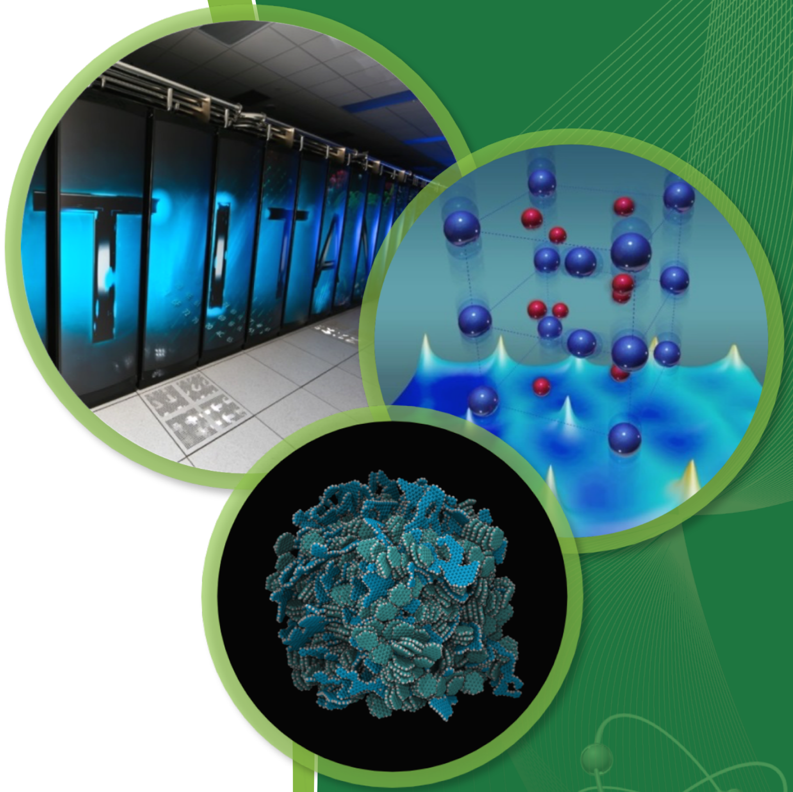
MODELING A FAST MOLTEN SALT REACTOR WITH ORION



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Introduction

- Molten salt reactors (MSRs) are being pursued by private companies as a viable technology that can enable a low-carbon future
- Companies have invested heavily in the design of different MSRs leading to a response from the US Department of Energy (DOE) to provide assistance in research and development
  - Gateway for Accelerated Innovation in Nuclear (GAIN) initiative
  - Established the DOE Office of Nuclear Energy MSR Campaign
- This talk will focus on analyzing a single MSR in ORION to understand the current capability of modeling MSRs with this tool and to identify any deficiencies in modeling MSRs accurately

Modeling MSRs

- An MSR was set up in ORION
- Simulation took advantage of inline ORIGEN depletion capabilities in ORION using an ORIGEN arplib file generated from a reactor physics simulation of a fast MSR
  - Ensures the fission yield and decay data comes from ENDF/B-VII
- Isotopic content of the salt evolves over time
- MSR design analyzed in this work reaches end of life after 20 years of operation and reaches equilibrium on approach to 20 years
- Certain MSR designs never reach equilibrium and continuously evolve over the entire life of the reactor
- Several assumptions had to be made to the input parameters in ORION due to the lack of current capability to account for certain behavior

MSR Reactor Physics Model

- Based on a modified design of molten chloride fast breeder reactor utilizing a uranium/plutonium fuel cycle
- Two-stream system
  - First stream circulates within the core; $PuCl_3$-NaCl fuel salt located at the center of the cylindrical reactor
  - Second stream is UCl_3-NaCl coolant salt located in the annular blanket surrounding the core region
  - The FSMSR analyzed here is a single-fluid design that combines these two salts (similar to expected modern chloride MSR designs)

MSR Reactor Physics Model

- Python script called ChemTriton used to model operation of FSMSR
  - Models salt treatment, separations, discards and fueling using single- or multi-zone unit cell models
  - Iteratively runs SCALE/Triton over small time steps to deplete the fuel salt and collects mass flow information at the end of the simulation
- Simulations for FSMSR used a single representative zone 2D unit cell model
- No structural components were represented in these models to simplify analysis
- Analysis uses 3-day depletion time steps
- Salt treatment and processing cycle times are set to 3 days for all fission products in order to remove them at each time step
- Continuous plutonium removal for the coolant salt

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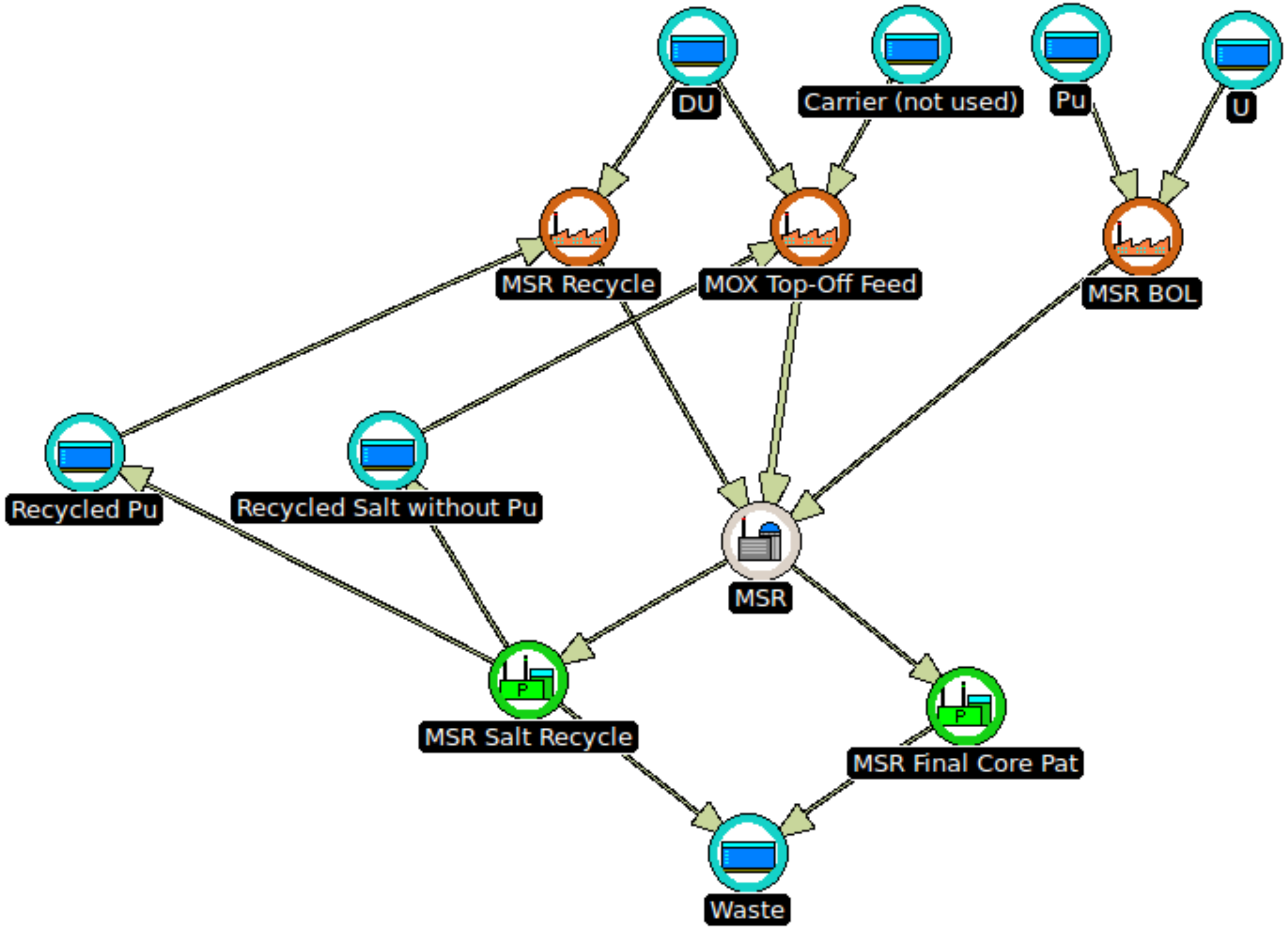
Cycle times for removals in salt treatment and separations

