ANNEX XI.

LONG-TERM SCENARIO STUDY FOR NUCLEAR FUEL CYCLE IN JAPAN

XI-1. INTRODUCTION

This evaluation was conducted in order to investigate several key indicators such as nuclear capacity, natural uranium demand, plutonium (Pu) stockpile and inventory, spent fuel (SF) stockpile, radioactive waste generation and disposal based on the long-term use of nuclear energy and a transition from light water reactors (LWRs) to fast reactors (FRs) with reprocessing of SF in Japan.

Three nuclear scenarios were selected as the target in the evaluation until around 2150, when the impact of the transition from LWRs to FRs would be most visible. The scenarios are as follows:

- Full reprocessing (FR deployment): All SF is reprocessed, and FRs are deployed for the replacement of LWRs after 2050;
- Partial reprocessing (Rokkasho Reprocessing Plant operation): SF exceeding the capacity of Rokkasho Reprocessing Plant (hereinafter referred to as "Rokkasho Plant") and all SF generated after the closure of the Rokkasho Plant are directly disposed after being stored in interim storage facilities;
- Full direct disposal: All SF is directly disposed.

Moreover, four nuclear power capacity cases shown in Fig. XI-1 and Table XI-1 were assumed for the scenarios above in accordance with the energy policy debate in Japan by the long-term plan-making subcommittee of the Atomic Energy Commission after the Fukushima Dai-ichi accident [XI-1]:

1) 30 GW in 2030 and remains constant after 2030 (A1);
2) 20 GW in 2030 and remains constant after 2030 (A2);
3) 30 GW in 2030 and gradual decrease to zero after 2030 (B1);
4) 20 GW in 2030 and gradual decrease to zero after 2030 (B2).

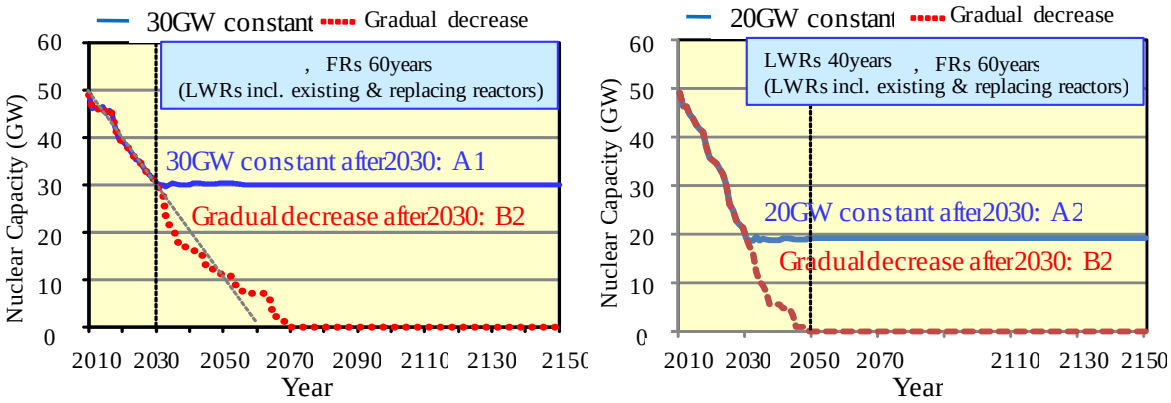


FIG. XI-1. Long-term nuclear energy scenarios for "Nuclear capacity 30 GW in 2030"(left),"Nuclear capacity 20 GW in 2030"(right).

TABLE XI-1. EVALUATION CASES

Scenario/ Nuclear capacity		Full reprocessing (FRs deployment)	Partial reprocessing* (Rokkasho operation)	Full direct disposal
A1)	30 GW constant	x	x	x
A2)	20 GW constant	x	-	x
B1)	Gradual decrease from 30 GW	x	x	x
B2)	Gradual decrease from 20 GW	x	-	x

* It was assumed that only Rokkasho Reprocessing Plant is in operation for reprocessing, and the SF that cannot be reprocessed at Rokkasho plant is directly disposed.

XI-1.1.Main assumptions for long-term scenario evaluation

The main assumptions for the long-term scenario evaluations are provided in Table XI-2. Those assumptions were made based on "the short-term scenario evaluations until 2030" conducted by the Technical Subcommittee on Nuclear Power, Nuclear Fuel Cycle, etc. established by the Atomic Energy Commission of Japan [XI-2, XI-3]. The assumptions on facilities were applied adequately in each case, as necessary (except that assumptions for reprocessing plant were considered only in recycling case). The cross-cutting characteristic evaluation tool to treat the whole nuclear fuel cycle supply-chain developed by JAEA was used in this study.

XI-2. RESULTS OF EVALUATIONS

XI-2.1.Cases A1 and A2 – constant after 2030

Nuclear capacities of Cases A1 and A2 are shown in Fig. XI-2 and Fig. XI-3. In the full reprocessing scenario of both cases, Pu recycling in LWRs of maximum 18 GW was conducted over 40 years by using Pu recovered from overseas and the Rokkasho Plant before the FR deployment. All LWRs were replaced with FRs in about 35 years after 2053 in the case of A1 (20 years after, in 2070, in the case of A2) considering the timing of the decommissioning of LWRs using Pu recovered from LWR reprocessing plants. On the other hand, in the partial reprocessing scenario, Pu recycling in LWRs with up to 20 GW was conducted for 40 years using Pu recovered from overseas and the Rokkasho Plant. In the direct disposal scenario, Pu recycling in LWRs with up to 14 GW in total with A1 (16 GW with A2) was conducted for 10 years using Pu recovered from overseas facilities.

Annual and cumulative natural uranium demands are shown in Fig. XI-4 and Fig. XI-5. The full reprocessing strategy made it possible to reduce natural uranium demand drastically after the FR deployment and to be fully independent from foreign natural uranium resources around 2090 in both cases, in addition to reducing annual natural uranium demand slightly even before the FR deployment. The cumulative natural uranium demand was reduced to about 45,000 t with A1 case (50,000 t with A2 case), less than half of the full direct disposal scenario at 2150. In the case of the partial reprocessing scenario, the natural uranium demand could be reduced by recycling Pu recovered from LWRs at the Rokkasho Plant, but natural uranium demand would remain almost the same as in the full direct disposal scenario in the long term.

Figures XI-6 and XI-7 provide SF stockpiles. Concerning the full reprocessing scenario, the SF stockpile remained at 12,000 t to 20,000 t with A1 (10,000 t to 20,000 t with A2) until

around 2060. Although the stockpile gradually lowered after 2060, the storage capacity could be nearly exhausted depending on the operational status of reprocessing plants (and the necessity to increase the capacity until around 2080 with A2). In the case of the partial reprocessing scenario, the SF stockpile was reduced by the operation of the Rokkasho Plant and stayed at 12,000 t to 20,000 t until around 2060. It increased again and eventually stayed at 25,000 t. Meanwhile, as the SF stockpile accumulated up to 40,000 t (35,000 t with A2) before 2050 and became constant at about 25,000 t (17,000 t with A2) after 2080 in the direct disposal scenario, additional storage capacity of 10,000 t to 20,000 t was required. If the Mutsu recyclable fuel storage center (Mutsu RFS) and the pool of the Rokkasho Plant are not available, up to 30,000 t of the capacity will be required.

Radioactive waste volumes and areas for geological disposal, high level radioactive waste (HLW) and low-level radioactive waste (LLW), and other categories of LLW are shown in Figures XI-8 to XI-11. Regarding the full reprocessing scenario, LLW (geological disposal category) volume increased due to the deployment of reprocessing facilities, whereas HLW (SF and vitrified waste) volume and area decreased. As a result, the total volume and area of radioactive wastes for geological disposal was reduced to less than half of that of the full direct disposal scenario. The total volume and area of radioactive wastes (geological disposal) in the case of the partial reprocessing scenario was less than that of the direct disposal scenario, but the difference was not significant. In the case of direct disposal scenario, SF was disposed in geological repository and its amount continuously increased. Besides that, other categories of LLW were also reduced in the full reprocessing scenario because wastes from operation of FRs for the near surface concrete pit disposal and the wastes from decommissioning of FRs for the near surface trench disposal decreased although waste for the sub-surface disposal increased due to the deployment of reprocessing facilities. In the case of the partial reprocessing scenario, there was no major difference in the total volume compared to that of direct disposal scenario, although LLW from reprocessing operation was increased.

TABLE XI-2. MAJOR ASSUMPTIONS

	Item	Condition
FR	Introduction timing	Demonstration reactor: deployment in 2025 Commercial Reactor: deployment in 2050 (to be deployed in accordance with Pu balance)
	Average burnup	Demo. reactor: 60 (Initial) -150 Wday/t, Comm. reactor: ~150 GWday/t (breeder reactor), ~145 GWday/t (burner reactor)
	Breeding ratio (Conversion ratio)	Demo. reactor: 1.1, Comm. reactor:early phase: ~1.1, thereafter: 1.03 Burner reactor: ~0.5
	Capacity per unit	Demo. breeder reactor: 750 MW(e), Comm. breeder reactor:1500 MW(e) Burner reactor: 1500MW(e)
	Lifetime/ Load factor	60 years / ~80%
LWR	Average burnup	BWR: 45 GWday/t, Reactors in the past: 30-40 GWday/t PWR: 49 GWday/t, Reactors in the past: 30-40 GWday/t Pu recycling: under 45 GWday/t, After 2030 all reactors: 60 GWday/t
	Capacity per unit	Past: actual record (including reactors under construction) Future reactors: 1200MW
	Lifetime/ Load factor	Existing reactors: 40years (reactors operated for more than 40 years are decommissioned in the end of 2012)/ Until 2011: actual record, After 2012: 80%
	Pu recycling	According to Pu utilization plan, including Pu recovered by overseas facilities

TABLE XI-2. MAJOR ASSUMPTIONS (cont.)

