P05F07

Initial Core Start-up Model of the JRTR Simulator

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Introduction to Zero-Decay Heat Model

☐ Why Zero-Decay Heat Model is required?

- ○ The initial condition of the simulator aims at the full-power operation and the equilibrium decay heat is assumed with the infinite operation time.

  → maximum decay heat is assumed.

- ○ A start-up operation of the initial core cannot be simulated appropriately under this condition because a significant decay heat exists for a very long time even if the reactor is scrammed.
  - ⏩ It takes about 10^9 seconds for the FP decay power to decrease to 0.02 % of the full-power assuming the infinite reactor operating time.
- ○ In order to eliminate the effect of the decay heat during a fresh core operation, an initial condition of zero-decay heat is required.

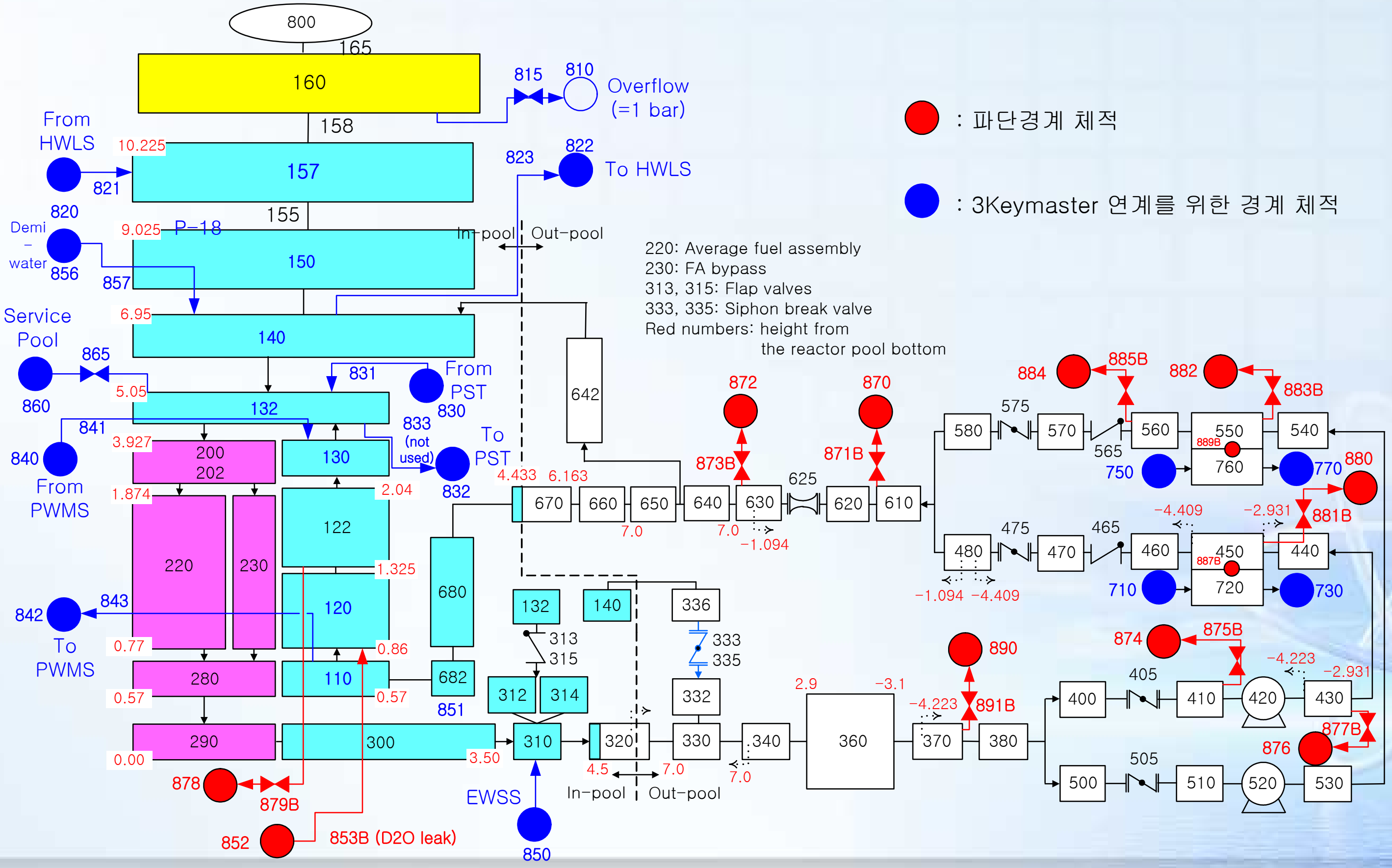
☐ Two Step Calculation for Zero-Decay Heat

