Current Status and Future Plan of Research and Development on Partitioning and Transmutation Technology in Japan

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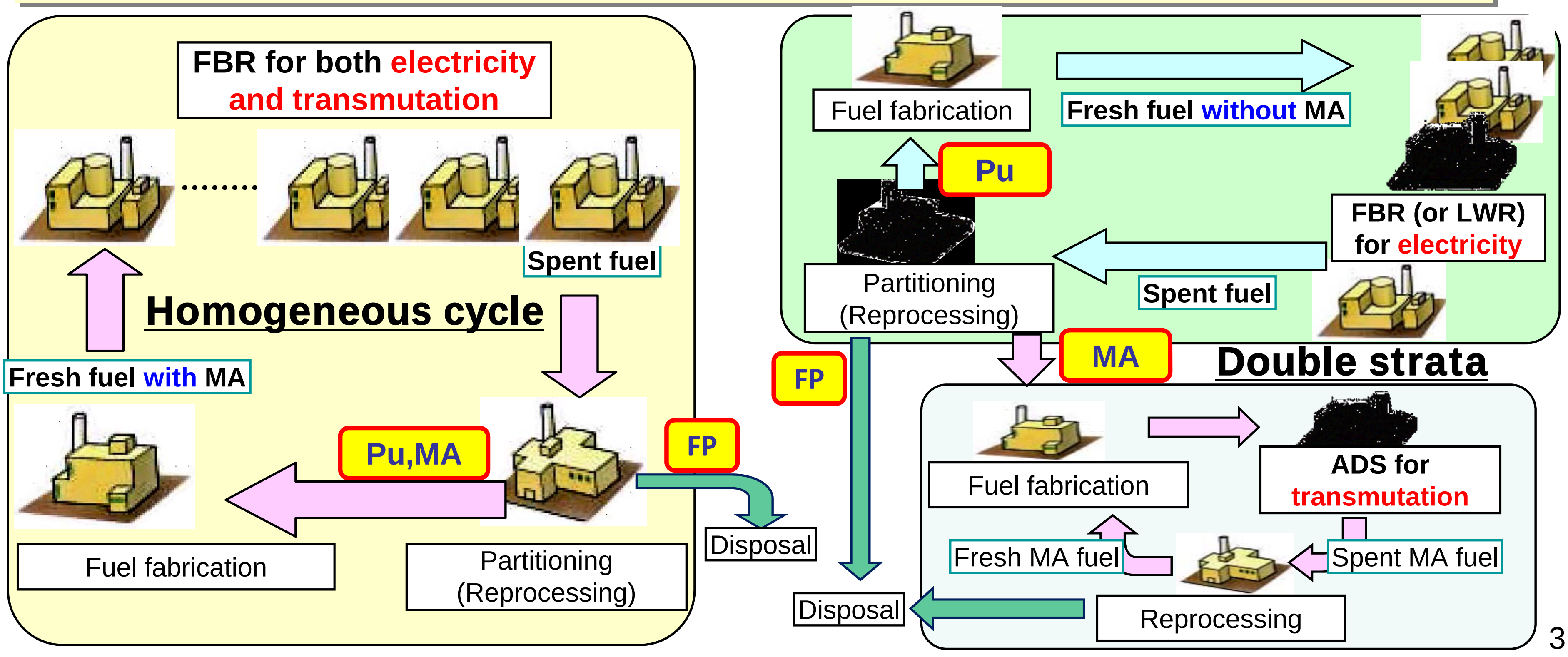
Contents

Brief History

- In 1988, **the "OMEGA" Program** was launched.
- In 2000, the program was reviewed by the Atomic Energy Commission (AEC):
  - ✓ It is appropriate to steadily promote R&D for two concepts:
    - ◆ Homogeneous recycling of MA using commercial FBR cycle (JNC, CRIEPI)
    - ◆ Double-strata concept using ADS (JAERI)
- In 2005, JAERI and JNC were merged, and JAEA was established
- These activities are continued in JAEA, and lots of effort has also been devoted into the estimation of the benefit of P&T in the high-level radioactive waste (HLW) management.



Check and Review (C&R) by Japan Atomic Energy Commission (JAEC)

- In August, 2008, JAEC launched the **Subcommittee on P&T Technology** under the Advisory Committee on R&D, and conducted the second C&R

- Purposes
  - To illustrate the **benefit and significance of P&T**
  - To review **current state of the art** concerning P&T technology in Japan
  - To discuss **how to conduct future R&D**

- Committee member
  - **Hajimu Yamana**, Professor of KURRI, Chair
  - Shinsuke Yamanaka, Professor of Osaka Univ.
  - Tomio Kawada, Director of Nuclear Waste Management Organization of Japan (NUMO)
  - Shinya Nagasaki, Professor of Tokyo Univ.
  - Tetsuo Fukazawa, Hitachi-GE Nuclear Energy Corp.
  - Yasushige Yano, Director of Nishina Accelerator Research Center, RIKEN
  - Yoshihiro Yamane, Professor of Nagoya Univ.
  - Toshio Wakabayashi, Professor of Tohoku Univ.

