



Systems Level Fuel Cycle Modeling in TMAP8 - A Demonstration

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Changing the World's Energy Future

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**Pacific
Basin
Nuclear
Conference**

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Adriaan Riet

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Investigator*

Fuel Cycle Model

System Name

Breeding zone

Tritium Extraction System

First Wall

Divertor

Heat Exchanger

Coolant Purification System

Vacuum Pump

Fuel Clean-up

Isotope Separation System

Exhaust and Water Detritiation System

Storage and Management

System number

1

2

3

4

5

6

7

8

9

10

11

$$\frac{dI_1}{dt} = \Lambda \dot{N}^- + (1 - \eta_2) \frac{I_2}{\tau_2} - \frac{I_1}{\tau_1} - \frac{I_1 \varepsilon_1}{\tau_1} - I_1 \lambda$$

$$\frac{dI_2}{dt} = (1 - f_{1-5}) \frac{I_1}{\tau_1} - \frac{I_2}{\tau_2} - \frac{I_2 \varepsilon_2}{\tau_2} - I_2$$

$$\frac{dI_3}{dt} = f_{p-3} \frac{\dot{N}^-}{\eta_f f_b} + f_{5-3} (1 - f_{5-6}) (1 - f_{5-10}) \frac{I_5}{\tau_5} + f_{6-3} (1 - \eta_6) \frac{I_6}{\tau_6} - \frac{I_3}{\tau_3} - \frac{I_3 \varepsilon_3}{\tau_3} - I_3$$

$$\frac{dI_4}{dt} = f_{p-4} \frac{\dot{N}^-}{\eta_f f_b} + (1 - f_{5-3}) (1 - f_{5-6}) (1 - f_{5-10}) \frac{I_5}{\tau_5} + (1 - f_{6-3}) (1 - \eta_6) \frac{I_6}{\tau_6} - \frac{I_4}{\tau_4} - \frac{I_4 \varepsilon_4}{\tau_4} - I_4$$

$$\frac{dI_5}{dt} = f_{1-5} \frac{I_1}{\tau_1} + \frac{I_3}{\tau_3} + \frac{I_4}{\tau_4} - \frac{I_5}{\tau_5} - \frac{I_5 \varepsilon_5}{\tau_5} - I_5$$

$$\frac{dI_6}{dt} = f_{5-6} (1 - f_{5-10}) \frac{I_5}{\tau_5} - \frac{I_6}{\tau_6} - \frac{I_6 \varepsilon_6}{\tau_6} - I_6$$

$$\frac{dI_7}{dt} = (1 - \eta_f f_b - f_{p-3} - f_{p-4}) \frac{\dot{N}^-}{\eta_f f_b} - \frac{I_7}{\tau_7} - \frac{I_7 \varepsilon_7}{\tau_7} - I_7$$

$$\frac{dI_8}{dt} = \frac{I_7}{\tau_7} - \frac{I_8}{\tau_8} - \frac{I_8 \varepsilon_8}{\tau_8} - I_8$$

$$\frac{dI_9}{dt} = (1 - f_{8-11}) \frac{I_8}{\tau_8} + \frac{I_{10}}{\tau_{10}} + \eta_2 \frac{I_2}{\tau_2} + \eta_6 \frac{I_6}{\tau_6} - \frac{I_9 \varepsilon_9}{\tau_9} - \frac{I_9}{\tau_9} - I_9$$

$$\frac{dI_{10}}{dt} = f_{5-10} \frac{I_5}{\tau_5} + f_{9-10} \frac{I_9}{\tau_9} - \frac{I_{10}}{\tau_{10}} - \frac{I_{10} \varepsilon_{10}}{\tau_{10}} - I_{10}$$

$$\frac{dI_{11}}{dt} = f_{8-11} \frac{I_8}{\tau_8} + (1 - f_{9-10}) \frac{I_9}{\tau_9} - \frac{\dot{N}^-}{\eta_f f_b} - I_{11}$$