Processing Type	Processing Group	Elements	Cycle Time	Removal Fraction
Salt treatment	Volatile gases	Xe, Kr	20 s	1
	Noble metals	Se, Nb, Mo, Tc, Ru, Rh, Pd, Ag, Sb, Te	20 s	1
	Seminoble metals	Zr, Cd, In, Sn	3 d	1
	Volatile fluorides	Br, I	3 d	1
Salt processing	Rare Earth elements	Y, La, Ce, Pr, Nd, Pm, Sm, Gd	3 d	1
		Eu	3 d	1
	Discard	Rb, Sr, Cs, Ba	3 d	1
	Plutonium	Pu	2875 d	0.00104

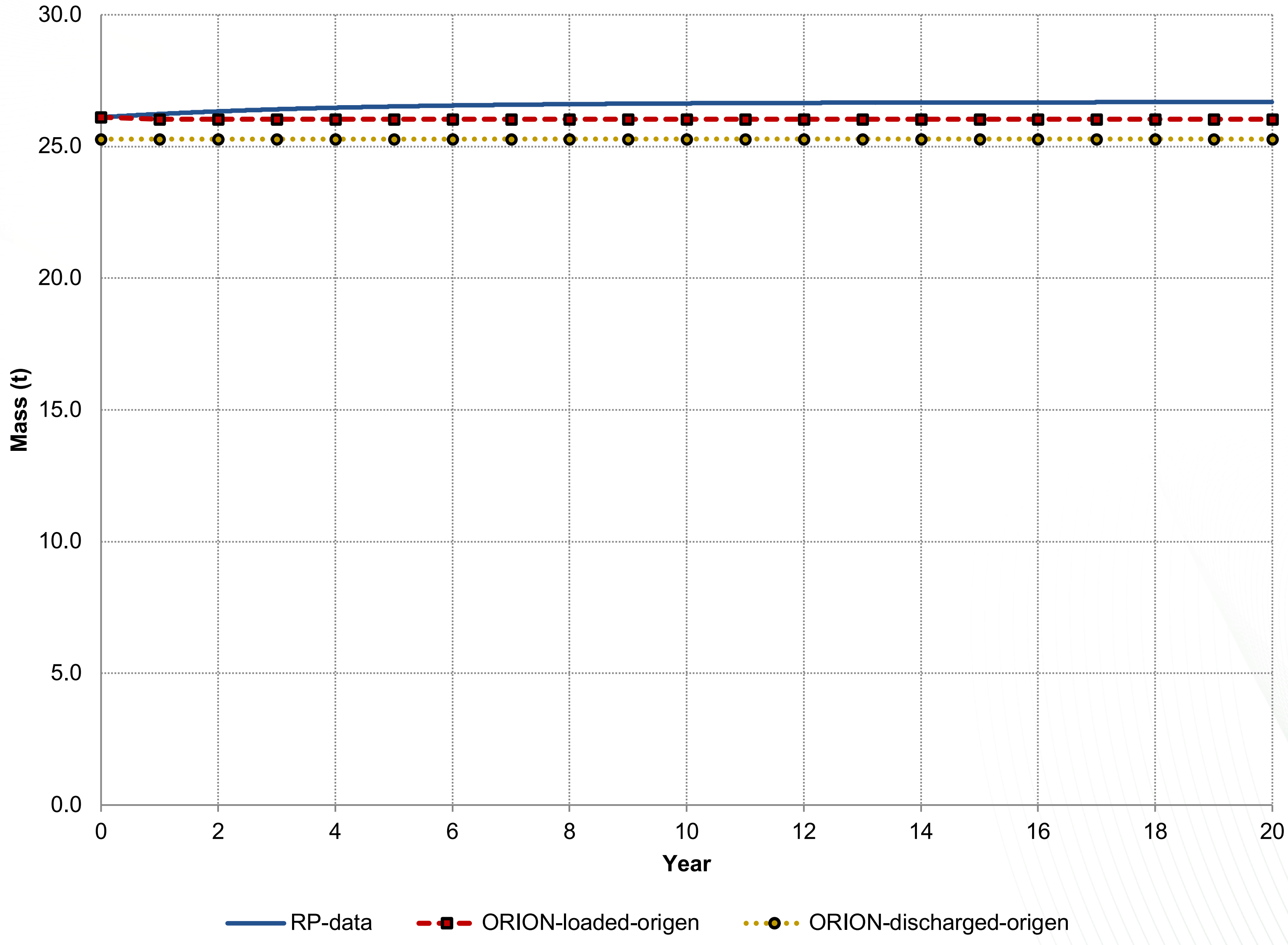
ORION Input Parameters

INPUT PARAMETER	PARAMETER VALUES
Heavy metal load (MT)	26.11
Thermal power (MWth)	2050
Thermal efficiency (%)	50
Electrical power (MWe)	1025
Load Factor (%)	100
Core life (years)	20
Time step (yr)	1
%Pu/HM at startup	10.298
Fuel density (g/cm^3)	2.11458
Power density (W/gHM)	77.1538
Pu removal fraction	1.270430E-01
Pu recycled fraction	8.729570E-01