Discussed Issues

- Significance of P&T
  - Benefit and cost, and introduction scenario
  - Variation of transmutation system (Homogeneous / Heterogeneous, FR / ADS)

- Current State of the Art
  - Review of studies performed by JAEA and CRIEPI
  - Technical level of each component of P&T
  - Current Status of J-PARC Transmutation Experimental Facility

- Future R&D
  - Direction of R&D
  - Organizing different concepts (Homogeneous / Heterogeneous / Dedicated)
  - Requirements for future infrastructures

Final Report was issued in April 2009

Transition Scenario and Impact of P&T
Summary of Different Systems

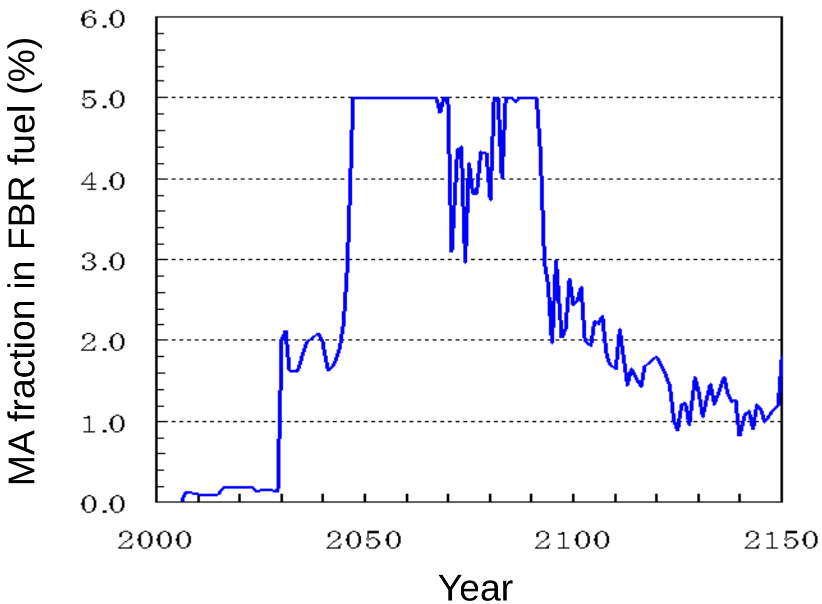
Items	FBR (Homogeneous MA loading)	FBR (Heterogeneous MA loading)	ADS
Fuel cycle	Homogeneous cycle	Heterogeneous cycle	Double-strata fuel cycle
Fuel composition	$(U, Pu, MA)O_2$ (U, Pu, MA)Zr metal MA contents: max.5%	$(U, Pu, MA)O_2$ (U, Pu, MA)Zr metal MA contents: ~20%	(MA, Pu)N+ZrN MA contents: ~60%
Reprocessign process	Advanced aqueous process(MOX) Pyrochemical process (metal)		Advanced aqueous and pyrochemical process
Transmutation	Sodium cooled FBR		LBE cooled ADS
Thermal power	3570 MWth (MOX) 3900 MWth (metal)	3570 MWth	800 MWth
Electric power	1500 MWe	1500 MWe	270 MWe
Composition of electricity generation (normalized at 58GW)	MA-loaded FBR: 58GW	FBR w/o MA: 43GW MA-loaded FBR: 15GW	FBR w/o MA: 58GW ADS: ~2GW
Transmutation rate per unit thermal power	**50 kg/GWth/y (MOX)** **60 kg/GWth/y (metal)** (MA contents 5%)	**30kg/GWth/y**	**310kg/GWth/y**

Transition Scenario and Impact of P&T
Transition Scenarios

Assumption

- The second reprocessing plant starts in 2047, where MA is recovered from LWR spent fuel for both UO_2 and MOX.
- FBR is introduced from 2050.
- Electricity generation is constant at 58GWe.

Homogeneous MA recycling by FBR



Transient from LWR to FBR will last for 60 years, and MA can be managed by adding MA to MOX fuel up to 5%.

Double-strata fuel cycle

Size of dedicated transmutation cycle to incinerate MA (Am+Cm) by ADS

1st. stratum (Commercial electricity generation cycle)
- LWR reprocessing: 1,200t/yr → 0t/yr
- FBR reprocessing : 0 → max. 600t/yr

↓ MA (Am+Cm):1.5~3t/yr

2nd. Stratum (Dedicated transmutation cycle)
- Number of ADS (800MWth): max. **8** units
- ADS reprocessing: 0 → max. **16**t/yr

