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“Present Status and Future Perspective
for Reducing Radioactive Waste
- Aiming for Zero-Release - ”

Reduction of Radioactive Waste by Accelerators

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Transmutation of Nuclides

Transmutation :
To change element and/or nuclide (isotope) by interacting with nucleus

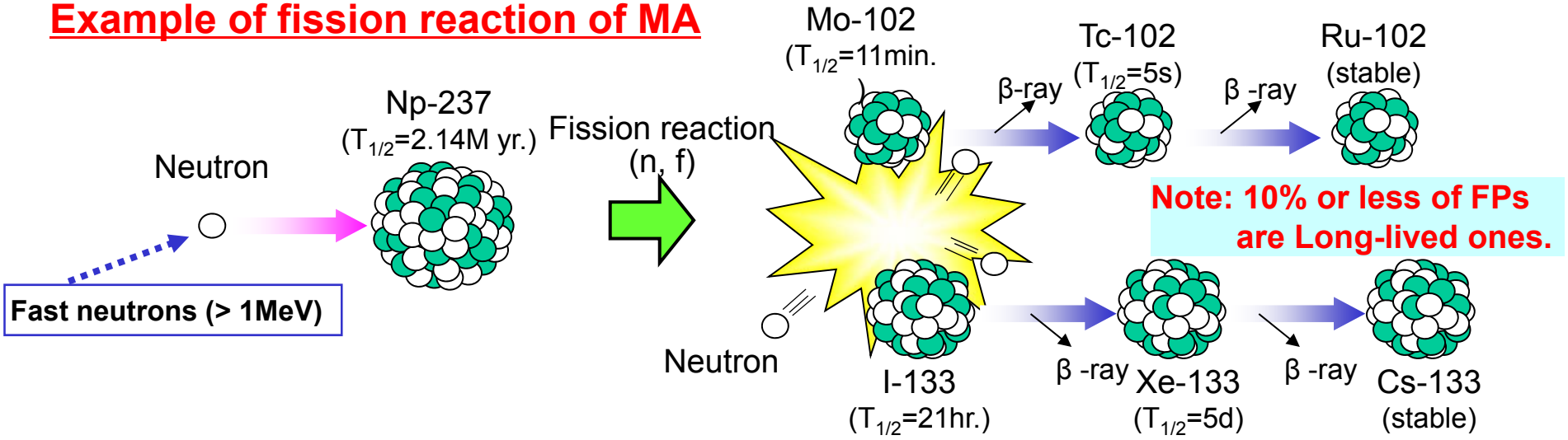
How to interact with nucleus:

Effective transmutation is possible

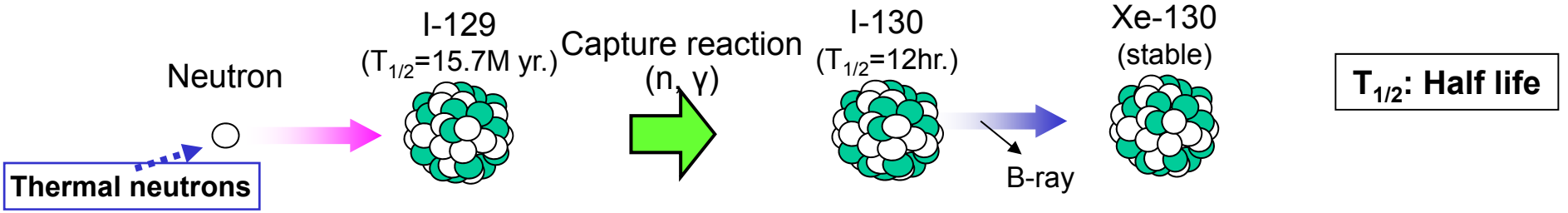
- **Neutron** → It can easily enter electrically-positive nucleus because of its electrically neutral nature.
  - **Neutron capture** (n,γ) : to increase mass number by 1
  - Neutron-induced **fission** (n,f) : to create 2 fission fragments and a few of neutrons
  - **(n,xn)** : to decrease mass number by x-1
- **γ-ray** → Though it is electrically neutral, electrons interfere interaction with nuclide
  - **Photo neutron reaction** (γ,n) : to decrease mass number by 1
  - **Photo fission** (γ,f) : to create 2 fission fragments and a few of neutrons
- **Thermal fusion** → High-density plasma is necessary
  - **D-D, D-T, etc.** : for light nuclides
- **Accelerated particle (or RI sourece)** → Particles are bombarded to target
  - **Proton, deuteron, α-ray, etc.** e.g.): $^{7}Li(p,n)^{7}Be$, $^{3}H(d,n)^{4}He$, $^{9}Be(\alpha,n)^{12}C$
  - **Spallation by proton** Target: Pb, W, U, etc.
  - **Heavy ion** e.g.): $^{16}O+^{238}U \rightarrow {}^{250}Fm+\cdots$

