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# 1 Intro/specification

This memo presents the modeling results of cases 1.1 to 1.3 of the EG29 scenario, induced by the use of a plutonium equivalent model for the fuel fabrication. Case 1 of the EG29 calculation involves the modeling of a single MOX-PWR at steady-state (see figure 1).

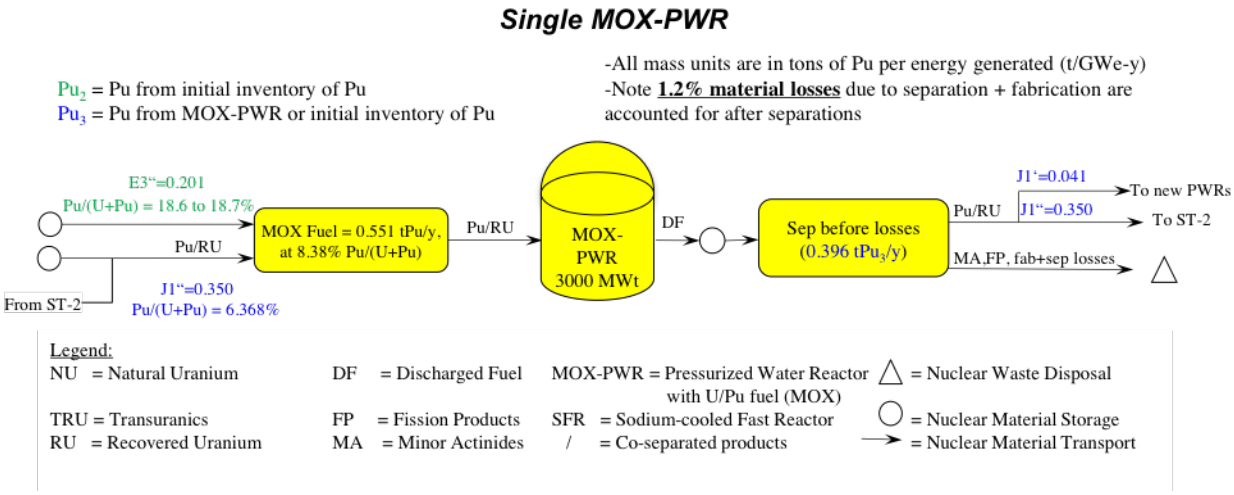


**Figure 1:** Schematic of Pu mass flow for Case 1.x

Case 1 is subdivided into three sub-cases corresponding to calculations of increasing fidelity:

- 1: without isotopic composition,
- 2: with isotopic composition and no decay,
- 3: with isotopic composition and decay.

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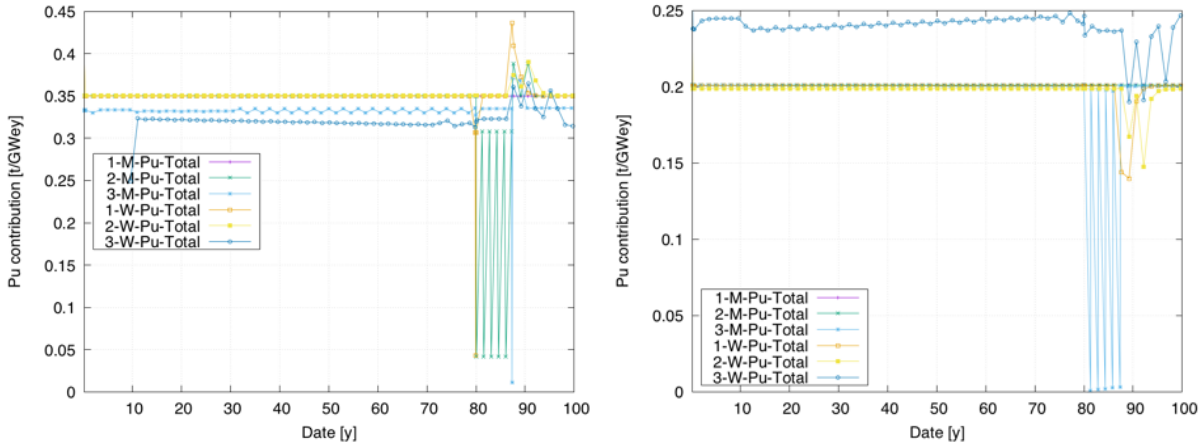
## 2 Fix mixing ratio vs Pu-equivalent theory

The first part of this memo is dedicated to the comparison between fixed ratio mix and pu-equivalent theory for the fuel fabrication process.