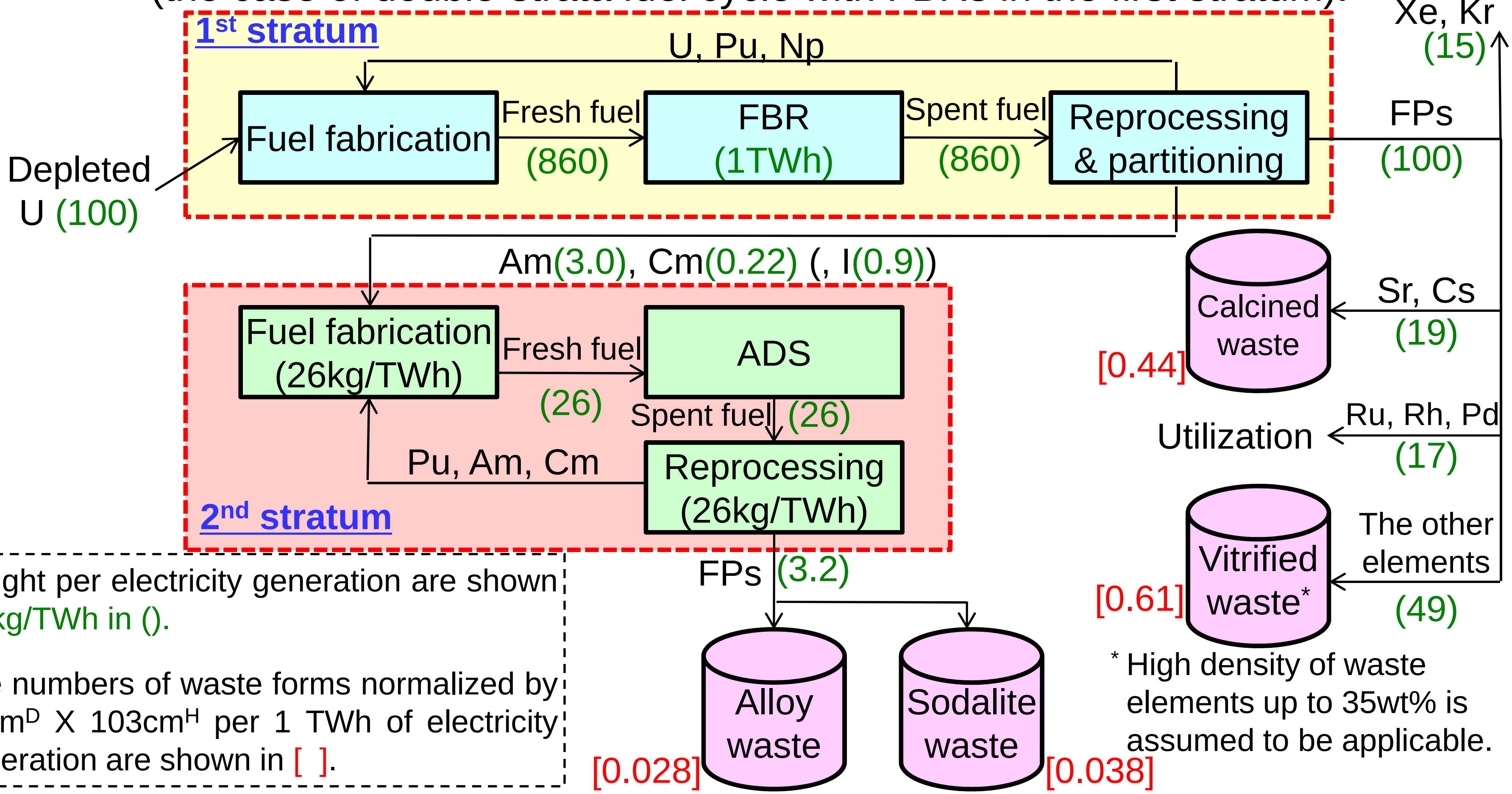
(note that MA fraction in heavy metal of fuel is about 60%)

Maximum 8 units of ADS can flexibly manage MA from both LWR and FBR

Transition Scenario and Impact of P&T
Innovative Fuel Cycle Incorporating P&T

- Concept of waste management incorporating P&T has been energetically investigated in these ten years rather than the reduction of radiotoxicity.

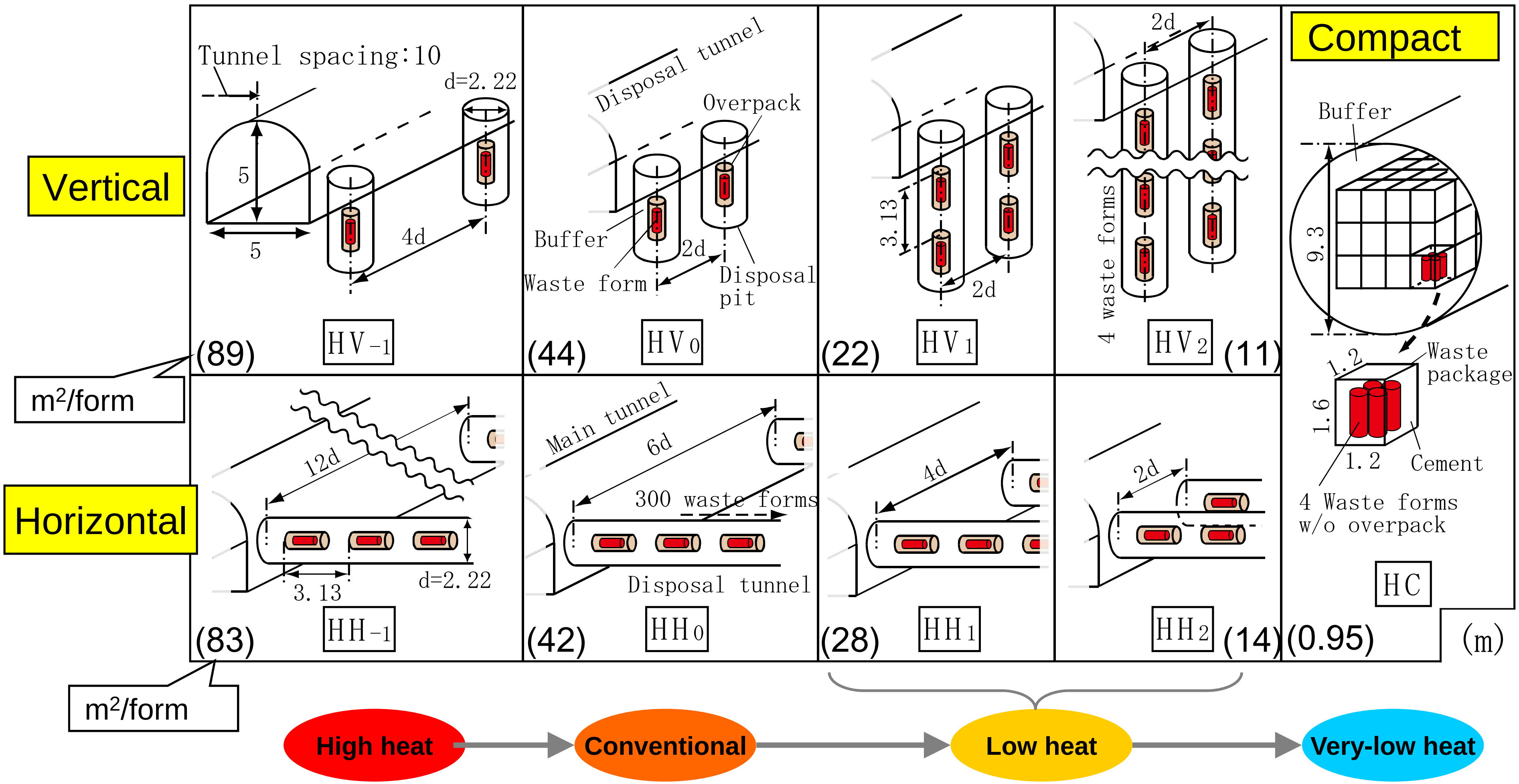
An example of full adoption of P&T
(the case of double-strata fuel cycle with FBRs in the first stratum).



