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A System Dynamics Study on the Prospect of Japanese Plutonium Balance

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ABSTRACT

The authors conducted a quantitative reevaluation of the short-term Japanese plutonium balance forecast until 2040 with a new numeric model, in the aim of contributing to the policy making toward the stable US-Japan alliance as well as the East Asian region. The Japanese nuclear fuel cycle was replicated as a system dynamics model on Stella with officially available statistical data. The Monte Carlo method was used to estimate the range of the capacities Japanese nuclear power plants until 2040. The simulation results showed the peak accumulation of plutonium in Japan would be observed around 2025. This indicates that while the plutonium

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imbalance in Japan would be a point of concern for the next five years, the situation will likely mitigate. Consequently, even if lowering the capacity of Rokkasho reprocessing plant were to be possible, it would not make a significant difference if it takes more than five years. As a result, the authors conclude that if we were to hurry the resolution of the current Japanese plutonium imbalance issues, the Japanese government has to either consider to limit the restarting of NPPs to newer plants or to cut the operation rate of Rokkasho reprocessing plant from the first year.

1. INTRODUCTION

The concerns regarding the Japanese plutonium balance leapt to public attention in the last few years primarily due to the heightened nuclear security tensions in the region, combined with the expected expiration of the U.S.-Japan Agreement for Cooperation on Peaceful Uses of Nuclear Energy in July 2018. The interests for the Japanese plutonium balance is nothing new; however, the unforeseen 2011 Fukushima accident threw Japanese nuclear policies into the blank state, at the time when the stable US-Japan alliance is most needed to stabilize the regional security. The inability of both US and Japanese governments to act and adopt to the new landscape is what really makes the Japanese plutonium balance issues today concerning.

Scholars have raised concerns on the prospect of plutonium surplus in Japan since 1990s. Berkhout, Suzuki, and Walker (1990) pointed out the possibility of the over-production of plutonium by Japan, presenting a forecast of Japanese plutonium production and consumption until 2010. Although the estimation method is robust and the scenario presumptions are off from the actual situation today, the study successfully illustrated the possibility of the plutonium over-production in Japan. More direct concerns were raised in the late 1990s by Manning (1995), Harrison (1996), and Kitamura (1996) among others, where political arguments were made that the plutonium over-production in Japan may be a proliferation risk in the region, albeit lacking quantitative discussions.

This trend continued in 2000s, where more studies threw concern posed concerns about the Japanese plutonium policy. Turner (2003) reviewed the prospect of MOX (plutonium mixed oxide fuel) operation in Japan, while providing critical views on the policy in terms of safety and economic perspectives. Pickett (2002) pointed out the accident at a fast-breeder reactor Monju in 2015 would pose additional difficulties to Japanese plutonium policy, while acknowledging the Japanese dilemma between the energy independence and the public pressure for safety and security.

Notable recent studies on this matter include those by Acton (2015) and Yamana (2015). These studies follow the trend of the preceding studies in a way; however, at the same time, these studies acknowledge the complex political situation of the Japanese nuclear policy today and the focused the study on more realistic policy proposals based their analyses. The estimation made by Yamana (2015) is a robust analysis, and it provides useful basis for policy making. However, in his estimation, Yamana 1) did not take the full nuclear fuel cycle into consideration and 2) presumed all nuclear power plants to be operated as long as it is younger than the plant's lifetime; in other words, the estimation is too optimistic for the Japanese nuclear fuel cycle. Acton (2015) discussed the political issues surrounding this issue comprehensively while providing a very insightful observations on the MOX operation in Japan. Yet, Action did not choose to go on to provide quantitative considerations about the future prospect of Japanese plutonium balance in his discussions.

Based on the situation, what is most needed now for policy makers than anything is a reasonable and grounded quantitative future prospect for this matter. While many preceding studies provides insightful qualitative discussions and analyses from political perspective, the authors believe it is numeric analyses that would prove truly useful for policy makers today. For this reason, the authors conducted a quantitative reevaluation of the short-term Japanese plutonium balance forecast until 2040 with a new numeric model, taking the discussions by Acton (2014) into the modeling to provide more grounded assumptions, in the aim of contributing to the policy making toward the stable US-Japan alliance as well as the East Asian region.

2. METHOD

The nuclear fuel cycle is a system comprised of stocks and flows, and thus, by nature, it is most suitable to be described as a system dynamics model. Therefore, in this study, the authors constructed a comprehensive nuclear fuel cycle model on Stella based on officially available Japanese statistical data to replicate Japanese nuclear fuel cycle. Modeling assumptions include:

- Total loaded amount (not to be confused with the consumption amount) of nuclear fuel [ton] per rated capacity [GW] and per electricity generation [TWh] was calculated based on the statistical data by Kyushu Electric Power Company (2018) as 79.80 ton/GW-rated power and 9.11 ton/TWh, respectively.

