Concept of Waste Management and Geological Disposal Incorporating Partitioning and Transmutation Technology

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Scope of the Presentation

- Benefits of P&T on Management of High-Level Radioactive Wastes (HLW):
  - ✓ Reduction of long-term radiological toxicity
  - ✓ Reduction of dose for future inhabitants

    } *To mitigate difficulties caused by long-term nature of radioactivity*
  - ✓ Reduction of amount of HLW
  - ✓ **Reduction of repository size**

    } *To extend capacity of a repository*
  - ✓ Recovery of valuable materials from wastes, and so on.

- Scope of the Presentation:
  - ✓ **Emplacement areas** for waste forms per unit power generation estimated for various reactors and various P&T schemes.
    - Reactor Type: **UO_2-LWR, MOX-LWR, and MOX-FBR**
    - Cooling time before reprocessing: **5 and 20 years**
    - Reprocessing: **PUREX, MA-recycling, and Full P&T for both MA and FP**
  - ✓ Coupling of P&T with **long-term predisposal storage of Sr-Cs**.

Fuel Burn-up and Decay Calculation

Reactor	Burn-up	U-235 or Pu enrichment	Pu-fissile fraction	MA fraction	Power generation efficiency
UO_2-LWR	43 GWd/t = 36MW/t X 1,194d	4.1 %	---	0.0%	34.0%
MOX-LWR	43 GWd/t = 36MW/t X 1,194d	6.1 %	68%	0.1%	34.0%
MOX-FBR	79 GWd/t = 72MW/t X 1,095d	17.3 %	64%	0.3%	38.5%

- Code: ORIGEN-2
- Cross section library: ORILIBJ32 (based on JENDL-3.2)
- Amount of actinides and fission products generated from 1tHM of spent fuel was calculated.

Separation of Elements

(1) Conventional PUREX reprocessing (Process-R)

- Recovery efficiency of U and Pu : 99.5 %.
- Conventional glass waste form was assumed as the HLW.

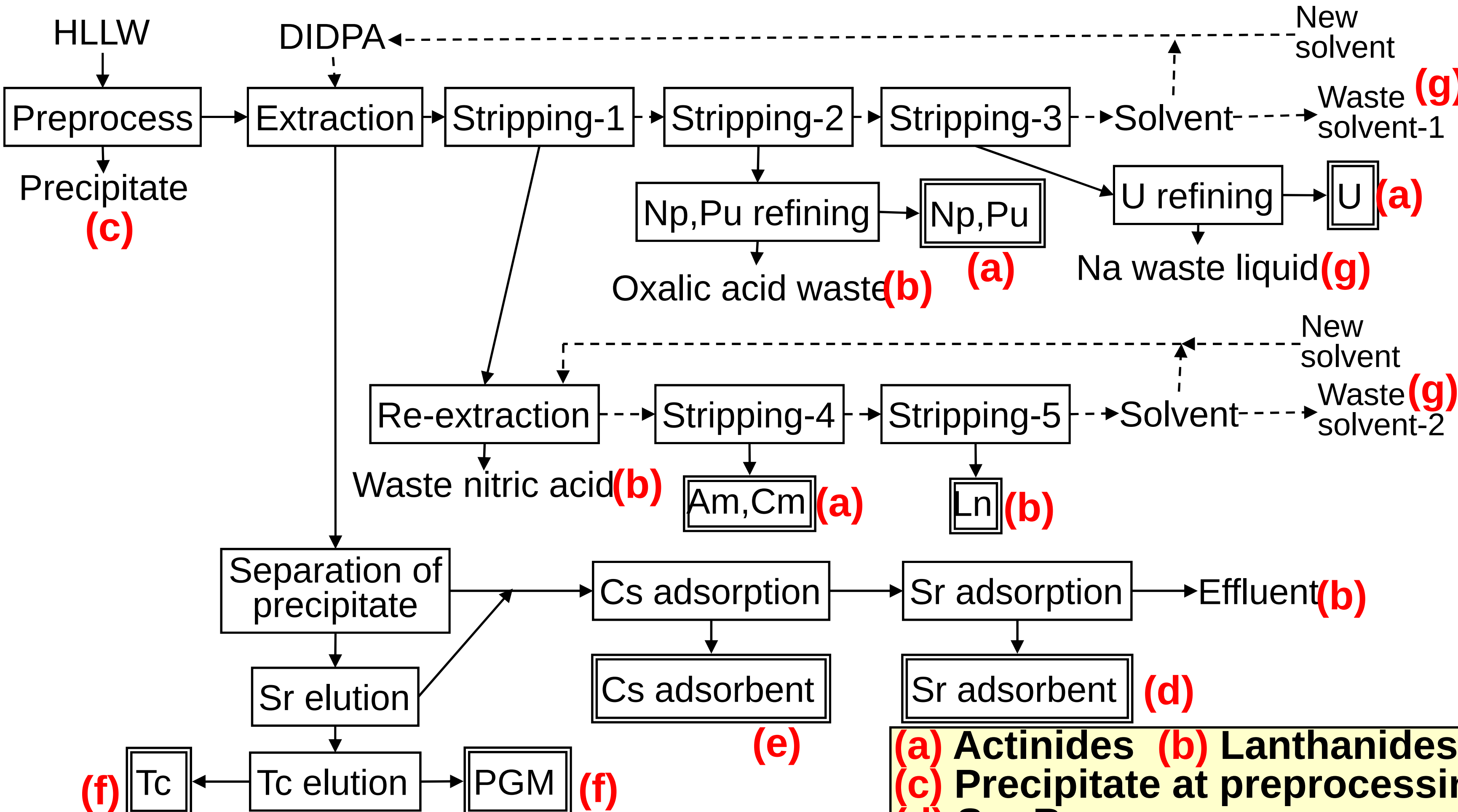
(2) MA recycling without partitioning FP (Process-A)

- After the “Process-R”, MA was recovered and transmuted.
- Recovery efficiency of MA: 99%
- Glass waste form containing FP and small amount of MA was assumed as the HLW.