Weight per electricity generation are shown by kg/TWh in ().

The numbers of waste forms normalized by 42cm^D X 103cm^H per 1 TWh of electricity generation are shown in [ ].

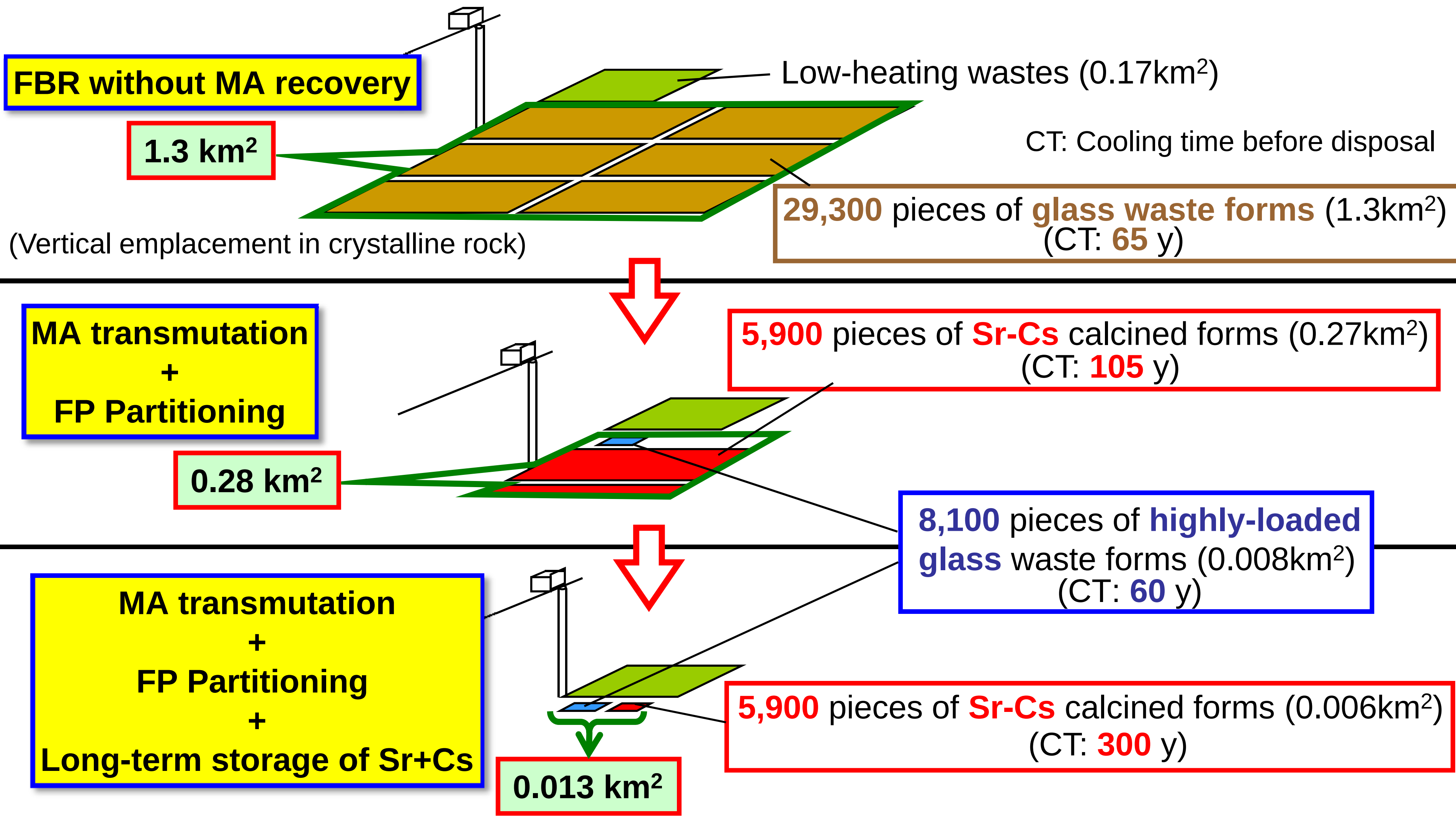
Transition Scenario and Impact of P&T
Concept of Waste Disposal



- Emplacement configuration can be chosen according to the heat density.
- Longer cooling time before disposal provides more condensed disposal.

