INL/CON-24-81231-Revision-0

Systems Level Fuel Cycle Modeling in TMAP8 - A Demonstration

October 2024

Changing the World's Energy Future

Adriaan Anthony Riet

Idaho National Laboratory

INL/CON-24-81231-Revision-0

Systems Level Fuel Cycle Modeling in TMAP8 - A Demonstration

Adriaan Anthony Riet

October 2024

Idaho National Laboratory
Idaho Falls, Idaho 83415

http://www.inl.gov

Prepared for the
U.S. Department of Energy
Under DOE Idaho Operations Office
Contract DE-AC07-05ID14517

Pacific Basin Nuclear Conference

PBNC 2024

Systems Level Fuel Cycle Modeling in TMAP8 – A Demonstration

Adriaan Riet

Nuclear Fuel Systems Principal Investigator

Idaho National Laboratory

American Nuclear Society

Fuel Cycle Model

System Name	System number
Breeding zone	1
Tritium Extraction System	2
First Wall	3
Divertor	4
Heat Exchanger	5
Coolant Purification System	6
Vacuum Pump	7
Fuel Clean-up	8
Isotope Separation System	9
Exhaust and Water Detritiation System	10
Storage and Management	11

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

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

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

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

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

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

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

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

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

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

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

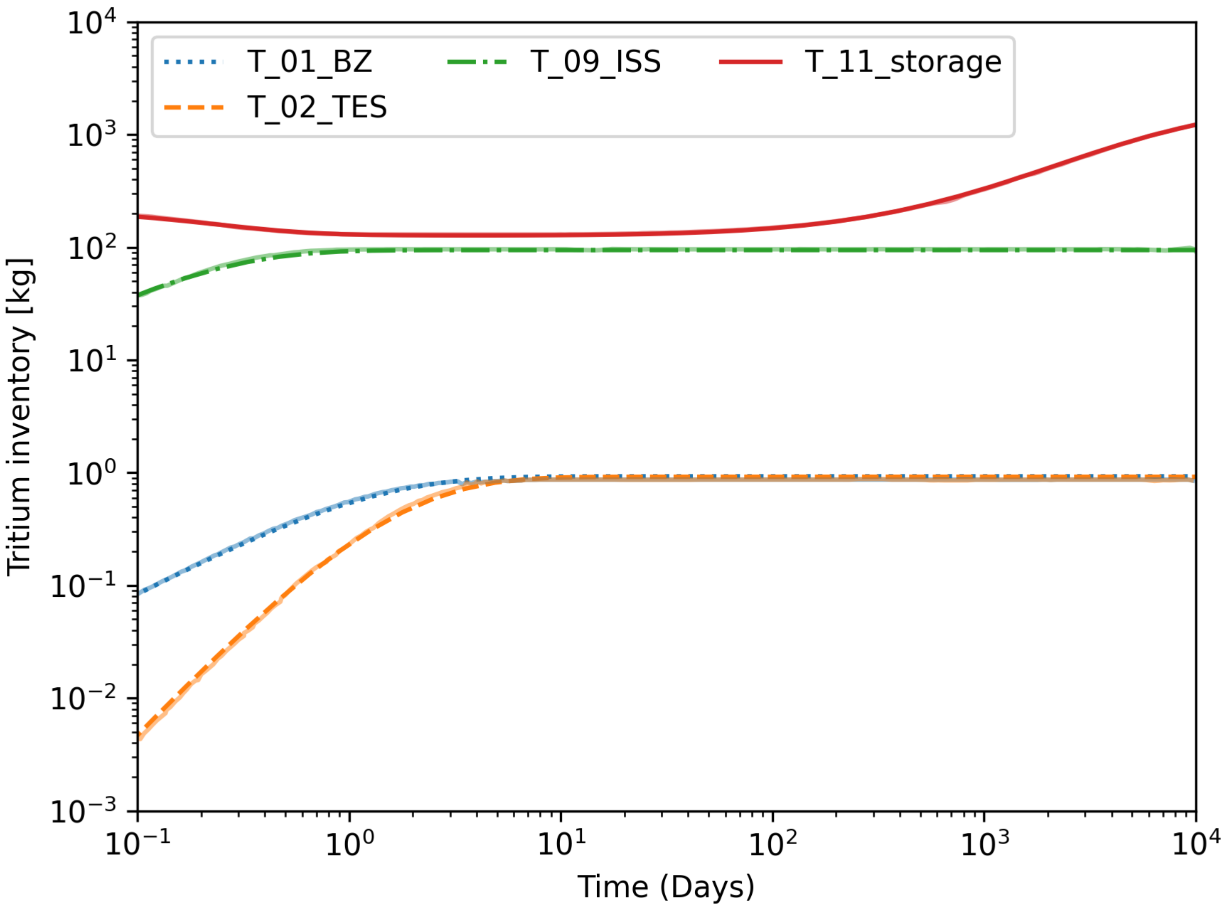
Sample Code – Equation 1

$$\frac{dI_1}{dt} = \left(\Lambda \dot{N}^{-} + (1-\eta_2)\frac{I_2}{\tau_2} - \frac{I_1}{\tau_1} - \frac{I_1 \varepsilon_1}{\tau_1} - I_1 \lambda\right) = 0$$

```
[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 (τ7)	1 s
residence8 (τ8)	1 s
residence9 (τ9)	14400 s
TBR (Λ)	1.9247
Initial value for T_11_storage	225.4215 kg



Place logo or company name here

ANS

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

ANS