(3) Full P&T for both MA and FP (Process-P)

- MA was recovered and transmuted, and FPs were partitioned into 5 categories.

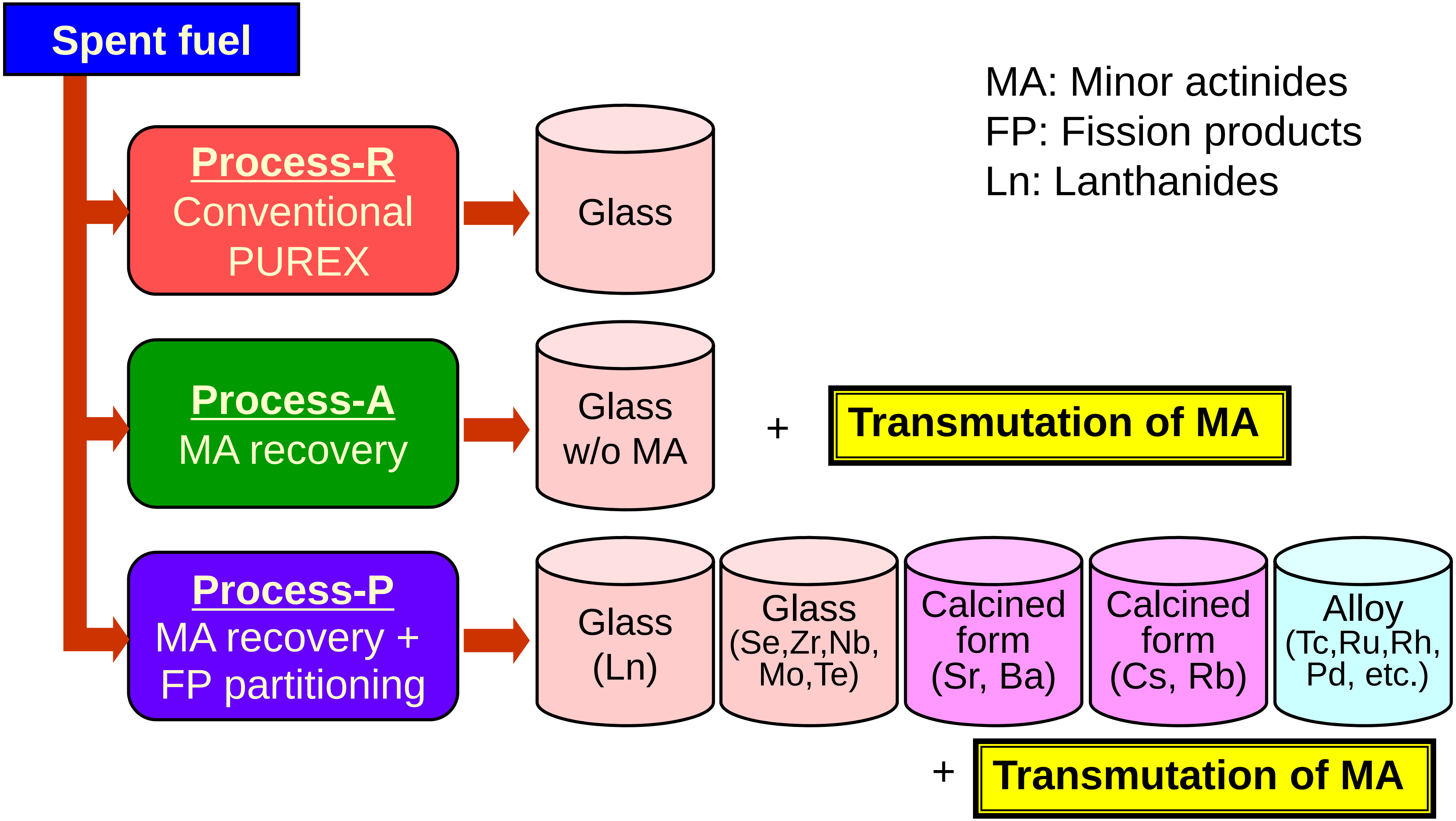
Separation of Elements
Flow Chart of Partitioning Process



(a) Actinides (b) Lanthanides
(c) Precipitate at preprocessing
(d) Sr , Ba
(e) Cs, Rb
(f) Tc and PGM
(g) Secondary wastes ---> neglected

Material flowchart for partitioning process based on **JAERI's 4-group Partitioning Process**

Waste Forms



MA: Minor actinides
FP: Fission products
Ln: Lanthanides

Waste Forms
Number of Glass Forms for Process-R and A

- Assumptions to estimate the number of glass waste forms for "Process-R" (conventional PUREX) and "Process-A" (MA recovery):

  - Volume: **150 L** (40cm$^{\phi}$ x 120cm^{H})
  - Weight: **400 kg**
  - Maximum fraction of waste oxides: **15 wt%** (60 kg)
  - Maximum fraction of MoO_3: **3 wt%** (12 kg)
  - Maximum heat generation rate at fabrication: **2.3 kW/piece**
  - Maximum temperature of the buffer material in the repository: **100 ºC**

    To calculate the temperature transient after the disposal, 3-dimensional heat conduction calculation was conducted by ABAQUS code.