Transmutation of Long-lived Nuclide by Neutron

Example of fission reaction of MA



Example of capture reaction of LLFP



Transmutation by Accelerator

Merit:

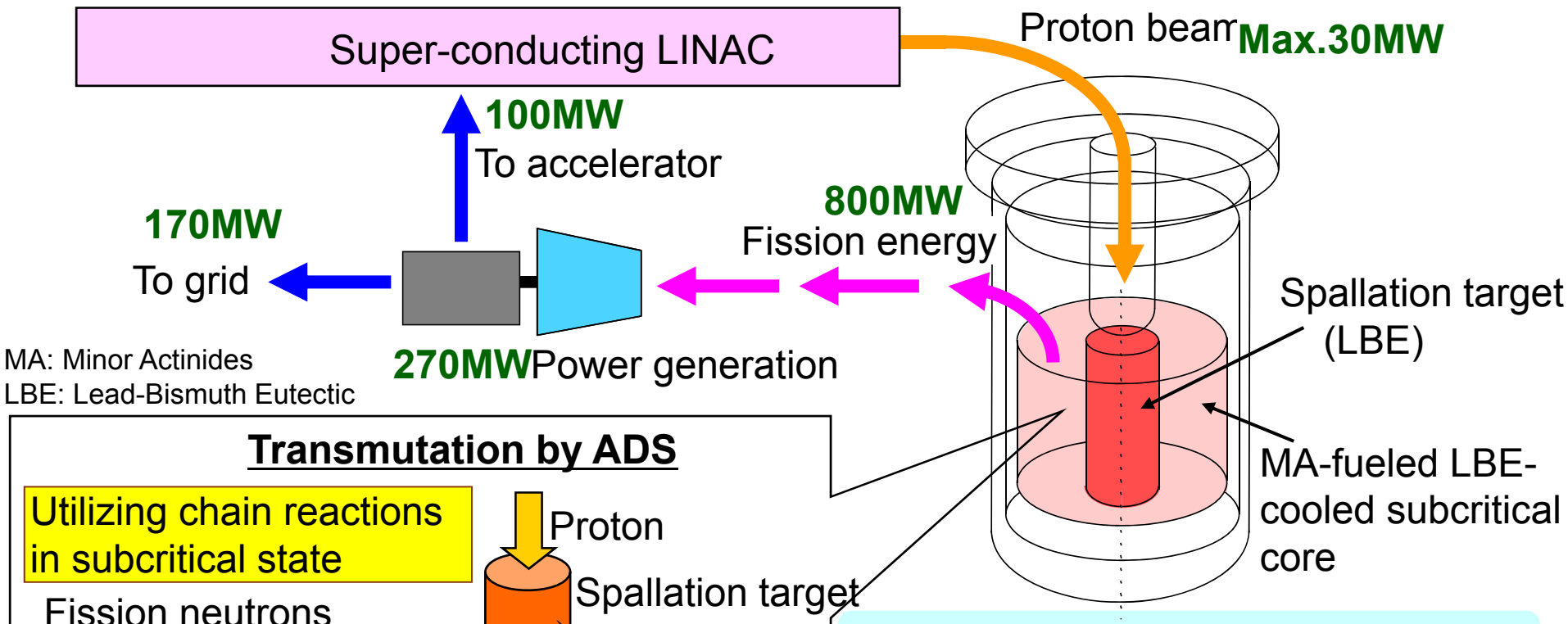
- It may be possible to chose suitable energy of incident particles.
- Strict safety requirement is not necessary for nuclear fuel of reactors. (It is possible to irradiate effectively only to target nuclides)

Demerit:

- Large energy input is necessary
- It is difficult to obtain enough number of particles. (The intensity is not sufficient presently.)

