ANNEX XX.

ANALYSIS OF ALWR BASED SCENARIO

XX-1. INTRODUCTION

The analysis method using the heterogeneous world model that considers the synergy among groups with different nuclear energy policies, instead of using the homogeneous world model, is expected to be one of realistic simulations. This Annex provides summary of the heterogeneous world model analysis carried out with the Japanese FAMILY-21 code on the Advanced Light Water Reactor (ALWR) based scenario, one of the themes of Task 2 of the SYNERGIES project (see Sections 2 and 3 of the report).

An analysis was performed for the purpose of checking adaptability of FAMILY-21 to the scenario analysis with the heterogeneous world model. At the same time, impacts on key indicators identified in comparison between the homogeneous world model and the heterogeneous world model were investigated.

XX-2. OBJECTIVE AND PROBLEM FORMULATION

The analysis of the ALWR basic scenario with the Japanese FAMILY-21 code was performed for the purpose of checking the adaptability of the code to a scenario involving the heterogeneous introduction of nuclear energy systems on a global scale. Furthermore, key indicators, such as LWR-MOX reactor capacity, reprocessing capacity, cumulative natural uranium demand, spent fuel stockpile, and HLW disposal volume were investigated to grasp the disparity and characteristics differentiating between the homogeneous world model and the heterogeneous world model.

Following the approach developed in the GAINS collaborative project [XX-1], within the two global models, homogeneous world model was assumed to be based on a single (common) nuclear power policy. In heterogeneous world model, the non-geographical group of countries 1 (NG1) was assumed to implement plutonium recycling in thermal reactors, under an uncertain nuclear fuel cycle policy in country group NG2, and the use of thermal reactors in a once-through option in the country group NG3 representing newcomer countries.

In a partially synergistic mode [XX-1], the spent fuel of NG2 was assumed to be transported to the NG1, and reprocessing and plutonium recycling were then performed in NG1. In the non-synergistic model, each group NG1, NG2, NG3 were independent and it was assumed that transportation of spent fuel and nuclear fuel materials are not carried out between the groups.

The evaluation was carried out for the nuclear power generation capacity with two growth patterns considered in the GAINS project [XX-1], as shown in Fig. XX-1. In this evaluation, eight cases shown in Table XX-1 were computed using FAMILY-21.

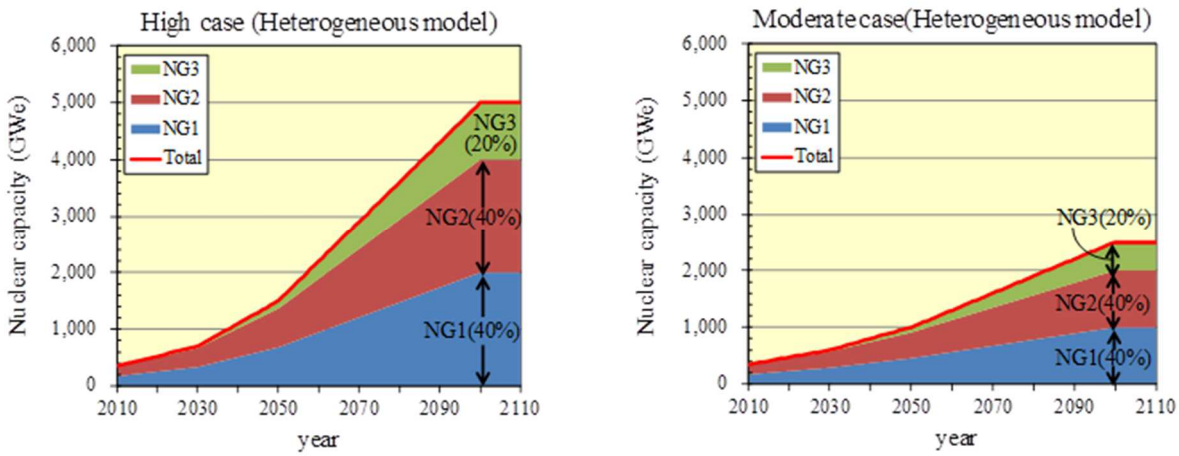

FIG. XX-1. The standard growth curves of nuclear capacity examined in the GAINS project [XX-1].

