The Tenth OECD Nuclear Energy Agency
Information Exchange Meeting on
Actinide and Fission Product Partitioning and Transmutation

Global Scenarios for Fast Reactor Deployment

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Hotel Lake View Mito, Mito, Japan

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1. Purpose

Based on homogeneous scenario concept, we grasp the maximum scale of FBR deployment, natural uranium saving benefit and so on if JSFR (main concept selected in the Japanese Feasibility Studies on Commercialized FBR Cycle System; sodium-cooled FBR with MOX fuel) is deployed in the world.

Main assumptions are as follows,

(1) Perspective of world nuclear generating electricity ;

IPCC SRES-B2 scenario, IIASA/WEC C2 scenario

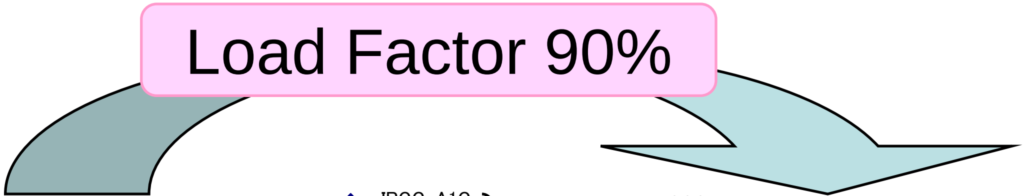
- about 2,000GWe at 2050, about 5,000GWe constant after 2100 in SRES-B2 scenario
- about 1,000GWe at 2050, about 2,200GWe constant after 2100 in IIASA-C2 scenario

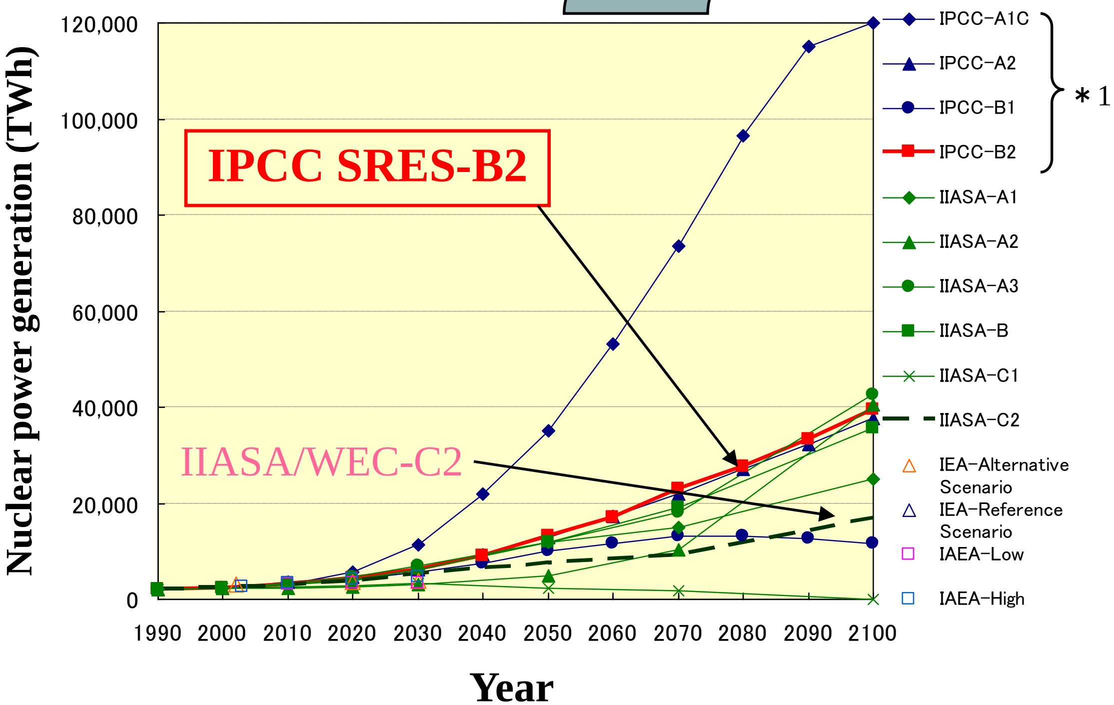
(2) Timing of FBR deployment in world key countries ;

- India : 2020
- Russia : 2020-2025
- France : about 2040
- China : 2030-2035
- Japan : about 2050

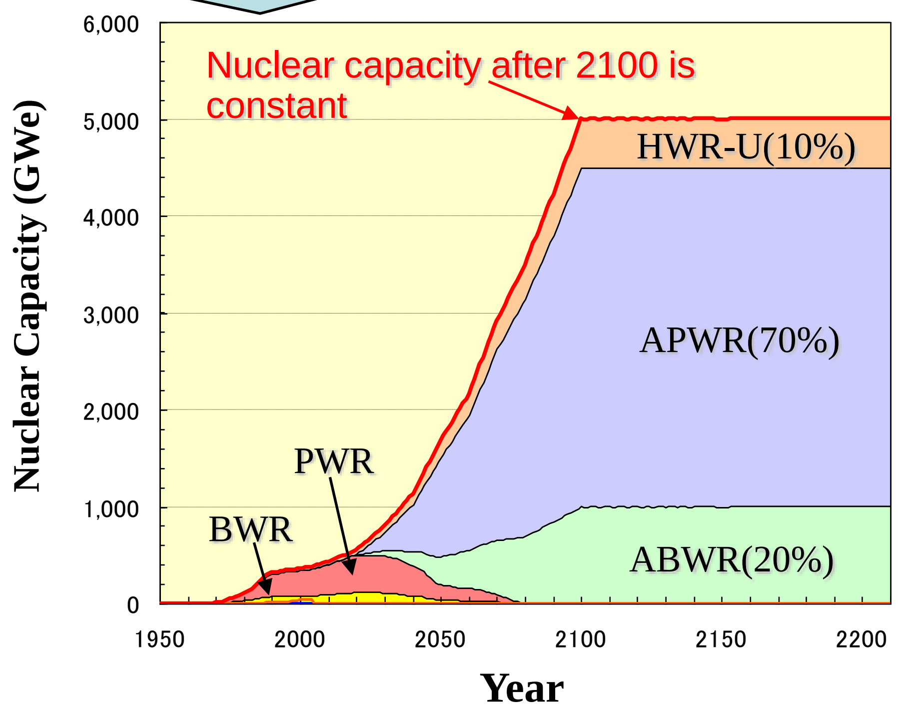
} FBRs are assumed to be deployed at 2020 - 2070

2.1 *Assumption of nuclear power generation and capacity in the world (IPCC SRES-B2)*





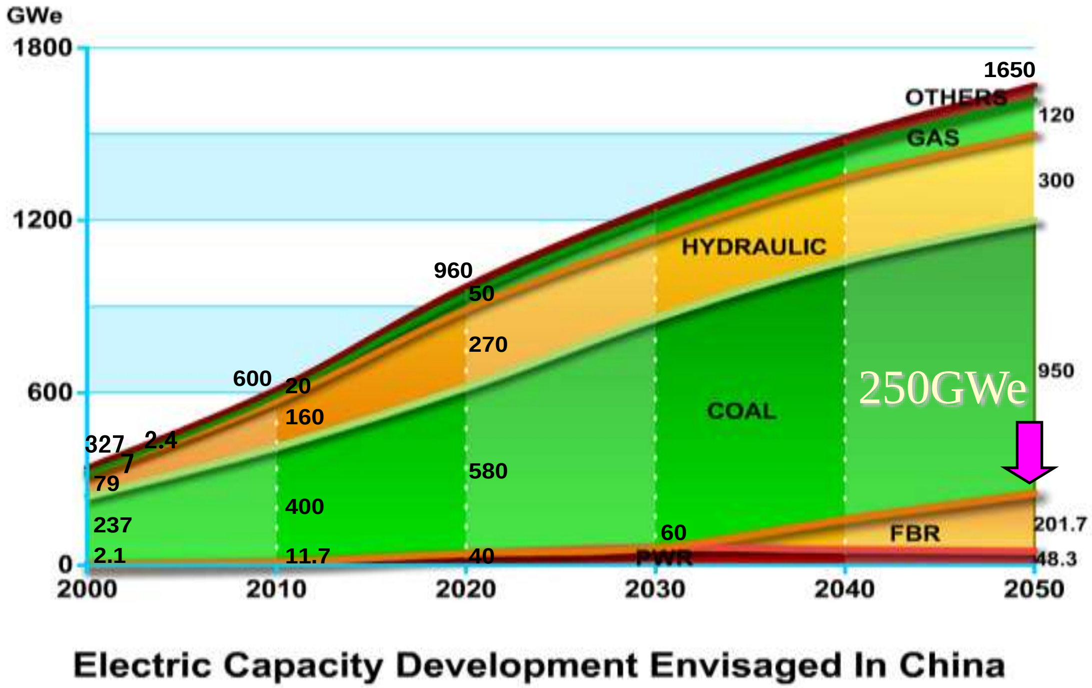
Typical perspectives for nuclear power generation