Two variations on fuel-building were calculated for each sub-case (1.1 to 1.3). The first calculation used a standard mixing fab (in Cyclus, the "cycamore::mixer"). This mixed the E3 and the J1 streams using a constant mixing ratio to build the MOX fuel for the PWR, labeled M. The second calculation used plutonium equivalent theory to determine the mixing fraction of each stream to build the MOX fuel, labeled W.




(a) J1" stream plutonium flow

(b) E3" stream plutonium flow

**Figure 2:** Evolution of the plutonium content in the J1" and E3" stream

The difference on J1" and E3" between all 6 calculations can be observed on Figure 2. First on should only consider in this study the time between 15 and 75y, as the calculation need almost 12y to rich an equilibrium and the first reactor is replaced at 80y (explaining the different fluctuations observed).

For both stream (J1" and E3"), the 2 cases without decay are similar in the 2 calculation methods (W and M). When decay is taking into account, one can observe a small reduction of the plutonium from J1" stream as well as a small increase of the plutonium from E3" stream directly due to $^{241}$Pu decay: the E3" is not affected much by the decay process as it contains mainly 239Pu, J1" stream contains a higher $^{241}$Pu content very sensitive to decay. The decay tends to decrease the reactivity potential of the J1" stream, which is compensate by the increase of the E3" stream in the mix.

## 3 Model enrichment prediction

The second part of this memo is dedicated to the comparison of the plutonium fraction in the fresh PWR-MOX fuel predicted using different kind of models. The model used can be divided in two categories, the one able to mix any stream to another (fix mixing ratio and pu-equivalent based model) and the one allowing only to mix a plutonium stream into a uranium stream.

For the first kind, the EG29 specification are applied as is (except for the fuel fabrication). For the second kind, the plutonium and uranium from J1" and E3" stream are separated. Then the plutonium from J1" and E3" are mixed according to the ratio provided in EG29 specifications. The model are used to determine

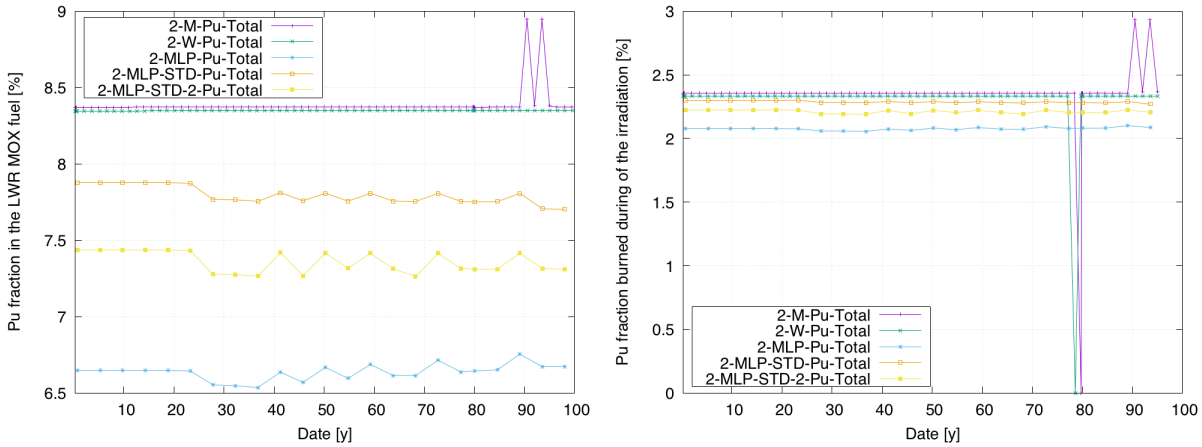
what proportion of this J1" + E3" plutonium stream are require to build the PWR-MOX fuel to achieve the EG29 specifications (LWR, 50GWd/t, 1/3 batching).