Transition Scenario and Impact of P&T

Image of Site Area



Normalized by 1.3×10^4 TWh of electricity generation by FBR (40 years x 40 GWe)

Transition Scenario and Impact of P&T
Results of C&R

- The final report mentioned that three aspects should be noted as significant feature of P&T technology in the waste management system.
  - Introduction of P&T technology into the waste management will reduce the long-term potential radiotoxicity of the HLW. It is, however, necessary to note that this benefit is dependent upon the recovery efficiency of actinides from the waste.
  - In the case of MOX fuel utilization in LWR or FBR, the MA transmutation can reduce the area of repository necessitated for unit electricity generation and/or shorten the pre-disposal storage of the waste. This means that MA transmutation possibly extend the capacity of repository or reduce the burden of waste storage.
  - Combination of MA transmutation and FP partitioning, coupled with the long-term pre-disposal storage of the waste forms, will possibly reduce the repository area and enhance flexibility to design the whole system of waste disposal as more reasonable one by combining various options of waste disposal. More detailed investigation is, however, necessary to verify the feasibility of the long-term storage and the waste disposal method.

Technical level of each component of P&T
Definition of Technical Level

- Technical level for each component of P&T was evaluated in the second C&R, where four levels were defined as:

  Level-1: **Feasibility study**: Concept of the technology is created, and preliminary analysis and basic experiment are under way to verify the validity of the concept.

  Level-2: **Basic research**: Basic experiment, measurement of basic properties of materials, design evaluation by calculation, etc. are under way to consolidate the technological basis of the concept.

  Level-3: **Semi- engineering research**: After the verification of the fundamental feasibility, small-scale experiment considering the final stage is under way. Verification of engineering feasibility has just started.

  Level-4: **Engineering research**: Considering the solutions for main technical challenges, development of devices, examination of the performance and experiment in realistic conditions are under way. Realization of the technology as a whole system is strongly intended.

More comprehensive and detailed discussion on TRL was conducted by a Task Force of AESJ and to be reported by Dr . Minato in this meeting. (Thursday afternoon)

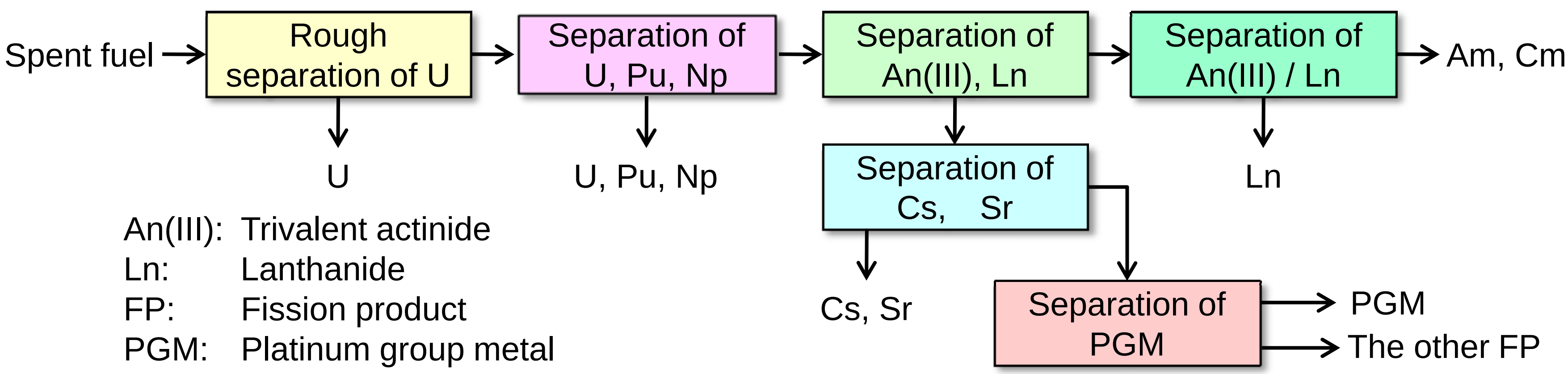
Partitioning Activities

- **Separation of An(III) and lanthanide from HLLW:**
  - ➢ Extraction chromatography method: CMPO, TODGA
  - ➢ TRUEX method
  - ➢ Invention of new extractants based on “CHON principle”: **TDdDGA**

- **Separation of An(III) from lanthanide:**
  - ➢ SETFICS method
  - ➢ Invention of new extractants: **PDA** (effective in high-concentration nitric acid.)