    The calculation model was based on the reference waste disposal concept of JNC (vertical emplacement type in hard rock)

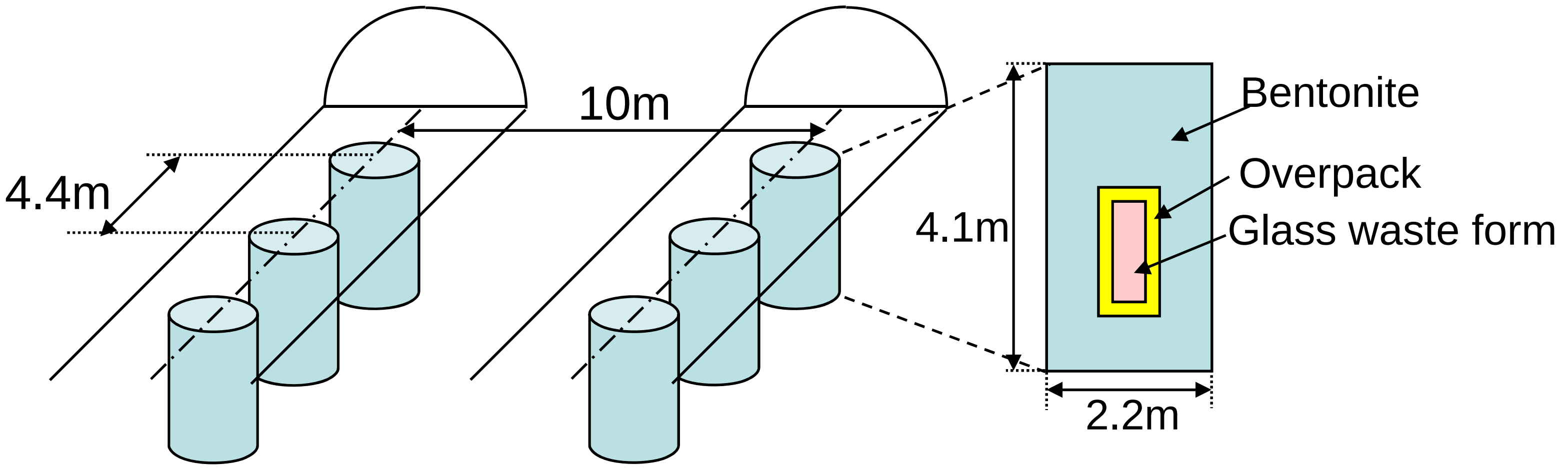
    Fixed conditions:

    - ✓Pitch of waste forms : **4.4 m**
    - ✓Distance between repository tunnels : **10 m**
    - ✓Depth of repository : 1,000 m
    - ✓Cooling period after fabrication before disposal : **50 years** (independent of cooling periods before the reprocessing)

Waste Forms
Emplacement of Glass Waste Form

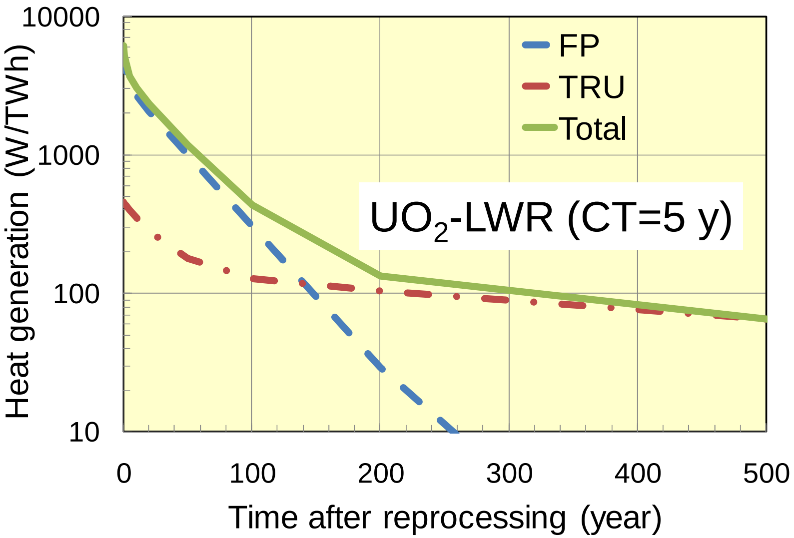
Reference waste disposal concept proposed by JNC in 2000 was adopted (vertical emplacement type)