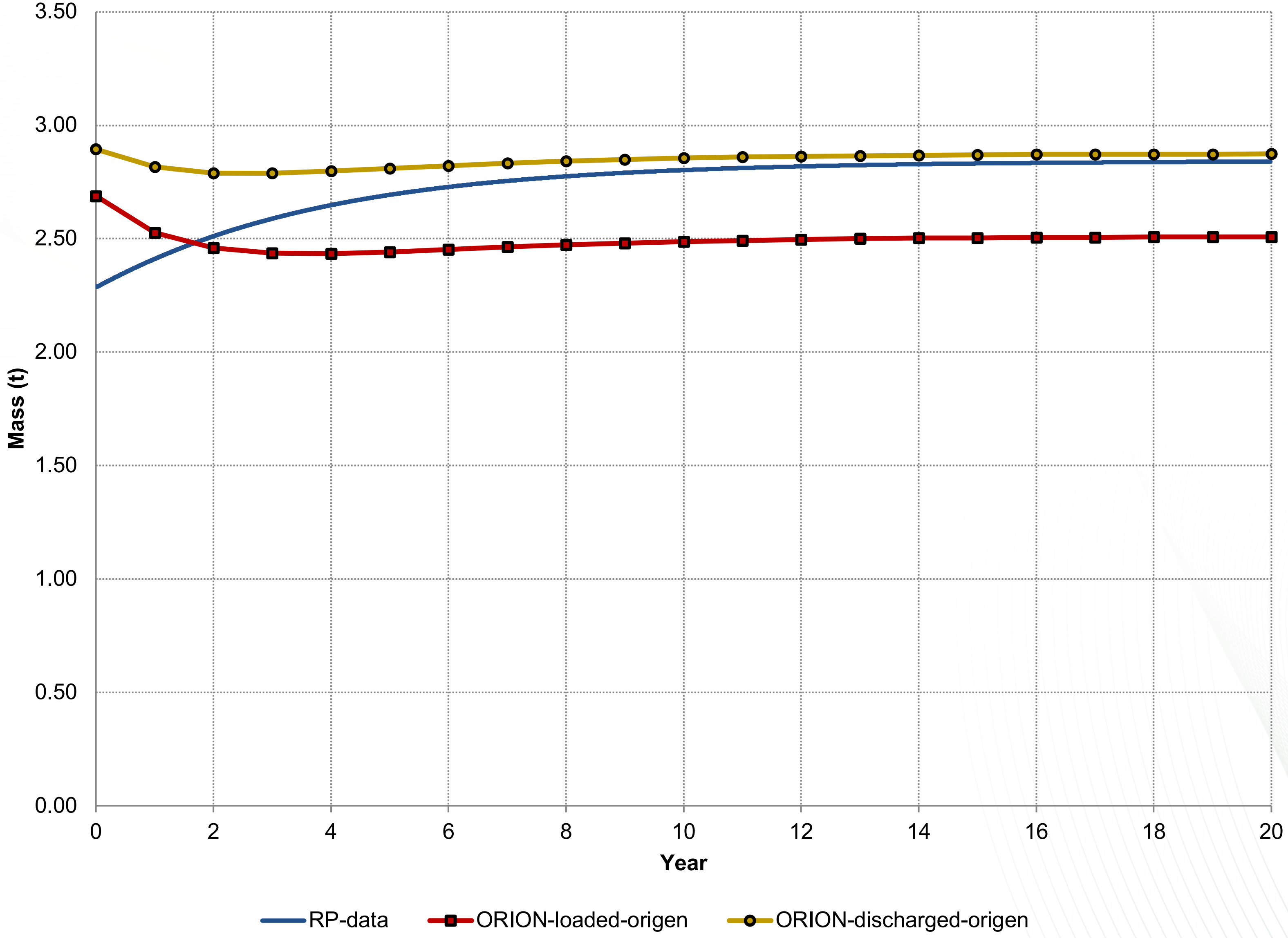
Single MSR Model at Equilibrium



Total Heavy Metal Loading



%Pu in Fuel