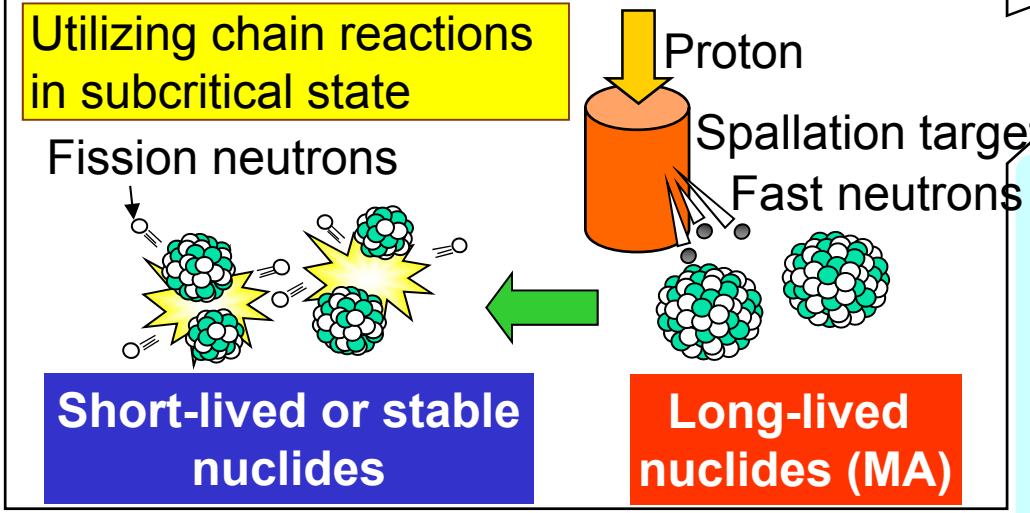
We are developing "Accelerator Driven System" (ADS) which is a combination of a nuclear reactor and an accelerator.

Accelerator Driven System (ADS)



Transmutation by ADS

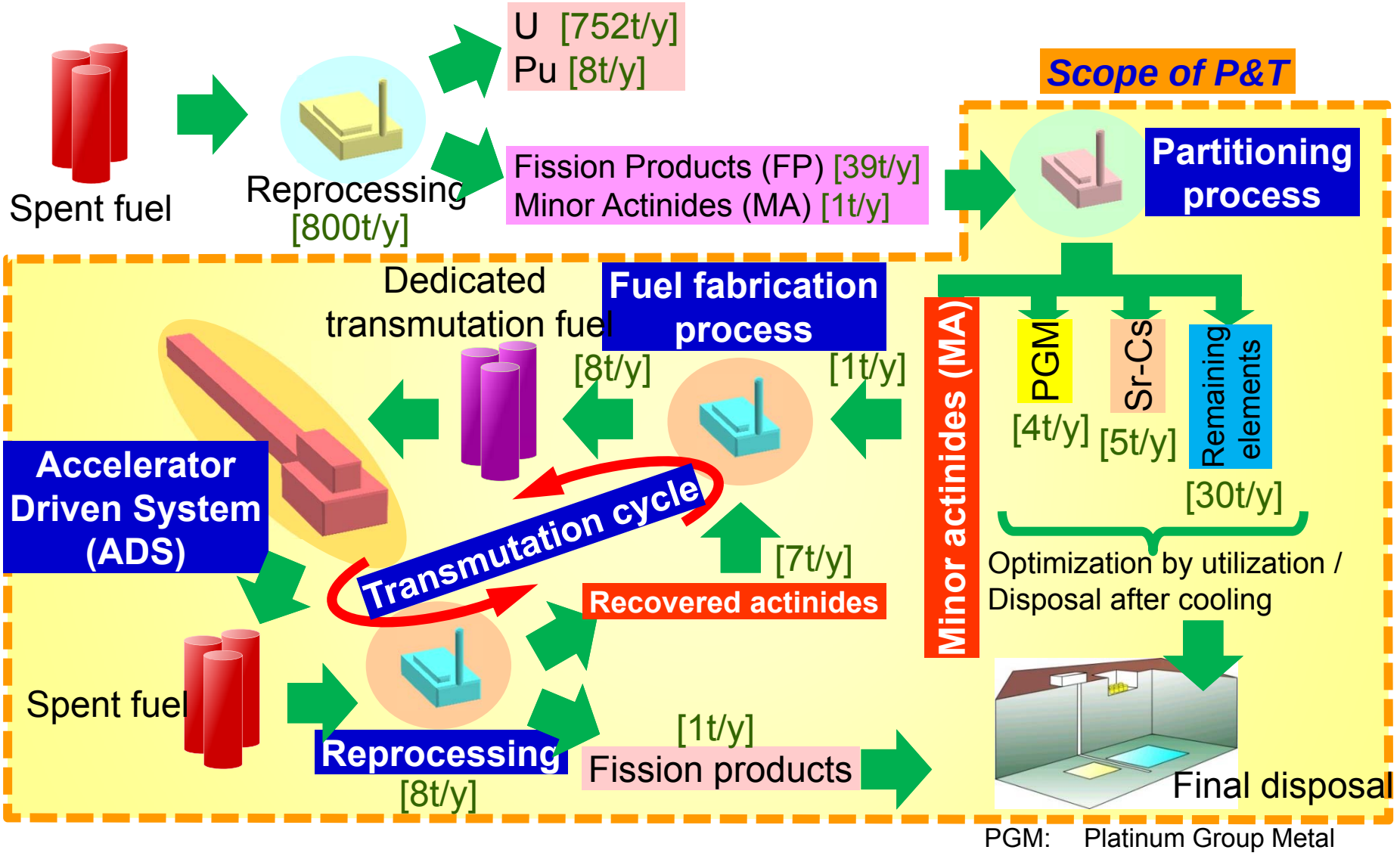
Utilizing chain reactions in subcritical state