TABLE XX-1. EVALUATION CASES

Scenario		Recycling of spent fuel			Nuclear capacity	
Model	Option for spent fuel (Mode*)	NG1	NG2	NG3	High	Moderate
Homogeneous	Once through	No			X	X
	Pu mono-recycling	Yes			X	X
Heterogeneous	Pu mono-recycling (Partially**)	Yes	No(*)	No	X	X
	Pu mono-recycling (Non)	Yes	No	No	X	X

* [Mode] Partially: Partially synergistic, Non: Non-synergistic
** The spent fuel of NG2 is reprocessed in NG1, and recovered plutonium is utilized in thermal reactors of NG1.

XX-3. ASSUMPTIONS, METHODS, CODES AND INPUT DATA USED

The main assumptions for the ALWR scenario analysis are listed in Table XX-2; they were set based on public documents and a study of Technical Sub Committee established by the Japan Atomic Energy Commission [XX-2 – XX-6].

The analysis of the ALWR based scenario was conducted through the use of the JAEA's calculation code FAMILY-21, developed to quantitatively assess the adaptability of the reactor system and its fuel cycle to future uncertain nuclear needs. This code has two advantages: its usability and the function to calculate the change of the isotopic composition of the nuclear fuel material by the code itself. In addition, FAMILY-21 has experience in benchmarking other scenario analysis codes [XX-7 and XX-8].

TABLE XX-2 MAJOR ASSUMPTIONS

	Item	Condition	Ref.
Reactor	Average discharge burn-up	PWR:49GWday/t, APWR:60GWday/t, HWR:7.0 GWday/t	[XX-2, XX-3]
	MOX use in LWRs	1/3 MOX fuel assemblies	[XX-2]
	Effective full power days	PWR: 1300, APWR: 1592, HWR: 292	[XX-2, XX-3]
	Lifetime/Load factor	60 years/ 85%	[XX-3]
Conversion/Enrichment	Lead time/Loss rate	1 year/ 1%	[XX-4, XX-5]
	Tails assay	0.2%	[XX-3]
Fuel fabrication	Lead time/Loss rate	1 year/ 1%	[XX-4, XX-5]
Reprocessing	Cooling time/Loss rate	5 years (minimum), U/Pu:2%	[XX-3]
	Treatment of recovered materials	Without reuse of recovered uranium and MA	[XX-3]
Waste storage	Intermediate storage period	50 years	[XX-2]
Geological repository	Disposal volume per fuel mass	4.52 m^3/package (Canister for spent fuel) 0.91m^3/package (Over pack for vitrified waste) (Upright position hard rock)	[XX-3]
	Deployment year	2025(Canister), 2047(Vitrified waste)	[XX-2]
Initial inventory in 2010	Spent fuel	Approx. 250 000 tHM (incl. approx. 500 tU HWR spent fuel)	[XX-4, XX-5]
	Plutonium	Approx. 256 tHM	[XX-6]
	Vitrified waste	Approx. 560 000 packages	[XX-3]

XX-4. SUMMARY PRESENTATION AND ANALYSIS OF THE RESULTS

In this sub-section summary of the results and their analysis are shown with respect to calculation results for three groups of countries – NG1, NG2 and NG3 – in the heterogeneous world model.

ALWR-MOX installation capacities of each case are shown in Fig. XX-2. In the homogeneous model, the ALWR-MOX share was about 37-38% of the world's total installed capacity, and it was approximately equal to the nuclear capacity of NG1. In the heterogeneous partially synergistic mode, the ALWR-MOX share was about 24-25% of the world's total installed capacity, and it was approximately equal to about 61-63% of the nuclear capacity of NG1. Likewise, in the heterogeneous non-synergistic mode, the ALWR-MOX share was about 15-16% of the world's total installed capacity, and it was approximately equal to about 38-40% of the nuclear capacity of NG1.