- **Separation of Sr and Cs from the other FP:**
  - ➢ Solvent extraction method
  - ➢ Extraction chromatography method: calix-crown R14 for Cs and crown ether for Sr
  - ➢ Ion exchange method

- **Separation of PGM:**
  - ➢ Electrolytic method
  - ➢ Adsorption method



An(III): Trivalent actinide
Ln: Lanthanide
FP: Fission product
PGM: Platinum group metal

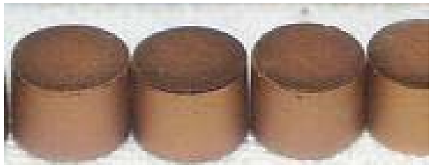
Partitioning
Results of C&R

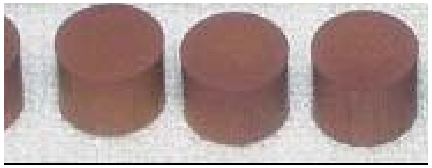
- The extraction chromatography for americium and curium separation has technical challenges to be overcome, and therefore it is considered still in **Level-2.**
    - To judge its feasibility in comparison with conventional solvent extraction methods, further R&D are necessary.
- The R&D activities to **explore innovative extractants** such as TODGA are highly appreciated because they are expected to dramatically enhance the performance of the separation process.
- The separation of Sr and Cs is in **Level-1** because promising process including the resultant waste form is still under investigation.
    - This process is considered important because of the possibility to reduce the area of repository, and hence **it is recommended to continue the R&D together with safe and reasonable concept of the pre-disposal storage.**

Fuel for MA Transmutation
Activities

- FBR:
  - MA-bearing (<5%) MOX fuel is the first candidate.
  - About 200 pieces of MOX pellets with **5% Am** and about 150 pieces with **2% Np + 2% Am** were sintered, and fuel pins were successfully fabricated to irradiate in JOYO.
  - R&D on metallic fuels are also under way. **U-Pu-Zr+2%MA+2%RE**, **U-Pu-Zr+5%MA** and **U-Pu-Zr+5%MA+5%RE** were fabricated at ITU, and they were successfully irradiated in PHENIX.
  - Higher loading of MA (~20%) into MOX fuel for heterogeneous recycling of MA in commercial FBRs is also being studied.
- ADS:
  - MA nitride fuel is the first candidate.
  - **(Pu, Am)N, (Np, Pu, Am)N, (Np, Pu, Am, Cm)N, (Pu, Am, Zr)N, (Pu, Am, Cm, Zr)N and (Pu, Am)N+TiN** were synthesized and the thermal properties were measured.
  - Some pellets were irradiated in JMTR and PHENIX.

(Np,Pu,Am,Cm)N


(Pu,Zr)N


PuN+TiN

Fuel for MA Transmutation
Results of C&R

- As for the MA-bearing MOX fuel, the fabrication method itself seems in Level-3. Its verification, however, has not yet done by using MA composition simulating LWR spent fuel containing curium, and therefore the technical challenges regarding the heat generation and high radiation field caused by MA are still to be solved. Hence the technical level is considered **between the Level-2 and -3**.

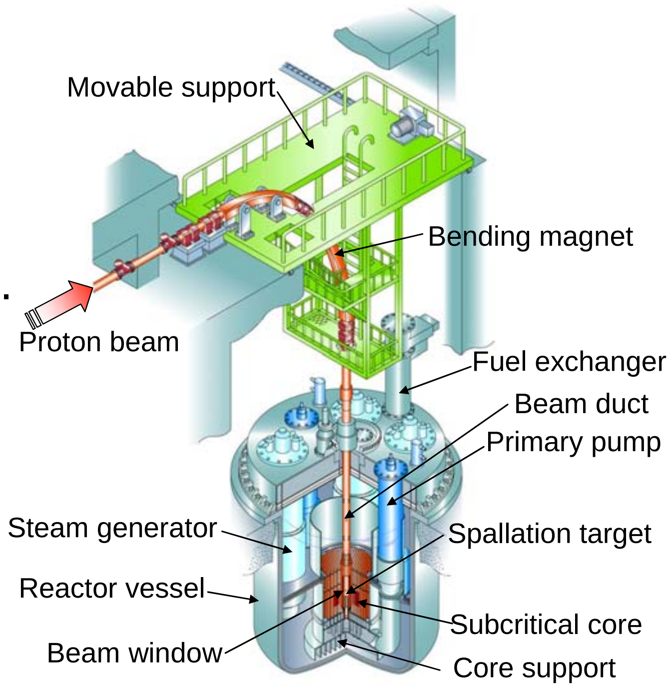
- As for the MA-bearing metallic fuel, the fabrication method itself seems in Level-3. The technical challenges concerning MA are still to be overcome, and hence the technical level is considered **between Level-2 and 3**.

- As for the dedicated nitride fuel, the principle of the fabrication method was verified, but investigation to extend it to engineering scale has not yet conducted. Therefore, the technical level is considered in **Level-2**.

Transmutation System Activities

- R&D of large-scale (~1500MWe) MOX FBR has been conducted as a part of **FaCT Project**.
  - ➢ MA content is limited below **5%** because of safety reason.
  - ➢ For metallic-fuelled FBR, a similar result was obtained.

- As for the ADS, an 800MWth lead-bismuth eutectic (LBE) cooled system driven by a proton LINAC was proposed
  - ➢ A feasible design to mitigate large **power peaking** was proposed by adopting 4-zone fuel loading and adjustment of inert matrix contents in the fuel.
  - ➢ Design study on a **beam window** showed that max. 30MW beam is acceptable, though experimental verification is necessary.
  - ➢ Thermal shock on reactor components by **beam trips** was investigated, and time-dependent criteria for beam trip frequency were established.
  - ➢ Various researches such as **corrosion** of materials by LBE, **velocity profiling** of LBE, properties of **irradiated materials** are being continued.