- It was assumed the one-third of the loaded fuel is replaced every 14 months (ATOMICA, 2000). This leads to the nuclear fuel consumption rate of 2.58 ton/TWh, which is consistent with the statistics by FEPC (2010).
- Only the nuclear power plants (NPPs) listed by FEPC (2018) were included in the model: no additional NPP constructions were considered.
- Out of one ton of spent fuel, it was assumed 10 kg of plutonium, 130 kg of uranium fuel, 810 of depleted uranium and 50 kg of HLW will be extracted at Rokkasho (Japan Atomic Energy Commission, 2012).

The constructed Japanese nuclear fuel cycle model is shown in Figure 1.

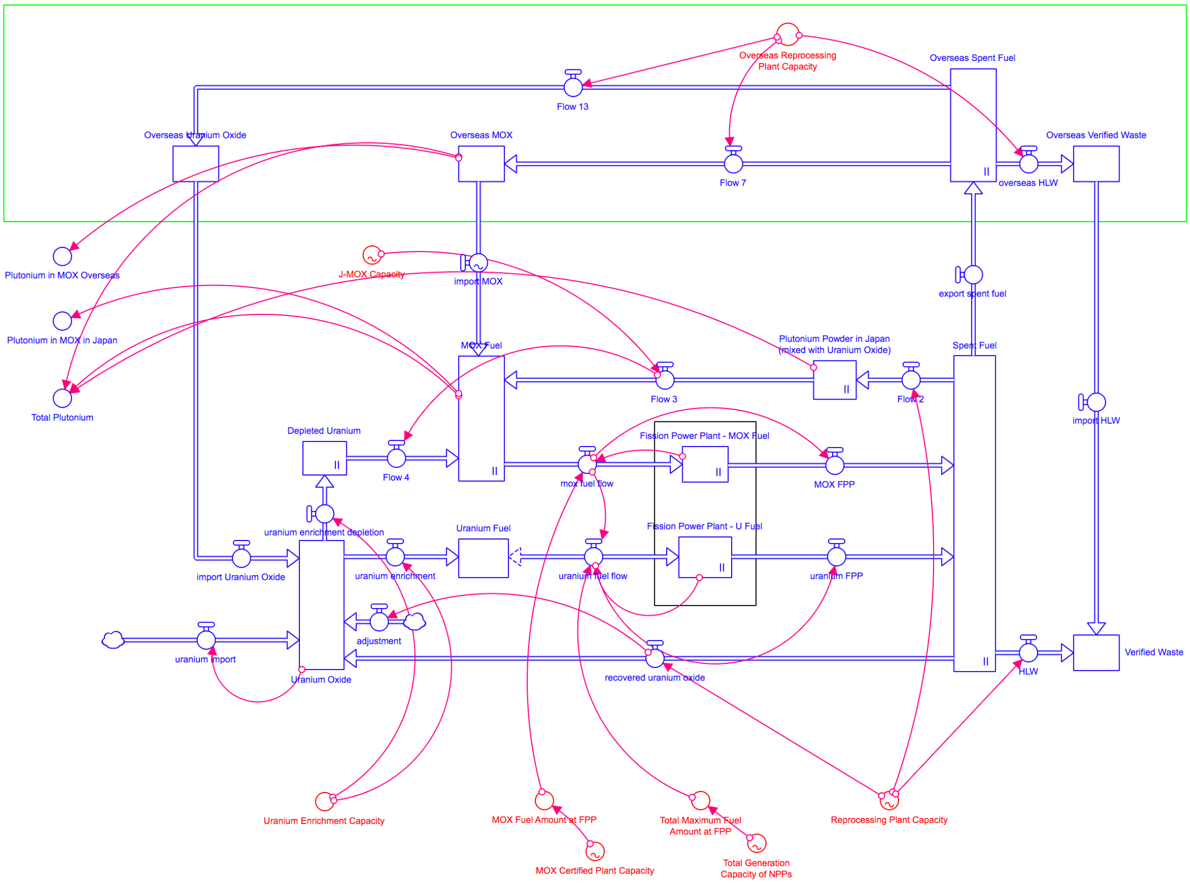


Figure 1 System Dynamics Model of the Japanese Nuclear Fuel Cycle

Here, the authors choose the following four essential capacities to be given externally as scenarios: the capacities of the restarted NPPs, the MOX operation, the Rokkasho reprocessing plant and the J-MOX fuel fabrication plant.