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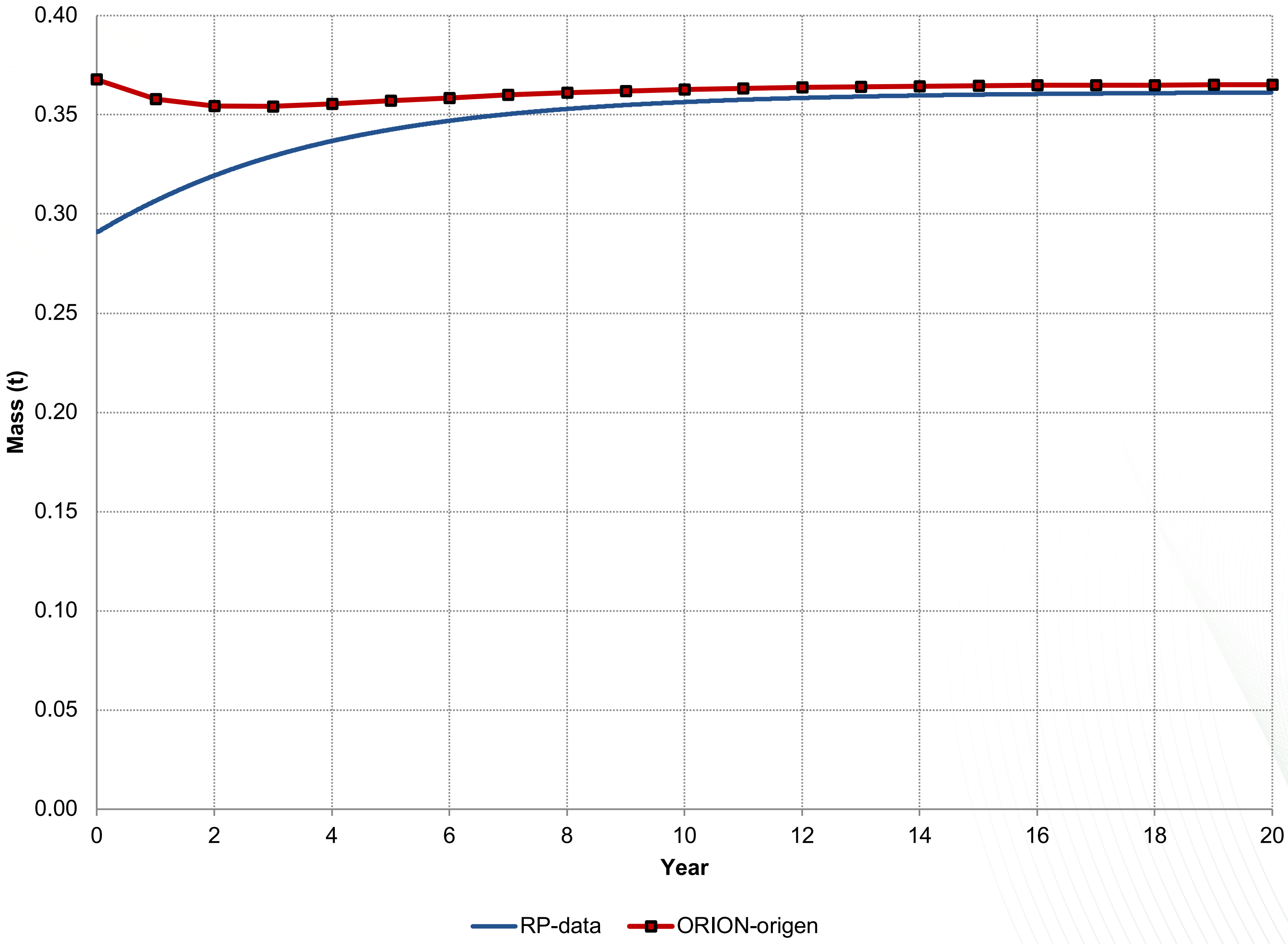
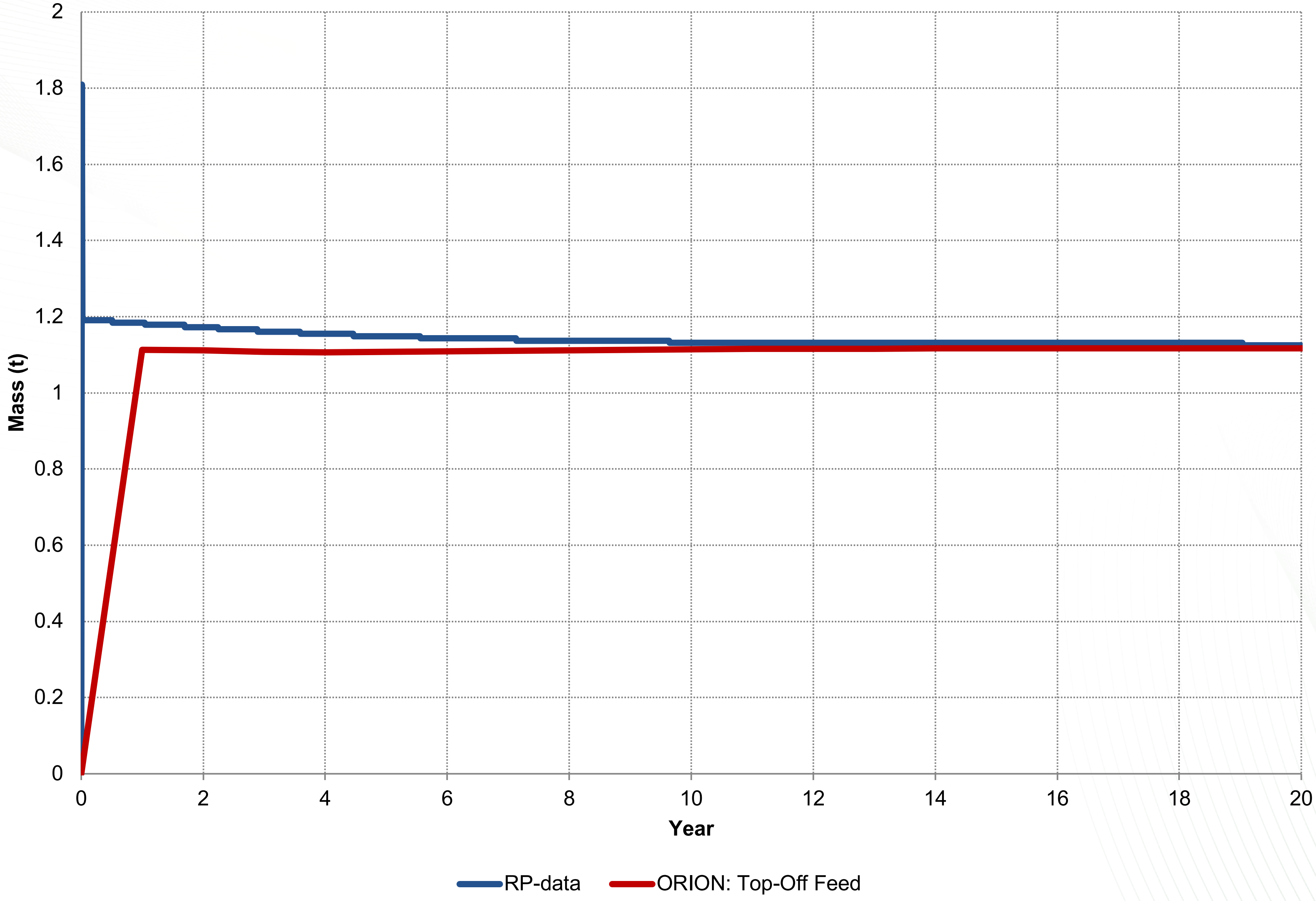
Pu Removal Rate