- ○ Step 1: Steady-state run to stabilize thermal-hydraulic condition
  - ⏩ Considering fission power only neglecting feedback and decay heat
- ○ Step 2: Transient run with immediate reactor scram
  - ⏩ Restoring feedback reactivity and decay heat calculation

JRTR PCS Analysis Model

❑ MARS Model for Primary Cooling System (PCS)

- ❍ Input deck for safety analysis of JRTR to simulate PCS and Rx pool
- ❍ Adding boundary volumes and junctions for interface with 3KeyMaster
  - ⏩To reflect change of boundary conditions between PCS and other system



● : 파단경계 체적

● : 3Keymaster 연계를 위한 경계 체적

220: Average fuel assembly
230: FA bypass
313, 315: Flap valves
333, 335: Siphon break valve
Red numbers: height from
the reactor pool bottom

Point Kinetics Model for JRTR

❑ Improvement of Point Kinetics

❍ Xenon transient model

$$\frac{d\hat{I}}{dt} = \lambda_I\left(\hat{N} - \hat{I}\right)$$

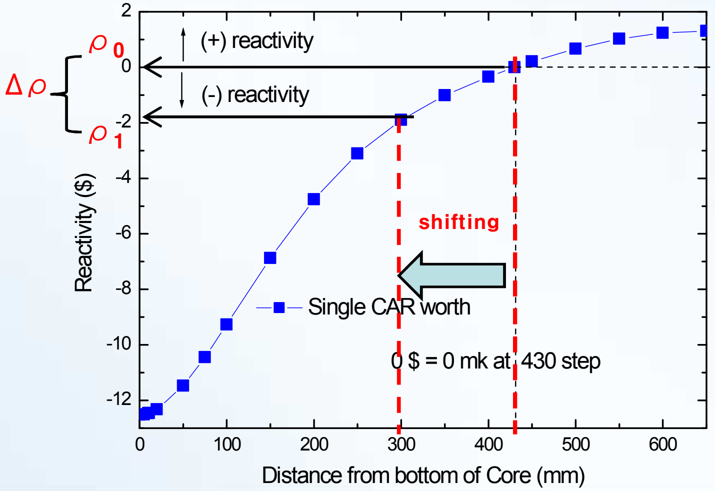
⇨ **I-135 produced by fission and decayed**

$$\frac{d\hat{X}}{dt} = \frac{\lambda_X + \lambda_e}{\gamma_X + \gamma_I}\left(\gamma_X\hat{N} + \gamma_I\hat{I}\right) - \left(\lambda_e\hat{N} + \lambda_X\right)\hat{X}$$

⇨ **Xe produced by fission and decay of I-135**
Decayed by neutron absorption and decay of itself

Variable	Description	Value	Unit	Remark
λ_I	Decay Constant of I-135	2.87E-05	1/s	
λ_X	Decay Constant of Xe-135	2.09E-05	1/s	
λ_e	Effective Decay Constant of Xe-135	1.51E-04	1/s	$\lambda_e = \sigma_{aX}\phi_0$
γ_I	Yield Fraction of I-135	5.60		
γ_X	Yield Fraction of Xe-135	3.00E-01		

❍ Shifting critical rod position by modifying bias reactivity



$$\rho(t) = \rho_i + \rho_{scram}(t) + \sum\rho_{feedback}(t) + \rho_{bias}$$

$$\rho(0) = \rho_i + \rho_{scram}(0) + \sum\rho_{feedback}(0) + \rho_{bias} = \rho_i$$

$$\therefore \rho_{bias} = -\sum\rho_{feedback}(0) - \rho_{scram}(0)$$

$$\boxed{\begin{aligned}\rho_{bias}' &= -\sum\rho_{feedback} - \rho_1' \\ &= -\sum\rho_{feedback} - \rho_0 - \Delta\rho \\ &= \rho_{bias} - \Delta\rho\end{aligned}}$$

$$(\because \Delta\rho = \rho_1 - \rho_0)$$

Point Kinetics Data (1)