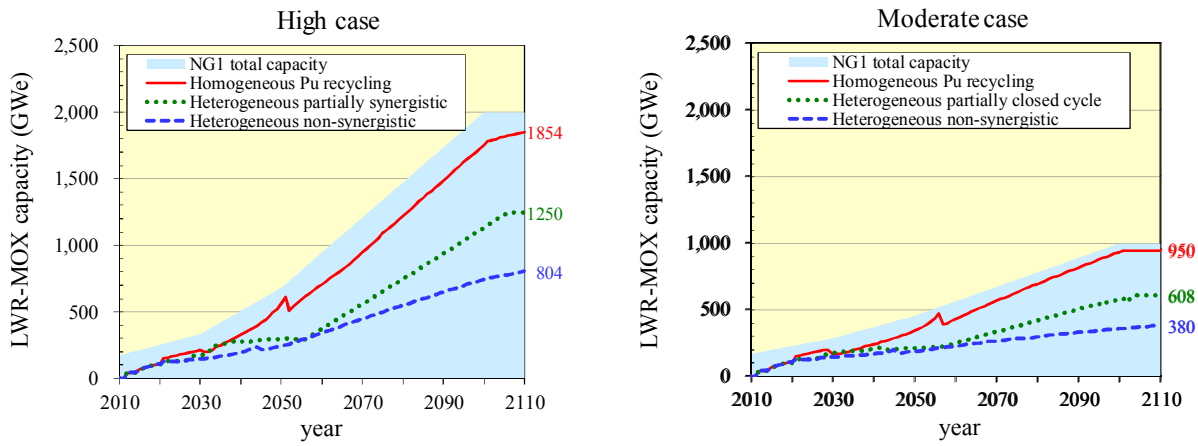

FIG. XX-2. ALWR-MOX installed capacity.

Reprocessing capacities for each case are shown in Fig. XX-3. In the nuclear-capacity high case in year 2110, reprocessing capacity was about 63 thousand ton/year with homogeneous model, about 42 thousand ton/year with heterogeneous partially synergistic mode, and about 27 thousand ton/year with heterogeneous non-synergistic mode. In the moderate case, the reprocessing capacities in 2110 were half of those of the high case. The reprocessing capacity of the homogeneous model became about 32 thousand ton/year; in heterogeneous partially synergistic mode it was about 20 thousand ton/year, and about 13 thousand ton/year in the heterogeneous non-synergistic mode.

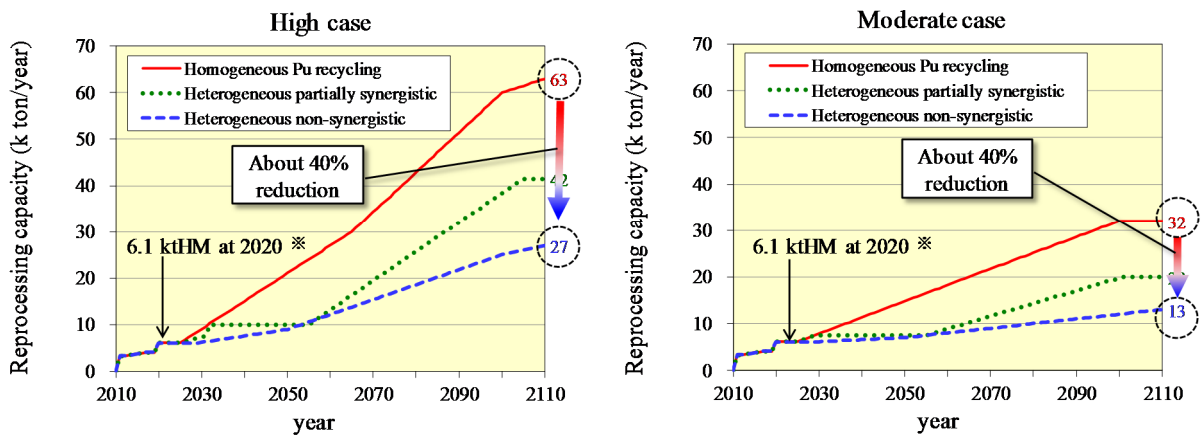

FIG. XX-3. Reprocessing capacity.

The capacity by 2020 is based on plants in operation and in the planning phase in each country (6100 tHM: THORP, UP-2, UP-3, RT-1, and the future plans of Russian Federation, China and Japan). The capacity after 2020 increases roughly in proportion to new fuel demand.