Characteristics of ADS:

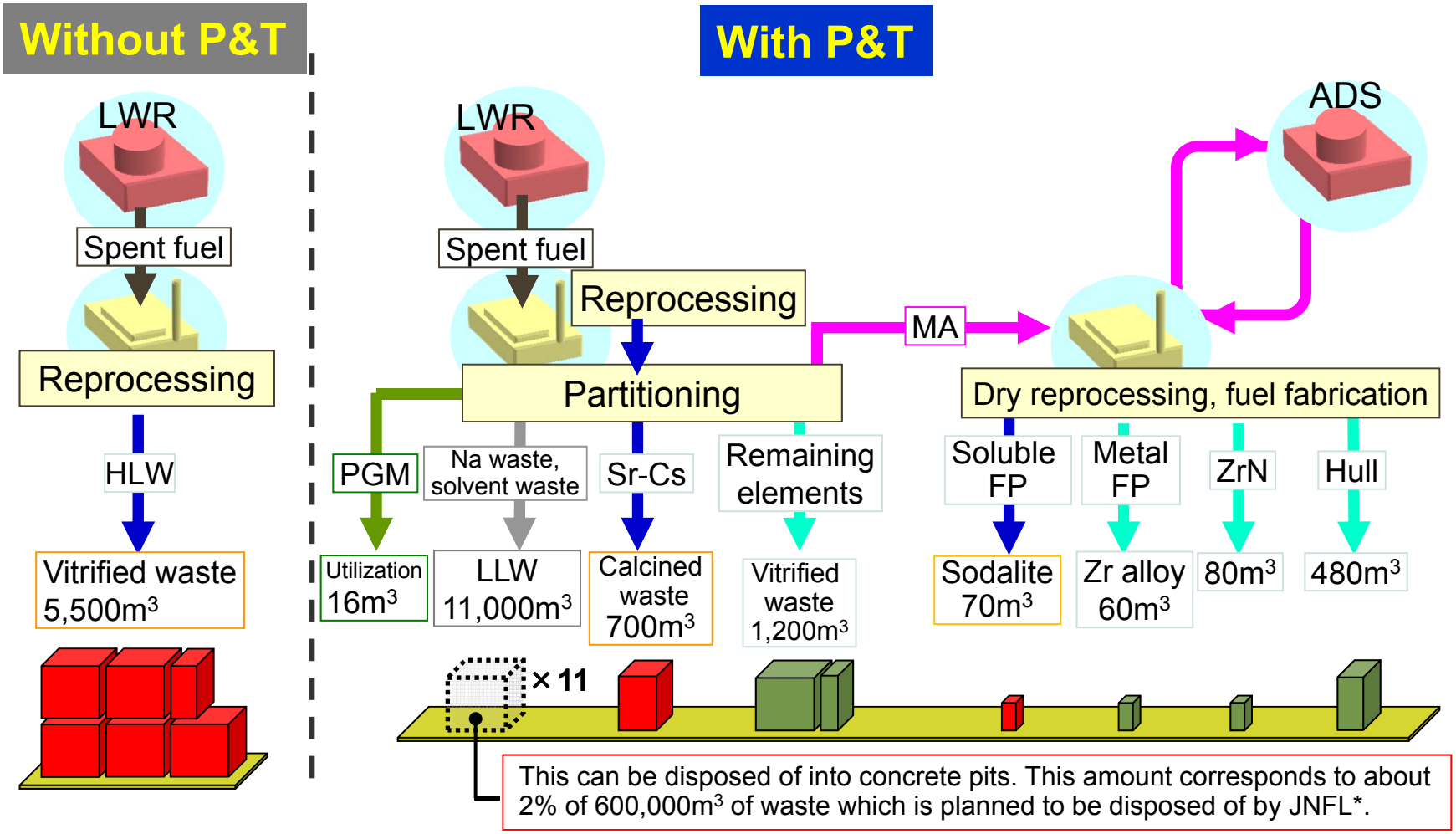
- Chain reactions stop when the accelerator is turned off.
  - ➔ Rapid increase of nuclear reactions will not occur.
- High MA-bearing fuel can be used.
  - ➔ MA from **10 LWRs** can be transmuted.
- LBE is chemically stable.