Glass waste forms for Processes-R, -A
$44 m^2$/piece

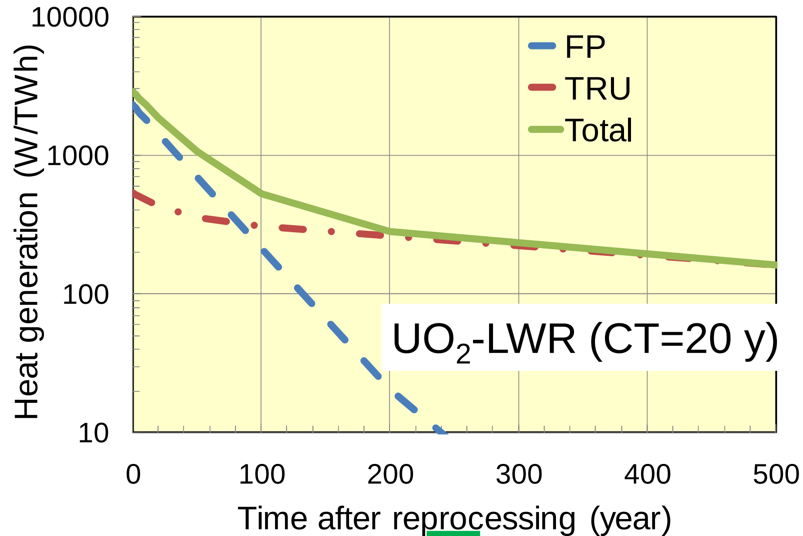


◆ **50-year cooling before disposal was commonly assumed**

Waste Forms
Heat Generation of HLW

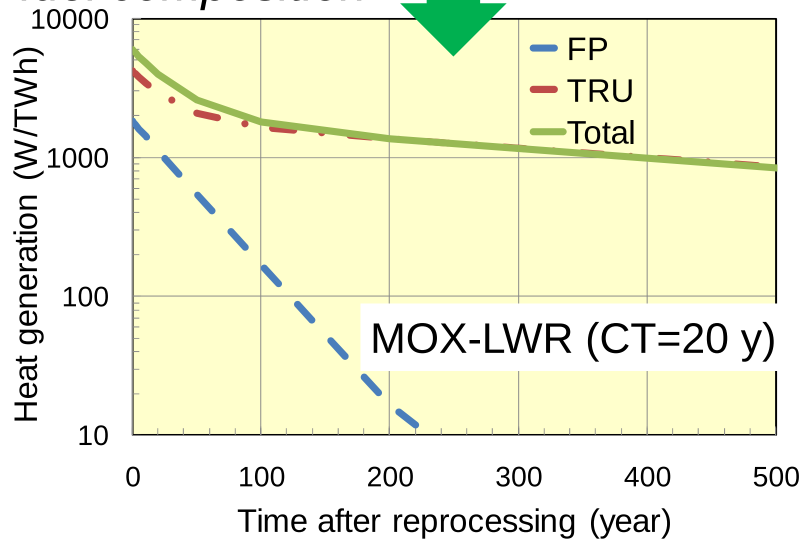


Effect of cooling time



CT: Cooling time before reprocessing

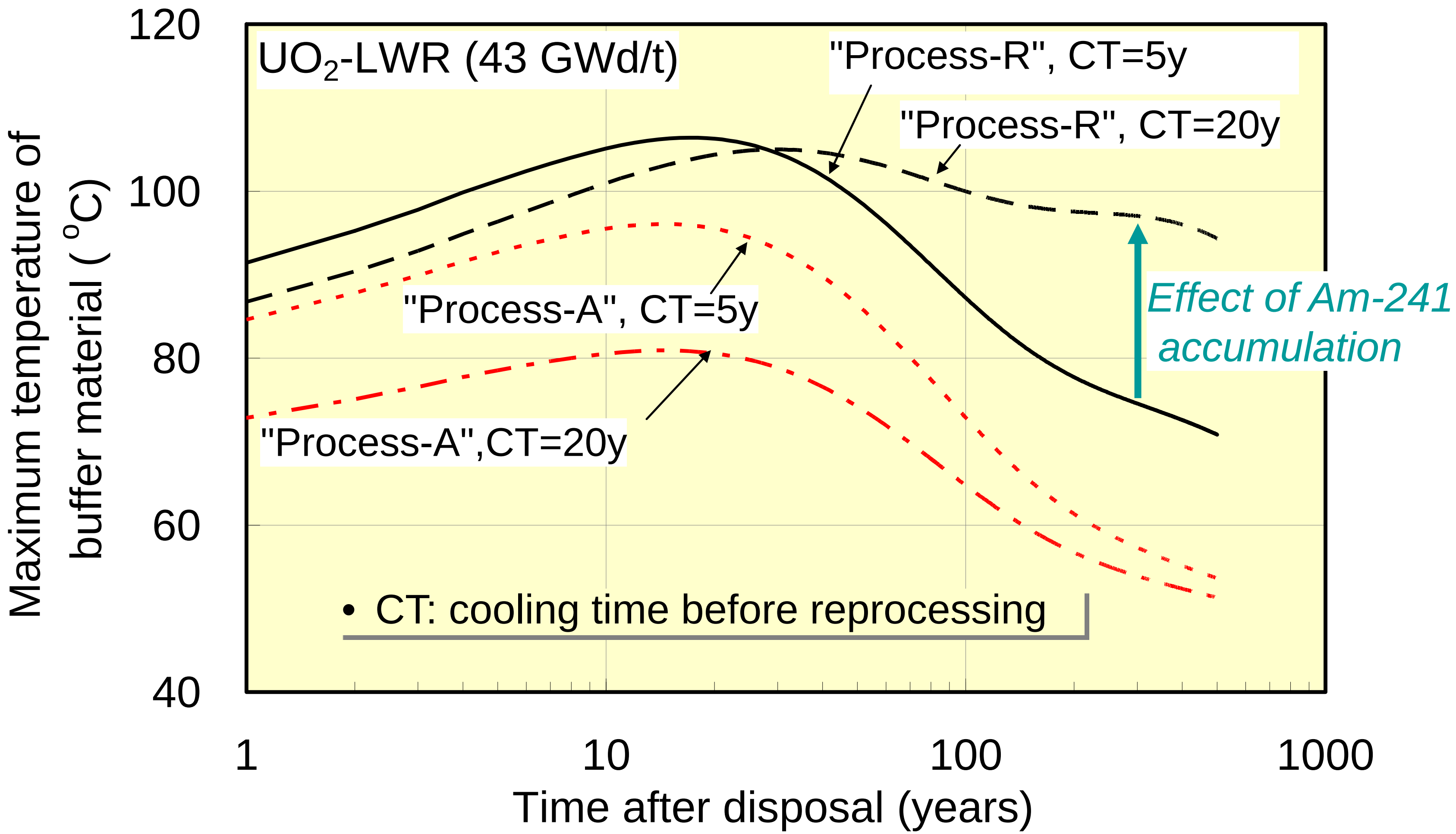
Effect of fuel composition



- The heat of TRU is influential for a long period.
- Longer cooling time and utilization of MOX fuel cause accumulation of Am-241 ($T_{1/2}$=432 years)