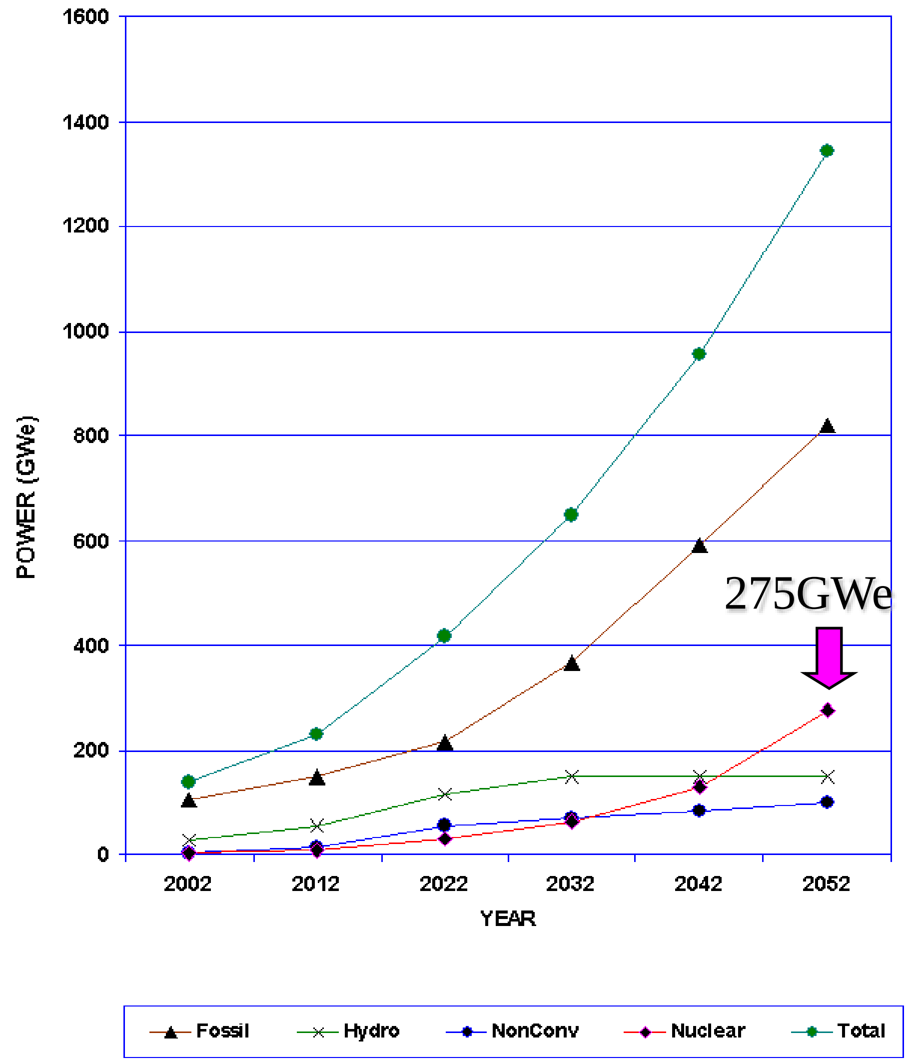
World nuclear power capacity in SRES-B2 (No FBR deployment)

Note IPCC :The Intergovernmental Panel on Climate Change, IIASA :International Institute for Applied System Analysis, WEC: World Energy Council
*1: By MESSAGE Code

2.2 *Perspectives for nuclear power generation and capacity in China and India*



Ref.)Mi Xu, Status and Prospects of Sustainable Nuclear Power Supply in China, GLOBAL2005, No.511, Tsukuba, JAPAN (2005).



Ref.)Department of Atomic Energy (DAE), http://www.dae.gov.in/

Electric capacity development envisaged in China **Projected Installed Power Capacity in India**

2.3 *Main assumptions of nuclear power reactor system - characteristic data -*

Life time		**60 years for all type of reactors**
Reactor type	**BWR**	**Burn-up 45GWd/t, for Reactors which will be deployed by 2019**
	ABWR	**Burn-up 60GWd/t, for Reactors which will be deployed after 2020**
	PWR	**Burn-up 49GWd/t, for Reactors which will be deployed by 2019**
	APWR	**Burn-up 60GWd/t, for Reactors which will be deployed after 2020**
	HWR-U	**Burn-up 8.3GWd/t, natural uranium fuels for CANDU**
	FBR	**High Breeding ratio type(Sodium-cooled, MOX fuel) : Breeding ratio 1.20, Average Burn-up 55GWd/t**
		Low Breeding ratio type(Sodium-cooled, MOX fuel) : Breeding ratio 1.03, Average Burn-up 115GWd/t
Deployment ratio	**BWR&ABWR**	**20% of all capacity except FBR**
	PWR&APWR	**70% of all capacity except FBR**
	HWR-U	**10% of all capacity except FBR**

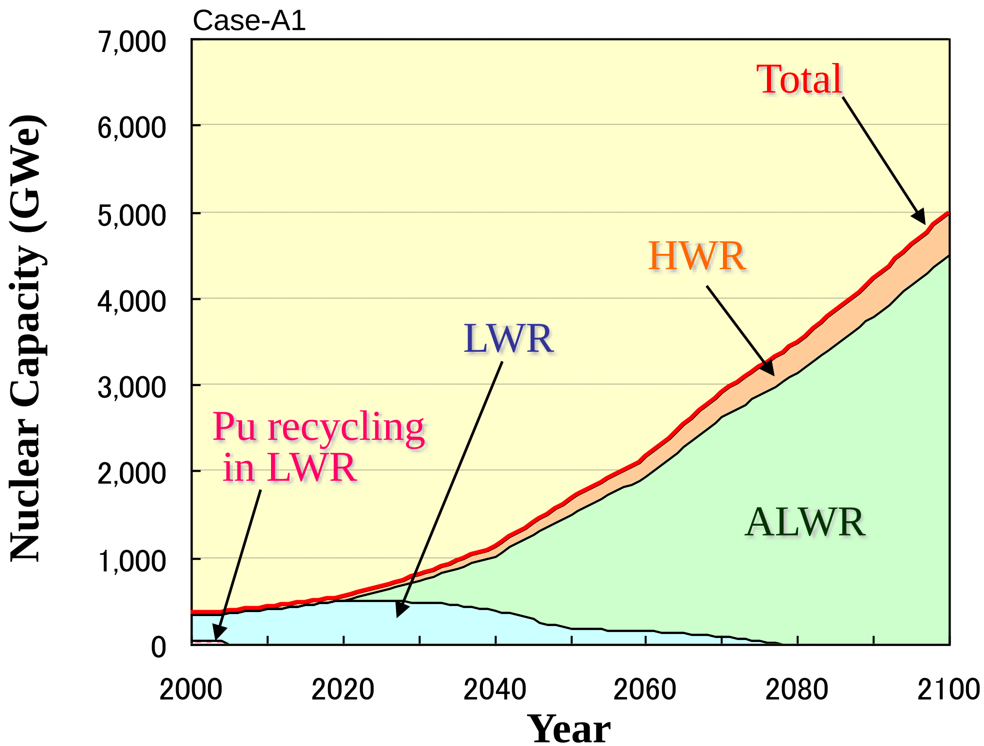
2.4 *Main assumptions of nuclear fuel cycle system*

Ex-core time period	LWR	4 years (Cooling time 3years, Reprocessing 0.5 year, Fab. & trans. 0.5 year)
	FBR	5 years (Cooling time 4years, Reprocessing 0.5 year, Fabrication 0.5 year) 3 years (Cooling time 2years, Reprocessing 0.5 year, Fabrication 0.5 year)
Enrichment plant		Capacity is not limited.
Fuel fabrication plant		Capacity is not limited.
Reprocessing Plant	LWR-UO2	-2009: 4,100 ton-HM/year 2010-just before FBR development: 4,900 ton HM/year After FBR deployment: The reprocessing plant capacity is gradually increased in accordance with amount of spent fuels discharged from FBR.
	LWR-MOX	They will be processed in the FBR reprocessing plant in 20-40 years.
	HWR	Long-term storage of spent fuels
	FBR	Reprocessing of all spent fuels
Loss factor	LWR, HWR	Enrichment 0%, Conversion0.5%, Fabrication 0.1%, Reprocessing 0.5%
	FBR	Fabrication 0.1%, Reprocessing 0.1%
U-235 enrichment		0.25%, 0.2%
Other		The uranium recovered from spent fuels is re-enriched

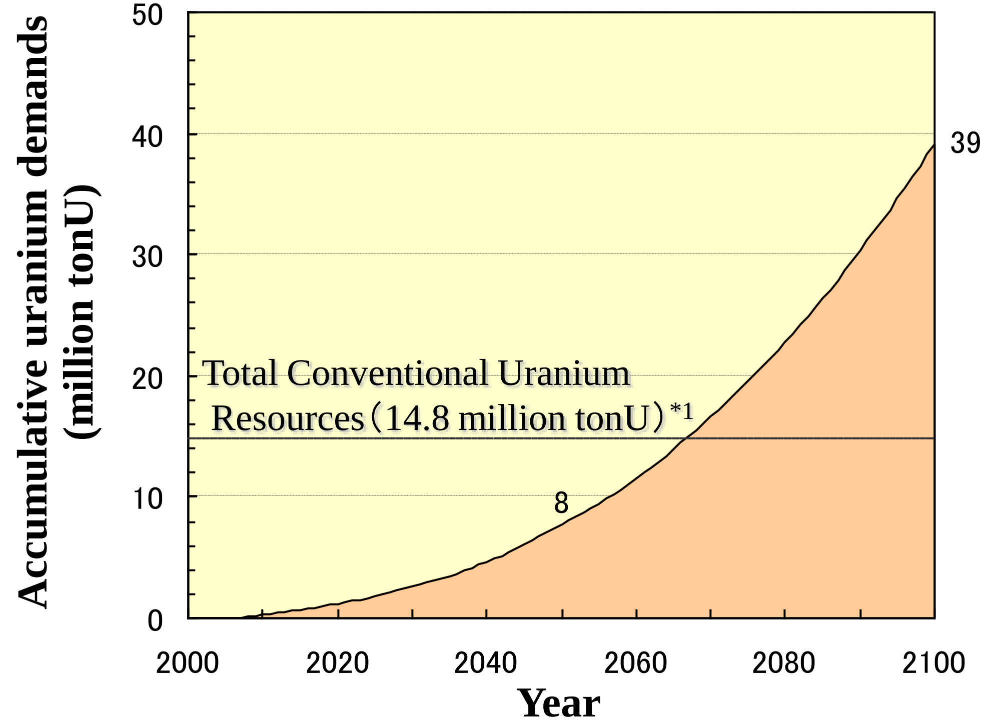
3. *Analysis cases for IPCC SRES-B2 scenario*

Case		FBR deployment		Tails assay		FBR Ex-core time period	
		In 2020	In 2030	0.25%	0.20%	5 years*1	3 years*2
Resources free	LWR once-through (A1)	-	-	X		-	-
	Deployment in 2030 (A2)		X	X		X	
	Deployment in 2020 (A3)	X		X		X	
	Uranium saving(A4)		X		X	X	
Resources restriction *3	LWR once-through（B1）		X	X			
	Base case（B2）		X	X		X	
	Ex-core Time 3 years（B3）		X	X			X
	Uranium saving（B4）		X		X	X	
Note	*1: 5 years (Cooling time 4years, Reprocessing 0.5 year, Fabrication 0.5 year) *2: 3 years (Cooling time 2years, Reprocessing 0.5 year, Fabrication 0.5 year) *3: Limitation of natural uranium 14.8 million ton U after 2005						