❑ Point Kinetics and Reactivity

$$\frac{dn(t)}{dt} = \frac{\rho(t)-\beta_{eff}}{\Lambda} n(t) + \sum_i \lambda_i C_i(t) + S$$

$$\frac{dC_i(t)}{dt} = \frac{\beta_{eff} f_i}{\Lambda} n(t) - \lambda_i C_i(t)$$

$$r(t) = r_i + \sum r_{fb}(t) + \sum r_{sc}(t) - r_B \qquad \left(r(t) = \frac{\rho(t)}{\beta_{eff}} \right)$$

where, r_i : initial reactivity

$r_B = \sum r_{fb}(0) + \sum r_{sc}(0)$, bias reactivity

r_{fb}: feedback reactivty

r_{sc}: scram and other reactivity

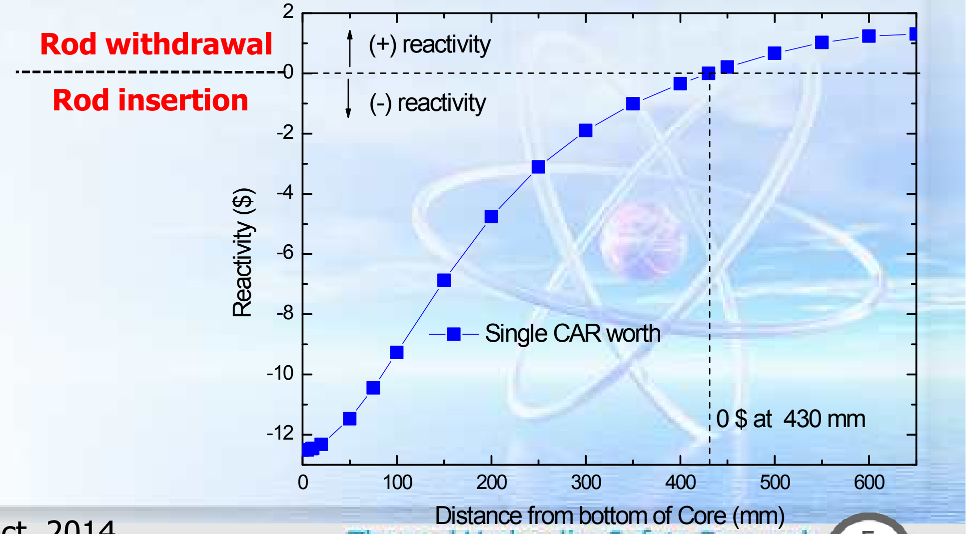
❑ Delayed Neutron Group

- ❍ MARS can deal with maximum six delayed neutron groups
  → Neglecting photo-neutron group

Group	Decay constant	Yield fraction (%)
1	0.0125	3.2
2	0.0317	16.8
3	0.1090	16.4
4	0.3170	45.6
5	1.3500	13.3
6	8.7300	4.7

❑ Rod Worth by Scram Reactivity

- ❍ Rod position vs. reactivity table
- ❍ Critical rod position
  - ⏩430 mm from bottom of core
  - ⏩Rod worth is zero at that height.



Point Kinetics Data (2)

- ☐ Feedback Reactivity
  - ○ Feedback reactivity is not considered in the 1st step.
  - ○ In the 2nd step, all reactivity from feedback with axial node weighting is considered.
    - ⏩Moderator temperature coefficient = -0.0054 mk/K
    - ⏩Fuel temperature coefficient = -0.01 mk/K
- ☐ Decay Heat Model
  - ○ 1st step calculation
    - ⏩Decay heat model is not included.
  - ○ 2nd step calculation
    - ⏩ANS73 model used with 1.0 gain value for B-E analysis
    - ⏩Actinide decay model is not used.
    - ⏩Power operational history option is used with zero operating time.
      - – For initial core start-up model
    - ⏩Reactor is scrammed at first to minimize decay power in Step 2 calculation.

Two-step Method for Zero-Decay Heat

❑ The 1st Step Calculation

- ❍ Steady-state run without feedback and decay heat
  - ‘no-gamma’ option used for decay heat model and all feedback reactivity = 0
  - Total reactor power: 5 MW (produced by fission only)
    - Thermal-hydraulic condition (temperature of fluid and heat structure) will be stabilized at the full power level.
    - Reference temperatures of fluid and heat structures, which will determine the feedback reactivity in the 2nd step calculation, are determined in this step.

