# Thermal-Hydraulic Modeling of the iPWR SMR Using RELAP5-3D

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# Outline

- Introduction
- Development Process
- iPWR RELAP5-3D model
- Steady-State Results
- Transient (Turbine Trip)
- Future work

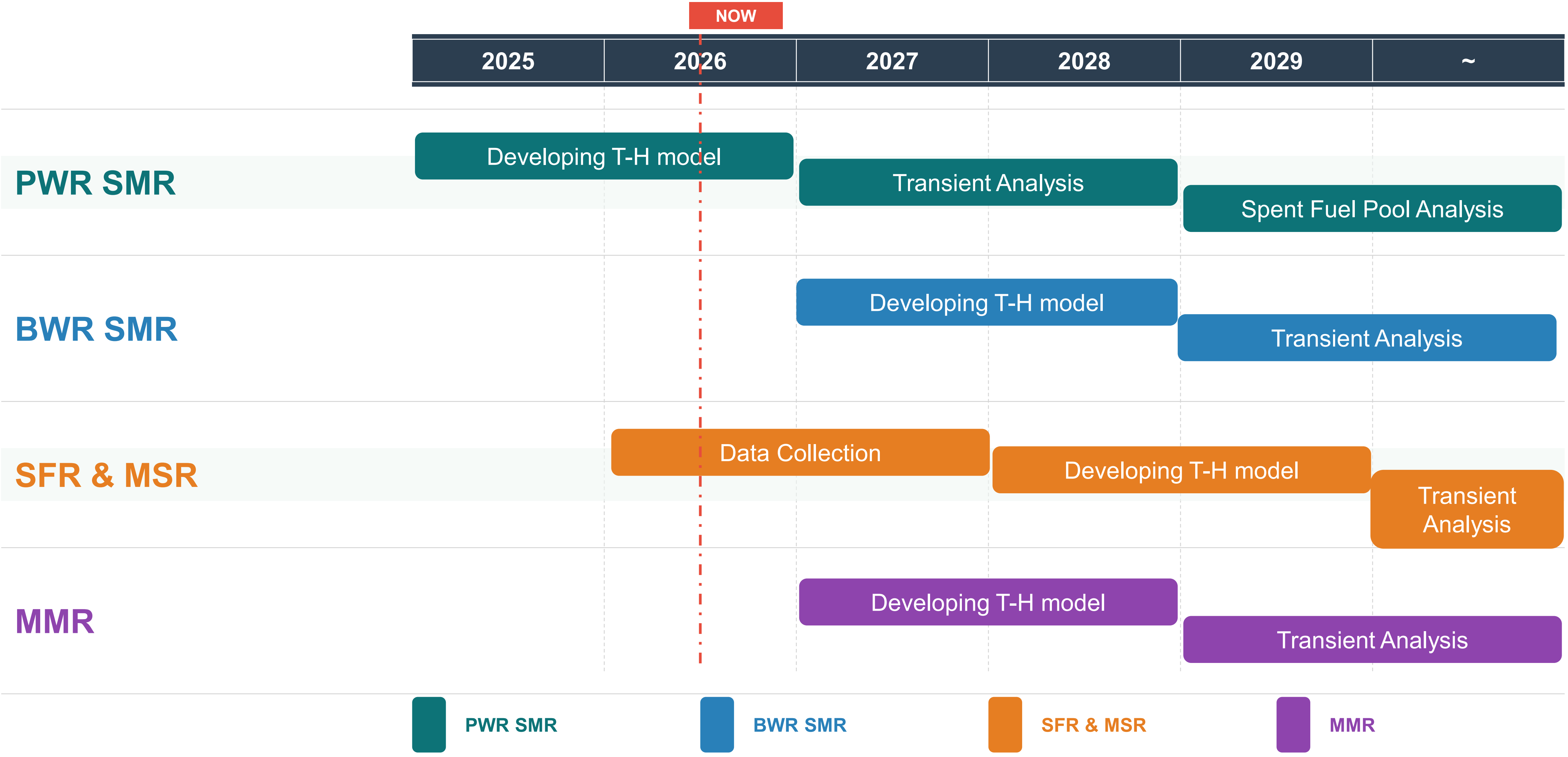
# Introduction-NARI SMR

2026 IRUG Meeting

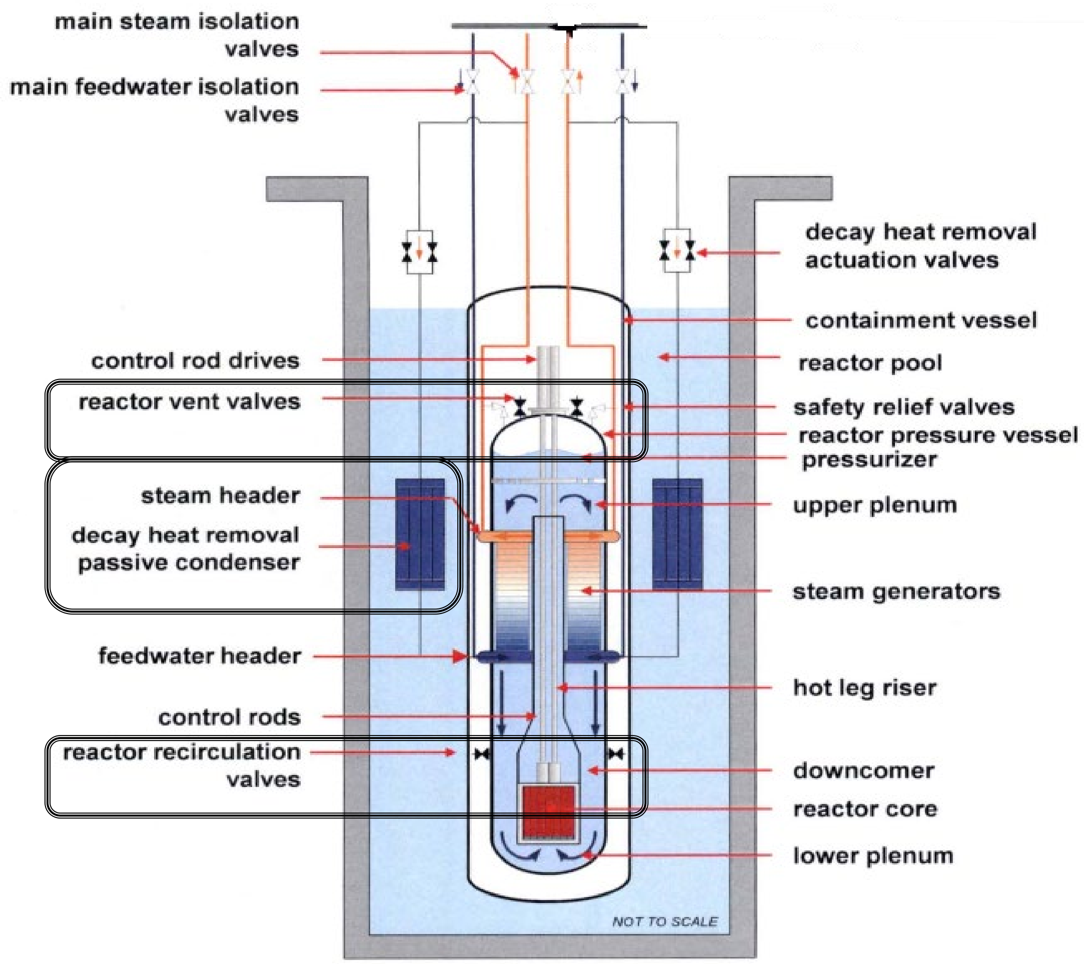
**Research on Small Modular Reactors**

1. **Reactor Operating Safety Analysis**
2. **Probability Risk Assessment**
3. **Radioactive Waste Management and Emergency Planning Zone**
4. **Fuel Materials, Seismic Structure and Digital Control**
5. **Offshore Advanced Reactors, Reactor Technical Assessment, Economic Analysis, Public Communication and Regulatory Study**

