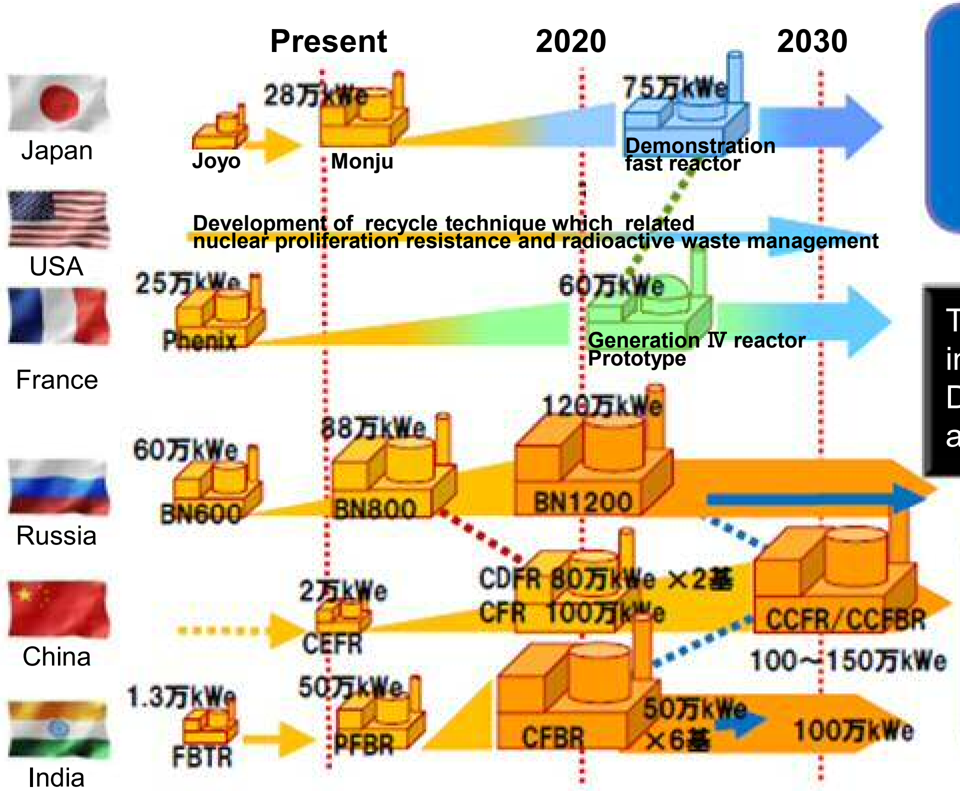
◎The MA burning capability is adjustable by means of arrangement of the core design and loading procedure

△Major LLFP nuclides( I-129,Tc-99,Cs-135,Zr-93,Sn-126 ) can be transmuted into short-lived nuclides in the fast reactor after isotope separation, extraction and enrichment process

△It is necessary to investigate the core design and develop LLFP targets assembly in order to evaluate LLFP transmutation capability

**Fast reactor cycle has a feasibility to reform the radioactivity of the waste into the same level of natural Uranium less than 1000 years**

# The development status of Sodium-cooled Fast Reactors




Japan, USA and France lead the world and aim at the step up to stage for development of generation Ⅳ reactors.

Through GIF*, the integration of international DB and guideline for safety and non-proliferation etc.

Russia, China and India accelerate the development of fast reactors based on existing technology.

The realization of FBR as comprehensive superior generation 4 reactor for
- Safety
- Non-proliferation
- Sustainability
- Economic efficiency