Double-strata Fuel Cycle Concept with ADS



PGM: Platinum Group Metal

Radioactive Wastes from Double-strata Fuel Cycle Concept



Normalized by **32,000tHM** of LWR spent fuel with 45GWd/tHM of burn-up after 4-year cooling

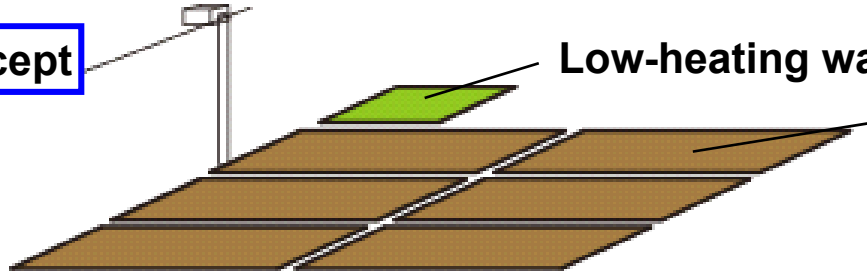
= Heat-generating waste
= Non-heat-generating waste
= LLW

* p.42, Document 3-1, Meeting for New Framework for Nuclear Energy Policy (5th. Meeting), Atomic energy commission

Reduction of Footprint Area of Waste Disposal by Coupling P&T with Long-term Storage

Normalized by 32,000tHM of 45GWd/t spent fuel

Conventional Concept



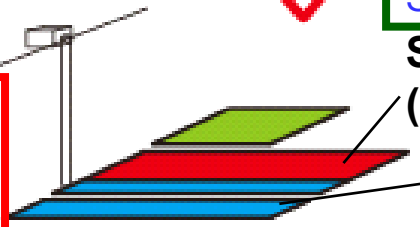
Low-heating wastes (0.13km^2)

HLW vitrified waste: 40,000
(CT: 50y, FA: 1.8km^2)

Partitioning and Transmutation (P&T)

Transmutation of MA is effective for reduction of very long-term potential toxicity and removal of long-lived heat-generating nuclide (Am-241)

Footprint area of waste can be reduced as 1/4 by coupling MA transmutation and separated disposal of Sr-Cs after 100-130 years of cooling

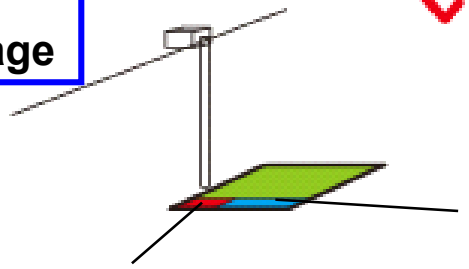


Sr-Cs calcined waste: 5,100
(CT: 130y, FA: 0.23km^2)

Highly-loaded vitrified waste: 8,300
(CT: 5y, FA: 0.18km^2)

P&T + Long-term Storage

Footprint area of waste can be reduced as 1/100 by applying long-term storage (about 300 years) to Sr-Cs with the result that all the wastes can be treated as low-heating wastes.



Highly-loaded vitrified waste: 8,300
(CT: 45y, FA: 0.01km^2)

Sr-Cs calcined waste: 5,100
(CT: 320y, FA: 0.005km^2)

CT: Cooling time before disposal
FA: Footprint area of wastes

Preliminary Cost Estimation for Double-strata Fuel Cycle Concept with ADS

Preliminary cost estimation of ADS (unit: Oku-yen = M$)

Items	Construction	Maintenance	Decommissioning	Total
ADS- reactor	1,700	2,720[a)]	140[b)]	4,560
ADS-accelerator	590	940[a)]	50[b)]	1,580
Total	2,290	3,660	190	6,140

a) 4% of construction cost is assumed annually. (Life time is assumed as 40 years)
b) 8% of construction cost is assumed.

Preliminary cost estimation of PT fuel cycle (unit: Oku-yen = M$)

Items	Cost
4 unit of ADS	**24,600**
Partitioning process	5,700
MA fuel fabrication	5,200
MA fuel reprocessing	4,500
Electric power selling	-7,500
Reduction of disposal cost	**-19,000**
Total	13,400

(Partitioning: 5tHM/y, MA fuel cycle: 10tHMt/y)

Quoted from JAERI-Review 2005-043 (2005).