# Introduction-NARI SMR



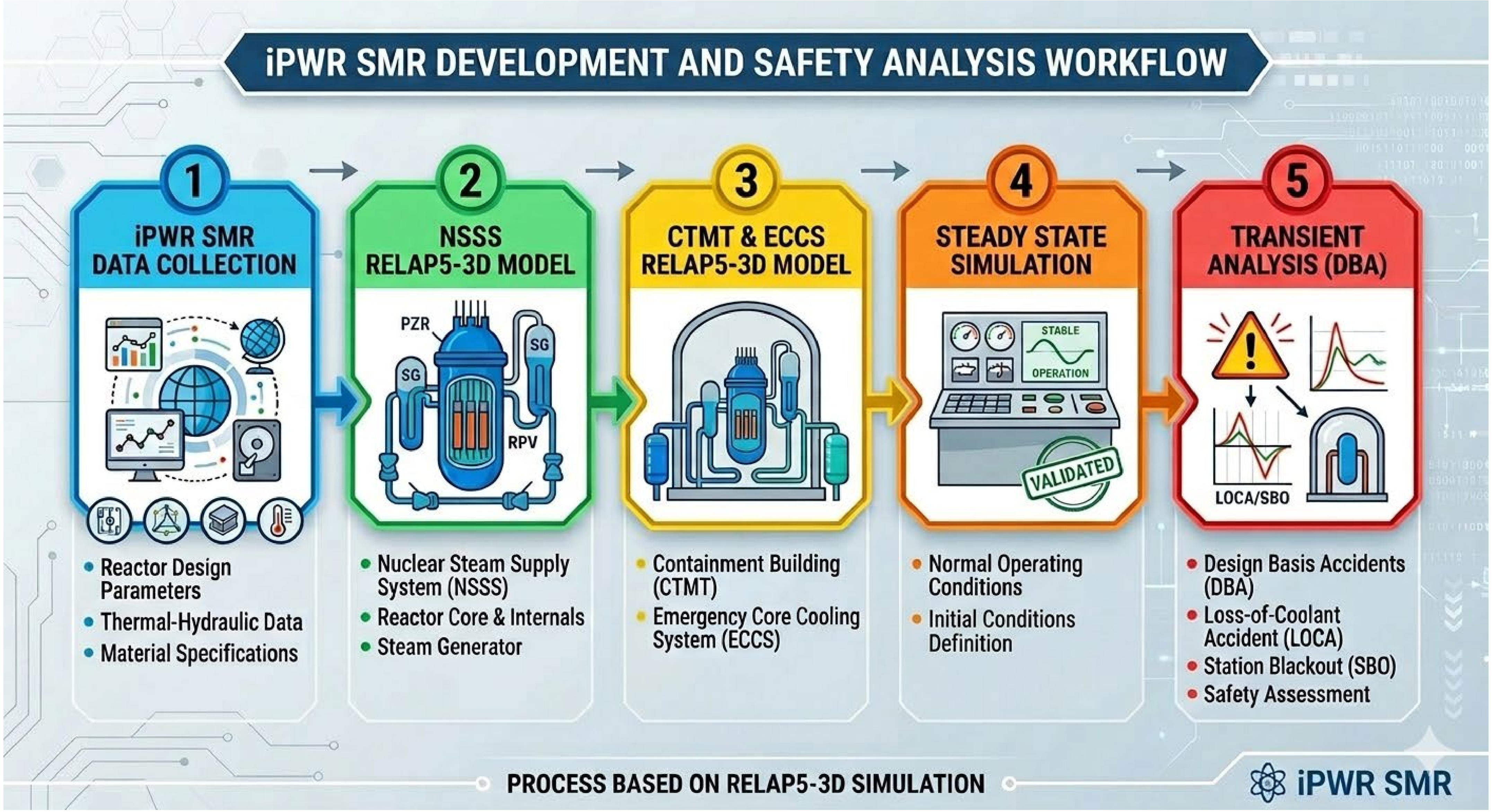
# Introduction-iPWR



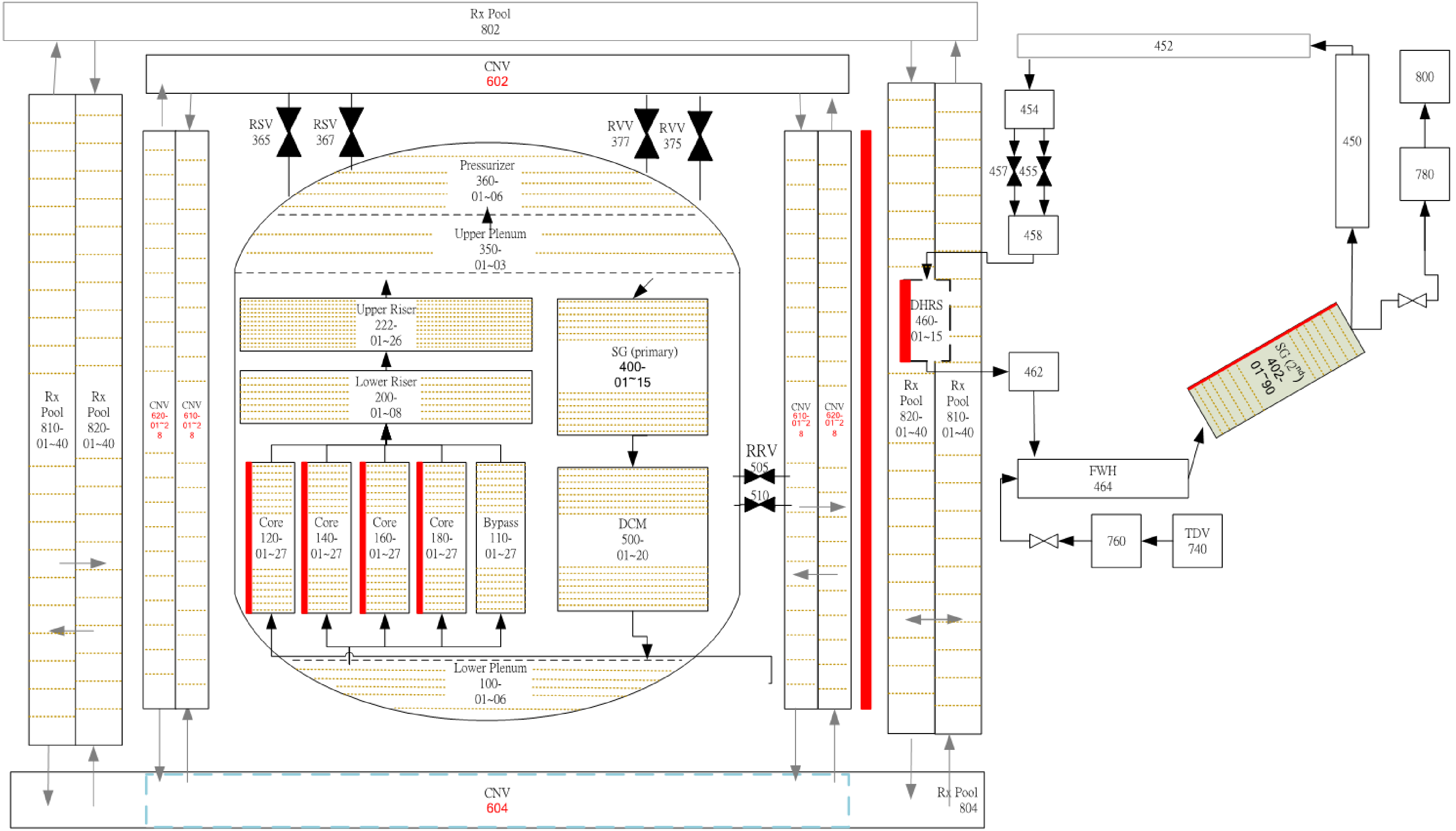

NuScale SMR module

- Integral Reactor Design
- No RCP->Natural Circulation
- HCSG
- Passive Safety system-> DHRS
- ECCS-> RVV & RRV