＊Generation Ⅳ International Forum

**Primary objectives of fast reactor development in each country**

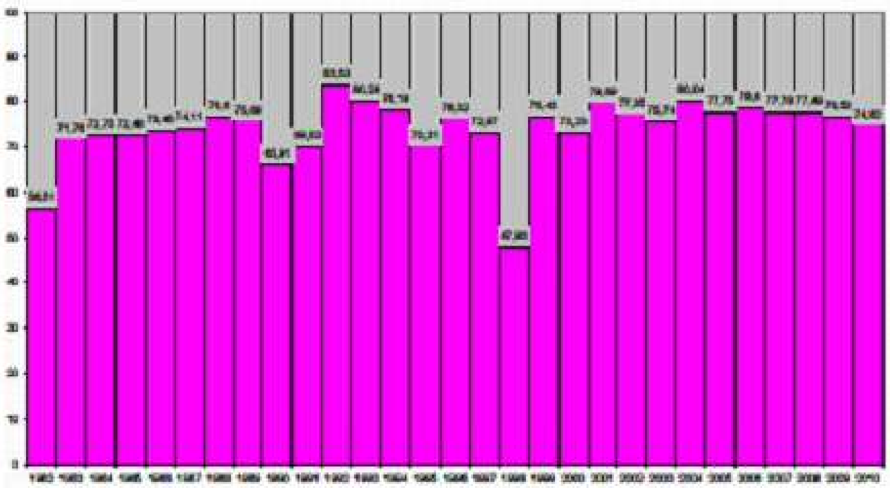
China･India：Improvement of energy self-sufficiency and resource utilization rates
France･Russia：In addition to the above, business chance as energy exporting country
USA：Changing the policy from direct disposal of spend fuel to effective utilization of spend fuel

Provided by Mr. Y. Sagayama/Chair Emeritus of GIF

# Great operational record in BN-600/Russia
# More than 70% availability during recent ca. 30 years

## Operational SFR experience gained in Russia (2/2)

**Change of load factor during the BN-600 power unit commercial operation**



**Achieved parameters on operation time and lifetime of the SFR equipment without overhaul, h**

| Type of equipment | BR-5/BR-10 | BOR-60 | BN-350 | BN-600 |
|---|---|---|---|---|
| Non-replaceable equipment: | | | | |
| Reactor vessel | 150 000 | 225 000 | 170 000 | 205 000 |
| Primary pipings | 300 000 | 225 000 | 170 000 | 205 000 |
| Sodium pumps | 170 000 electro magnetic | 260 000 mecha nical | 100 000 mecha nical | 105 000 mecha nical |
| Intermediate heat exchangers | 300 000 | 225 000 | 170 000 | 205 000 |
| Steam generators | - | 155 000 reverse SG | 150 000 | 125 000 evapo-rators |

The last outside sodium leak occurred at the BN-600 17 years ago – in May 1994.
As for leaks in SG, during recent 26 years of the BN-600 operation there was only one small leak in SG more than 20 years ago in January 1991.

# Development steps in the future

**Step-1：Commercialization of FR**

→Full usage of Uranium by nuclear transformation from U-238 to Pu-239.

→Consume Pu in used LWR fuel.
Reduce decay period of radioactive waste by Pu burning, e.g., from Pu-239 with $2.4 \times 10^4$y half-life to Pu-244 with $8.08 \times 10^7$y.
($10^6$ y order in direct disposal can be reduced to $10^5$ y order)

**Step-2：Introduction of FR with MA-bearing fuel**

→Full usage of Uranium with MA bearing fuel.
→Simultaneous achievement of fuel production and MA burning.
(Improve MA recovery rate and reduce decay period down to $10^3$ y order)

**Step-3：LLFP transmutation in FR with MA-bearing fuel**

→Reduce decay period to natural U level by LLFP separation, extraction and life-shortening by nuclear transformation.

(It is probably achievable to reduce decay period from 1000 years to ca. 300 year order, by improving recovery rates of MA and LLFP)

# Concluding remarks

1. **SCNES is consisted of FRs and TRU cycles(chemical and isotope separations) toward the zero-release.**
2. **FRs would achieve both "fuel production" and "transmutation of radioactive materials", and then it will be possible for the sustainable usage of nuclear energy. FR cycle system will shorten the duration of radioactivity for MA and LLFPs.**
3. **For this purpose, a wide range of R&Ds on FRs and MA/LLFP separation & transmutation technologies should be enhanced step by step.**
4. **In order to solve long-term and difficult R&D issues, the center of excellence with a sense of responsibility should clarify the R&D roadmap and then achieve the R&Ds with collaborating Universities, research Institutes and industries without borders, which treat a cutting edge technologies.**

# *Thank you for your attention!*

Prototype FBR “Monju”