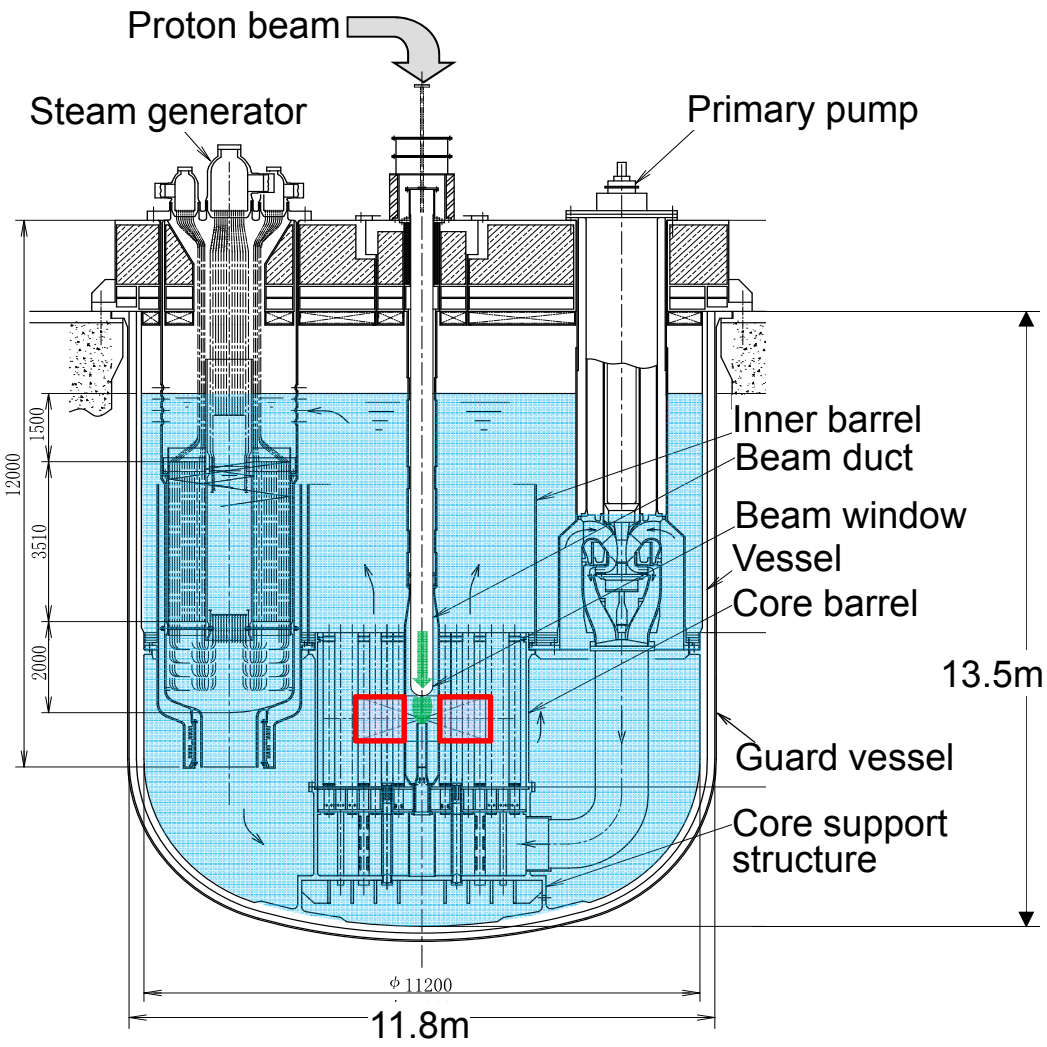
- Influence to electricity cost:
  + 0.12 ~ 0.13yen/kWh (discount rate: 0 %)
- 0.6% increase of consumer price (~20yen/kWh)

➔ **12 – 13 yen/month increase** of electricity cost of each family, assuming 1/3 of monthly consumption (300kWh/month) is supplied by nuclear.