	Item	Condition
Enrichment facility	Uranium tails	Based on the plan (up to 1500 SWU), Overseas enrichment plants are assumed to be met the demand Tail assay: 0.25%
LWR fabrication facility	Commercial facility	Existing fuel fabrication facilities, Processed within the capacity based on new fuel demand, MOX fuel fabrication capacity: ~130 t/year
FR fuel fabrication facility	Demo. facility	Starts operation prior to the demo. reactor deployment; fabricates mainly fuel for the demo. FR
	Commercial facility	Starts operation prior to the FR deployment 100 t/year or 200 t/year (constructed according to the demand) MA upper limit 5%
LWR reprocessing facility	Rokkasho Reprocessing Plant	Operation until 2052 (2012: 80 tU, 2013: 320 tU, 2014: 480 tU, 2015: 640 tU, after 2015: 800 tU)
	SF transportation	SF is transported to the reprocessing plant after the cooling period if reprocessing is available; SF is continuously stored at the reactor site if not available
	SF storage facility	Capacity: 3000 tHM (Rokkasho Reprocessing Plant)
	Processing	Fuel of BWR & PWR is mixed and reprocessed (assumed acceptable annual volume of SF is all mixed)
	Future reprocessing facilities after Rokkasho Plant	Starts operation after the closure of the Rokkasho; Possible for reprocessing of MOX fuel and high burnup fuel; does not recycle recovered U; MA recovering is considered; Fuel of BWR & PWR is mixed and reprocessed within the capacity (assumed acceptable annual volume of SF is all mixed)
	Vitrification facility	Production conditions for vitrification: 1.25 cask/t
FR fuel reprocessing facility	Demo. facility	Starts operation after the demo. reactor deployment; Reprocesses mainly fuel for the demo. reactor
	Commercial facility	Starts operation after the FR deployment, 100 t/year or 200 t/year (constructed according to the demand), MA recovery considered (breeder reactor), Transuranium elements are vitrified (burner reactor)
	SF transportation after the cooling period	Transported to the reprocessing plant if reprocessing is available Continuously stored at the reactor site unless reprocessing is available
	Vitrification facility	Production conditions for vitrified waste: FP oxide 10%, 2.3 kW/cask
Storage facility	SF site storage capacity	Based on the actual capacity
	LWR SF interim storage facility (Mutsu RFS)	Starts operation: 2013, Storage term: within 50 years Max capacity: 5000 t, Annual storage:200 – 300 t/year
	SF storage facility	Recycling: storage period of less than 40 years Direct disposal: storage period of 48 years The capacity to be increased on demand
	HLW storage and management facility	Storage period: 50 years, constructed according to the plan in the near term, the capacity to be increased on demand
Geological Repository	Vitrified waste	Starts operation in around 2037: upright position in hard rock
	SF direct disposal	Starts operation in around 2047: upright position in hard rock
	LLW disposal repository	Starts operation based on the needs （except geological disposal）
Others	Ex-core time	LWR cycle: 4 years or more /FR cycle: 5 yearrs or more
	Using Pu recovered by overseas facilities	Use by Pu recycling
	Fuel cycle losses	Fuel fabrication: 0.1%, Reprocessing: ~0.5% (LWR) / ~0.8% (FR)

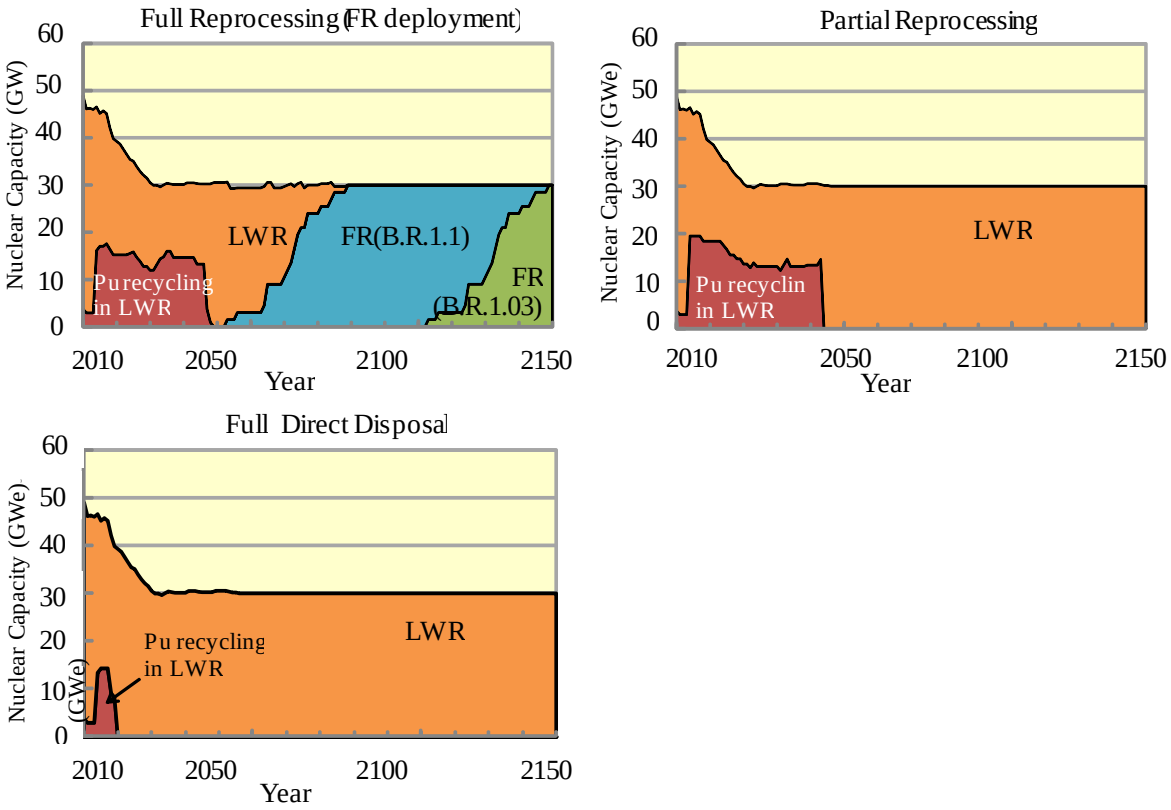


FIG. XI-2. Nuclear capacity for case A1 (30 GW constant).

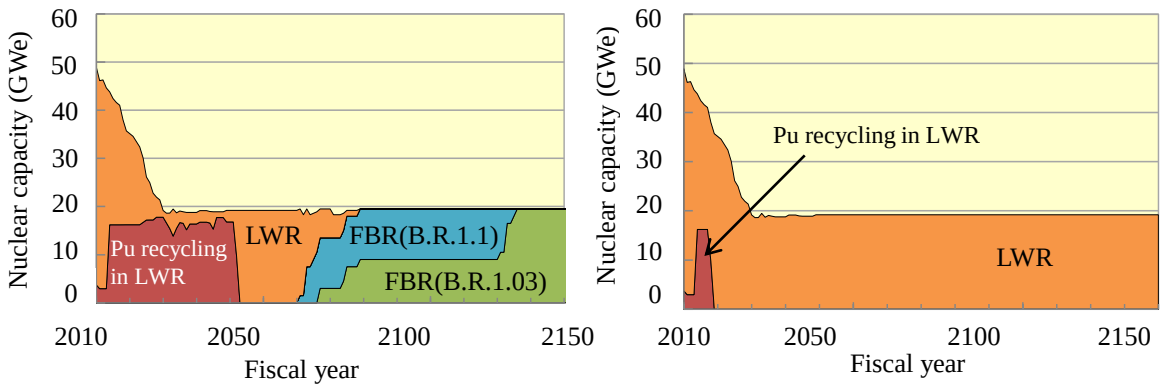


FIG. XI-3. Nuclear capacity for case A2 (20 GW constant).

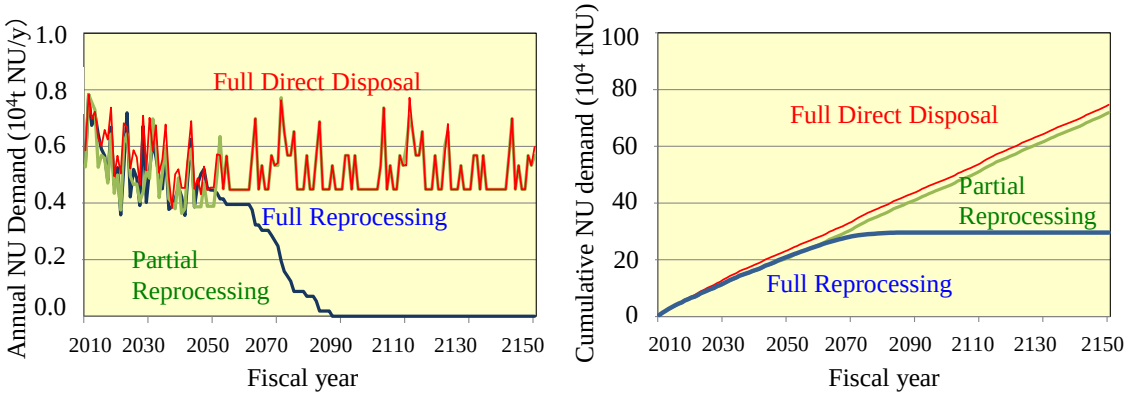


FIG. XI-4. Comparison of annual NU demand (left) and cumulative NU demand (right) for case A1 (30 GW constant).