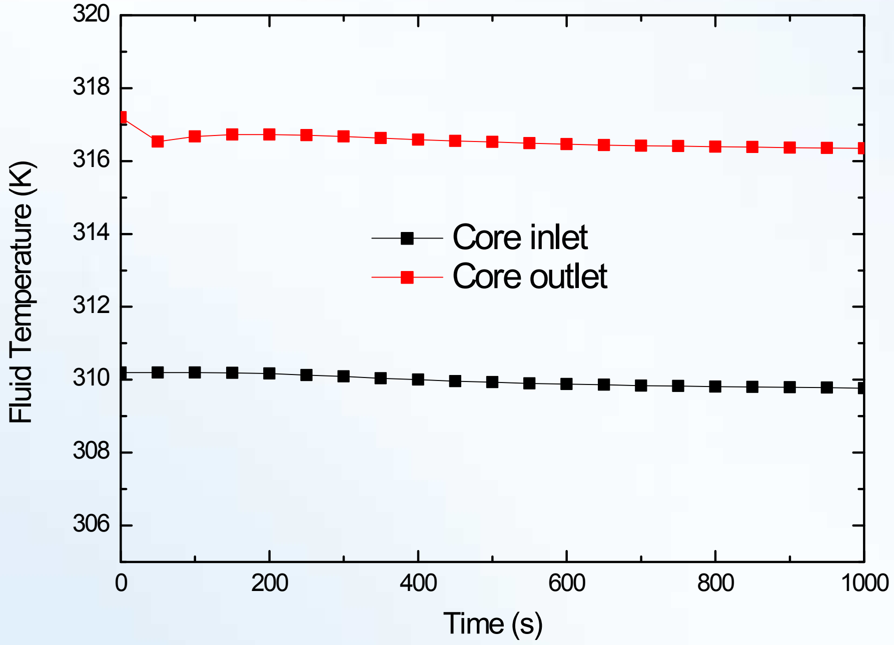
❑ The 2nd Step Calculation

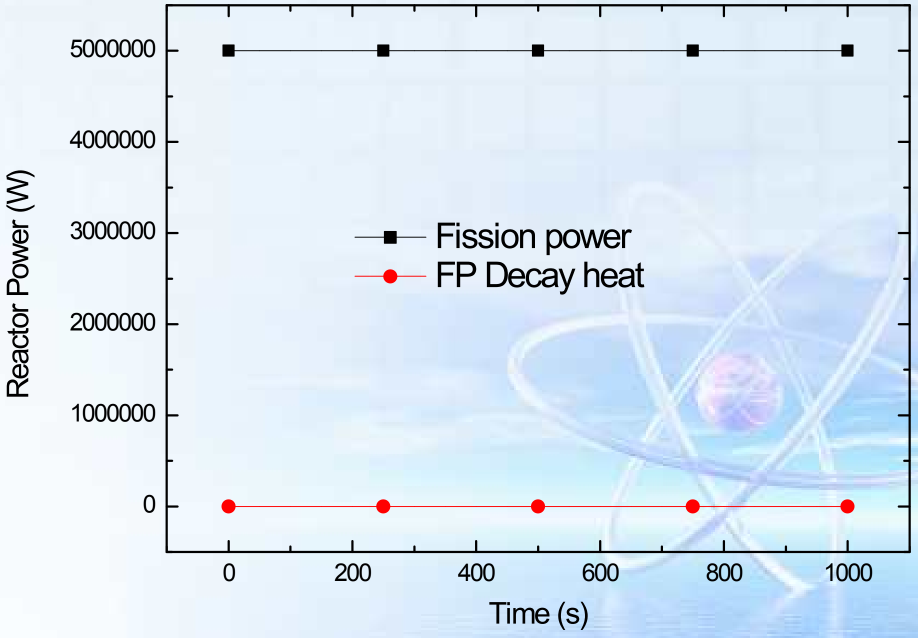
- ❍ Restart run with feedback and decay heat by using rstplt file from 1st step
  - All existing inputs for kinetics are replaced with new inputs.
  - ‘gamma’ option is used for decay heat and feedback reactivity is restored.
  - Power history data → zero operating time
  - Reactor scram should be invoked at first to decrease decay heat power.
    - Fission product decay heat is proportional to the fission power.
    - Without reactor scram, fission product decay heat would be increased drastically and reach a significant level in short time.