4.1 *Nuclear capacity and Cumulative U demands of LWR once-through in the world*



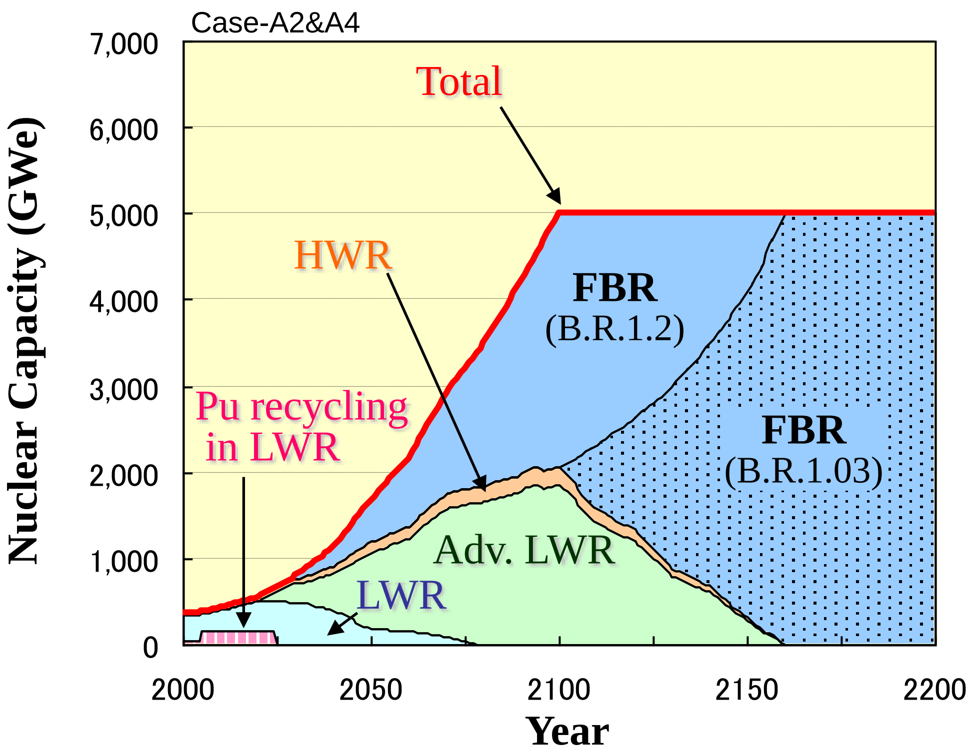
World nuclear capacity (Case-A1:LWR once-through)



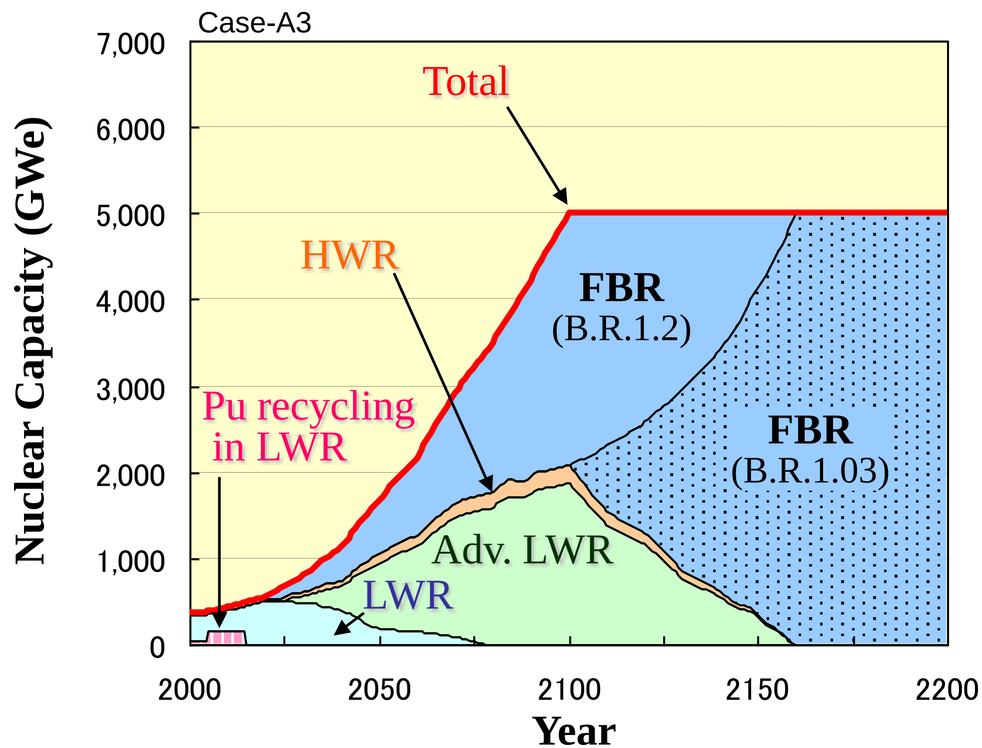
World cumulative natural uranium demands after 2005 (Case-A1:LWR once-through)

*1 OECD/NEA-IAEA. Uranium 2005:Resources, Production and Demand (2006)

4.2 *Nuclear capacity of CaseA2-A4*

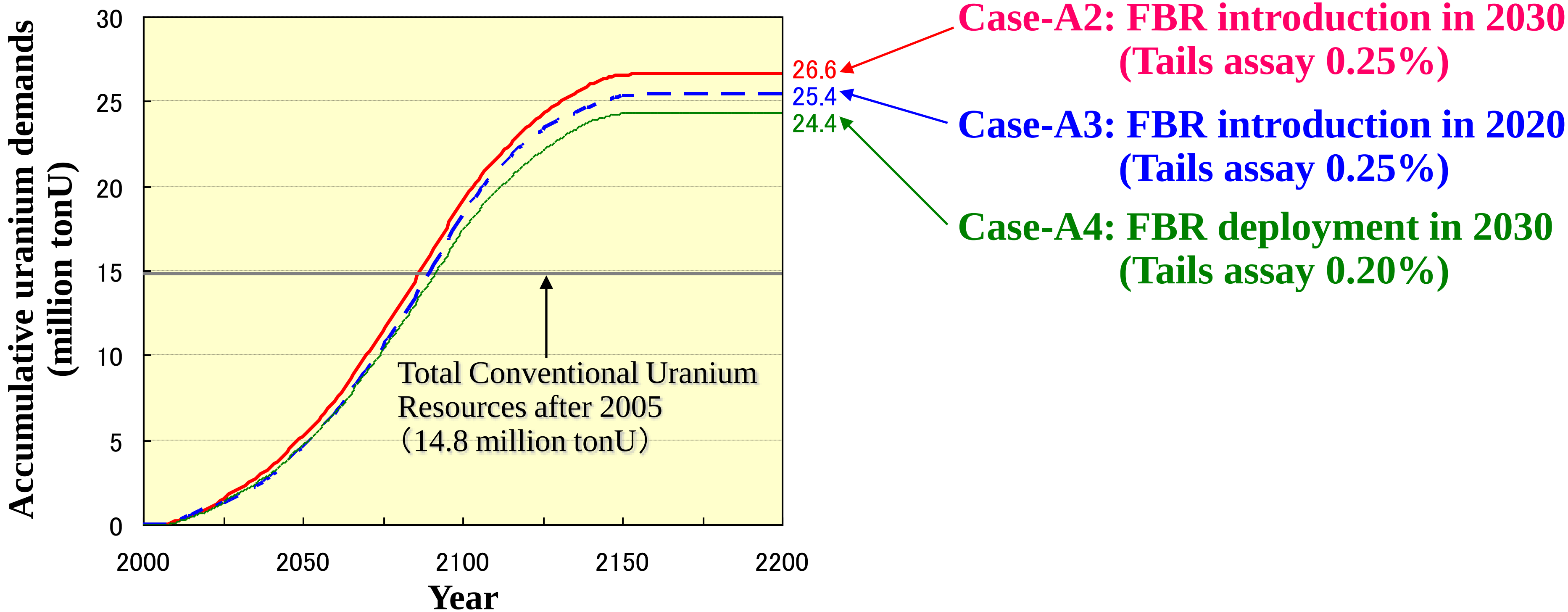


World nuclear capacity
(Case-A2&A4:FBR deployment in 2030)



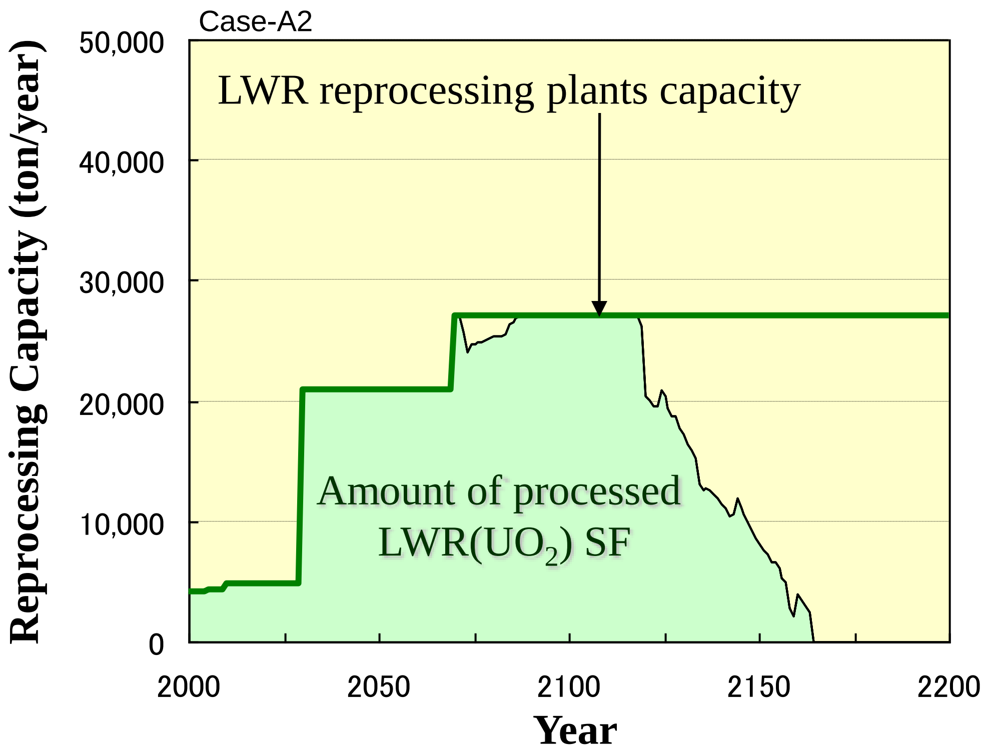
World nuclear capacity
(Case-A3:FBR deployment in 2020)