The capacities of NPP and MOX operation: the future prospect of NPPs in Japan is highly uncertain given that the restarting of NPPs is more a political issue than a technical one. For this reason, the authors used the Monte Carlo method to estimate the range of the capacities of NPP and MOX operation until 2040. Based on the statistical data since 2013, when the new safety regulation came into force in Japan, it was calculated that; the chance that a given stopped NPP can apply for the recertification is 12.44% for a given year; the application get through with a probability of 13.55% each year after the application; and that 17.58% of the certified NPP can start operation again for a given year after the certification. Based on these probabilities, the Japanese NPP capacities until 2040 was calculated with Monte Carlo method. In addition, the chances of a NPP to be able to start MOX operation was calculated in a similar manner based on the report by Dr. Acton (2014). Here, the authors utilized the "Prospect" shown on Table 1 of the report, where it was assumed NPP with Prospect = 1 has 14.3% of MOX operation while Prospect = 7 plants have 85.7%.

The capacities of Rokkasho reprocessing plants and J-MOX fuel fabrication plants: while the capacities of these plants are 'entrapped (Acton, 2014)' by the political constrains, changing the operational capacities of these plants is not impossibility granted there will be a strong political will. This point was also brought up in the report by Dr. Acton (2014). For this reason, the capacities of these plants were treated as variables to see the impact of reduced operations of the Rokkasho reprocessing plant.

The full details of the system dynamics model will be published at a later date as a full paper, after the feedbacks and discussions with the professional concerned, including scholars, government officials, power plant operators and local representatives.

3. RESULTS

The estimated capacities of NPPs and MOX operations in Japan until 2040 was obtained as Figure 2. The blue lines are the estimate capacities for NPPs, while the red lines show the MOX operation. The solid line shows the central case (50th percentile), while the dotted line shows more extreme cases.

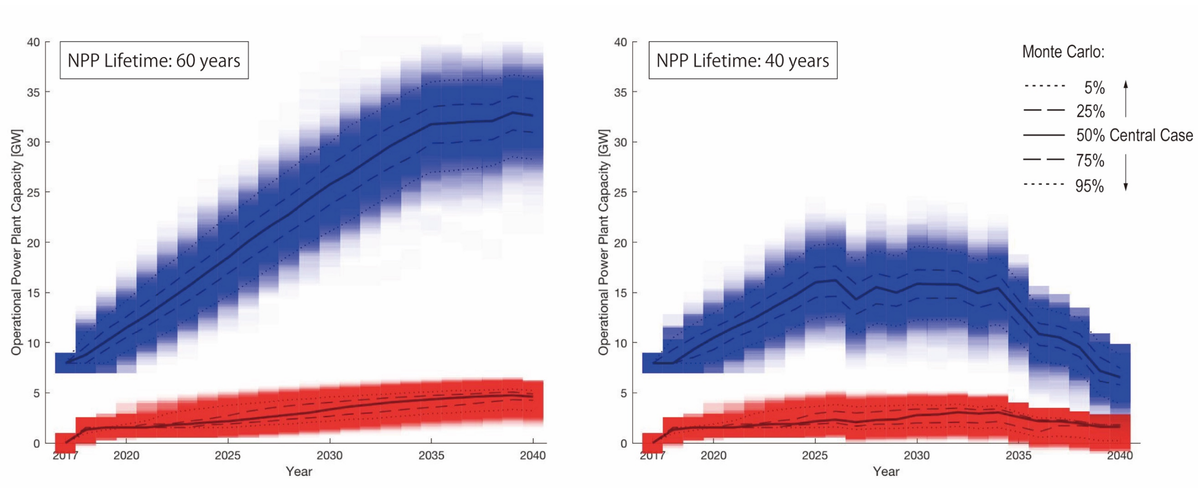
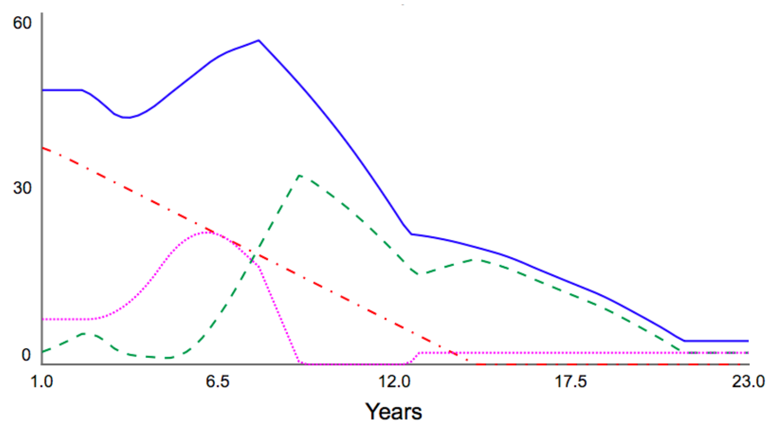
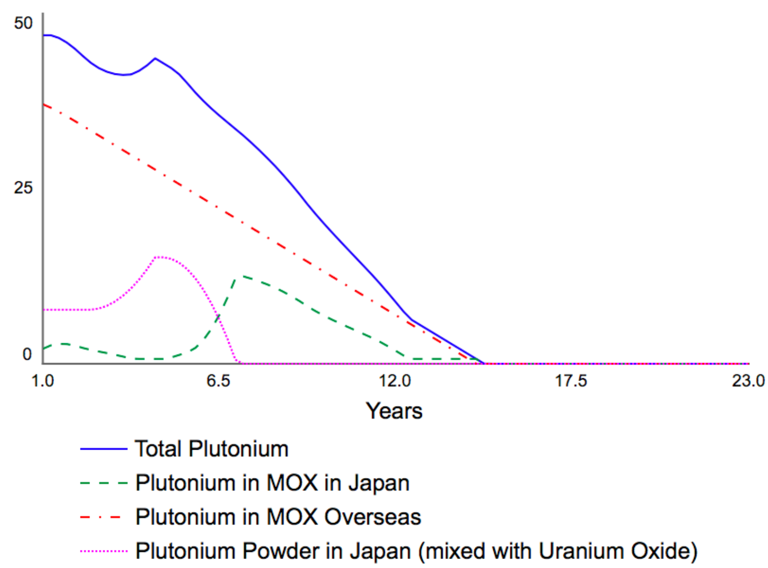