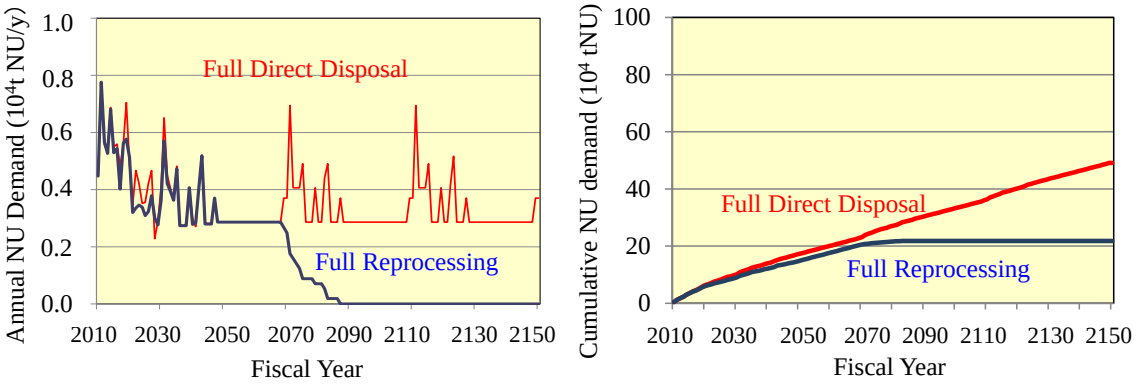
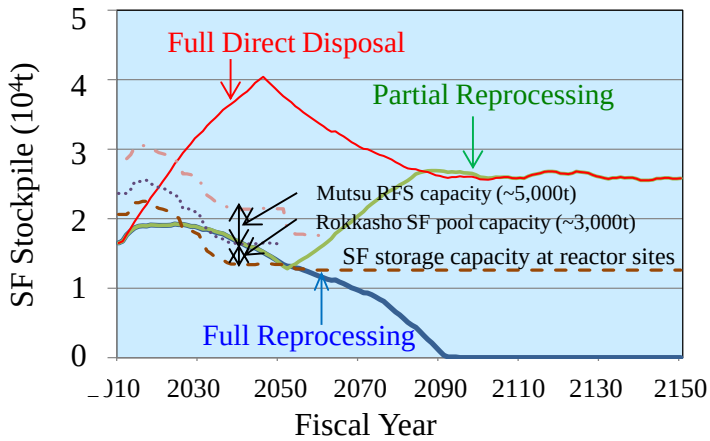
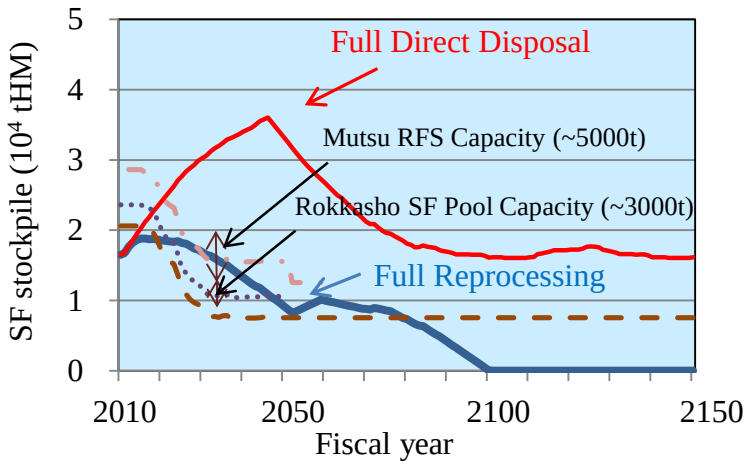


FIG. XI-5. Comparison of annual NU demand (left) and cumulative NU demand (right) for case A2 (20 GW constant).



NOTE: Each SF occupancy of 5 out of 17 reactor sites in Japan exceeds 70% (as of the end of Sep. 2011)

FIG. XI-6. Comparison of SF stockpile for case A1 (30 GW constant).



NOTE: Each SF occupancy of 5 out of 17 reactor sites in Japan exceeds 70% (as of the end of Sep. 2011)

FIG. XI-7. Comparison of SF stockpile for case A2 (20 GW constant).

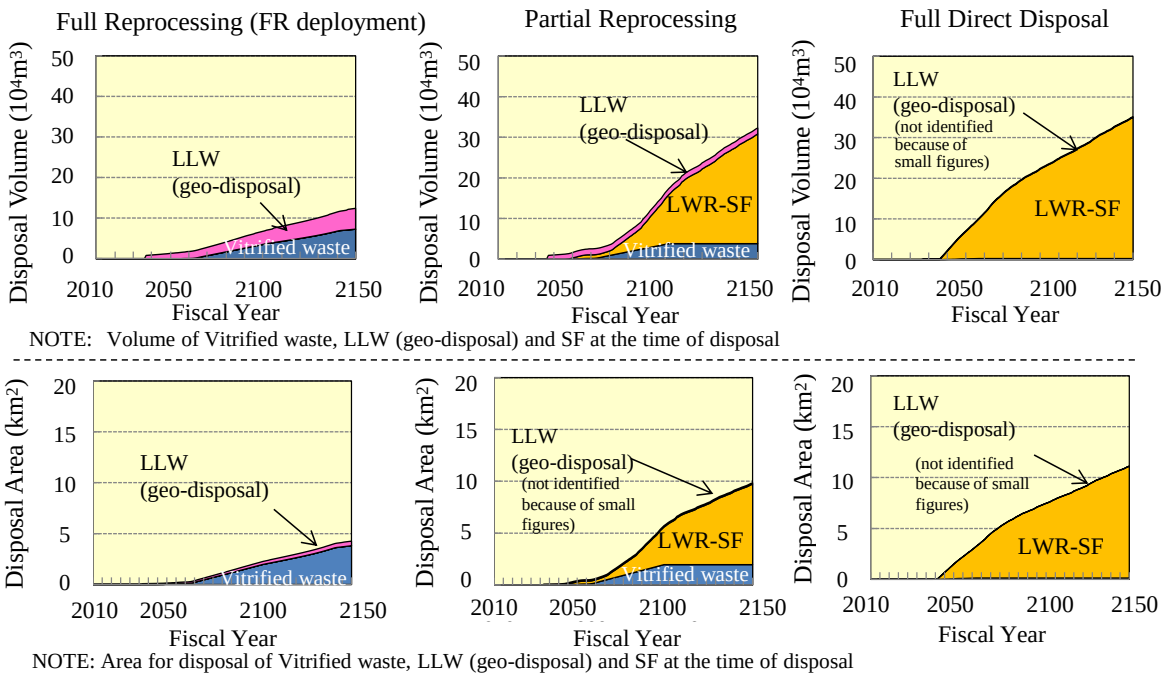


FIG. XI-8. Disposal volume (above) and area (below) of HLW and LLW (geological disposal) for case A1 (30 GW constant).

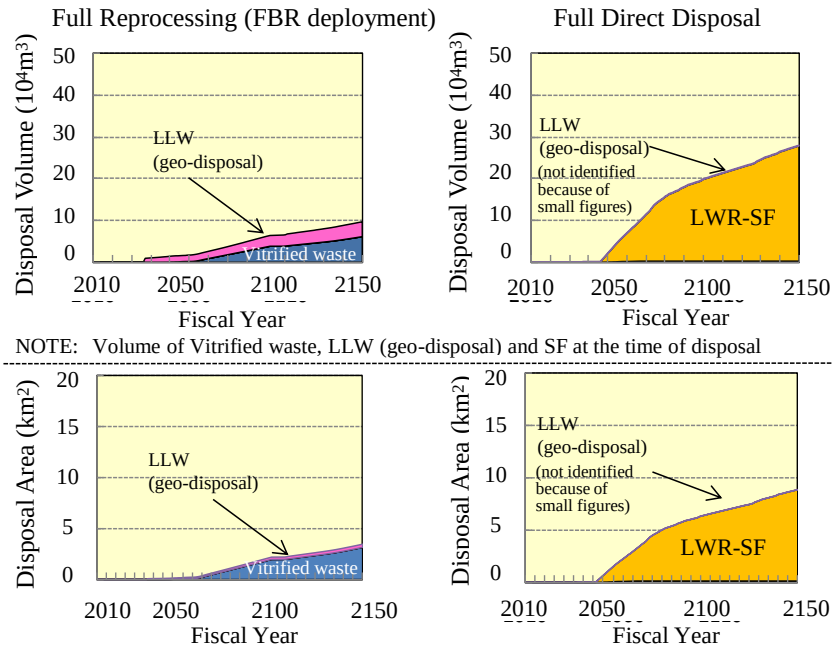


FIG. XI-9. Disposal volume (above) and area (below) of HLW and LLW (geological disposal) for case A2 (20 GW constant).

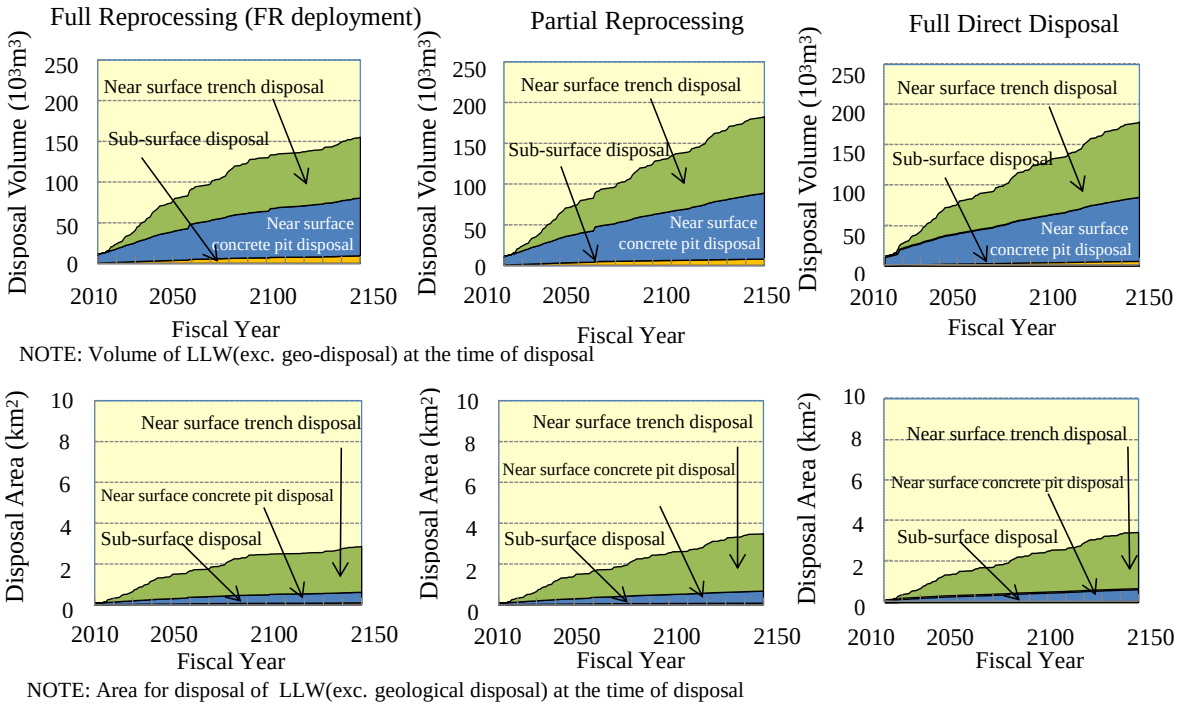


FIG. XI-10. Disposal volume of LLW (other categories) for case A1 (30 GW constant).