Top-Off Feed In Each Step



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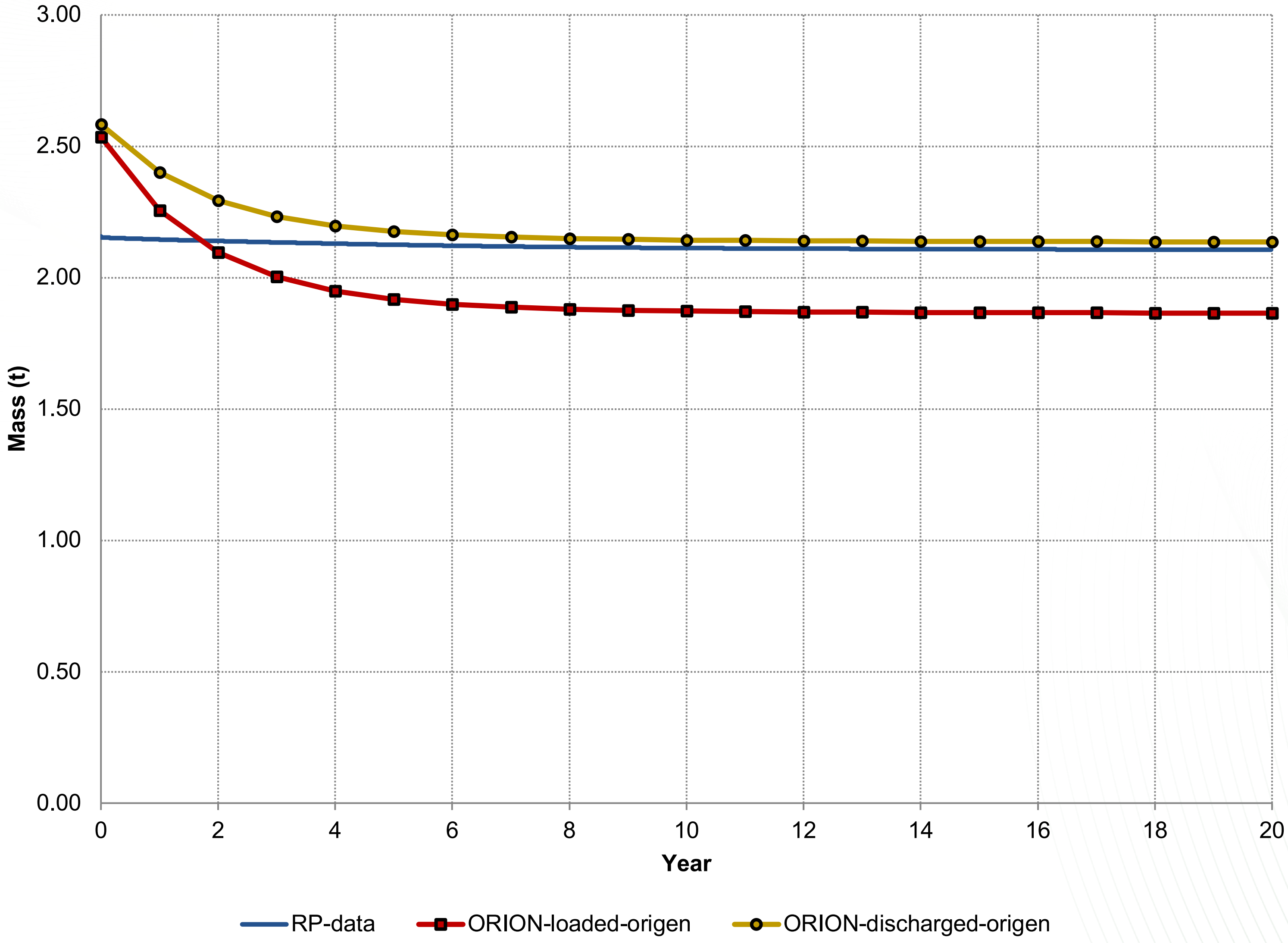
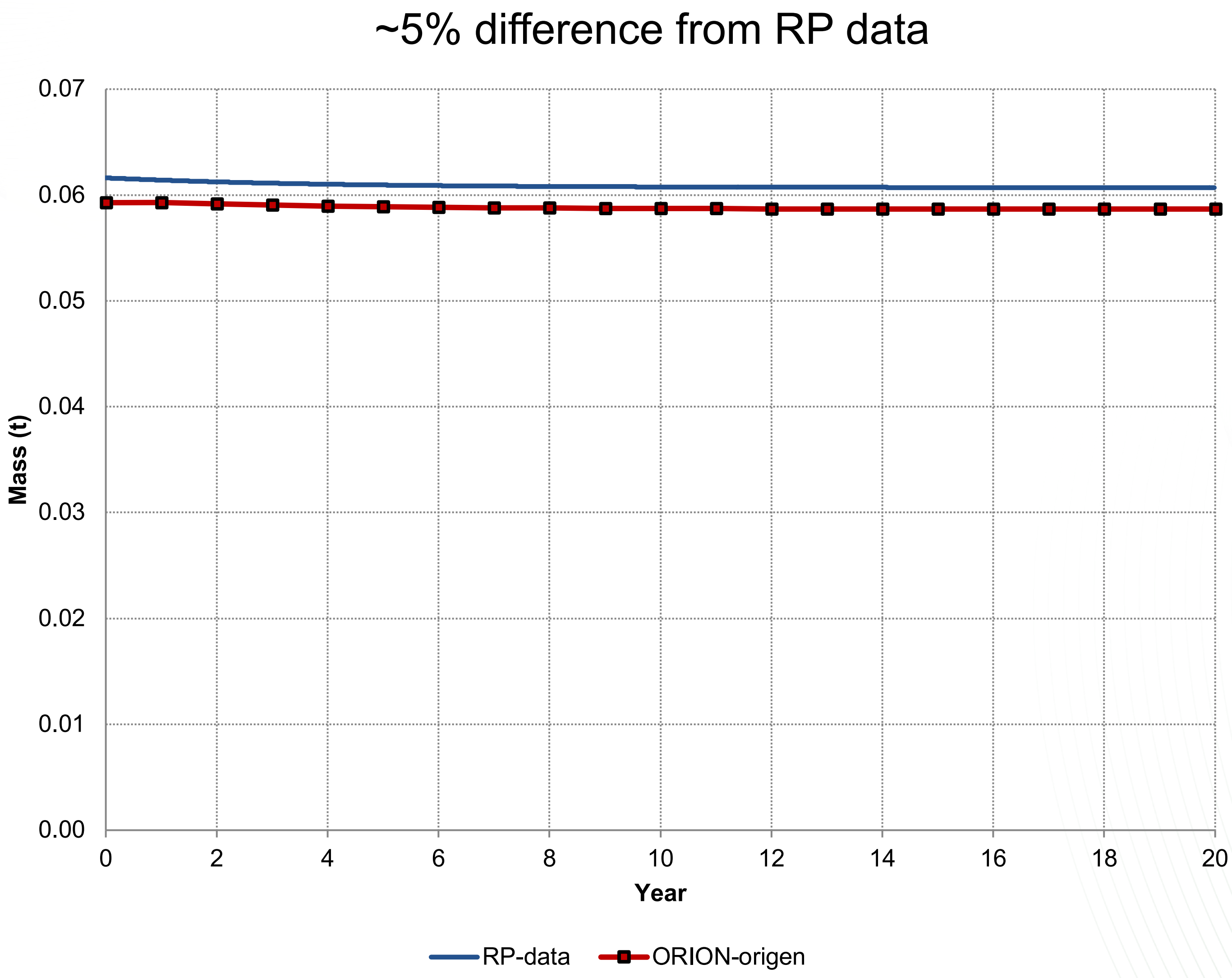
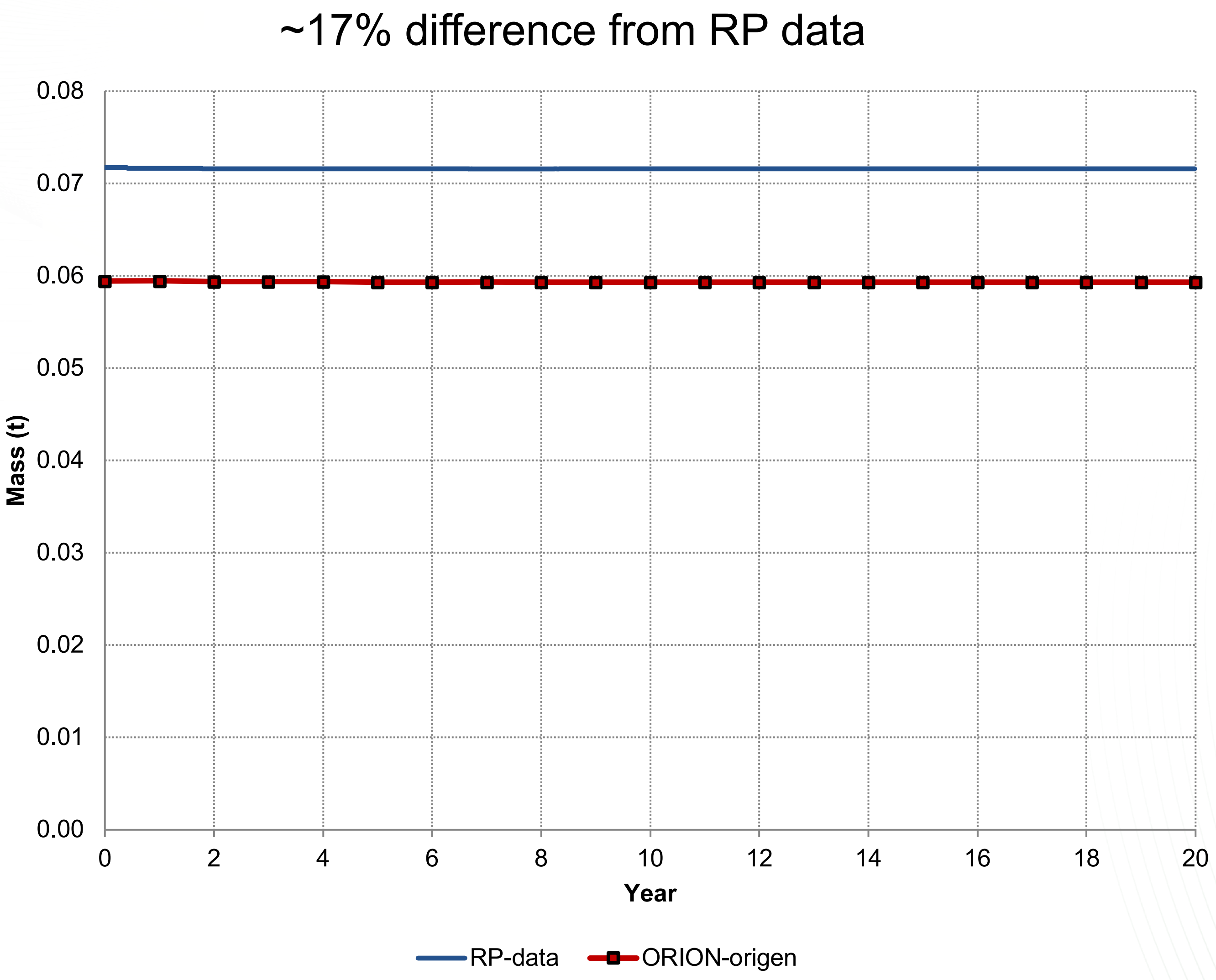
^{239}Pu Loading