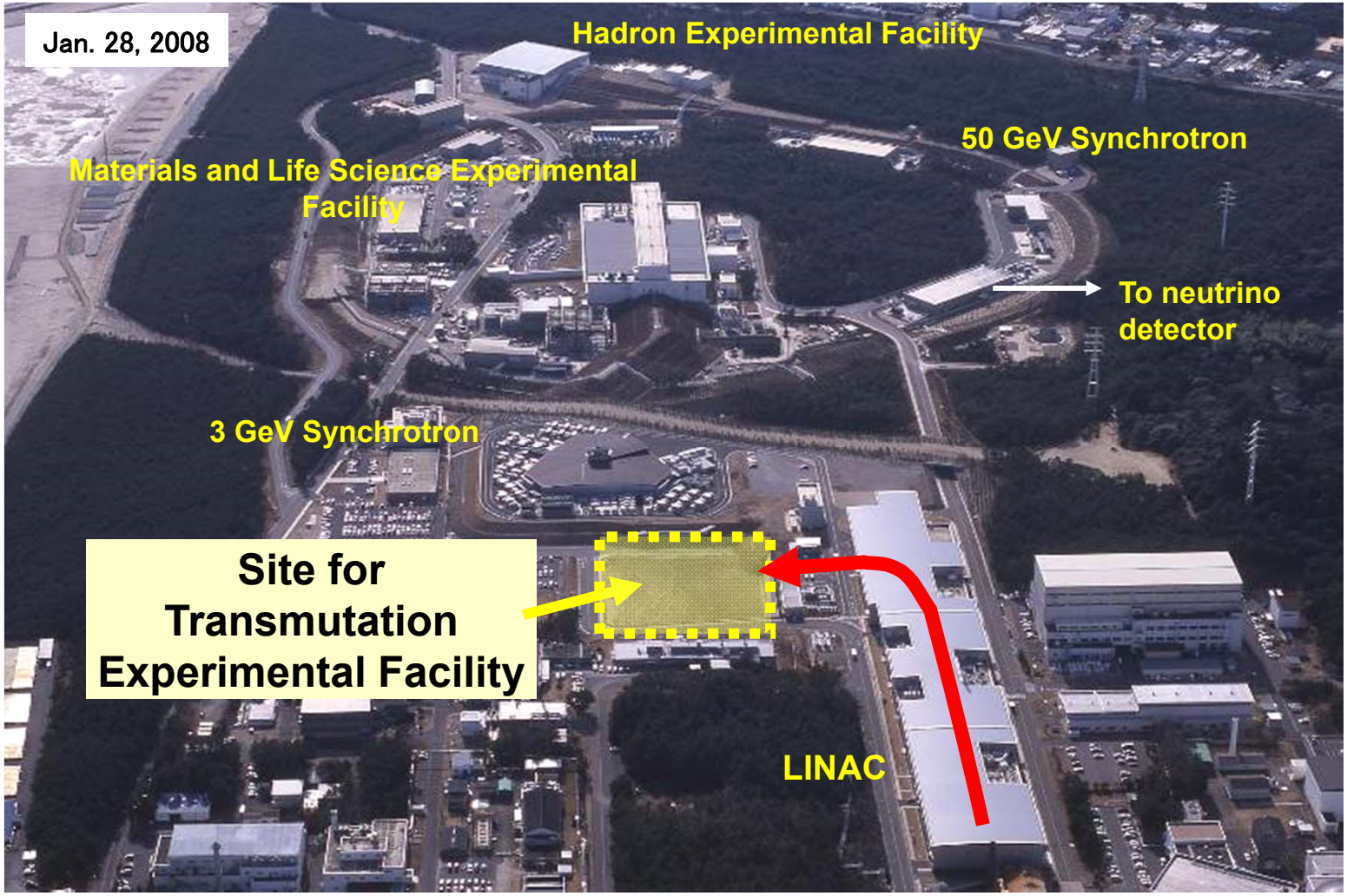
- **Simple electricity cost of ADS: 21yen/kWh**
- **It is necessary to improve the accuracy of cost estimation for ADS and new disposal concept**

Conceptual Specification and View of ADS

- Proton beam: 1.5GeV
- Spallation target: Pb-Bi
- Coolant: Pb-Bi
  Inlet: 300℃, Outlet: 407℃
- Maximum k_{eff} = 0.97
- Thermal output: 800MWt
- MA initial inventory: 2.5t
- Fuel composition:
  (MA +Pu)N + ZrN
- Transmutation rate:
  10%MA / y
- Fuel exchange:
  600EFPD, 1batch
- Primary pump: 2 units
- Steam generator: 4 units
- Decay heat removal system:
  3 units



Japan Proton Accelerator Research Complex: J-PARC



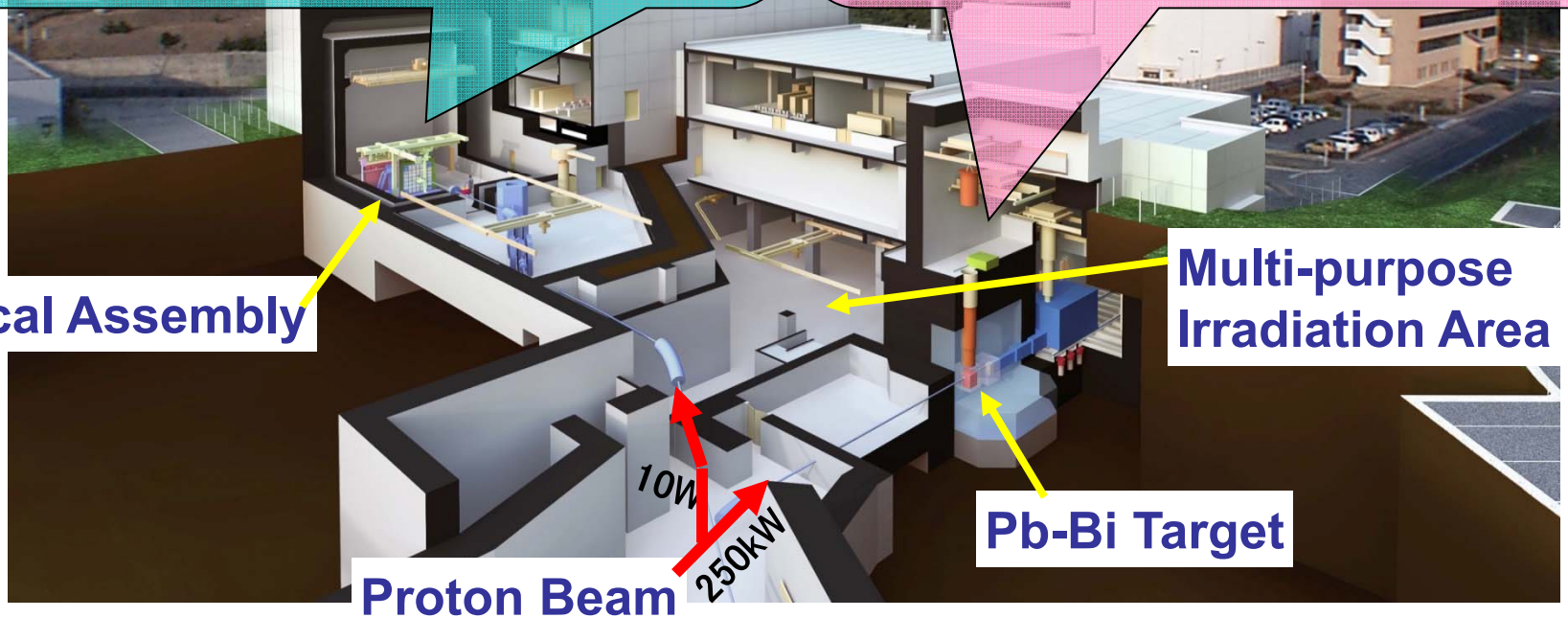
Transmutation Experimental Facility (TEF) of J-PARC