4.3 ***Cumulative Natural Uranium demands of Case A2-A4***

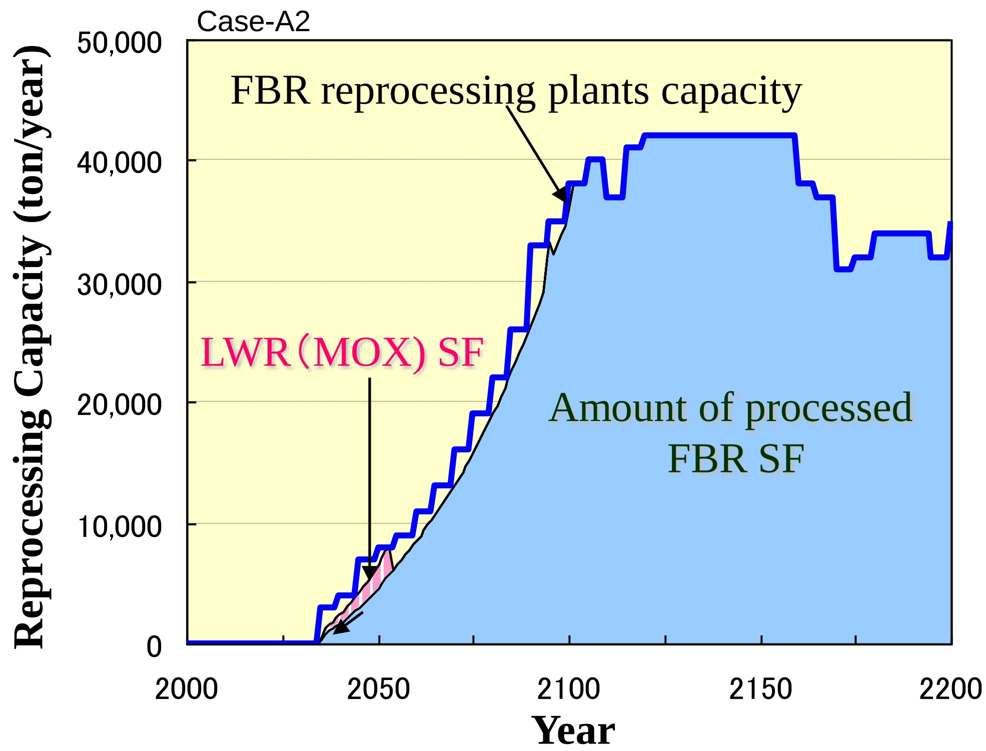


World cumulative natural uranium demands after 2005

4.4 *Capacity for each type of reprocessing plants of Case-A2*

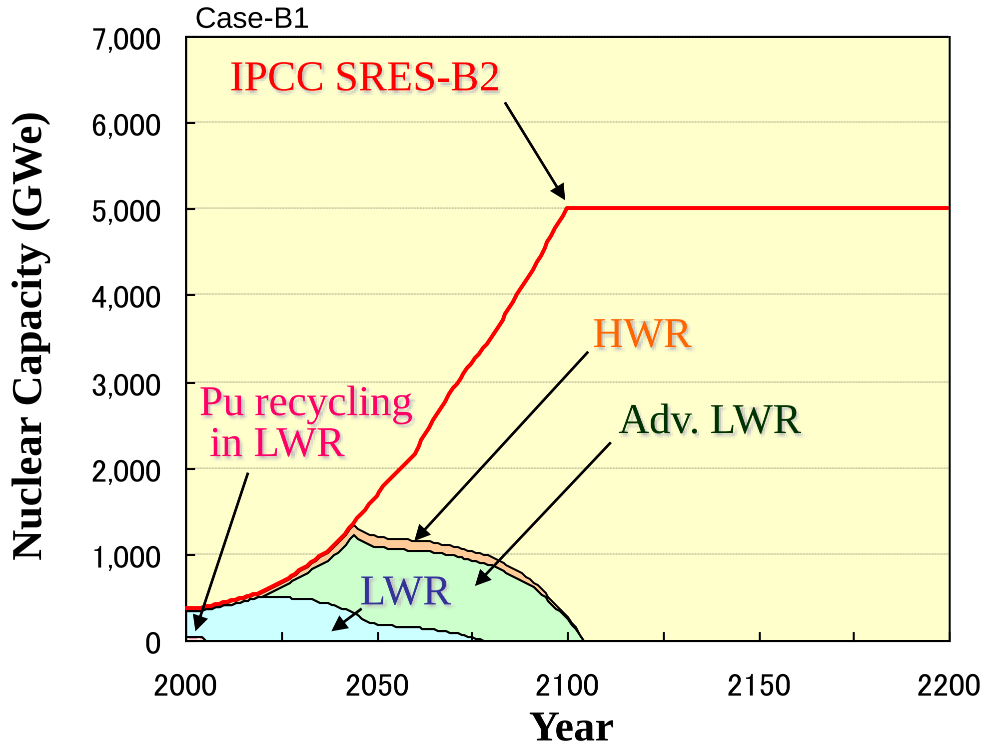


LWR reprocessing plants capacity in the world (Case-A2: FBR deployment in 2030)

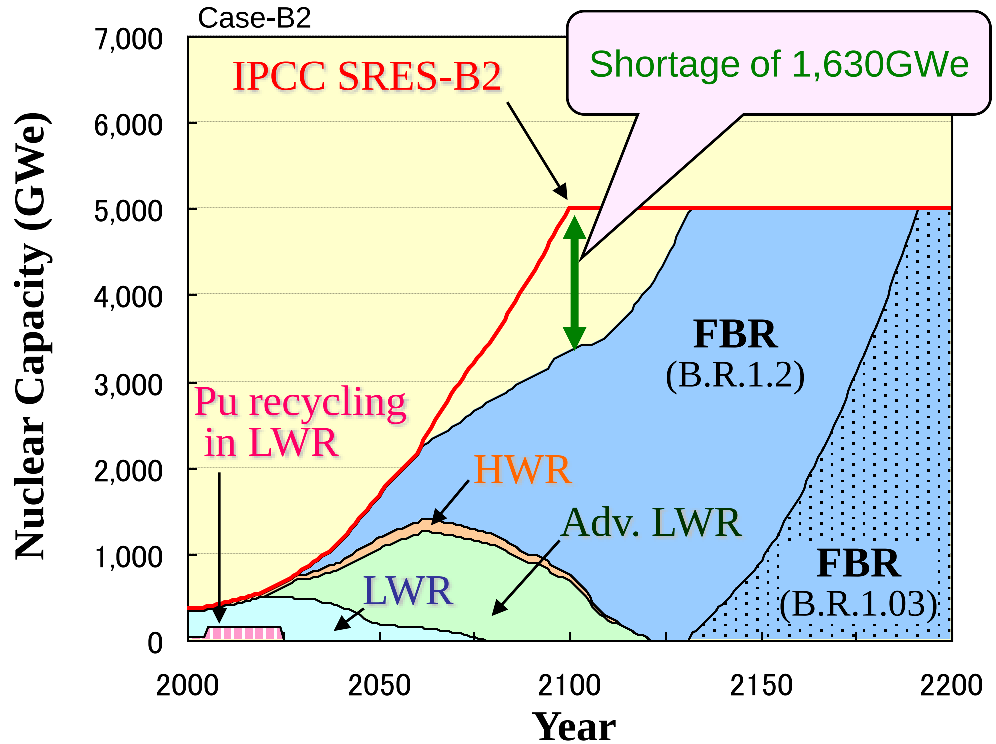


FBR reprocessing plants capacity in the world (Case-A2: FBR deployment in 2030)

4.5 *Nuclear capacity of Case-B1&B2*

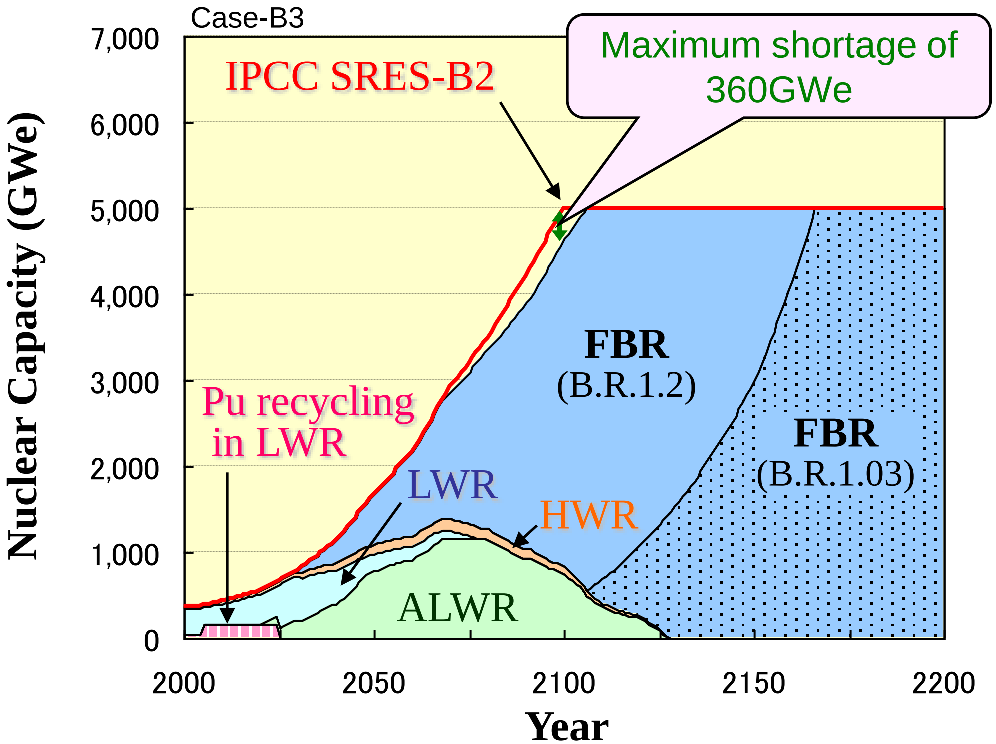


World nuclear capacity
(Case-B1: LWR once-through_)