The natural uranium demand for each case is shown in Fig. XX-4. In the homogeneous model, about 10% of natural uranium demand with both high case and moderate case in 2110 were saved by introducing ALWR-MOX. Meanwhile, the natural uranium demand in the heterogeneous model increased slightly compared to that of the homogeneous model because of the decrease of the ALWR-MOX share. In the ALWR based scenario, the saving quantity of the natural uranium was proportional to the ALWR-MOX share.

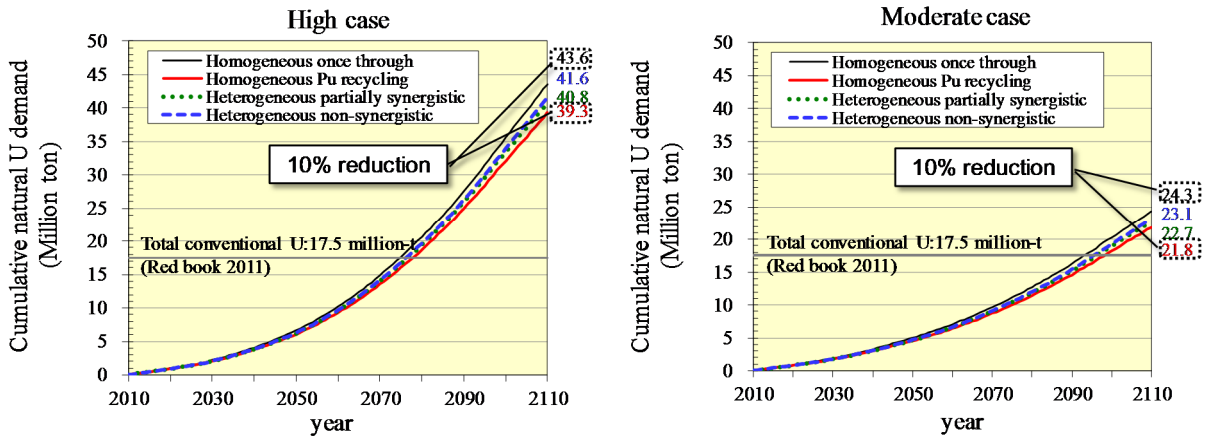

FIG. XX-4. Cumulative natural uranium demand.

Spent fuel stockpiles of each case are shown in Fig. XX-5. In the homogeneous model, the spent fuel stockpiles of the plutonium mono-recycling case were about half in comparison with the once-through case in 2110, owing to the introduction of the reprocessing. The spent fuel stockpiles of the heterogeneous model in 2110 increased by about half compared to those of the homogeneous model because of the decrease of reprocessing capacity. The spent fuel transported to the disposal site was excluded from these calculation results.