Results: 1st Step Run

❑ Steady-state Run Results

- ❍ Running for 1000 sec. to stabilize thermal-hydraulic conditions
- ❍ Fluid conditions are stabilized in 1000 sec.
  - ⏩Core inlet and outlet temperature are slightly changed but almost stabilized.
  - ⏩Heat structures also become equilibrium as fluid conditions become stable.
- ❍ Reactor power is maintained at constant value during calculation
  - ⏩No feedback and no decay heat

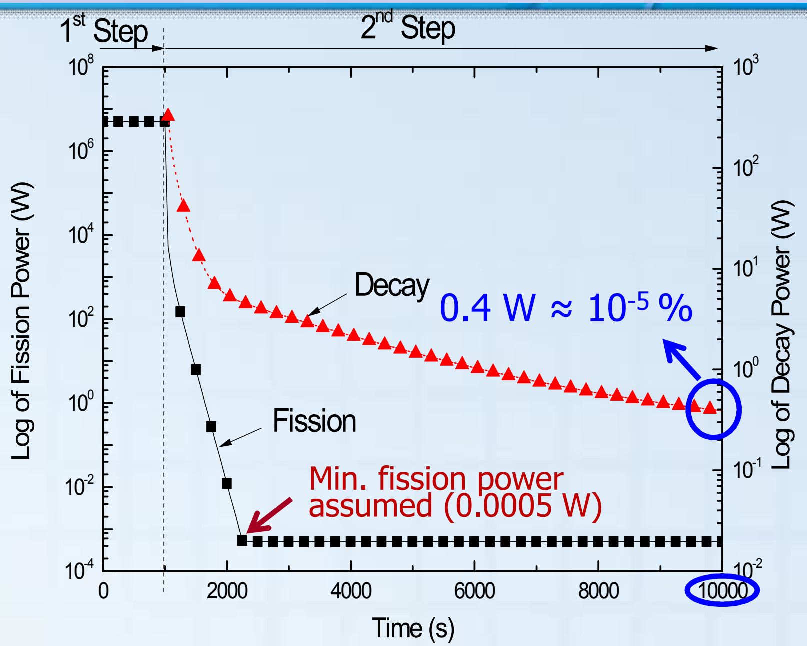




Results: 2nd Step Run

❑ Restart Run Results

- ❍ Running for 9000 sec. to decrease decay heat by using 1st rstplt
- ❍ All rods are fully inserted into core at first to simulate reactor scram.
  - ⏩At first, a certain amount of decay heat is generated due to significant fission power but decreased as fission power is vanished.
    - – A little of decay heat is generated but negligible.
  - ⏩Finally, decay heat is decreased to negligible level (0.4 W) for 9000 s only.
  - ⏩Calculation time is quite less than that of case when maximum decay heat is assumed.