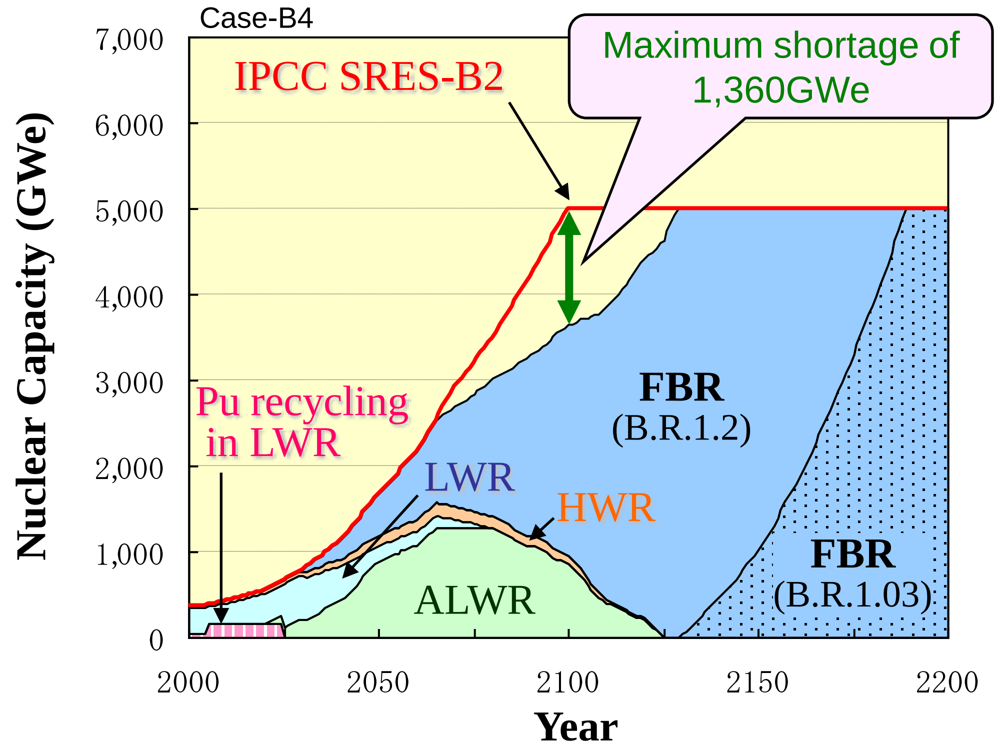


World nuclear capacity
(Case-B2:Base case)

4.6 ***Nuclear capacity for each type reactor of Case-B3&B4***

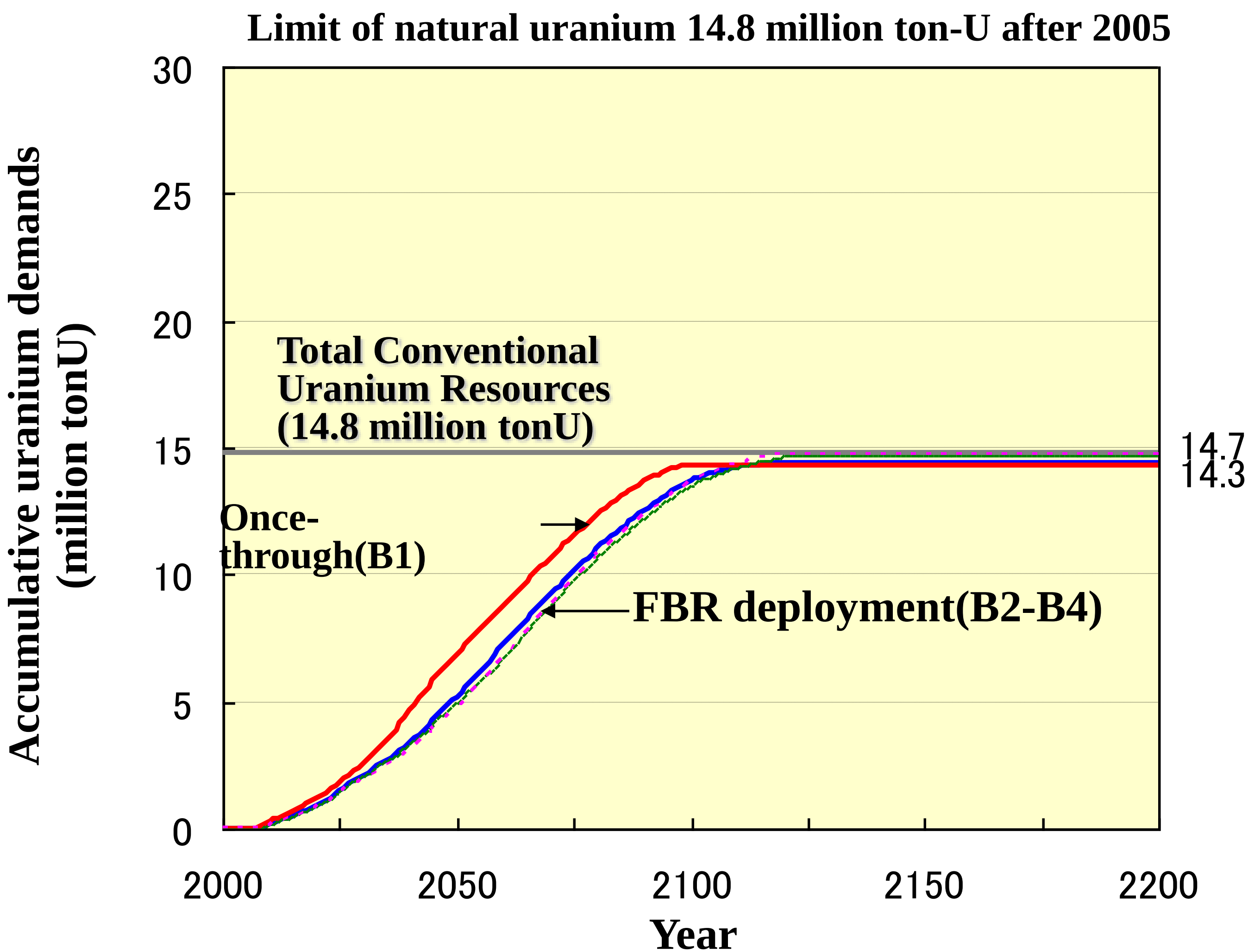


World nuclear capacity
(Case-B3:Ex-core time period 3years)



World nuclear capacity
(Case-B4:Tails assay 0.2%)

4.7 *Cumulative Natural Uranium demands of Case B1-B4*



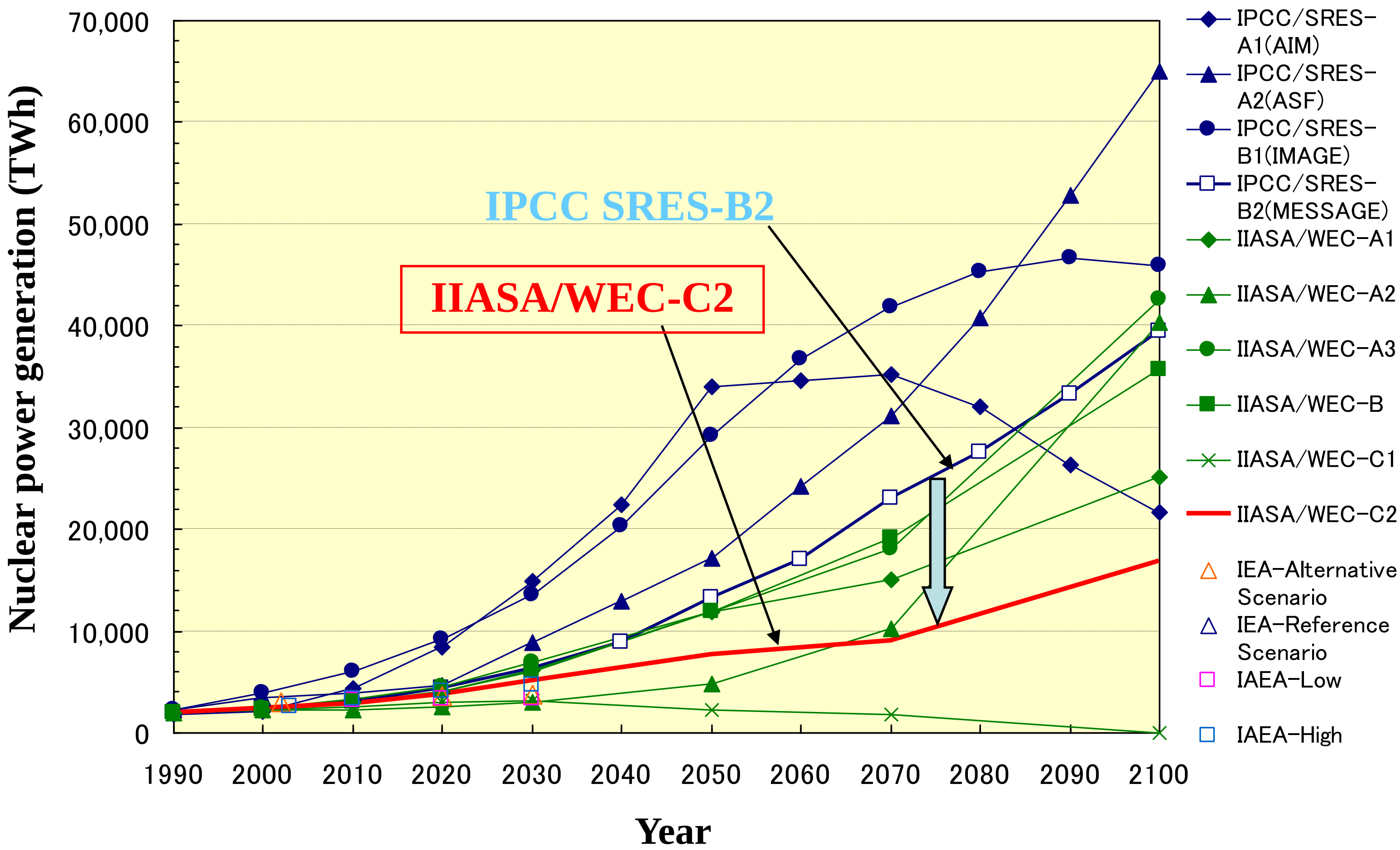
World cumulative natural uranium demand after 2005 (Case B1-B4)