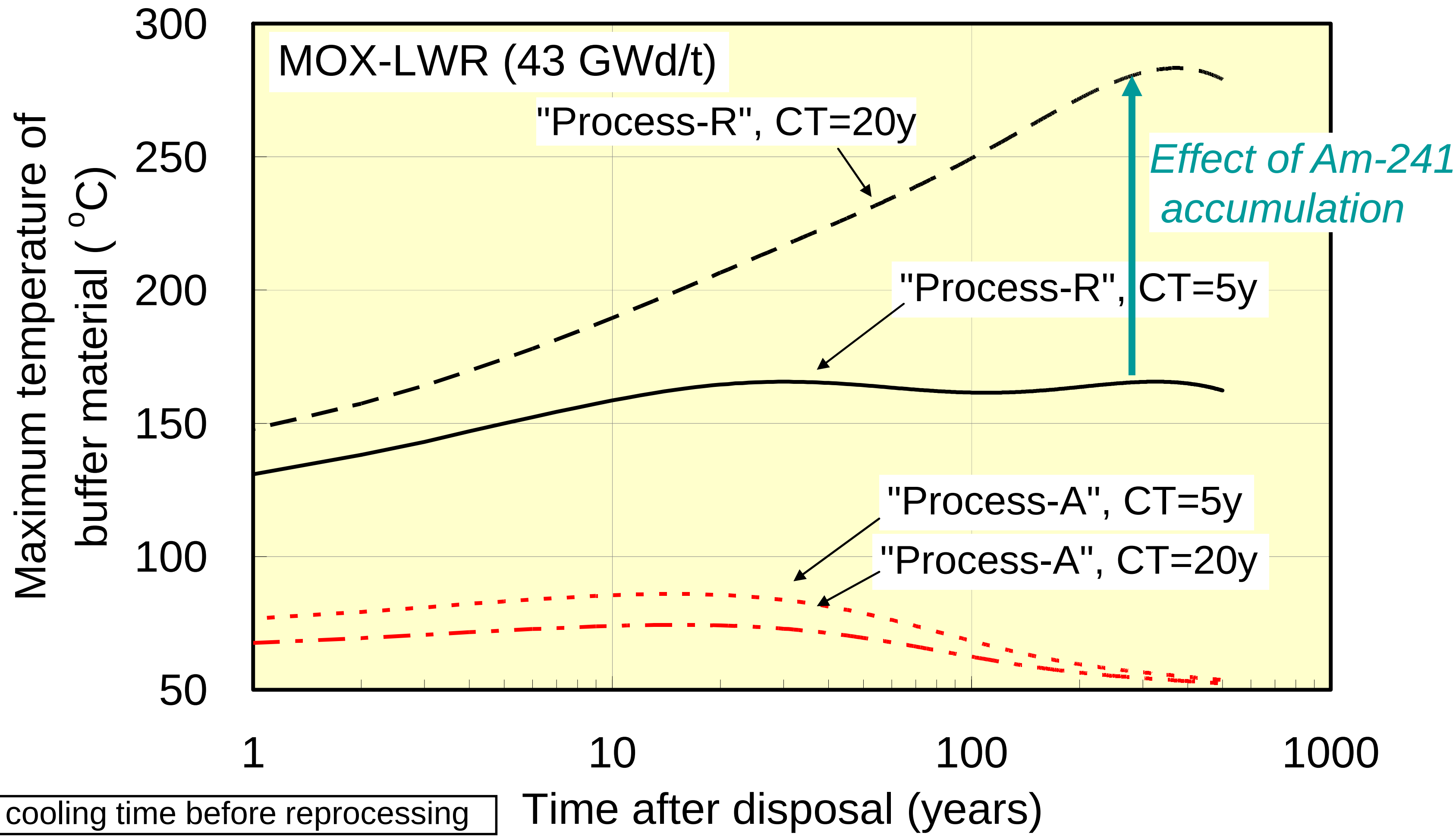
Waste Forms
Temperature of Buffer Material (UO_2-LWR)

- Normalized by 1 tHM of spent fuel.
- The content of waste elements were restricted so as to adjust the maximum buffer temperature at 100ºC.



Waste Forms
Temperature of Buffer Material (MOX-LWR)

- The effect of Am-241 accumulation is significant.
- The maximum temperature is found at 300 y after disposal



- CT: cooling time before reprocessing

Waste Forms
Number of Waste Forms for Process-P

- Wastes for full P&T (Process-P)

  (b) Lanthanides : Glass waste form, 150 L, 400 kg
  Maximum fraction of waste oxides: **35 wt%** (140kg)

  (c) Precipitate at preprocess : Glass waste form, 150 L, 400 kg
  Maximum fraction of waste oxides: **35 wt%** (140kg)
  Maximum fraction of MoO_3: **8 wt%** (32 kg)