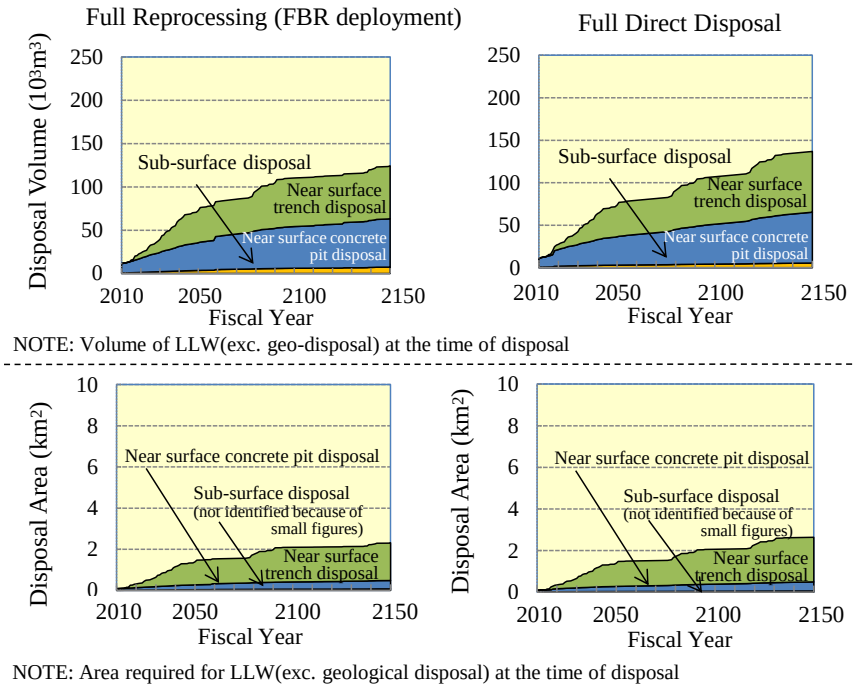


FIG. XI-11. Disposal volume of LLW (other categories) for case A2 (20 GW constant).

MA inventories are shown in Figures XI-12 and XI-13. In the full reprocessing scenario, the MA inventory in the whole fuel cycle was kept low by the Pu and MA recycling in FRs. Before the start of the disposal repository for vitrified waste at 2037, most of MA inventories in ground facilities were included in vitrified wastes generated at Rokkasho Plant where no MAs were recovered, and in SF in interim facilities. After the start of the repository, vitrified wastes were disposed in underground, the SF was decreased with reprocessing for FR deployment started at 2050, and then main inventory sifted to the MA in fuel at reactors. In the case of the partial reprocessing scenario, the total inventory was larger than in the full direct disposal scenario due to the inventory in vitrified wastes generated at the Rokkasho Plant. The MA generated by fission and decay of Pu was increased in disposal facilities in the partial reprocessing scenario and the full direct disposal scenario.

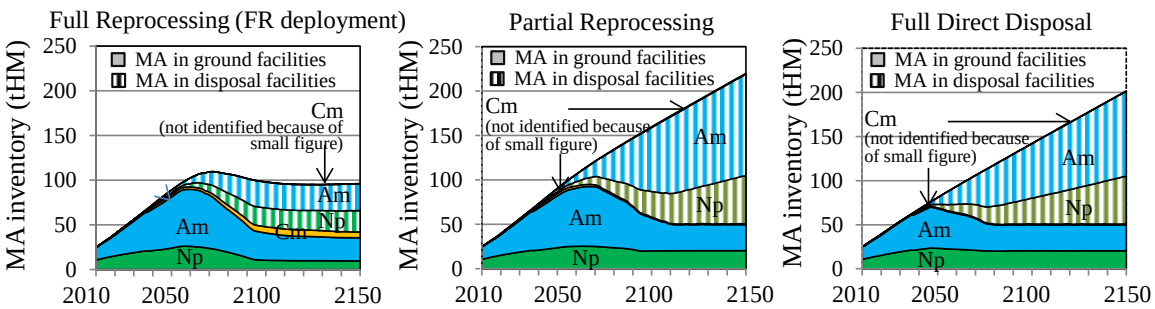


FIG. XI-12. MA inventory in the nuclear fuel cycle of case A1 (30 GW constant).

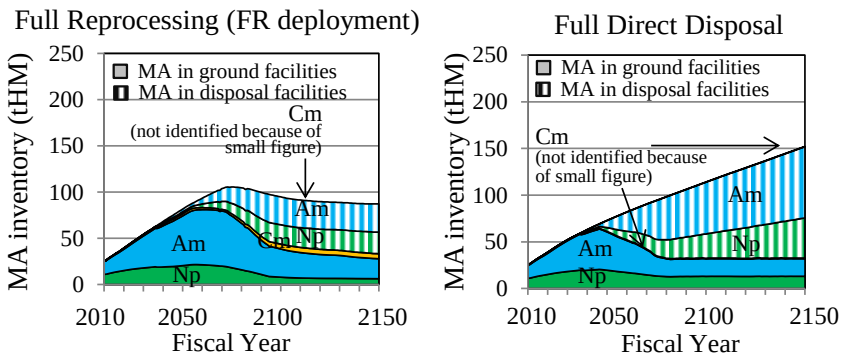


FIG. XI-13. MA inventory in the nuclear fuel cycle of case A2 (20 GW constant).

Figures XI-14 and XI-15 provide the fissile Pu (Puf) stockpiles. Although Puf from reprocessing plants was added to the current Puf stockpile in the case of the full reprocessing scenario and the partial reprocessing scenario, it was reduced by the implementation of Pu recycling in LWRs or LWR/FR deployment. After the FR deployment in the full reprocessing scenario, it was possible to transition to the FR cycle with adequate use in a balance of the inventory and the necessary stockpile as fuels. In the cases of the full direct disposal scenario, it was necessary to secure capacities to fabricate approximately 2.3t of Puf which had already previously been extracted in Japan to MOX fuel due to the expected cancellations of domestic MOX fuel fabrication plant constructions.

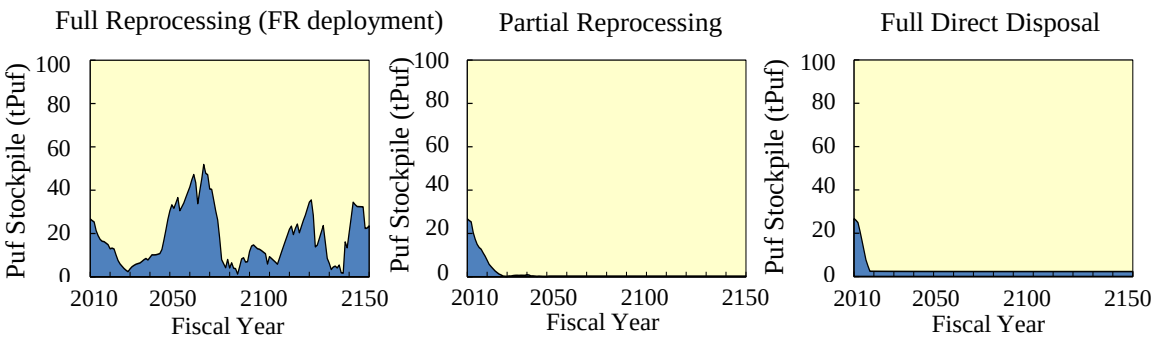


FIG. XI-14. Fissile Pu stockpile of case A1 (30 GW constant).

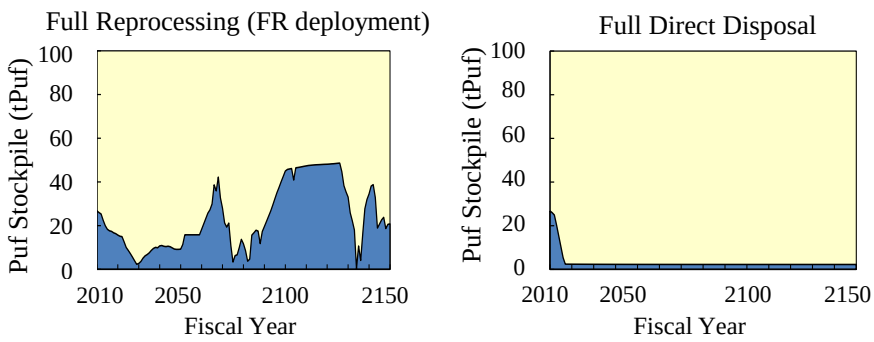


FIG. XI-15. Fissile Pu stockpile of case A2 (20 GW constant).

Pu inventories are shown in Figures XI-16 and XI-17. In Cases A1 and A2 in the full reprocessing scenario the full reprocessing strategy enabled to lower Pu inventory in the

whole fuel cycle by the FR deployment following the implementation of Pu recycling in LWRs. In the partial reprocessing scenario, although the increase of the Pu inventory was kept low by the implementation of Pu recycling in LWRs in the short term, after the closure of the Rokkasho Plant and termination of Pu recycling in LWRs, the amount of Pu in SF was increased similarly to that of direct disposal scenario. On the contrary, in the full direct disposal scenario, large amount of Pu remained in the SF in storage facilities on ground for a cooling process in the short term and in geological repositories in the long term.

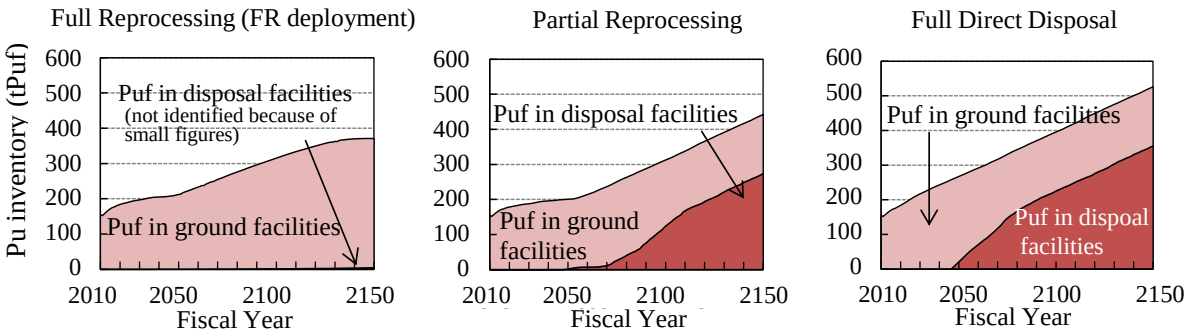


FIG. XI-16. Pu inventory in the nuclear fuel cycle of case A1 (30 GW constant).