4.8 *Summary of scenario study in IPCC SRES-B2 scenario*

Case		Cumulative natural uranium demand (million ton U)		Nuclear capacity in 2100 (GWe)	The year when shift to FBR will finish * (year)	The year when nuclear generation will reach SRES-B2 case
		at 2100	maximum			
Resource free	LWR once-through (A1)	39.1	-	5,000	-	-
	Introduction in 2030 (A2)	19.1	26.6	5,000	2160	-
	Introduction in 2020 (A3)	18.2	25.4	5,000	2160	-
	Uranium saving(A4)	17.4	24.4	5,000	2160	-
Resource restriction	LWR once-through (B1)	14.3	-	290	-	-
	Base case (B2)	13.7	14.4	3,371	2121	2132
	Ex-core Time 3years(B3)	13.5	14.7	4,641	2128	2106
	Uranium saving(B4)	13.6	14.7	3,642	2125	2129

*) At the year when all LWRs will be replaced by FBR

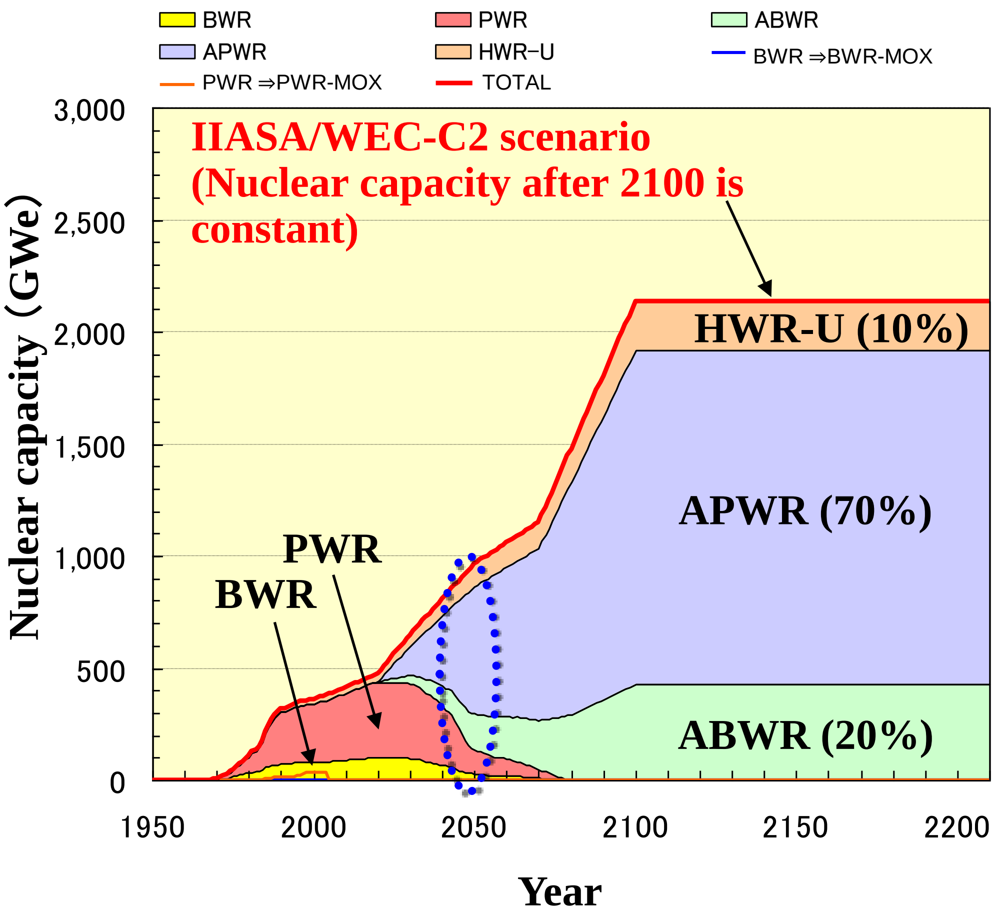
5.1 *Assumption of nuclear power generation and capacity in the world (IIASA/WEC-C2)*



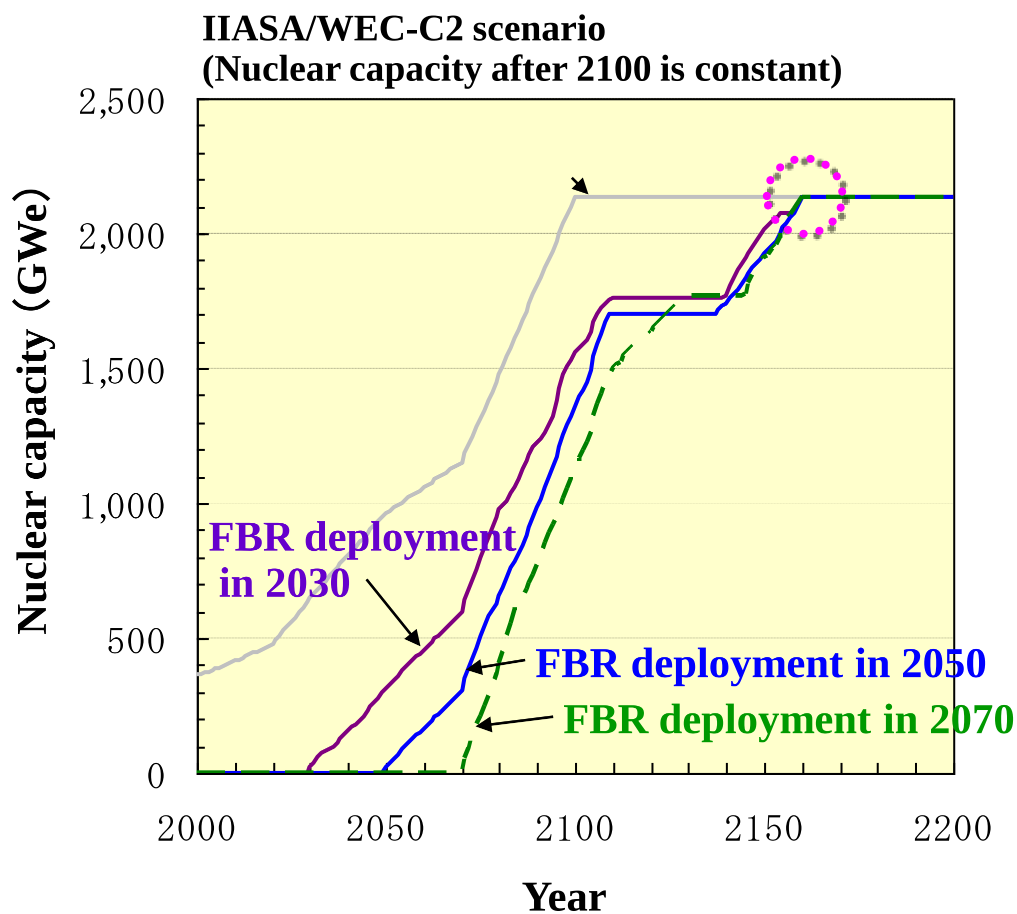
Typical perspectives for nuclear power generation

Note IPCC :The Intergovernmental Panel on Climate Change), SRES: Special Report Emission Scenarios
IIASA : International Institute for Applied System Analysis, WEC: World Energy Council

5.2 *Nuclear capacity in IIASA/WEC-C2 scenario*

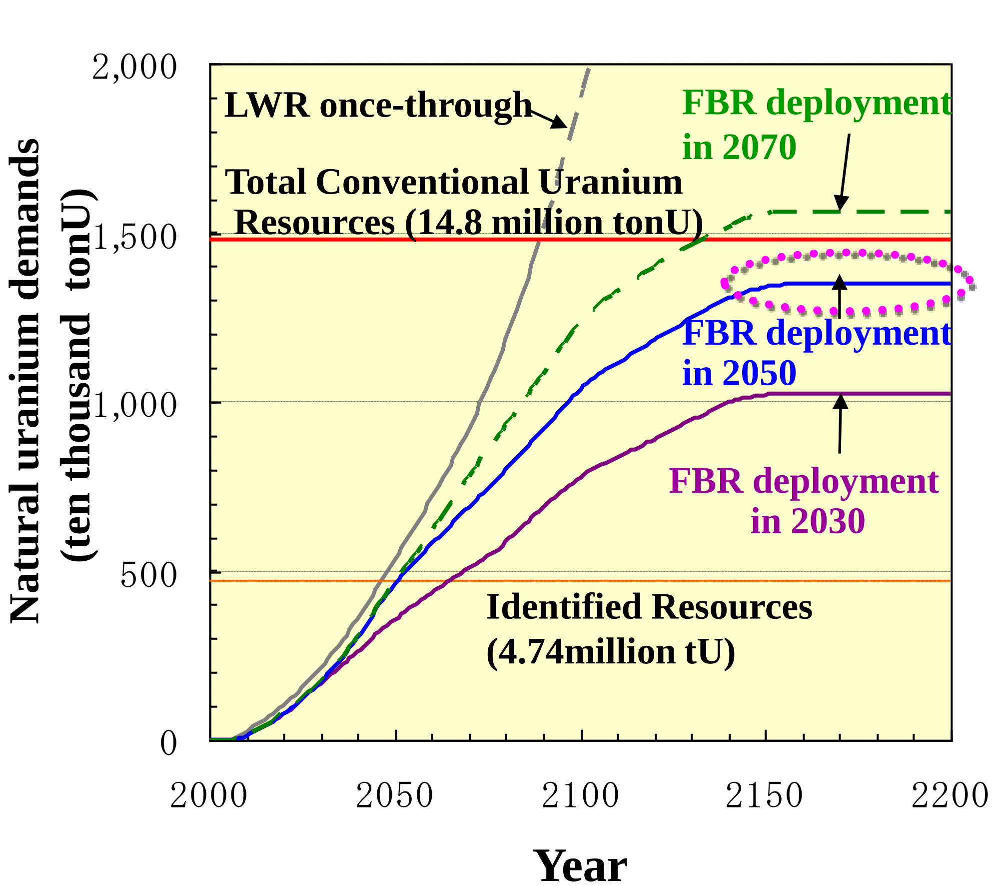


World nuclear power capacity (IIASA/WEC-C2)