Conceptual view of 800 MWth LBE-cooled ADS

Transmutation System
Results of C&R

- As for the transmutation by FBR, the current accuracy of MA nuclear data is satisfactory for conceptual study but not yet sufficient for evaluation of safety parameters.
  - It is recommended to **conduct integral experiment using 10 kg order of americium and curium, which is an important issue for both FBR and ADS**.

- As for the transmutation by ADS, remarkable progress was seen, but accumulation of basic data is still necessary to proceed to the engineering verification. The technical level is, therefore, considered **in Level-2**.

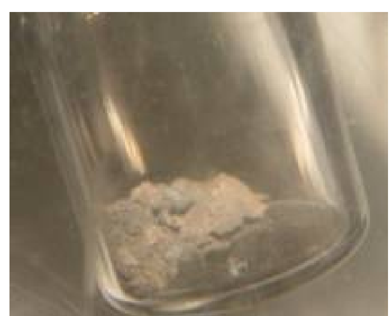
Transmutation Fuel Recycling *Activities*

- The aqueous process for MOX fuel of FBR is being developed **under the FaCT**.

- Metallic fuel for FBR will be reprocessed by dry process.
  - A small-scale electrolytic refining test for unirradiated **U-Pu-Zr metallic fuel** was carried out, and dissolution of fuel on an anode and deposition behavior of U and Pu on a cathode were verified.

- Nitride fuel for ADS will also be reprocessed by dry process.
  - Electrolytic refining tests for **AmN, UN** with elements simulating fission products, and UN and PuN **with inert matrix diluents**, and so on, were carried out.
  - Moreover, **a series of experiments** to recover uranium and plutonium in a cadmium cathode, to nitride them and to fabricate (U, Pu)N pellets were successfully carried out.

Cd cathode U and Pu



Recovered (U,Pu)N powder

Nitride pellet

Transmutation Fuel Recycling
Results of C&R

- As for the dry process of metallic fuel for FBR, the technology level is in **Level-3** as a whole, though a part of the technology is already in the **Level-4**.
  - It is recommended to accumulate further basic data for peripheral technologies such as process of salt waste.

- As for the dry process of nitride fuel for ADS, the activities are still on the stage of principle verification in laboratory scale, and therefore the technology level is in **Level-2**.
  - It should be noted that since this technology has many common aspects with that for metallic fuel, **collaborative approach of these two fuel types is recommendable**.

Recommendations for Future R&D (1)

- The R&D activities on P&T **should be linked strongly with those of FBR** because the purpose of P&T is identical to one of targets that FBR is expected to achieve in the future. From this viewpoint, R&D should be promoted not to explore the maximum effect of P&T but to achieve required **total performance of the future energy system on safety, economy, environmental sustainability, resource saving, and proliferation resistance**.
- This is true also for the double-strata fuel cycle concept, and the merit to isolate dedicated transmutation cycle from commercial power generation cycle should be discussed in a careful way.
- Although the technology is growing up from basic research level to semi-engineering level in general, **information to evaluate the performance of the whole system is not sufficient**. Fundamental data, therefore, should be accumulated and expanded for the future.
- Two types of concepts, the homogeneous FBR fuel cycle and the double-strata fuel cycle, **should be promoted under strong coordination**. Results of periodical assessment on the performance of the system should be reflected on their R&D activities.

Recommendations for Future R&D (2)

- Important issues for homogeneous MOX FBR fuel cycle:
  - reliable **MA separation** process
  - feasible fuel fabrication process under **high heat generation and high dose rate**
  - **safety core design** with containing MA up to 5%, and
  - reliable fuel performance for **high burn-up**.

- For metallic-fuelled FBR, R&D should be continued to verify its engineering feasibility.

- Important issues for double-strata fuel cycle:
  - **accelerator** with sufficient safety, reliability and economy,
  - feasibility of a **beam window**,
  - **reactor physics** of subcritical core including its **controllability**,
  - design of **LBE-cooled subcritical reactor**,
  - feasibility of **dry process for nitride fuel,** and
  - reliable **fabrication of nitride fuel** with appropriate performance.

Recommendations for Future R&D (3)

- For separation processes in common, it is important to accumulate knowledge and experience by **hot experiments in laboratory scale**, **cold examination of devices in engineering scale** and **demonstrative test using simulated high-level liquid waste**, before proceeding to hot demonstration of the technology in engineering scale.

- For MA-bearing fuels in common, **database of material properties of fuels including curium is not sufficient**, and it is not possible to judge the engineering feasibility to fabricate it under high heat generation and high dose rate. It is, therefore, important to **continue the acquisition of fundamental data**.

- For transmutation systems in common, **fundamental data to evaluate safety and performance of the systems are not sufficient** at present, and therefore it is recommended to enhance the activities on **MA nuclear data** in existing facilities and to **provide an experimental facility to conduct reactor physics experiments using MA**. The Transmutation Physics Experimental Facility proposed under **the J-PARC Project** is one of the candidates to conduct such an experiment.