Transmutation Physics Experimental Facility: TEF-P

Purpose: To investigate physics properties of subcritical reactor with low power, and to accumulate operation experiences of ADS.
Licensing: Nuclear reactor: (Critical assembly)
Proton beam: 400MeV-10W
Thermal power: <500W

ADS Target Test Facility : TEF-T

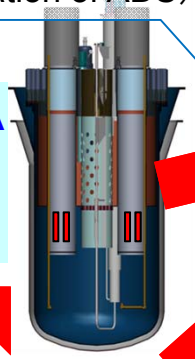
Purpose: To research and develop a spallation target and related materials with high-power proton beam.
Licensing: Particle accelerator
Proton beam: 400MeV-250kW
Target: Lead-Bismuth Eutectic (LBE, Pb-Bi)

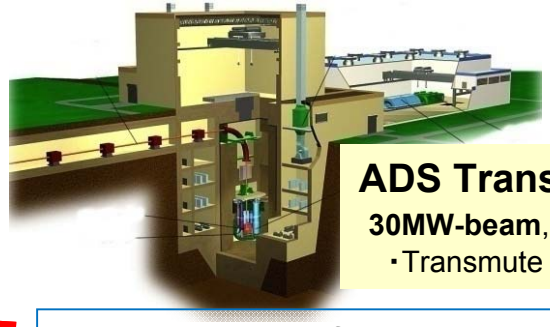


Roadmap to Realize Transmutation Technology with ADS

Power

ADS without MA fuel
（LBE coolant, Accelerator, Operation of ADS）





ADS Transmutation plant
30MW-beam, 800MW$_{th}$
・Transmute 250kg of MA annually

Experimental ADS➔MYRRHA
~2.4MW-beam, 50~100MW$_{th}$
・Engineering feasibility of ADS and fuel irradiation

Reactor physics of MA transmutation system and material development for spallation target material

Advanced material for beam window

TEF in J-PARC
250kW-beam
・LBE target technology
・Reactor physics of transmutation system

	TEF in J-PARC	MYRRHA
Purpose	R&D for elemental technology (LBE target, Reactor physics)	Fuel irradiation, Accumulation of operation experience of ADS
Power	250kW-beam TEF-P : 500W (max.)	2.4MW-beam Power : 50~100MW$_{th}$
MA	Mock-up experiment of transmutation system with massive MA (kg order)	Irradiation experiment with small amount of MA

- **Collaboration of J-PARC and MYRRHA** will lead development, demonstration and improvement of transmutation technology in the world.
- In 2030's, knowledge and experience for realization of ADS can be obtained.

Basic research (LBE loop test, KUCA experiments)

2010 2020 2030 year

In Conclusion

- Accelerator Driven System (ADS) for effective transmutation of minor actinides (MA) is under research and development.
- The transmutation technology with ADS is a combination of high-power accelerator technology, fast reactor technology and nuclear fuel cycle technology that have been developed so far in Japan.
- It is required for Japan to contribute to establishment of socially-acceptable nuclear power by collaborating with countries in the world and playing a leading role in the research and development on reduction of volume and toxicity of high-level radioactive wastes.