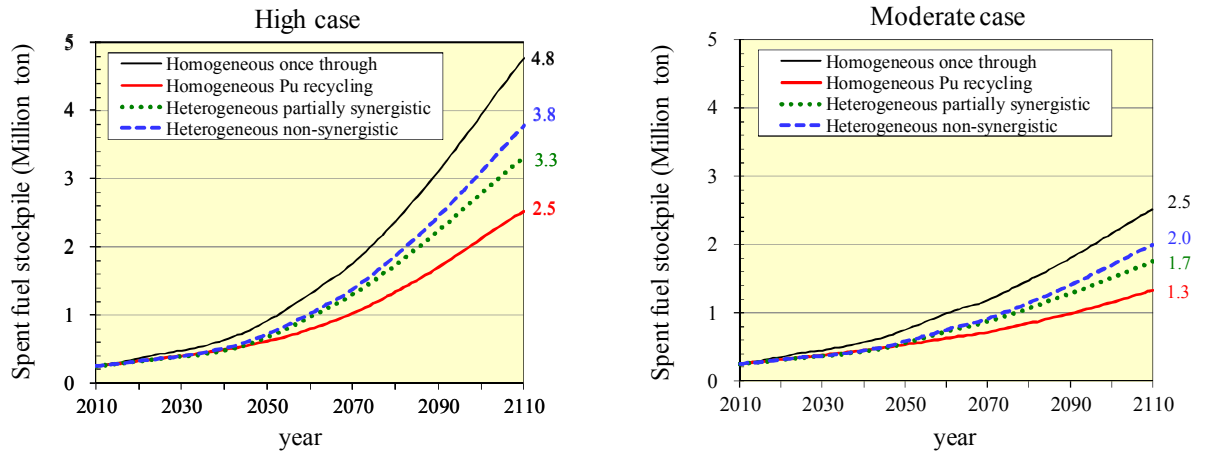

FIG. XX-5. Spent fuel stockpile.

High level waste (HLW) disposal volumes for each case are shown in Fig. XX-6. In the homogeneous model, HLW volume is reduced by plutonium mono-recycling for the introduction of ALWR-MOX reactors, because in this case HLW was assumed to be processed into vitrified glass, which is more compact than spent fuel. The reduction of HLW volume with the heterogeneous model is about half of the homogeneous model, owing to the decrease in the reprocessing capacity. A longer evaluation period is needed to evaluate effects on HLW volume because the effect caused by capacities of reactors and reprocessing plants is manifested after around 2064 (i.e., a long-term storage period of 50 years is needed before final disposal).

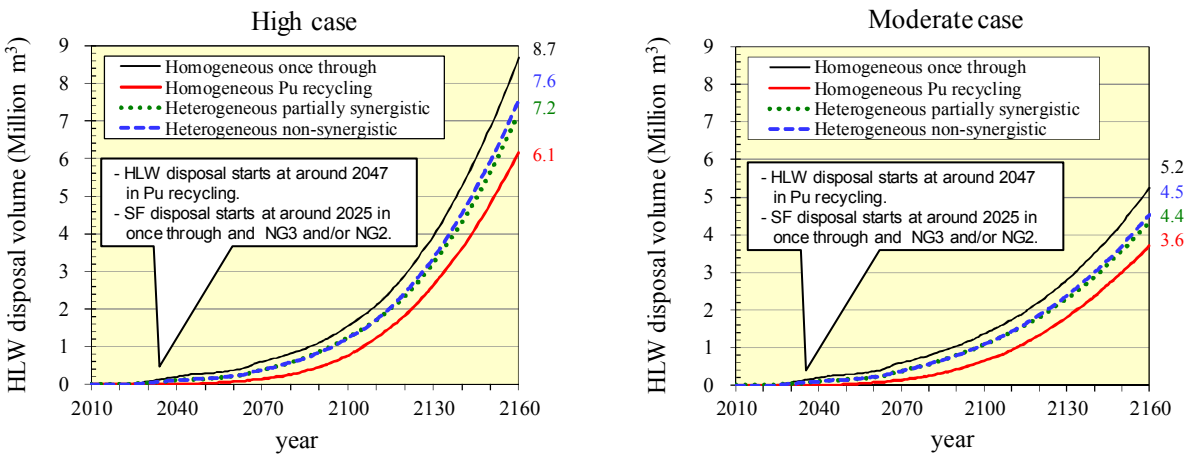

FIG. XX-6. HLW (spent fuel and vitrified waste) disposal volume.

XX-5. CONCLUSIONS

The analysis of the ALWR bases scenario for Task 2 of the SYNERGIES project was conducted using the Japanese calculation code FAMILY-21. This evaluation revealed that in the heterogeneous world model the ALWR-MOX share, the reprocessing capacity, and the HLW volume reduction are about half of those of the homogeneous world model. In other words, the homogeneous world model is suitable for analyzing a high estimate of the impact of an adopted scenario, while the heterogeneous world model is effective for evaluations considering future uncertainty.

REFERENCES TO ANNEX XX

[XX-1] INTERNATIONAL ATOMIC ENERGY AGENCY, Framework for Assessing Dynamic Nuclear Energy Systems for Sustainability, Final Report of the INPRO Collaborative Project on Global Architectures of Innovative Nuclear Energy Systems with Thermal and Fast Reactors and a Closed Nuclear Fuel Cycle (GAINS), IAEA Nuclear Energy Series NP-T-1.14, (2013)

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