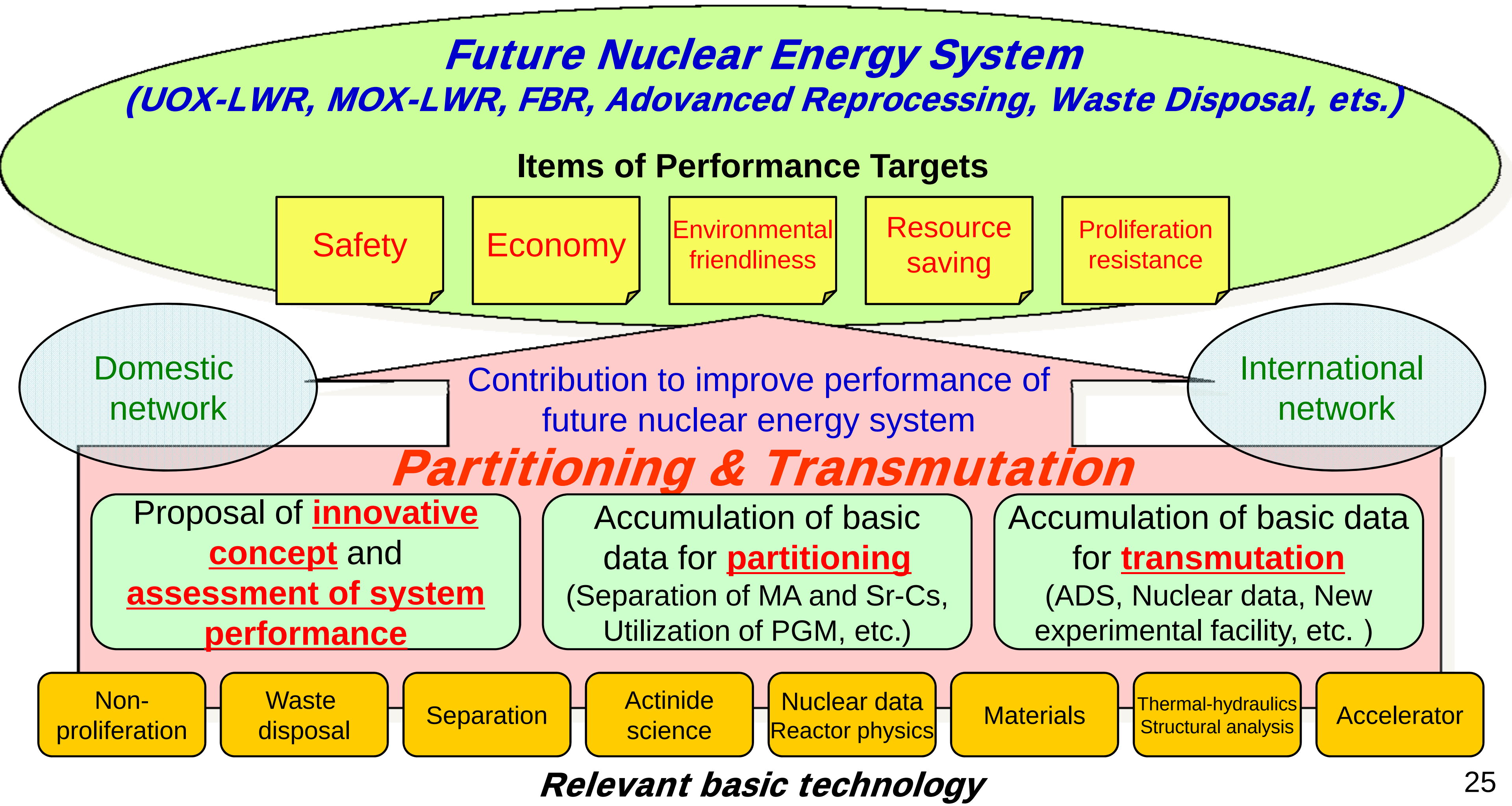
- For ADS, further accumulation of fundamental data is necessary by collaborating with same kind of activities overseas, development of accelerator neutron sources and development of FBR. **The J-PARC** is expected to play an important role to conduct an accelerator-reactor coupling experiment.

Recommendations for Future R&D (4)

- To continue the R&D on P&T technology, it is important to **provide assessment tools of the performance of the whole system**, to facilitate coordination between basic research and engineering development (**vertical collaboration**) and to facilitate interdisciplinary synergy among different areas of science and engineering (**horizontal collaboration**).
- In 2010, C&R on the FaCT Project is scheduled. This seems a good opportunity to **define concrete R&D plan for P&T technology**. It is recommended to propose reasonable and strategic plans of **acquisition of fundamental data, benchmark experiments and provision of experimental facilities**.

How to Proceed with R&D

- To reduce burden of HLW disposal, R&D on P&T are promoted with taking account of the recommendations by 2nd C&R, which pointed out the importance of respect for performance targets of whole nuclear fuel cycle system.



Conclusion

- R&D on P&T technology showed significant progress in Japan.
- The second C&R was conducted by JAEC in 2008-2009.
- The final report mentions that the significance of the P&T technology is in three points:
  - reduction of the potential hazard,
  - mitigation of the requirement for geological repository site, and
  - enhancement of the options in the design of the whole system of waste disposal.
- The current technology levels of the P&T were evaluated.
  - Although the technology levels of some parts of the FBR cycle system are between basic research and engineering demonstration, the P&T technology in general is still in the basic research because of the lack of experimental data for MA
  - It was, therefore, strongly recommended to accumulate the experimental data for MA as a common basis for both FBR and ADS.