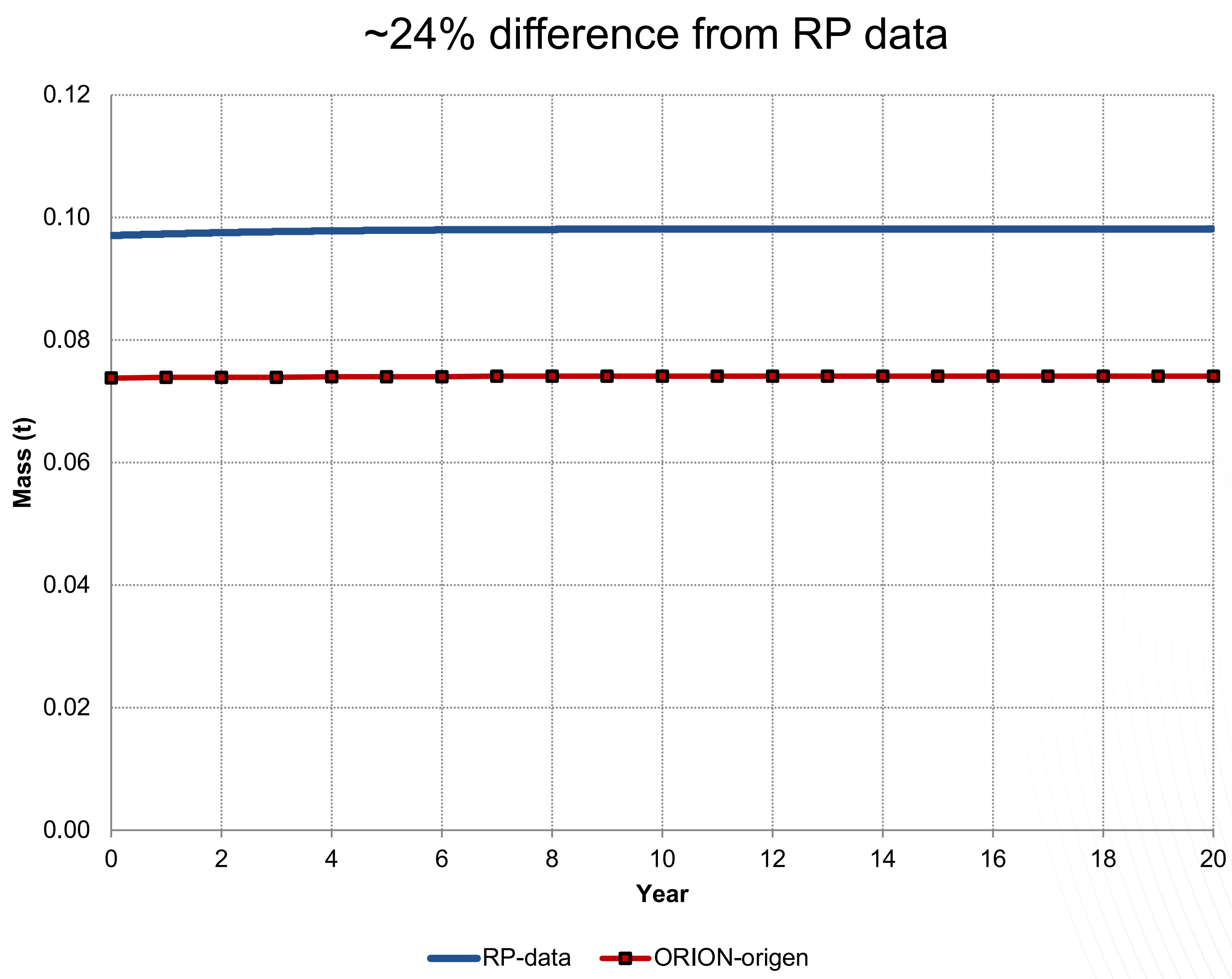
Zirconium Removal Rate



Cerium Removal Rate (Rare Earth Element)



Ruthenium Removal Rate (Noble Metal)