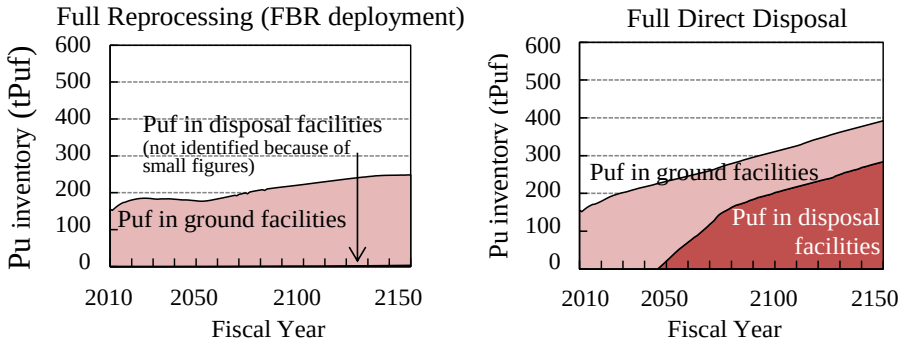


FIG. XI-17. Pu inventory in the nuclear fuel cycle of case A2 (20 GW constant).

XI-2.2.Cases B1 and B2 - gradual decrease after 2030

Nuclear capacity evolution Cases B1 and B2 are shown in Figures XI-18 and XI-19. In the full reprocessing scenario of both cases, Pu recycling in LWRs with up to 17 GW in total was conducted, followed by the deployment of FRs with up to 5 GW in total, which focused on reducing environmental impact through burning of Pu and MA. The capacity and implementation period for Pu recycling in LWRs was less than those in the partial reprocessing scenario due to keeping of Pu needed to the deployment of FRs. In the partial reprocessing scenario, Pu recycling in LWRs with up to 20 GW in total was conducted for about 50 years, using Pu recovered from overseas and the Rokkasho Plant. In the full direct disposal scenario, Pu recycling in LWRs with up to 14 GW in total with B1 (16GW in total with B2) was conducted for around 10 years, using Pu recovered from overseas.

Annual and cumulative natural uranium demands are shown in Figures XI-20 and XI-21. In the full reprocessing scenario, the cumulative natural uranium demand was slightly lower than that of the full direct disposal scenario and the annual natural uranium demand was slightly larger than that in the partial reprocessing scenario because the capacity of LWRs was

larger than the partial reprocessing scenario for Pu recycling with FRs. In the partial reprocessing scenario, the annual natural uranium demand was slightly lower than that of the full direct disposal scenario because Pu recovered from the Rokkasho Plant was recycled in LWRs, resulting in approximately 30,000 t less of the cumulative natural uranium demand in 2150.

Figures XI-22 and XI-23 provide the SF stockpiles. Concerning the full reprocessing scenario, SF stockpile remained at under 20,000 t. However, after 2030 the storage capacity for SF stockpile may become tight considering the operational status of the reprocessing plants and the closure of the Mutsu RFS. In the partial reprocessing scenario, the SF stockpile also remained at under 20,000 t, and new interim storage facilities were required to increase the capacity. In the full direct disposal scenario, SF stockpile reached up to 40,000 t with B1 (35,000 t with B2) before 2050. Additional capacity of up to 20,000 t was required, which will be more challenging in the partial reprocessing scenario. If Mutsu RFS and the pool of Rokkasho Plant are not available, up to 30,000 t (35,000 t with B2) of the capacity will be required.

Radioactive waste volumes and areas for geological disposal and other categories of LLW are shown in Figures XI-24 to XI-27. Regarding the full reprocessing scenario and the partial reprocessing scenario, LLW (geological disposal category) volume increased due to the deployment of reprocessing facilities, whereas the volume and area of total radioactive wastes decreased. The full reprocessing scenario, in particular, the reprocessing of all SF enabled the reduction of the total volume and area of geological disposal radioactive wastes to the half of those of the full direct disposal scenario. On the other hand, other categories of LLW were identified to yield no major difference in the total volume and area compared with those of the full direct disposal scenario although LLW (for the sub-surface disposal, the near surface concrete pit disposal and the near surface trench disposal) from decommissioning of FRs and FR reprocessing facilities was larger. In the partial reprocessing scenario, also no major difference was identified in the total volume and area compared with those of the full direct disposal scenario although they were slightly larger due to LLW (for the sub-surface disposal and the near surface concrete pit disposal) by the operation of the Rokkasho Plant.

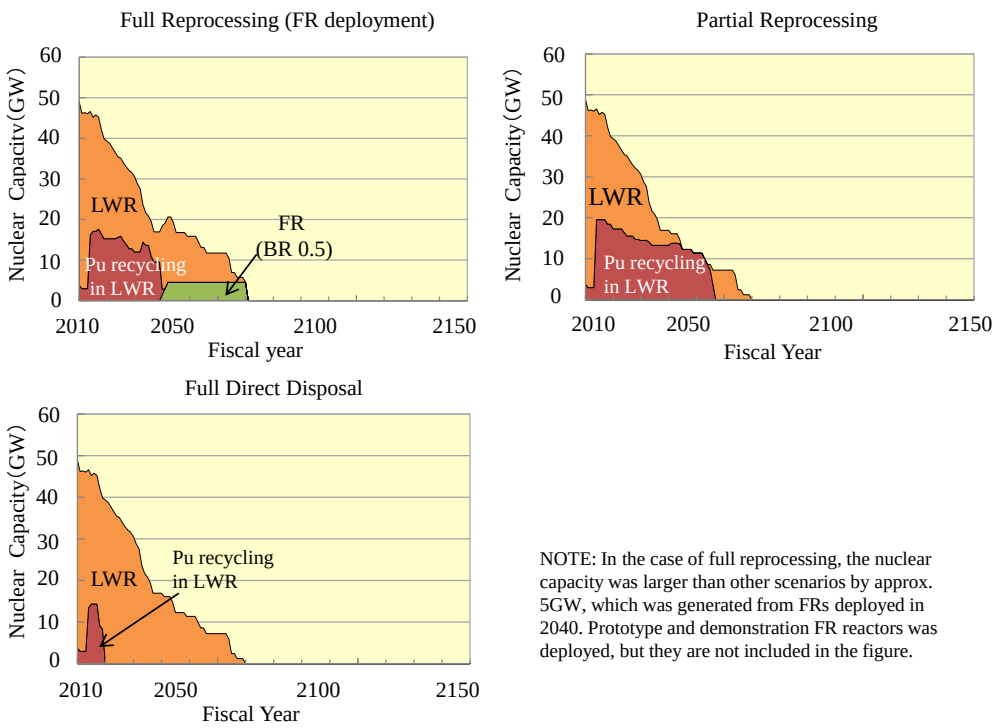
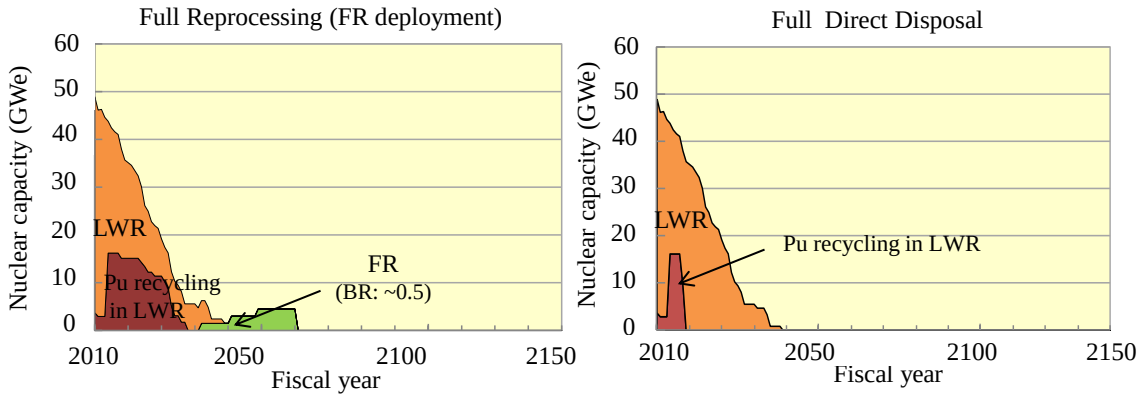


FIG. XI-18. Nuclear capacity for case B1 (gradual decrease from 30 GW).



NOTE: In the case of full reprocessing, the nuclear capacity was deferent with the case of full direct disposal by the deployment of FR in 2040. Prototype and demonstration FR reactors was deployed, but they are not included in the figure.

FIG. XI-19. Nuclear capacity for case B2 (gradual decrease from 20 GW).

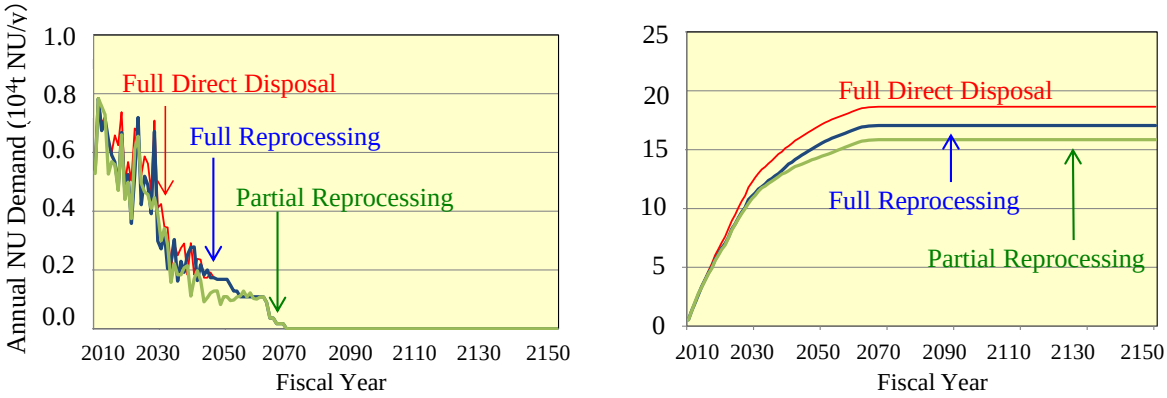


FIG. XI-20. Comparison of annual NU demand (left) and cumulative NU demand (right) for B1 (gradual decrease from 30 GW).