  (d) Sr, Ba : Calcined forms, 14 L, 5.3 kg of waste elements

  (e) Cs, Rb : Calcined forms, 14 L, 4.5 kg of waste elements

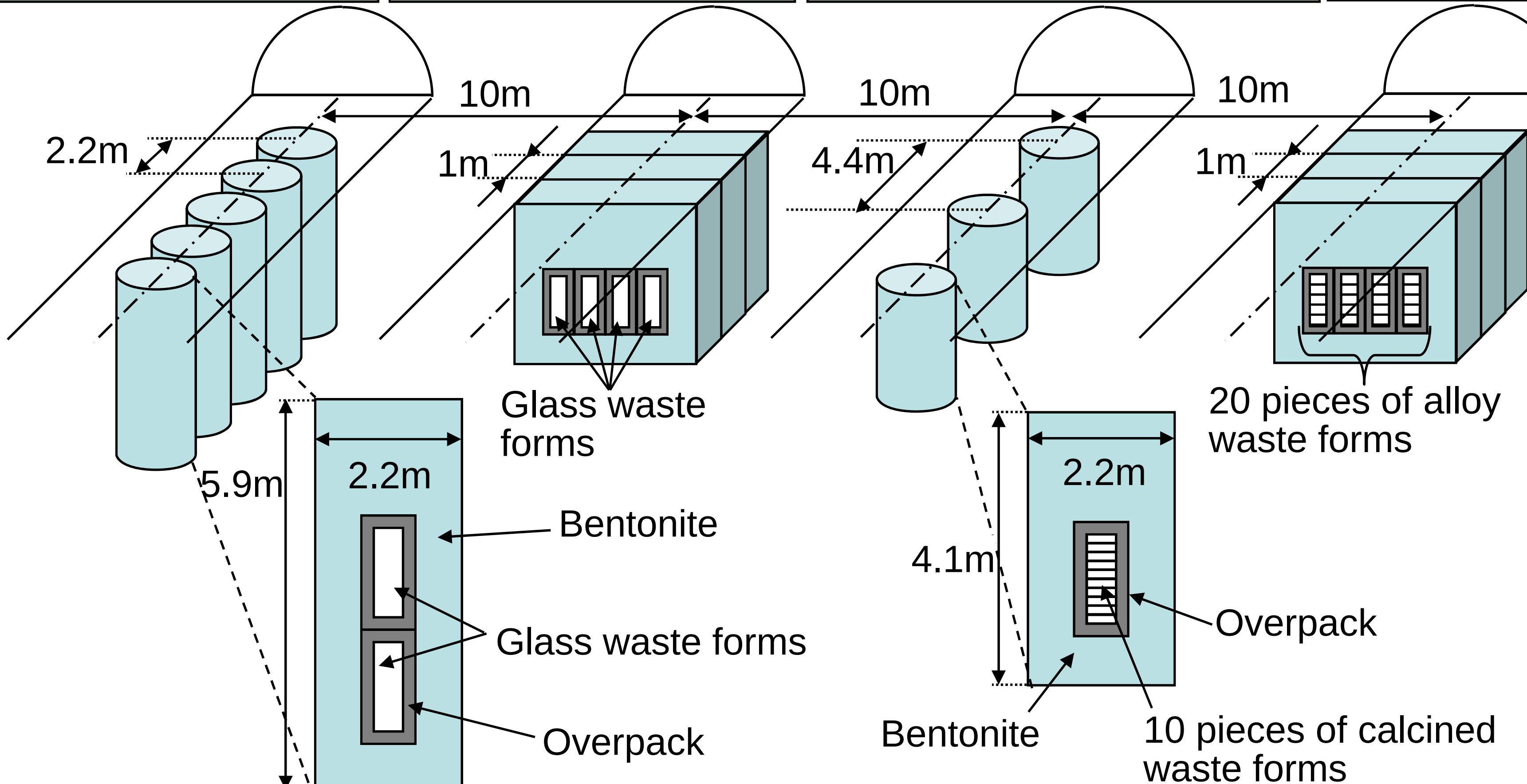
  (f) Tc-PGM : Metallic waste form, 7.5 L, 60 kg
  Maximum fraction of waste metal: 4wt%, 2.4kg)

  (g) Secondary waste : neglected because of its small radioactivity

Estimation of Repository Area
Emplacement of Novel Waste Forms

$8 W/m^2$ was assumed to be the maximum allowable heat generation ($350 W/44 m^2$)

(b) Ln (glass)	(c) Precipitation (glass)	(d),(e) Sr+Ba, Cs+Rb	(f) Tc-PGM (alloy)
11 m^2/piece	2.5 m^2/piece	(calcined) 4.4 m^2/piece	0.5 m^2/piece
3~34-year cooling	**0~7-year cooling**	**90~150-year cooling**	**0~5-year cooling**