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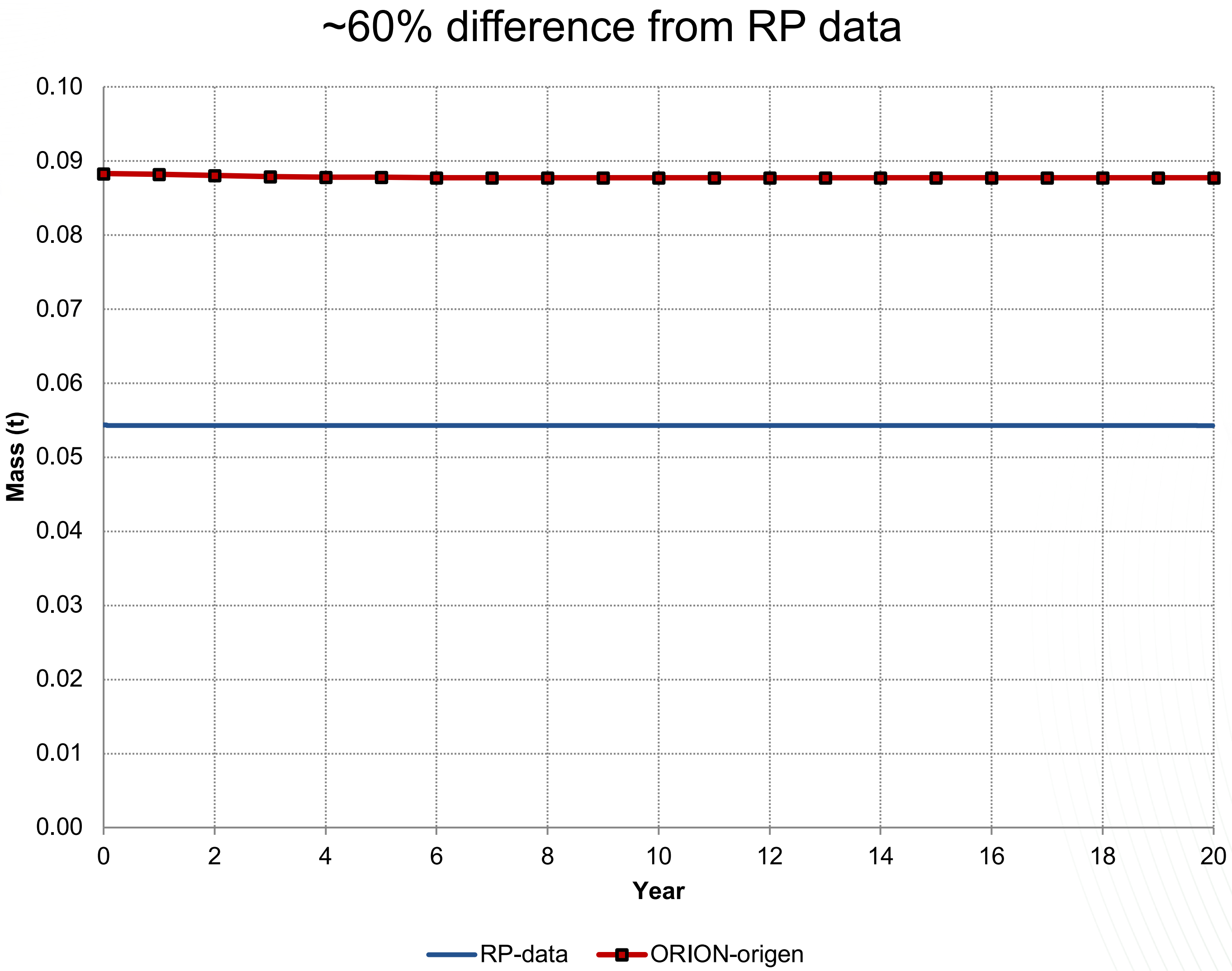
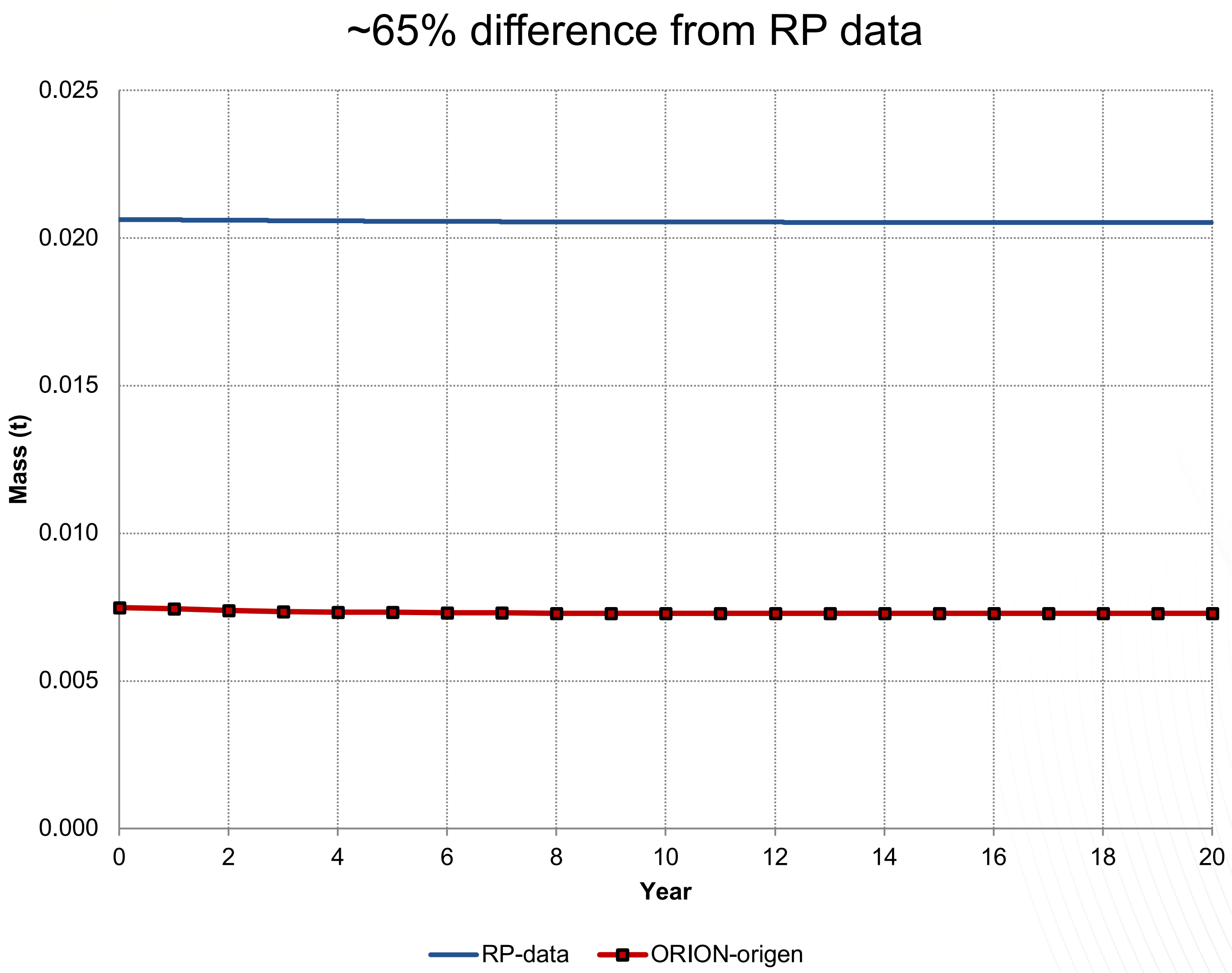
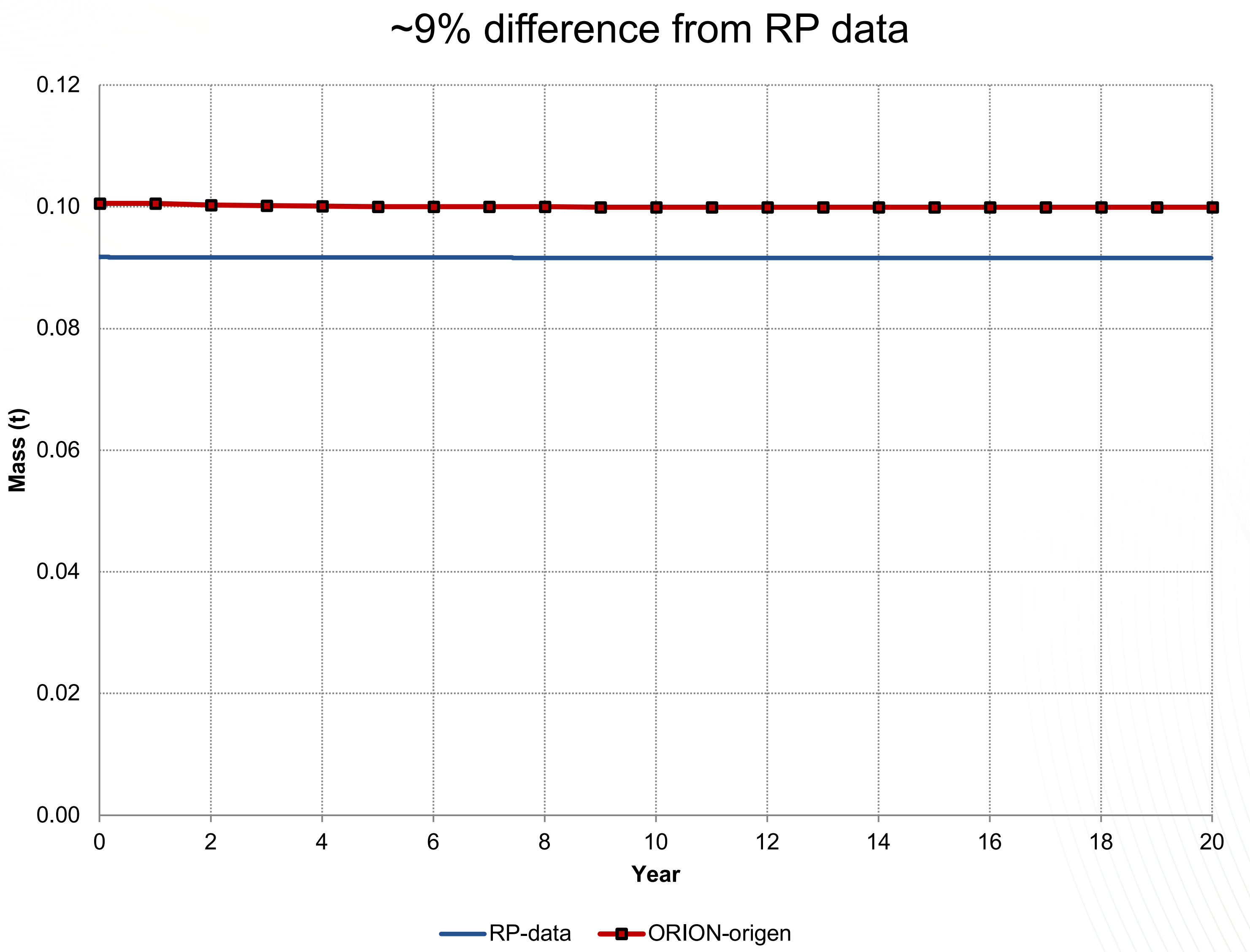
Cesium Removal Rate



Iodine Removal Rate (Volatile Fluoride)