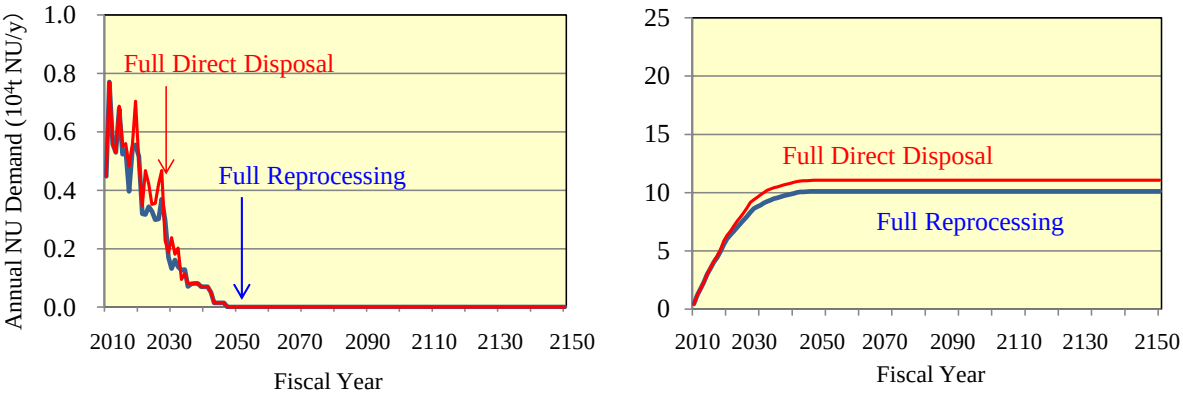
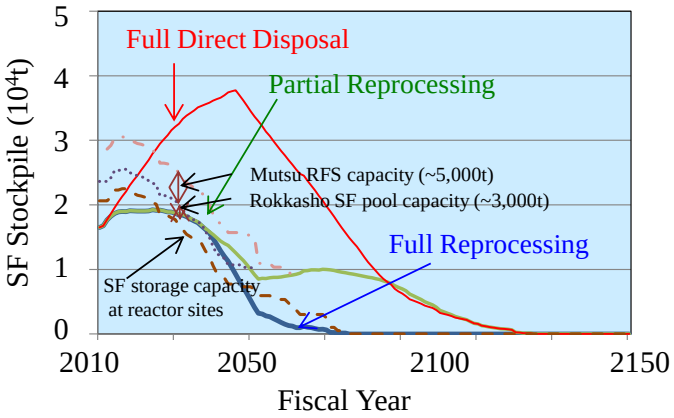
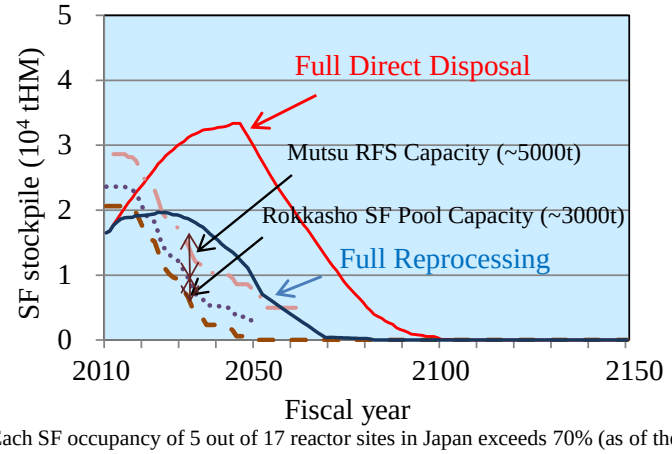


FIG. XI-21. Comparison of annual NU demand (left) and cumulative NU demand (right) for B2 (gradual decrease from 20 GW).



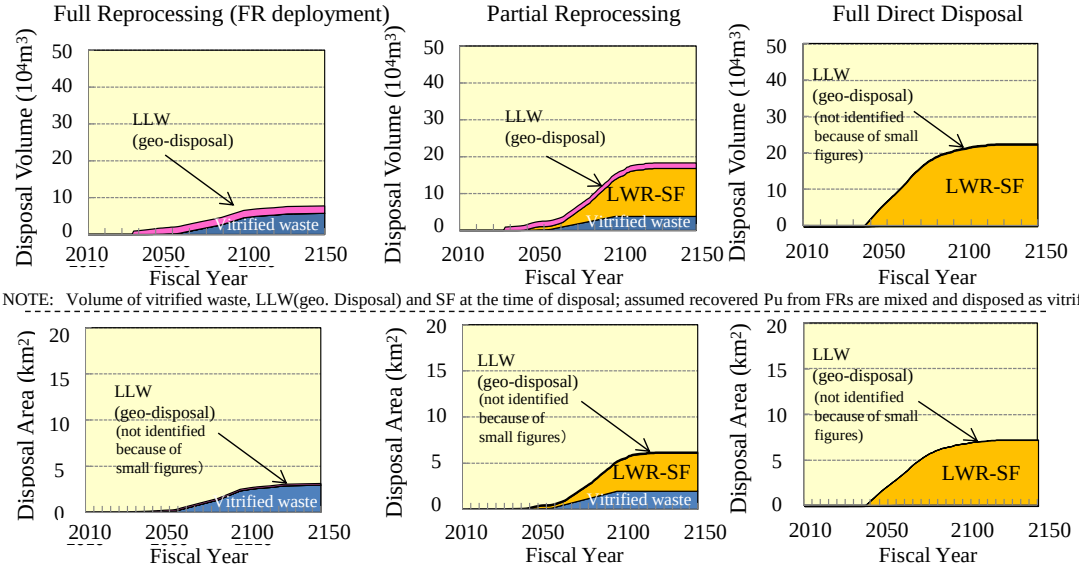
NOTE: Each SF occupancy of 5 out of 17 reactor sites in Japan exceeds 70% (as of the end of Sep. 2011)

FIG. XI-22. Comparison of SF stockpile for case B1 (gradual decrease from 30 GW).



NOTE: Each SF occupancy of 5 out of 17 reactor sites in Japan exceeds 70% (as of the end of Sep. 2011)

FIG. XI-23. Comparison of SF stockpile for case B2 (gradual decrease from 20 GW).



NOTE: Volume of vitrified waste, LLW(geo. Disposal) and SF at the time of disposal; assumed recovered Pu from FRs are mixed and disposed as vitrified waste

NOTE: Area of vitrified waste, LLW(geo. Disposal) and SF at the time of disposal; assumed recovered Pu from FRs are mixed and disposed as vitrified waste

FIG. XI-24. Disposal volume (above) and area (below) of HLW and LLW (geological disposal) for case B1 (gradual decrease from 30 GW).

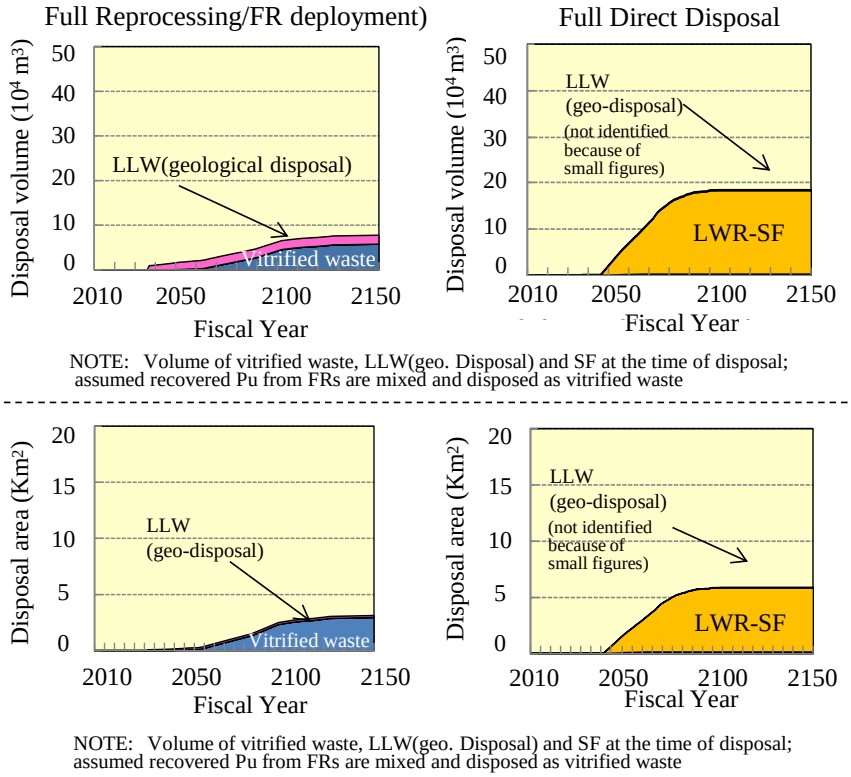


FIG. XI-25. Disposal volume (above) and area (below) of HLW and LLW (geological disposal) for case B2 (gradual decrease from 20 GW).