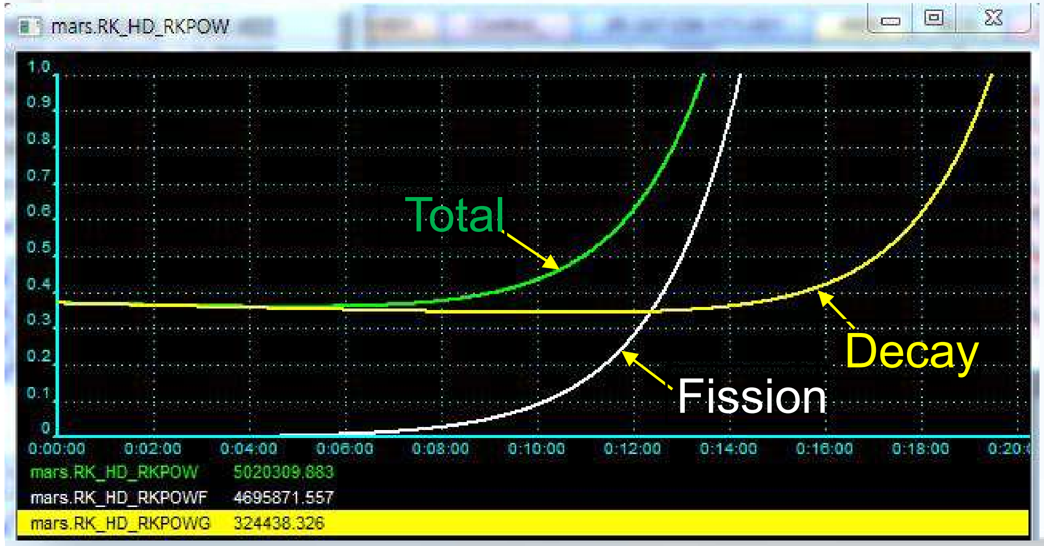
Initial Core Start-up Simulation

❑ Assumptions

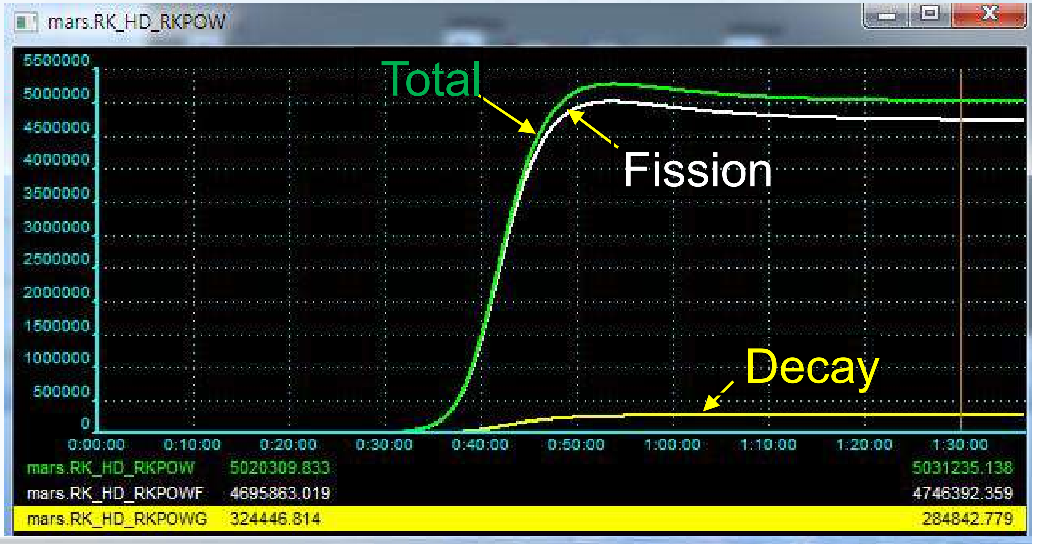
- ❍ All reactor control systems including RRS and RPS are not used.
- ❍ Xenon poison is not considered.
- ❍ Secondary cooling system (SCS) is under normal operation.
- ❍ Withdrawing all CARs to critical position for the start-up operation
  - ⏩ Remember that all reactivity feedback should be zero at full power level.

❑ Reactor Power

- ❍ Positive reactivity is inserted due to low fluid and fuel temperature (+$ 0.08)
- ❍ Slight power overshoot is estimated before decay heat is in equilibrium.


mars.RK_HD_RKPOW

mars.RK_HD_RKPOW 5020309.883
mars.RK_HD_RKPOWF 4695871.557
mars.RK_HD_RKPOWG 324438.326