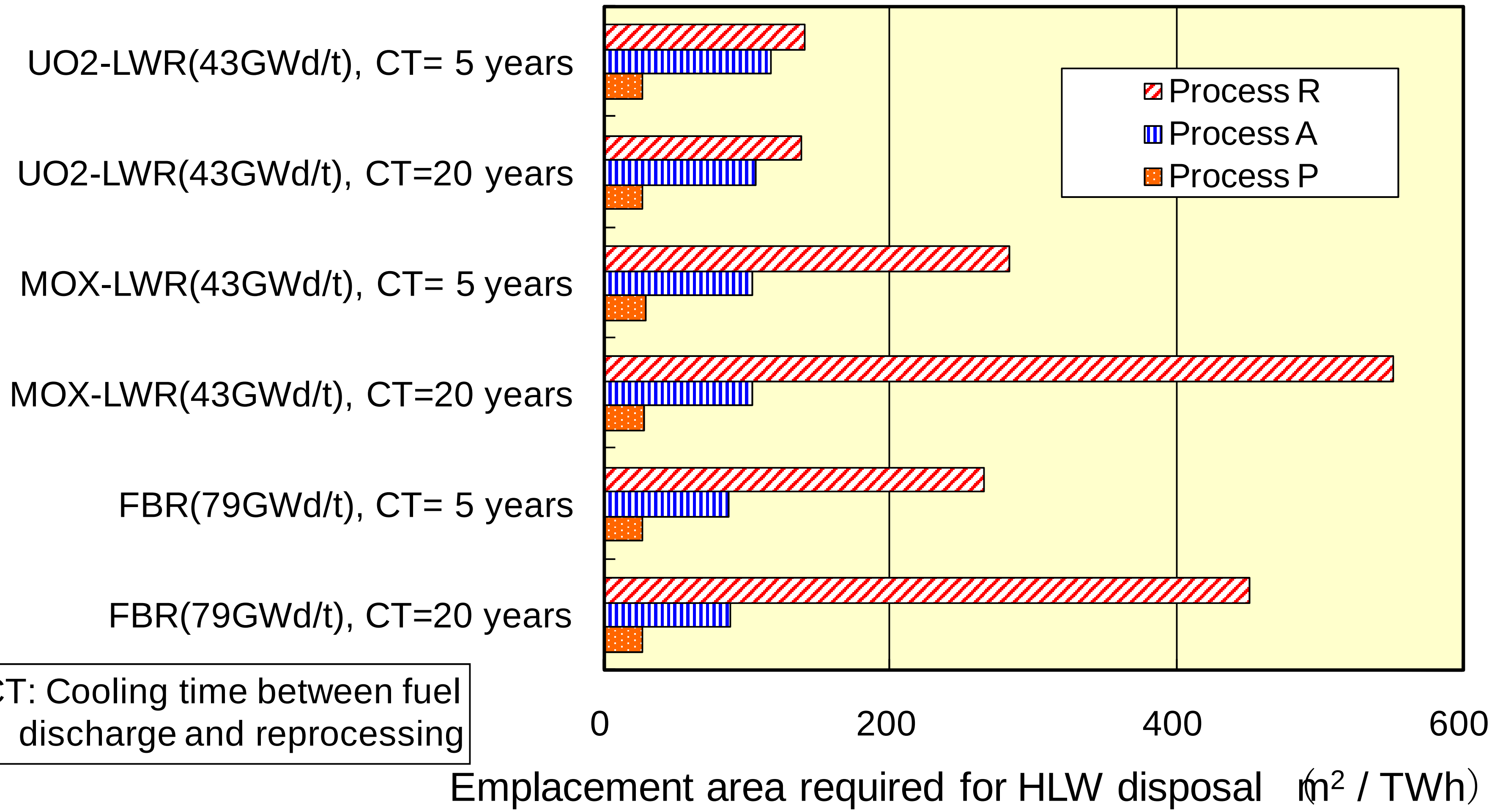
Estimation of Repository Area Breakdown for Process-P

Calculated emplacement area for waste forms per 1TWhe of electricity

Reactor	Cooling time	(b) Ln	(c) Precipitation	(d) Sr, Ba	(e) Cs, Rb	(f) Tc-PGM
		High-density glass (150L)		Calcined form (14L)		Alloy (7.5L)
UO_2-LWR	5 y	3.36	1.37	**8.68**	**10.74**	2.95
	20 y	3.36	1.37	**9.29**	**9.54**	2.96
MOX-LWR	5 y	3.14	1.26	**8.24**	**11.66**	4.16
	20 y	3.14	1.26	**9.06**	**10.44**	4.17
Pu-FBR	5 y	2.69	1.08	**6.94**	**12.20**	3.72
	20 y	2.69	1.08	**7.63**	**11.21**	3.72

•Emplacement area for Process-P is dominated by Sr and Cs.

Estimation of Repository Area
Results of Total Emplacement Area



CT: Cooling time between fuel discharge and reprocessing

- **MA transmutation stabilizes the emplacement area for Pu utilization.**
- **Full P&T has a potential to reduce the emplacement area down to 1/4 - 1/5.**

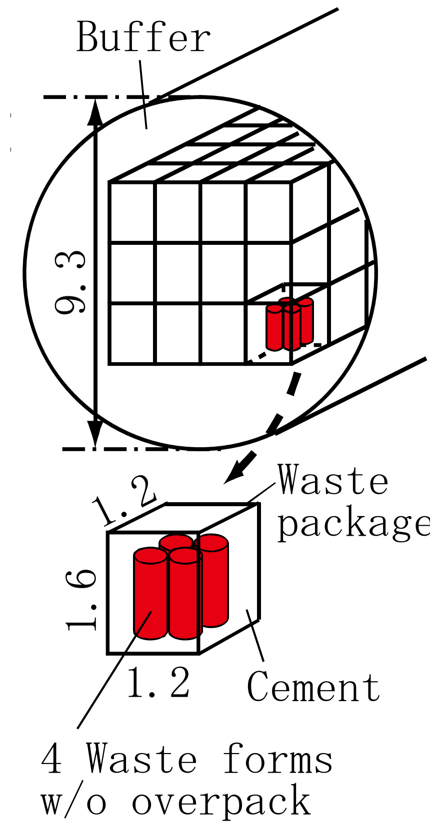
P&T Coupled with Long-term Predisposal Storage

- Once MA is removed from HLWs, their heat generation is dominated by Sr-90 and Cs-137, and decays with their half-lives, 30 years.
- Hence, compact emplacement will be achievable by extending the period of the predisposal storage.
- Recent study [*] shows that a very compact configuration is applicable if the waste forms (same size as the glass waste form) are sufficiently cooled down.
- In this study, **4 W/piece** was adopted as a criterion.

(*) : K. Nishihara, et al., J. Nucl. Sci. Technol., 45(1), 84 (2008).