The different model used are:

- fix mixing ratio between J1" and E3" stream, (M)
- pu-equivalent based model to mix J1" and E3" stream, (W)
- Neural Network (NN) trained with irradiation stopped at a k of 1.01 (mean k of all batches), 3 batches, (MLP)
- NN with irradiation stopped at a mean a k of 1.034, 3 batches, (MLP-STD)
- NN with irradiation stopped at a mean a k of 1.034, 4 batches. (MLP-STD-2)

Note that, the calculation based on neural network usage have been extended 300y in order to allow the calculation to reach the equilibrium (since the initial composition are close at the fix recipe calculation equilibrium).

## 3.1 No decay




(a) Plutonium fraction in the MOX fuel loaded in PWP.

(b) Plutonium fraction burned furing the irradiation.

**Figure 3:** Evolution of the plutonium loaded in the PWR and burned during the irradiation. Thos calculation are performed without decay management.

On Figure 3(a), one can observe the evolution of the plutonium enrichment loaded in the PWR fuel depending of the model considered for the fabrication. Focusing on case 2, (no decay), we can observe that the Neural network model using a k of 1.01 clearly under estimate the amount of plutonium require comparatively to the other models: the require reactivity is lower. We can as expected observe the effect of the batching (3or 4) on the neural network models using a k of 1.034, which predict an initial enrichment close to the one use on the more standard models: 7.5% versus 7.8%.

Unstead the recipe based calculation, all the calculation involving Neural Network fuel fabrication model, require a dedicated depletion calculation to determine the composition of the fuel after irradiation. On Figure 3(b), the evolution of plutonium fraction burned during the irradiation for the different models. As

expected, all recipe based calculation (fix mixing ratio and Pu-equivalent) have very close results around 2.4%. The only fluctuation here is coming from rounding errors. The Neural network baed calculation reach a burning plutonoium amount between 2 and 2.4%.

For all fabrication model used, the behavior without decay very closed to expected: we observe a small variation of the amount of plutonium: the composition of the plutonium is constant with allow the equilibrium to be maintain.

## 3.2 Decay

When decay is taking into account, all model base on neural network increase the enrichment in plutonium by $2.5-3\%$. This increase is due to 2 main effects: the $^{241}$Pu decay and change in the final isotopic composition of the fuel.

The decay of $^{241}$Pu is causing the degradation of the plutonium quality and to the production of $^{241}$Am (acting as a neutronics poisons), both of those effect tends to increase the amount of plutonium require to build the fuel.

The effect of the presence of the initial inventory which is required to start the calculation, is as limited as possible: all calculation have been tuned to reduce at the minimum the amount of initial storage (which depends on the model used). Moreover, when the decay is activated, the model used to calculate the evolution of the composition predict an higher plutonium content in the MOX fuel after irradiation. As a thermal spectrum is very sensitive to the fuel composition, a higher plutonium content and $^{241}$Am content might change the spectrum enough to slightly change the capture cross section on both 238U and plutonium increasing the breading ratio of the fuel. We can observe also that as the $^{241}$Pu fraction decrease in the used MOX composition, the amount of plutonium in the fresh fuel reaches an equilibrium closer to the initial fix ratio.

Even if the different model predictions fail to agree on a common equilibrium, the point of the study is not determining which calculation is correct or not (both are probably correct), but to highlight the sensitivity of the equilibrium state to the isotopic composition and the modeling choice (particularly on thermal reactor): having too strong constrains on the definition of the fuel cycle might lead us on the wrong path...

In order to highlight this statement 3 addition calculations have been performed using the plutonium equivalent theory. In this calculation the fuel cycle is the same as the one described as Case 1.3, but the initial inventory has been increased by 10 50 and 100%.