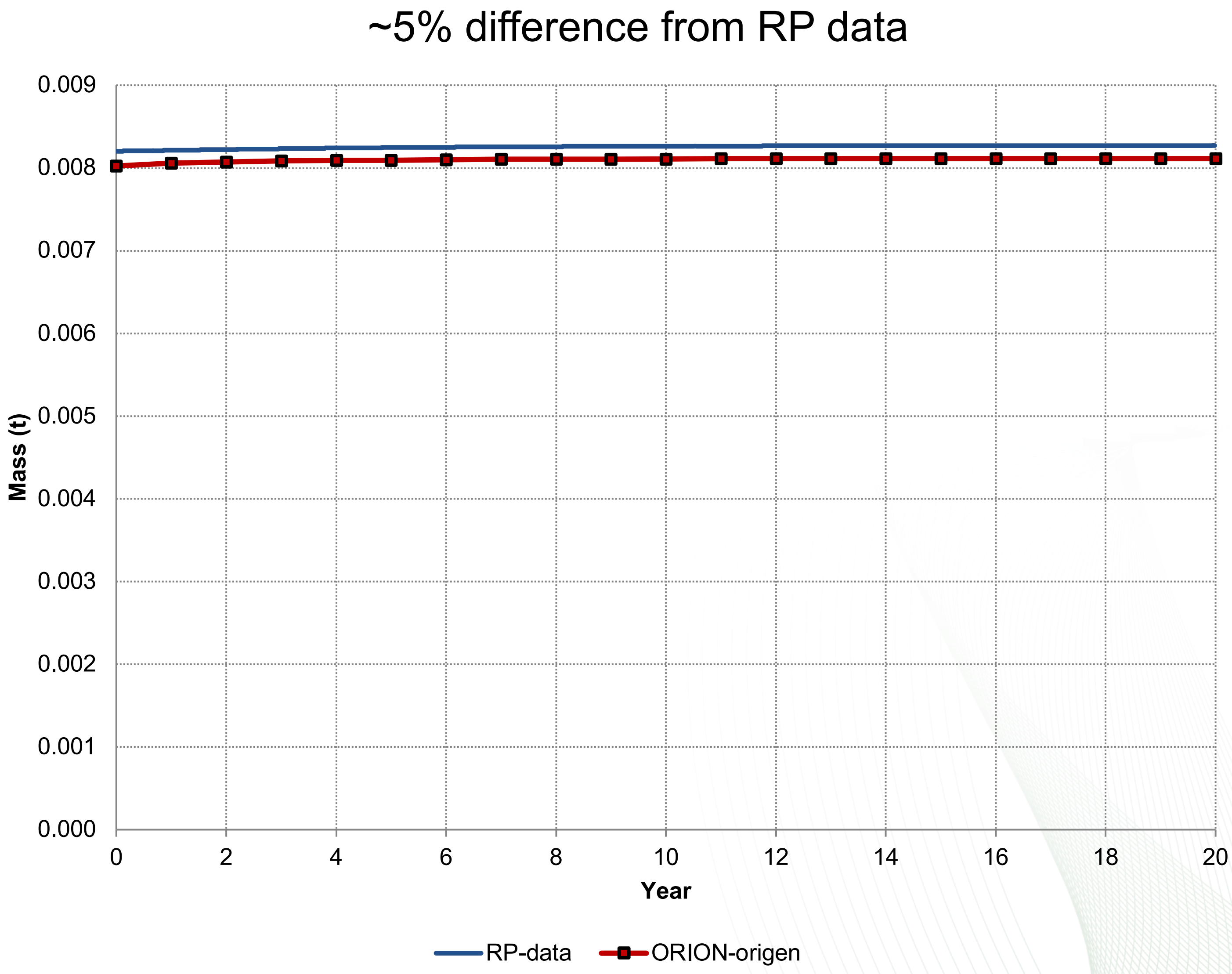


Xenon Removal Rate



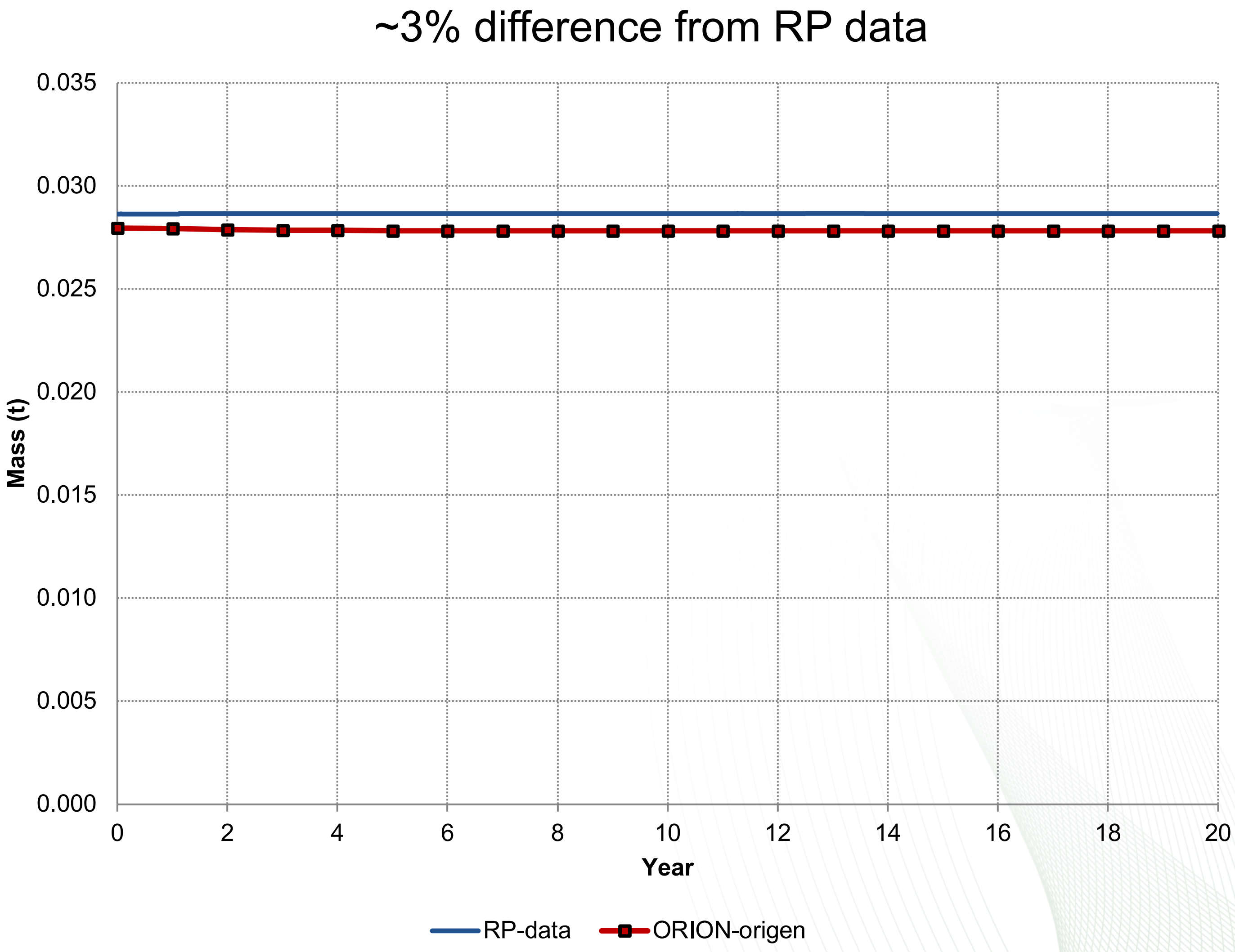
^{148}Nd

- Stable isotope
- Directly correlated to the fission rate in a system
- Suggests that stable nuclides can be simulated with better agreement with the reactor physics models



^{137}Cs

- Half-life is 30 years
- Confirms theory that fission product generation of longer-lived isotopes can be easily compared between reactor physics and fuel cycle models



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Conclusion

- Results from the single ORION MSR model agree well with the reactor physics model
- It is harder to make comparisons between the two models for short-lived nuclides due to differences in depletion time steps taken in the two models
- There are some differences as a result of larger timesteps taken in the ORION MSR model
  - However, there is good agreement in the results from the discharged fuel and the reactor physics data
- Future work will focus on performing transition analyses with MSRs

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