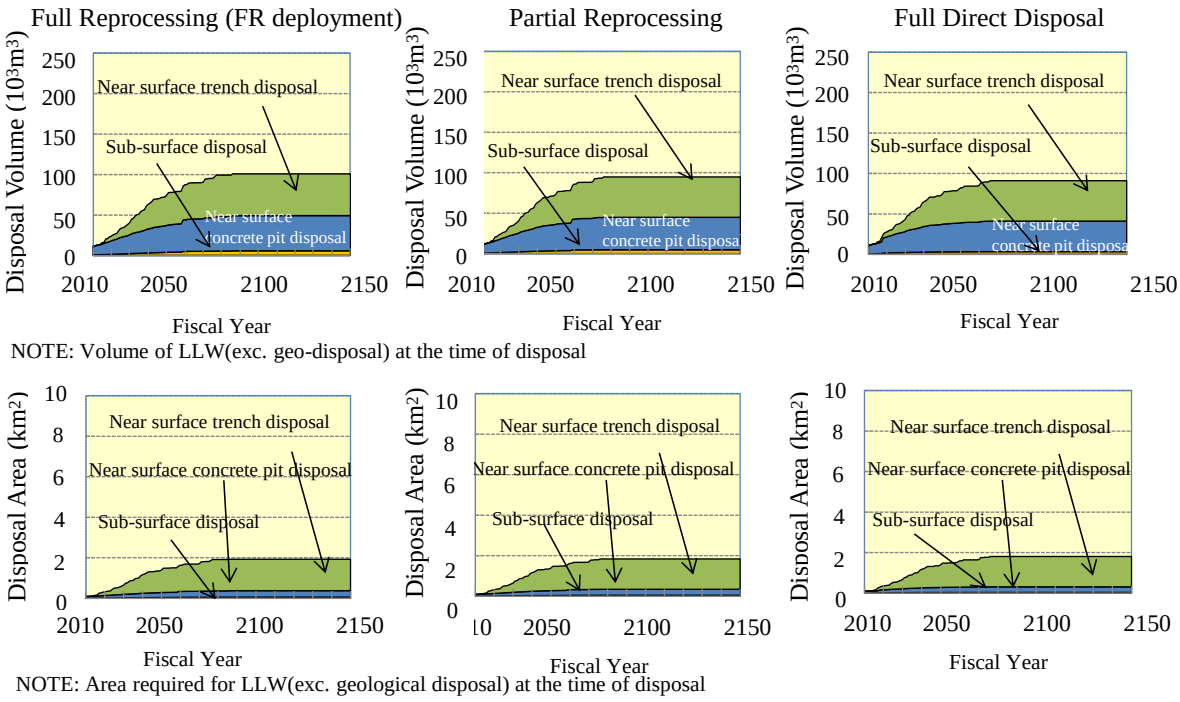


FIG. XI-26. Disposal volume of LLW (other categories) for case B1 (gradual decrease from 30 GW).

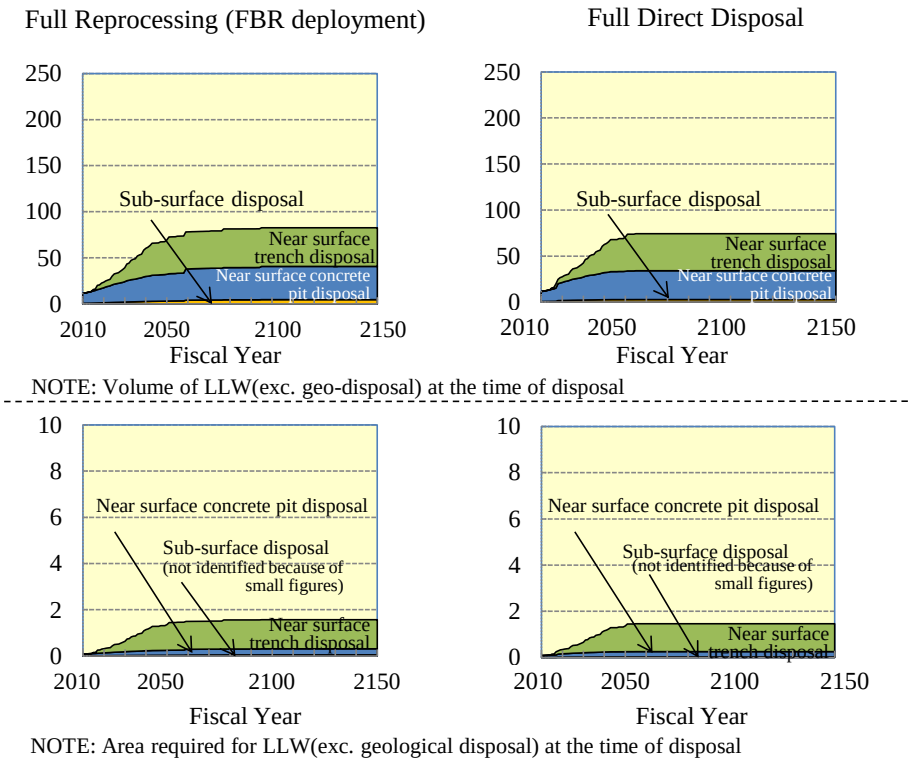


FIG. XI-27. Disposal volume of LLW (other categories) for case B2 (gradual decrease from 20 GW).

MA inventories are shown in Figures XI-28 and XI-29. No major differences were identified in the total inventory between three scenarios although the inventory of the partial reprocessing scenario was slightly larger than in other scenarios by the MA included in vitrified wastes generated at the Rokkasho Plant. The MA in ground facilities of the full reprocessing scenario remained until around 2140, and increased in disposal facility in the reprocessing scenario due to vitrified wastes generated at FR reprocessing plant with no TRU recovered, although the deployment of fast burner reactors (C.R. ~ 0.5) decreased the total Pu inventory.

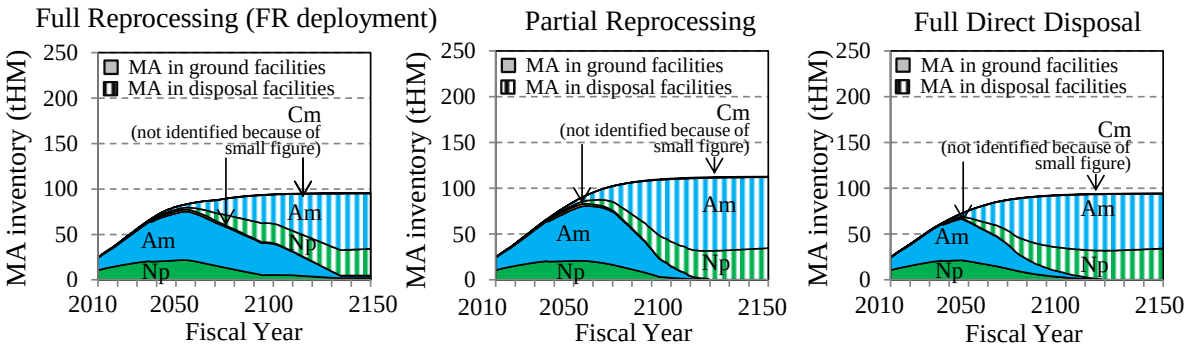


FIG. XI-28. MA inventory in the nuclear fuel cycle of case B1 (gradual decrease from 30 GW).

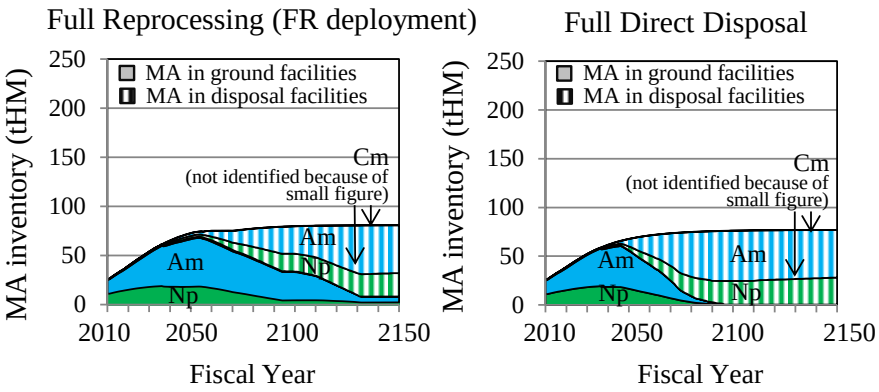


FIG. XI-29. MA inventory in the nuclear fuel cycle for case B2 (gradual decrease from 20 GW).

Figures XI-30 and XI-31 provide the Puf stockpiles. Although Puf from reprocessing plants was added to the current Puf stockpile in the full reprocessing scenario and the partial reprocessing scenario, it was reduced by the implementation of Pu recycling in LWRs or LWR/FR deployment. After the FR deployment, it was possible to finally decrease the Pu stockpile with adequate use in a balance of the inventory and the necessary stockpile as fuels. In the full direct disposal scenario, it is necessary to secure capacities to fabricate approximately 2.3t of Pu fissile which had previously been extractedin Japan to MOX fuel due to the expected cancellations of domestic MOX fuel fabrication plant constructions.

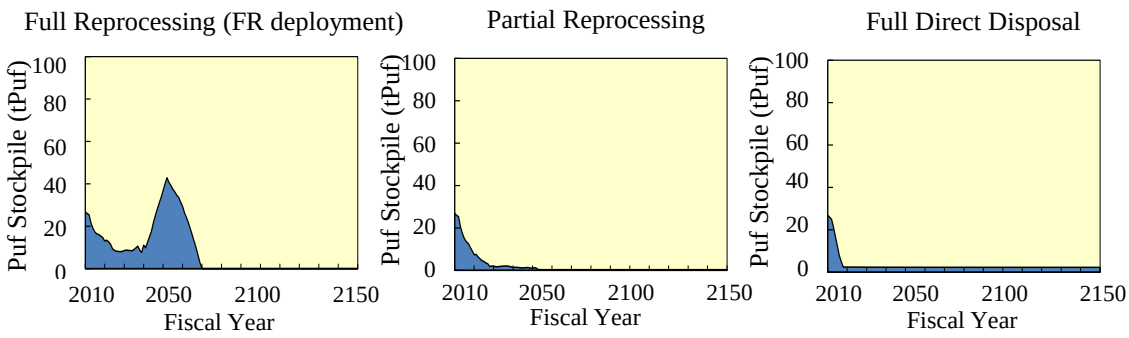


FIG. XI-30. Fissile Pu stockpile for case B1 (gradual decrease from 30 GW).

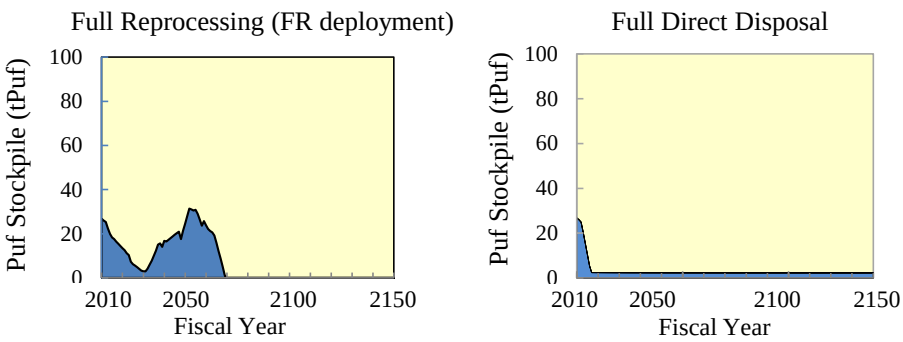


FIG. XI-31. Fissile Pu stockpile for case B2 (gradual decrease from 20 GW).