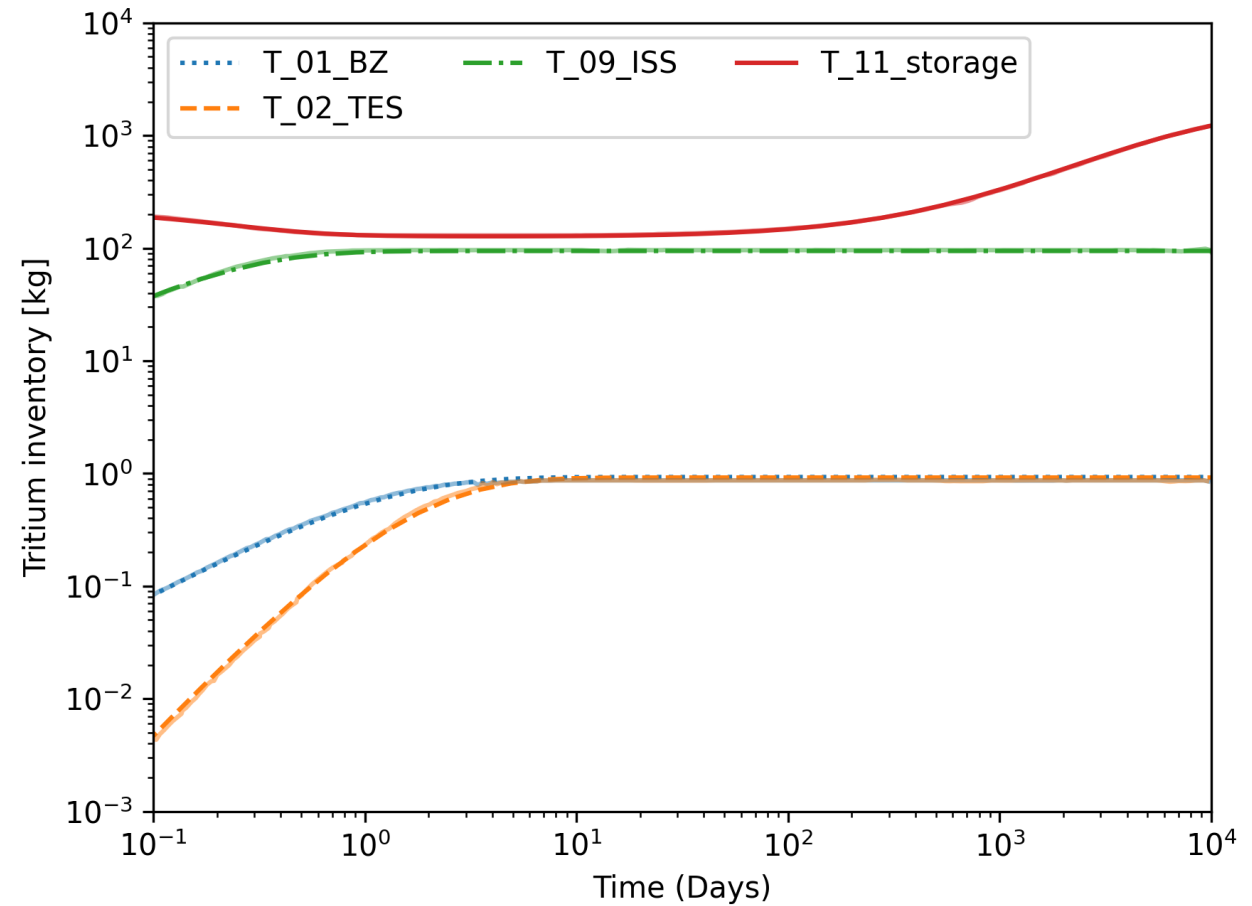
Sample Code – Equation 1

$$\frac{dI_1}{dt} = \left(\lambda N - \left((1 - \eta_2) \frac{I_2}{\tau_2} + \frac{I_1}{\tau_1} + \frac{I_1 \epsilon_1}{\tau_1} - I_1 \lambda \right) \right) = 0$$

```
[ScalarKernels]
[I1]
# Breeding Zone
type = ParsedODEKernel
expression = '-(tritium_burn_rate * TBR + (1 - TES_efficiency)*T_02_TES/residence2 - T_01_BZ/residence1 -
T_01_BZ*epsilon1/residence1 - T_01_BZ*tdecay)'
variable = 'T_01_BZ'
coupled_variables = 'T_02_TES'
postprocessors = 'TBR tritium_burn_rate TES_efficiency residence1 residence2 tdecay epsilon1'
[]
[I1t]
type = ODETimeDerivative
variable = T_01_BZ
[]
[]
```

Comparison with Abdou 2021

Parameter	Value
residence7 (τ_7)	1 s
residence8 (τ_8)	1 s
residence9 (τ_9)	14400 s
TBR (Λ)	1.9247
Initial value for T_11_storage	225.4215 kg



Possibilities

- Able to substitute sub-applications at varying levels of model sophistication
 - Heat exchanger
 - Tritium extraction system
 - Blanket
- Feedback between systems possible through this model
- TMAP8 can be incorporated with other MOOSE-based FEM tools to accommodate more advanced physics
- Example problem publicly available example online
https://mooseframework.inl.gov/TMAP8/examples/fuel_cycle/index.html