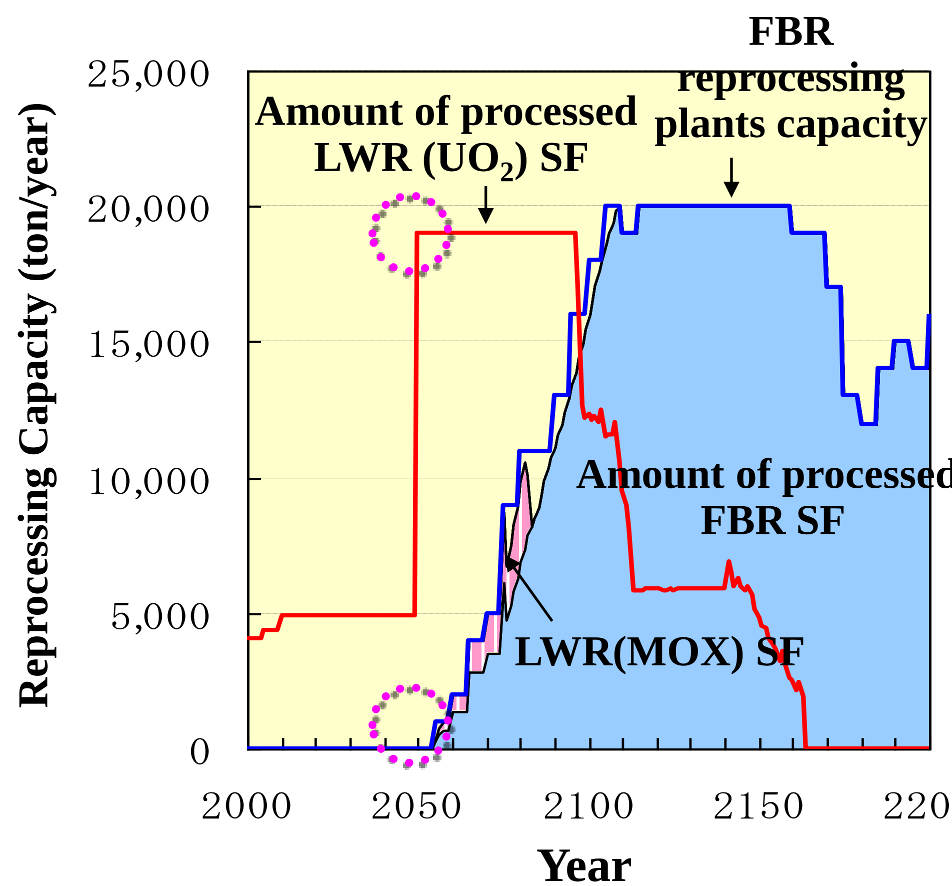


FBR deployment capacity

5.3 *Cumulative U demands and Capacity for reprocessing plants of IIASA/WEC-C2 scenario*



World cumulative natural uranium demands after 2005



FBR reprocessing plants capacity (FBR deployment in 2050)

6. ***Conclusions***

- In IPCC SRES-B2 scenario, cumulative natural uranium demands will exceed the total conventional uranium resources of 14.8 million ton (OECD/NEA-IAEA, Uranium 2005), even if FBRs are deployed at 2020.

- Under constrained condition of the total conventional uranium resources, it is difficult to supply electricity assumed in IPCC SRES-B2 scenario.

- Shortening of the duration of the ex-core time period and decrease of tails assay concentration have effects on decrease of cumulative natural uranium demands.

- In IIASA/WEC-C2 scenario, cumulative uranium demands will saturate within 14.8 million ton, if FBRs with about 1.2 BR are deployed before 2050.

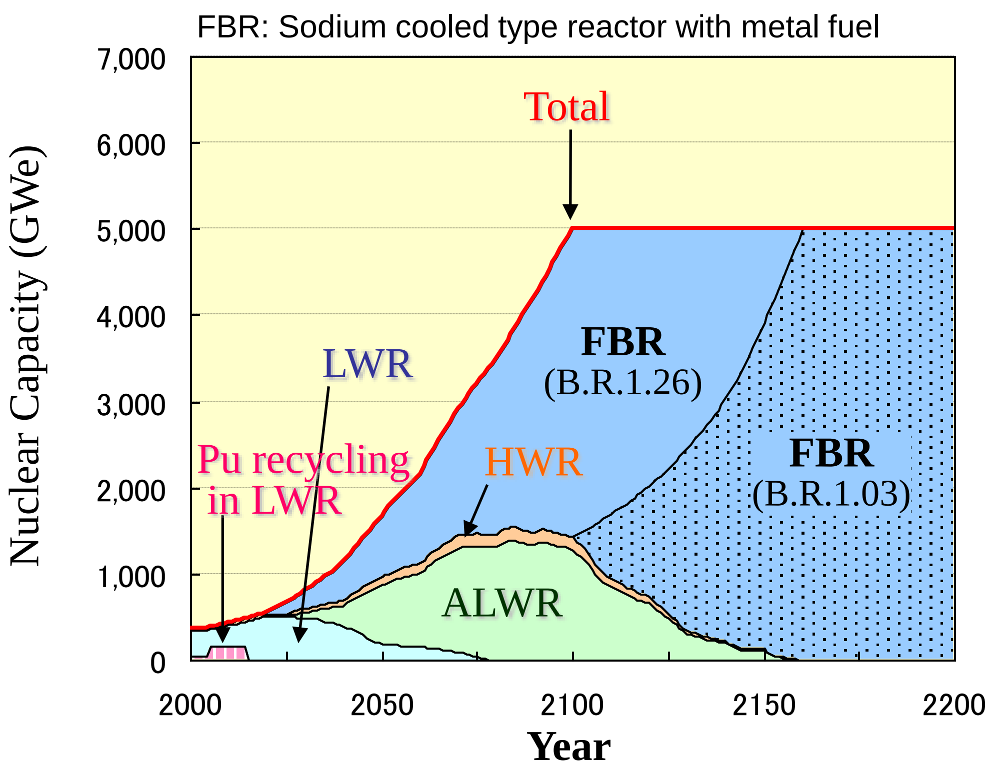
Appendix

Natural Uranium Resources

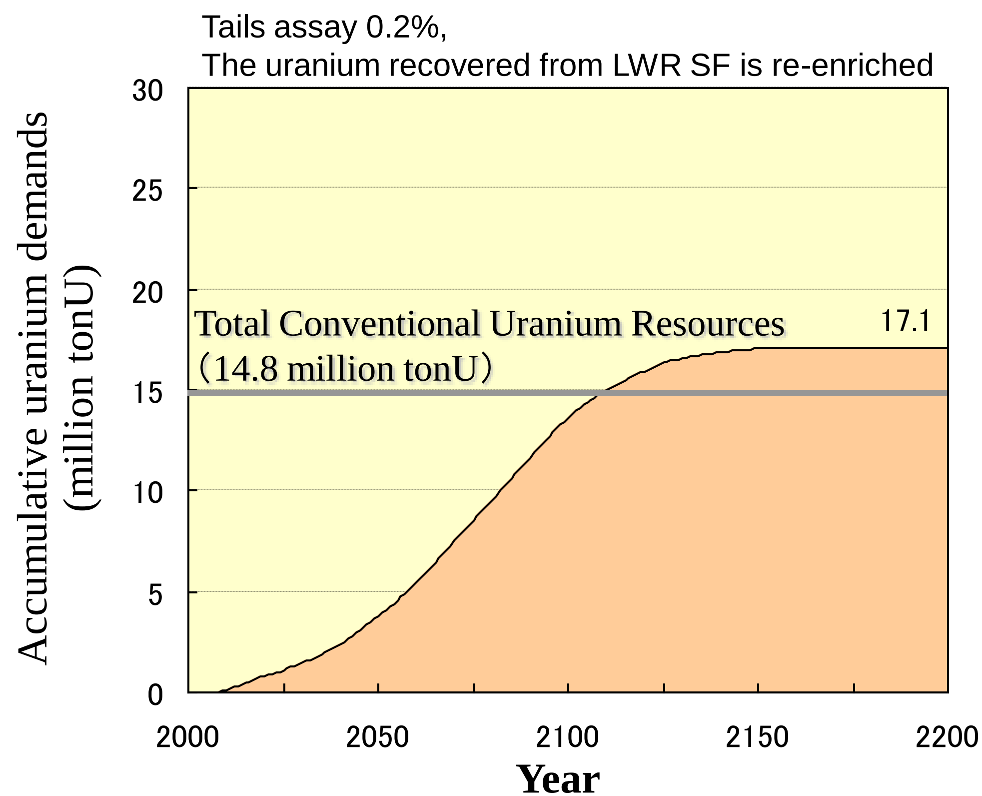
OECD/NEA-IAEA.Uranium 2005:Resources, Production and Demand(2006)