Pu inventories are shown in Figures XI-32 and XI-33. The Pu inventory in the entire FR cycle in the full reprocessing scenario was reduced to around half of that of the full direct disposal scenario by the implementation of Pu recycling in LWRs followed by the FR (C.R. ~ 0.5) deployment with up to 5 GW in total. The Pu inventory in the entire FR cycle in the partial reprocessing scenario was also reduced by the implementation of Pu recycling in

LWRs with up to 20 GW in total, but after the closure of the Rokkasho Plant and the termination of Pu recycling in LWRs, Pu remained in SF similarly to that in the full direct disposal scenario. In the full direct disposal scenario, Pu inventory in SF increased during the period of LWR operation. Large amounts of Pu remained in SF in storage facilities on the ground in a cooling process in the short term and in SF disposed in geological repositories in the long term.

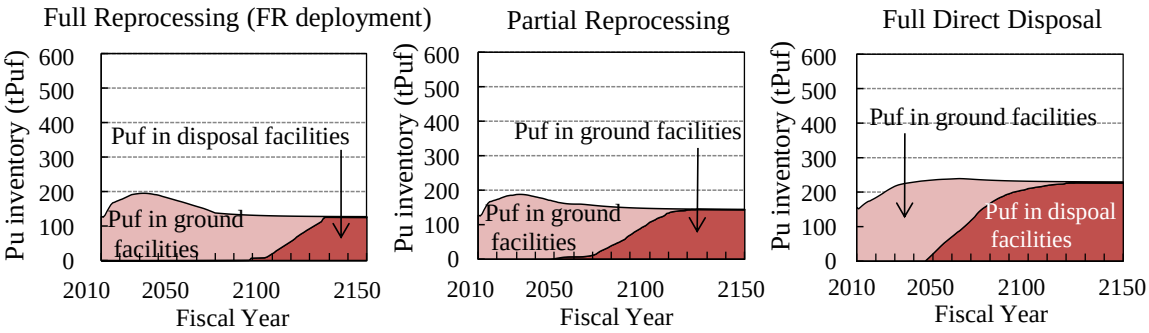


FIG. XI-32. Pu inventory in the nuclear fuel cycle for case B1 (gradual decrease from 30 GW).

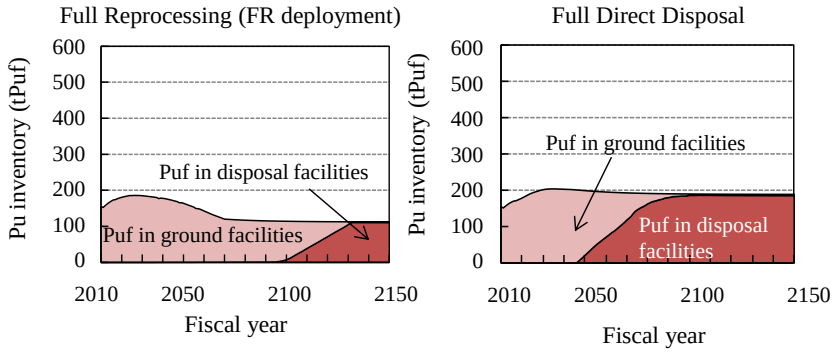


FIG. XI-33. Pu inventory in the nuclear fuel cycle for case B2 (gradual decrease from 20 GW).

XI-3. SUMMARY

This evaluation was conducted in order to investigate several key indicators such as nuclear capacity, natural uranium demand, Pu stockpile and inventory, SF stockpile, radioactive waste generation and disposal based on the long-term use of nuclear energy and the transition from light water reactors (LWRs) to Fast Reactors (FRs) with reprocessing of SF in Japan.

As results, it was indicated that the full reprocessing strategy has a potential to reduce natural uranium demand, SF stockpile, radioactive waste and Pu inventory compared with the partial reprocessing and direct disposal strategy in the both constant and gradual decrease after 2030 cases. Especially in the case of the constant after 2030, the effects for reduction of them were significant. In light of international long-term prospects, the full reprocessing strategy would be possible to reduce radioactive waste and Pu inventory in the world through international cooperation. The summaries of the results are as follows.

(1) Nuclear capacity

– In the constant after 2030 case with A1 and A2, after maximum 18 GW of Pu recycling in LWRs, all LWRs were replaced with FRs in about 35 years after

2053 (20 years after 2070 with A2) considering the timing of the decommissioning of LWRs. On the other hand, in the partial reprocessing scenario, Pu recycling in LWRs with up to 20 GW was conducted for 40 years. In the direct disposal scenario, Pu recycling in LWRs with up to 14 GW (16 GW with A2) in total was conducted for 10 years.

- In the gradual decrease after 2030 case with B1 and B2, after maximum 17 GW of Pu recycling in LWRs, FRs with up to 5 GW in total were deployed focusing on reducing environmental impact though burning of Pu and MA. In the partial reprocessing scenario, Pu recycling in LWRs with up to 20 GW in total was conducted for about 50 years. In the full direct disposal scenario, Pu recycling in LWRs with up to 14 GW (16 GW with B2) in total was conducted for about 10 years.

(2) Natural uranium demand

- In the constant after 2030 case with A1 and A2, the natural uranium consumption was reduced by full reprocessing and about half of cumulative consumption of natural uranium decreased compared with that in the full direct disposal in 2150. Moreover, FR deployment enabled nuclear power generation without imported uranium resources after around 2090. In the partial reprocessing scenario, although the natural uranium demand was slightly reduced by implementing Pu recycling in LWRs, it remained in the same level as that of the direct disposal in the long term.
- In the gradual decrease after 2030 case with B1 and B2, the reduction effect of full reprocessing was not significant with full disposal. In the partial reprocessing scenario, the effect was slightly larger than the full reprocessing scenario because the capacity of LWRs was smaller.

(3) Pu stockpile and inventory

- In the constant after 2030 case with A1 and A2, the Pu balance was maintained by the implementation of Pu recycling in LWRs followed by the FR deployment in the full reprocessing scenario. It was possible to transition to the FR cycle keeping the Pu balance after the FR deployment. The increase of the Pu inventory in the entire FR fuel cycle was kept low by recycling Pu in SF. In the partial reprocessing scenario, the Pu balance was kept by the implementation of Pu recycling in LWRs before the FR deployment. Pu in SF increased and large amounts of Pu remained in SF in the long term. In the direct disposal scenario, it was necessary to secure capacities to fabricate approximate 2.3 t of Puf which had previously been extracted in Japan to MOX fuel due to the expected cancellations of domestic MOX fuel fabrication plant constructions. Pu in SF increased and large amounts of Pu remained in SF for interim storage facilities and SF for geological disposal.
- In the gradual decrease after 2030 case with B1 and B2, the Pu stockpile was eventually reduced by the implementation of Pu recycling in LWRs and followed by the FR deployment although Pu from reprocessing was added to the current Pu stockpile in the short term. The Pu inventory in the full reprocessing scenario was reduced to around the half of that of the full direct disposal scenario. In the full direct disposal scenario, it was necessary to secure capacities to process approximate 2.3 t of Puf which had previously been extracted in

Japan to MOX fuel due to the expected cancellations of domestic MOX fuel fabrication plant constructions. The Pu inventory remained in SF disposed in geological repositories in the long term.

(4) SF stockpile

- In the constant after 2030 case with A1 and A2, although full reprocessing kept the storage capacity for SF stockpile maximum of approximate 20,000 t and decreased it, it may become tight even after 2030, considering the availability of reprocessing plants and the closure of Mutsu RFS, and would need to be increased. The SF stockpile also stayed at the same level of that of the full reprocessing scenario until around 2060, but then it went up and eventually stayed at approximate 25,000 t. In the partial reprocessing and the direct disposal scenario, the storage capacity would need to be increased by up to 10,000 t to 20,000 t in the future. If the Mutsu RFS and the pool in the Rokkasho Plant are not available, up to 30,000 t of additional capacity will be required in the the direct disposal scenario.
- In the gradual decrease after 2030 case with B1 and B2, although full reprocessing and partial reprocessing kept the storage capacity for SF stockpile maximum of approximate 20,000 t and decreased it, it may become nearly full even after 2030, considering the availability of reprocessing plants and the closure of Mutsu RFS, and would need to be increased. In the direct disposal scenario, the storage capacity would need to be increased by up to 10,000 t to 20,000 t in the future. If the Mutsu RFS and the pool in the Rokkasho Plant are not available, up to 30,000 t to 35,000 t of additional capacity will be required in the direct disposal scenario.

(3) Radioactive waste generation and disposal

- In the constant after 2030 case with A1 and A2, the volume and area of radioactive wastes and MA inventory in the full reprocessing scenario were the smallest and less than half of those in the partial reprocessing scenario and the direct disposal scenario. The total volume and area of other categories of LLW in the full reprocessing scenario were also smallest compared with the partial and full disposal scenarios, although they were slightly larger by the operation of reprocessing facilities.
- In the gradual decrease after 2030 case with B1 and B2, the volume and area of radioactive wastes for geological disposal and MA inventory in the full reprocessing scenario were the smallest and decreased by half of that in the direct disposal scenario. Regarding the total volume and area of other categories of LLW of the full reprocessing scenario and the partial reprocessing scenario, no major differences were identified in the total disposal volume and area compared to that of the full direct disposal scenario although they were slightly larger due to LLW (for sub-surface disposal, near surface concrete pit disposal and near surface trench disposal) from the operation and decommissioning of FRs and reprocessing facilities.

REFERENCES TO ANNEX XI

[XI-1] CABINET OFFICE, Technical Subcommittee on Nuclear Power, Nuclear Fuel Cycle, etc., Exposition for the mass-flow and economical evaluation (2012) (in Japanese).

[XI-2] KIYOSHI ONO, Long-term mass-flow evaluation with the nuclear fuel cycle for the nuclear ratio II (15%), 14th Technical Subcommittee on Nuclear Power, Nuclear Fuel Cycle etc. (2012) (in Japanese).

[XI-3] KIYOSHI ONO, ET AL, Japanese Fast Reactor Deployment Scenario Study after the Fukushima Accident, International Conference on Fast Reactors and Related Fuel Cycles: Safe Technologies and Sustainable Scenarios (FR13), organized by IAEA, France, Paris, 4-7 March 2013, paper CN-199-31(2013).