Figure 2 Estimated Capacities of NPP (Blue) and MOX Operation (Red) until 2040

Figure 3 shows the estimated trajectories of the accumulated plutonium amount along with its breakdowns for the central case (50th percentile case) shown in Figure 2, for both cases for the NPP lifetime of (a) 60 years and (b) 40 years.



(a) NPP lifetime = 60 years



(b) NPP lifetime = 40 years

Figure 3 Plutonium Accumulation in Japan (Year 1 corresponds to 2017)

4. DISCUSSION

It is important to note that **when we assumed the NPP lifetime to be 40 years, the observed amount of plutonium accumulation was reduced dramatically** (cf. Figure 3 (b)). It is primarily due to the fact that MOX operations were planned for relatively newer NPPs to begin with; as a result, when the plant lifetime was reduced to 40 years, the production of the plutonium decreased while the ratio of MOX operation increased. This is why, in spite of the fact that the plutonium consumption itself was also decreased for the case (b), the overall plutonium balance improved dramatically. **This is the first study to point this out** since this finding was only made possible by considering the full picture of nuclear fuel cycle comprehensively as a system.

In the case of the (a) NPP lifetime = 60 years scenario, which is the de facto Business-as-Usual case for Japan, **the peak amount of the accumulated plutonium was observed around 2025**. This indicates that while the current plutonium imbalance in Japan is certainly a point of concern for another five years, the situation will likely mitigate, even with the conservative assumptions by the authors.

On the other hand, the fact that the peak amount comes around 2025 indicates the following: even if lowering the capacity of the Rokkasho reprocessing plant were to be possible, **it would not make a significant difference if it takes more than five years to achieve it**. Similarly, 4th generation reactors or fast reactors would also be too late come to mitigate the current imbalance.

Therefore, we conclude this study as follows.

1) The plutonium imbalance in Japan would mitigate after 2025. Therefore, while it is certainly a point of concern for another five years, it may not pose a long-time proliferation threat to the region

2) If we were to hurry the resolution of the current Japanese plutonium imbalance issues, we have to either consider **to limit the restarting of NPPs to newer plants** (cf. lifetime = 40 years case) or **to cut the operation rate of Rokkasho reprocessing plant from the start**. For the former option, there would be adverse effects on the Japanese economy in the form of electricity price rise. As for the latter option, given the strong opposition expected from the local representatives in case of enforcing such policy, it might be desirable to announce a prospect of utilizing Rokkasho reprocessing plant in full in the future after the peak, presumably around 2035, or even a prospect of embracing foreign spent fuel from the region to occupy the surplus capacity.

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