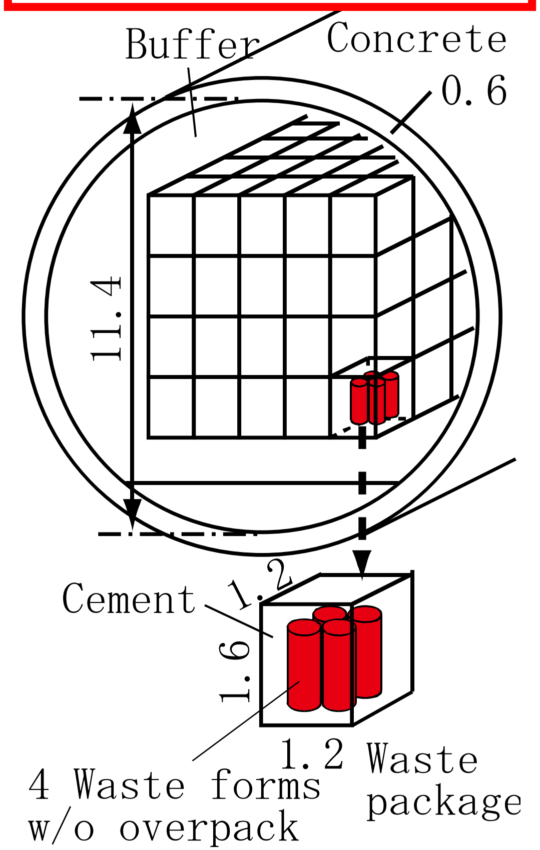
Very Compact Configuration of Disposal

Crystalline rocks



Distance between tunnels: 38m
0.95m²/piece

Sedimentary rocks



Distance between tunnels: 50m
0.76m²/piece

- These concepts are based on the repository design for compressed waste forms of the hulls and end pieces of LWR spent fuels.

Time Periods of Predisposal Storage for Very Compact Disposal

Reactor	Cooling time	Process-R	Process-A
		HLW	HLW w/o MA
		Normal glass (150L)	
UO_2-LWR	5 y	1800 y	**330 y**
	20 y	2600 y	**330 y**
MOX-LWR	5 y	6000 y	**600 y**
	20 y	3500 y	**700 y**
Pu-FBR	5 y	3800 y	**850 y**
	20 y	3200 y	**950 y**

Influence of MA leaking into waste. (MOX-LWR and Pu-FBR rows)

Reactor	Cooling time	Process-P				
		(b)Ln	(c)Precipitation	(d)Sr, Ba	(e)Cs, Rb	(f)Tc-PGM
		High-density glass (150L)		Calcined form (14L) X 10		Alloy (7.5L) X 20
UO_2-LWR	5 y	60 y	9 y	**320 y**	**330 y**	110 y
	20 y	45 y	0 y	**310 y**	**320 y**	100 y
MOX-LWR	5 y	75 y	9 y	**320 y**	**330 y**	70 y
	20 y	60 y	0 y	**310 y**	**320 y**	50 y
Pu-FBR	5 y	90 y	10 y	**320 y**	**320 y**	70 y
	20 y	80 y	0 y	**310 y**	**310 y**	50 y

Five Typical Concepts of Waste Management and Geological Disposal (UO$_2$-LWR, CT=5 y)

Case	Waste	Waste form	Volume	Predisposal storage	Emplacement area
Process-R	HLW	Normal glass	479 L	50 y	**140 m^2**
Process-A	HLW w/o MA	Normal glass	398 L	50 y	**117 m^2**
Process-P	Ln	High-density glass	46 L	18 y	3.4 m^2
	Precipitation	High-density glass	82 L	5 y	1.4 m^2
	Sr, Ba	Calcined form	28 L	130 y	8.7 m^2
	Cs, Rb	Calcined form	34 L	150 y	11 m^2
	Tc-PGM	Alloy waste	44 L	7 y	3.0 m^2
		Total	234 L	(Av. 44 y)*	**27 m^2**
Process-A with long-term predisposal storage	HLW w/o MA	Normal glass	398 L	330 y	**2.5 m^2**
Process-P with long-term predisposal storage	Ln	High-density glass	46 L	60 y	0.3 m^2
	Precipitation	High-density glass	82 L	9 y	0.5 m^2
	Sr, Ba	Calcined form	28 L	320 y	0.2 m^2
	Cs, Rb	Calcined form	34 L	330 y	0.2 m^2
	Tc-PGM	Alloy waste	44 L	110 y	0.3 m^2
		Total	234 L	(Av. 122 y)*	**1.5 m^2**

* Average period weighted by the volume of the wastes

Five Typical Concepts of Waste Management and Geological Disposal (MOX-FBR, CT=5 y)

Case	Waste	Waste form	Volume	Predisposal storage	Emplacement area
Process-R	HLW	Normal glass	903 L	50 y	**265 m^2**
Process-A	HLW w/o MA	Normal glass	298 L	50 y	**87 m^2**
Process-P	Ln	High-density glass	37 L	23 y	2.7 m^2
	Precipitation	High-density glass	65 L	5 y	1.1 m^2
	Sr, Ba	Calcined form	22 L	100 y	6.9 m^2
	Cs, Rb	Calcined form	39 L	120 y	12 m^2
	Tc-PGM	Alloy waste	56 L	7 y	3.7 m^2
		Total	219 L	(Av. 39 y)	**27 m^2**
Process-A with long-term predisposal storage	HLW w/o MA	Normal glass	298 L	850 y	**1.9 m^2**
Process-P with long-term predisposal storage	Ln	High-density glass	37 L	90 y	0.2 m^2
	Precipitation	High-density glass	65 L	10 y	0.4 m^2
	Sr, Ba	Calcined form	22 L	320 y	0.2 m^2
	Cs, Rb	Calcined form	39 L	320 y	0.3 m^2
	Tc-PGM	Alloy waste	56 L	70 y	0.4 m^2
		Total	219 L	(Av. 125 y)	**1.5 m^2**

Conclusions

- **Recovery and transmutation of MA can play an important role in stabilizing the repository area for the future Pu utilization**.

- If further **extension of the capacity of a repository** is required for the sustainable utilization of the nuclear fission energy by both UO_2 and MOX fuels, the **full P&T would be a very powerful** measure to reduce the total emplacement area down to about **1/5** of the conventional disposal concept planned in Japan.

- **Coupling of P&T with long-term predisposal storage** will provide us significant (maximum about 2 orders) reduction of repository area, though the burden of storage for about 300 years and the high efficiency of MA separation should be the next challenges.