<table>
<tr><th rowspan="2">Cost ranges</th><th colspan="2">Identified Resources (million ton U)</th><th colspan="2">Undiscovered Resources (million ton U)</th><th rowspan="2">Total Conventional Uranium Resources (million ton U)</th></tr>
<tr><th>Reasonably Assured Resources</th><th>Inferred Resources</th><th>Prognosticated Resources</th><th>Speculative Resources</th></tr>
<tr><td>Cost range unassigned</td><td>—</td><td>—</td><td>—</td><td>2.98</td><td rowspan="7">14.80</td></tr>
<tr><td rowspan="2"><US$130/kgU</td><td colspan="2">4.74</td><td rowspan="2">2.52</td><td rowspan="6">4.56</td></tr>
<tr><td>3.30</td><td>1.45</td></tr>
<tr><td rowspan="2"><US$80/kgU</td><td colspan="2">3.80</td><td rowspan="4">1.70</td></tr>
<tr><td>2.64</td><td>1.16</td></tr>
<tr><td rowspan="2"><US$40/kgU</td><td colspan="2">2.75</td></tr>
<tr><td>1.95</td><td>0.80</td></tr>
</table>

Sample results of sodium cooled type reactor with metallic fuel

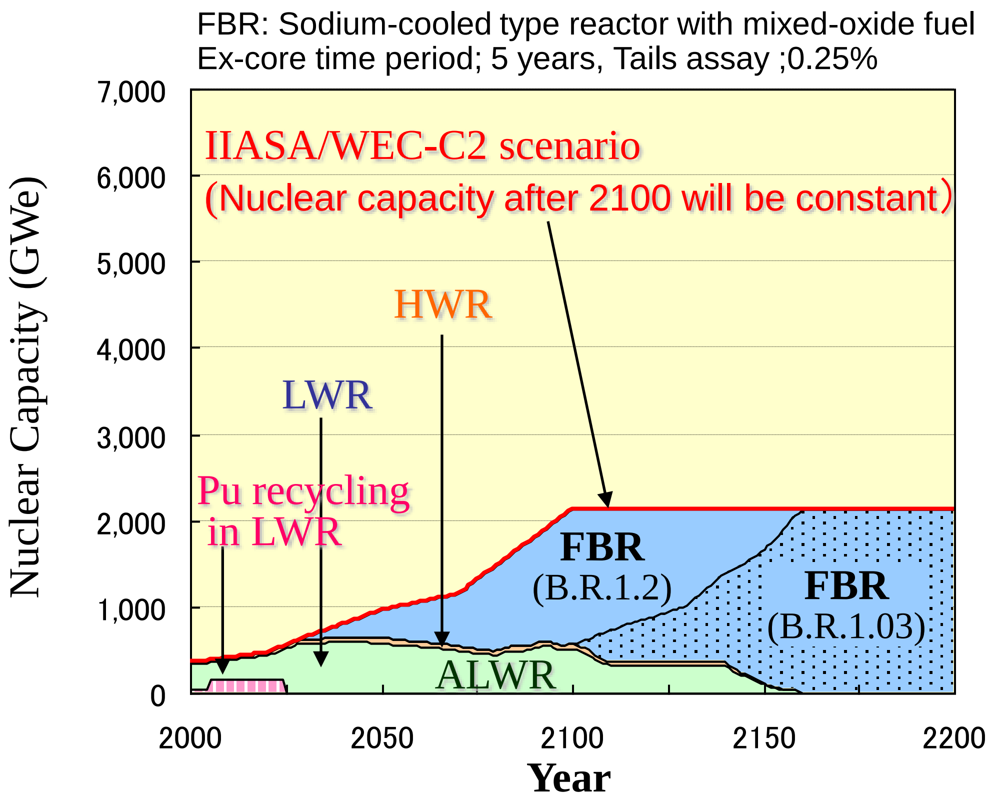


World nuclear capacity
(FBR with metal fuel deployment in 2020)

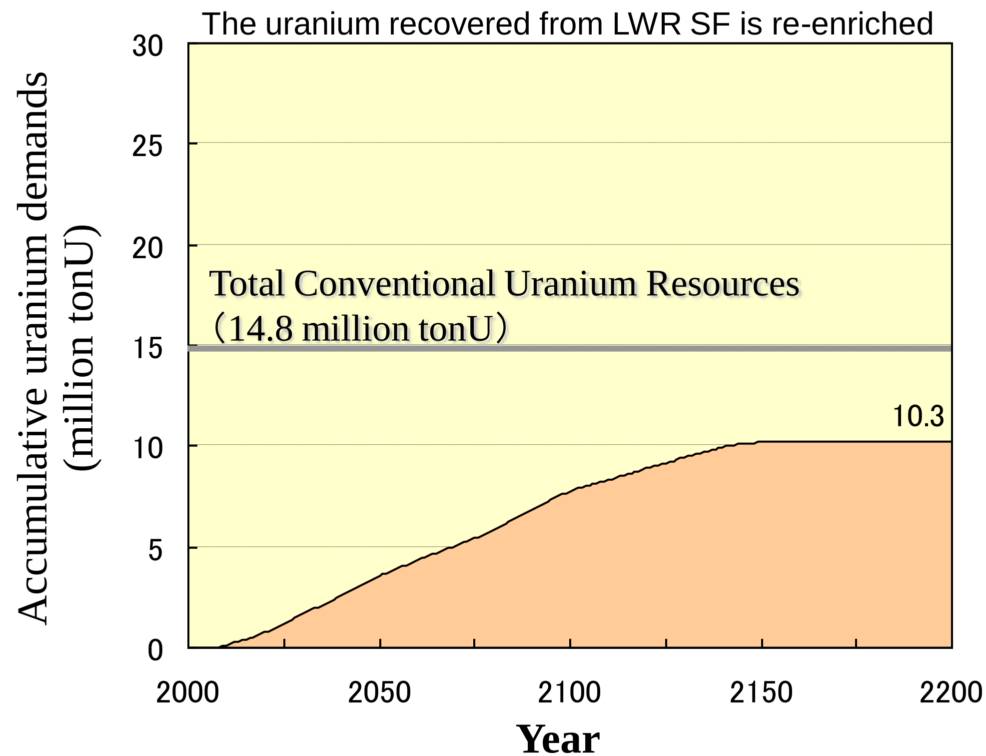


World cumulative natural uranium demand after 2005

Sample results of IIASA/WEC-C2 scenario analysis



World nuclear capacity for IIASA/WEC-C2 case
(FBR deployment in 2030)



World cumulative natural uranium demands after 2005
(IIASA/WEC-C2 case)

Fuel mass balance for FBR

Coolant / Fuel type/form		Sodium, Mixed-oxide/Pellet						Sodium, Metal/Casting					
Core type		Breeding core type			Break-even core type			Breeding core type			Break-even core type		
Electricity output	(MWe)	1,000			1,000			1,000			1,000		
Average burn-up	(MWd/t)	54,300			114,900			55,400			153,000		
Breeding ratio	(-)	1.20			1.03			1.26			1.03		
Load factor	(%)	90.0			90.0			90.0			90.0		
Life time	(Years)	60			60			60			60		
		Core	Axial blanket	Radial Blanket	Core	Axial blanket	Radial Blanket	Core	Axial blanket	Radial Blanket	Core	Axial blanket	Radial Blanket
Initial core loading													
Heavy metal	(ton)	31.663	39.094	29.656	50.079	19.261		48.753	24.366	15.101	65.176		
Uranium	(ton)	23.850	39.094	29.656	39.753	19.261		42.712	24.366	15.101	57.370		
Plutonium	(ton)	7.461	0.000	0.000	9.861	0.000		5.860	0.000	0.000	7.572		
Fissile plutonium	(ton)	4.563	0.000	0.000	6.031	0.000		4.128	0.000	0.000	5.334		
Uranium enrichment	(%)	0.300	0.300	0.300	0.300	0.300		0.300	0.300	0.300	0.300		
Equiribrium fuel charge													
Heavy metal	(ton/year)	4.749	5.864	4.448	5.141	1.977		8.163	4.080	2.529	5.332		
Uranium	(ton/year)	3.577	5.864	4.448	4.081	1.977		7.152	4.080	2.529	4.694		
Plutonium	(ton/year)	1.119	0.000	0.000	1.012	0.000		0.981	0.000	0.000	0.619		
Fissile plutonium	(ton/year)	0.684	0.000	0.000	0.619	0.000		0.691	0.000	0.000	0.436		
Uranium enrichment	(%)	0.300	0.300	0.300	0.300	0.300		0.300	0.300	0.300	0.300		
Initial core discharge													
Heavy metal	(ton/year)	4.560	5.848	4.445	4.945	1.967		7.886	4.072	2.525	5.191		
Uranium	(ton/year)	3.436	5.788	4.423	3.909	1.939		6.852	4.036	2.506	4.544		
Plutonium	(ton/year)	1.071	0.060	0.022	0.988	0.028		1.002	0.036	0.018	0.627		
Fissile plutonium	(ton/year)	0.645	0.055	0.021	0.599	0.026		0.705	0.035	0.018	0.440		
Uranium enrichment	(%)	0.258	0.278	0.288	0.257	0.269		0.247	0.280	0.282	0.269		
Equiribrium fuel discharge													
Heavy metal	(ton/year)	3.991	5.799	4.433	4.357	1.937		7.330	4.058	2.517	4.482		
Uranium	(ton/year)	3.011	5.560	4.345	3.392	1.823		6.253	3.950	2.462	3.797		
Plutonium	(ton/year)	0.925	0.239	0.088	0.916	0.113		1.044	0.108	0.055	0.663		
Fissile plutonium	(ton/year)	0.527	0.221	0.084	0.537	0.102		0.732	0.104	0.054	0.460		
Uranium enrichment	(%)	0.108	0.207	0.252	0.100	0.168		0.125	0.239	0.245	0.077		
Final core discharge													
Heavy metal	(ton)	28.400	38.856	29.599	45.248	19.054		45.459	24.287	15.061	59.116		
Uranium	(ton)	21.421	37.789	29.215	35.469	18.319		39.095	23.840	14.835	50.782		
Plutonium	(ton)	6.616	1.062	0.383	9.306	0.734		6.171	0.445	0.225	8.082		
Fissile plutonium	(ton)	3.857	1.002	0.371	5.549	0.680		4.355	0.432	0.220	5.691		
Uranium enrichment	(%)	0.165	0.238	0.269	0.159	0.212		0.172	0.258	0.263	0.146		