mars.RK_HD_RKPOW

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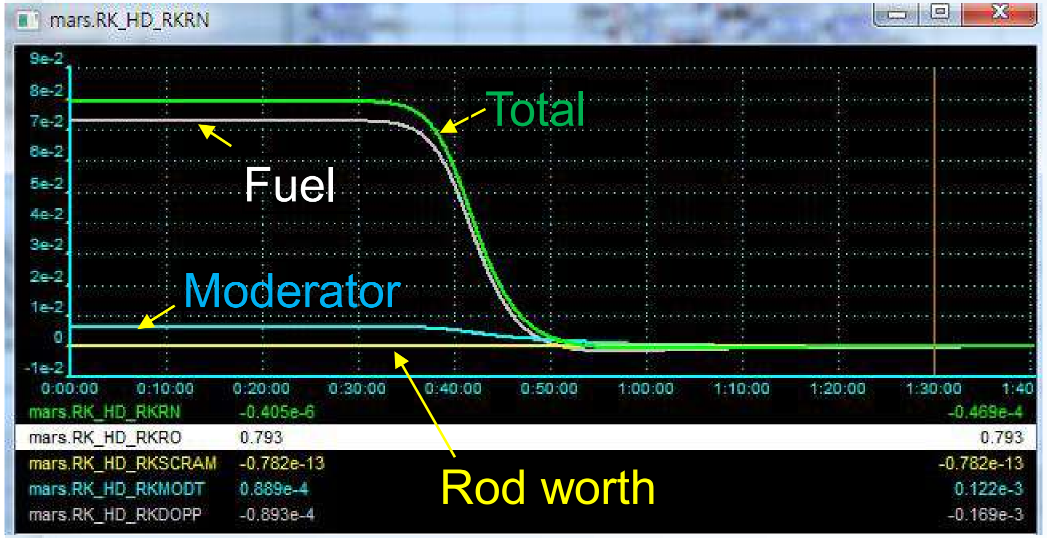
mars.RK_HD_RKPOWF 4695863.019 4746392.359
mars.RK_HD_RKPOWG 324446.814 284842.779

Initial Core Start-up Simulation

❑ Reactivity and Fluid Temperature

- ❍ Rod worth is zero because all rods are in critical position.
- ❍ Both fuel and moderator reactivity are decreased as core exit temperature increases after 30 minutes.
- ❍ As fluid temperature increases, total reactivity comes to zero.
- ❍ Core inlet temperature slowly increases as core outlet temperature increases.



```
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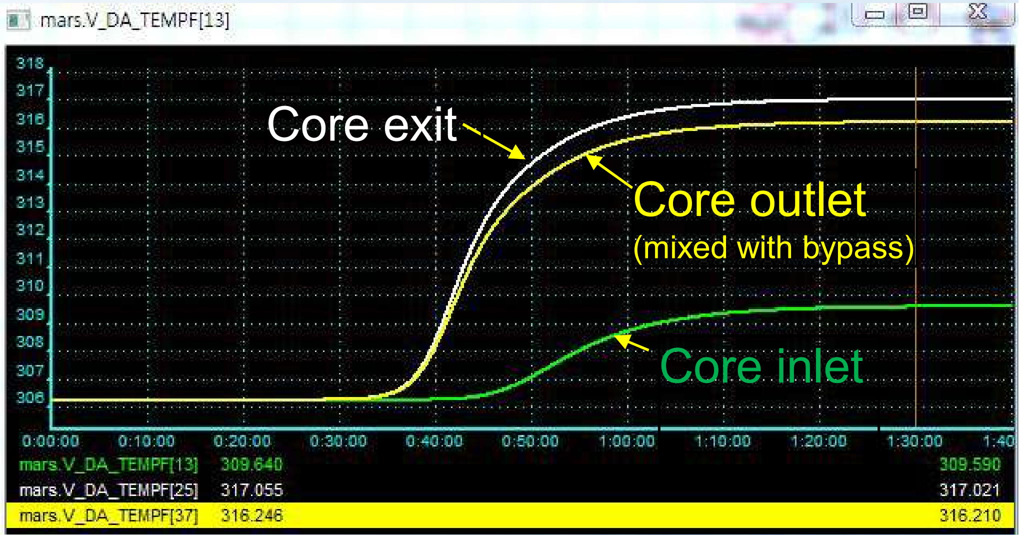
mars.RK_HD_RKRO       0.793          0.793
mars.RK_HD_RKSCRAM   -0.782e-13     -0.782e-13
mars.RK_HD_RKMODT     0.889e-4       0.122e-3
mars.RK_HD_RKDOPP    -0.893e-4      -0.169e-3
```



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mars.V_DA_TEMPF[13]   309.640   309.590
mars.V_DA_TEMPF[25]   317.055   317.021
mars.V_DA_TEMPF[37]   316.246   316.210
```

Summary

- Nearly zero-decay heat condition has been generated with two-step calculation method by using the MARS code to simulate the start-up operation of the fresh core.
- This is very effective way to simulate the start-up operation because the decay power which can affect the temperature of the coolant and fuel during the operation is at extremely low level.
- As for simulator application, this method has been successfully applied into the JRTR simulator.
- This method will be applicable to not only the simulator but also general safety analysis for the initial core by using the MARS code.