# Development Process



# iPWR RELAP5-3D model



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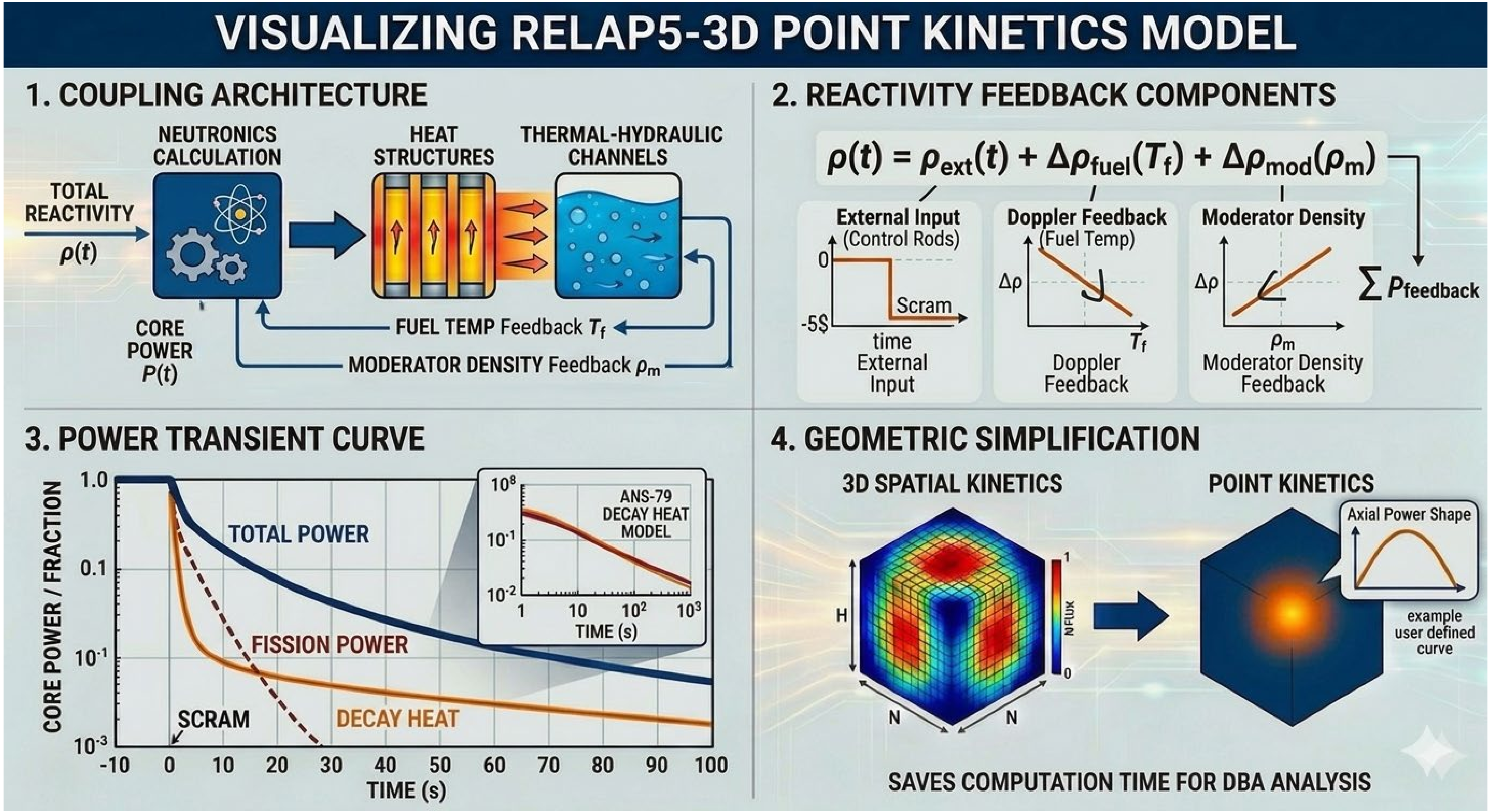


# iPWR RELAP5-3D model

Doppler feedback

1. **Establish the power table steady state.**
2. **Get the htvat ($T_{f0}$)**
3. **Assume FTC=-0.0021 \$/°F，**
   $$R = FTC \times \left(T_f - T_{f0}\right)$$
4. **Generate the Doppler Reactivity Table(300006XX)**
5. **Get the s.s. fuel temperature from output, replace the data into kinetics model deck.**

| * | fuel temperature(F) | reactivity |
|---|---|---|
| 30000601 | 100.0 | 1.50465 |
| 30000602 | 500.0 | 0.66465 |
| 30000603 | 816.5 | 0 |
| 30000604 | 1000.0 | -0.38535 |
| 30000605 | … | … |
| 30000606 | … | … |
| 30000607 | … | … |
| 30000608 | … | … |
| 30000609 | … | … |

```
0   At time=      1500.00      sec        str.no.   mesh point temperatures      (degF)
 4000-001    429.05      460.75
 4000-002    435.77      463.22
 4000-003    442.06      465.55
 4000-004    447.81      467.67
 4000-005    452.77      469.52
 4000-006    457.08      471.13
 4000-007    475.54      490.19
 4000-008    479.37      491.62
 4000-009    482.60      492.83
 4000-010    485.28      493.84
 4000-011    487.52      494.68
 4000-012    489.28      495.34
 4000-013    495.95      503.23
```

# iPWR RELAP5-3D model

RELAP5-3D Reactor Excursion & Leak Analysis Program 2026 IRUG Meeting

## Moderator feedback

$$\mathrm{MDC} = \mathrm{MTC}/\left(\frac{\partial\rho}{\partial T}\right)_P$$

$$\left(\frac{\partial\rho}{\partial T}\right)_P$$

(1)At Pressure=2000 psia，calculate the $(\partial\rho/\partial T)$ under different fluid temperature

**(2)Correlation：**

$1/\left(\frac{\partial\rho}{\partial T}\right)_P$ **v.s. density**

$$\frac{1}{\left(\frac{\partial\rho}{\partial T}\right)_P} = -1.2319\rho + 42.215$$

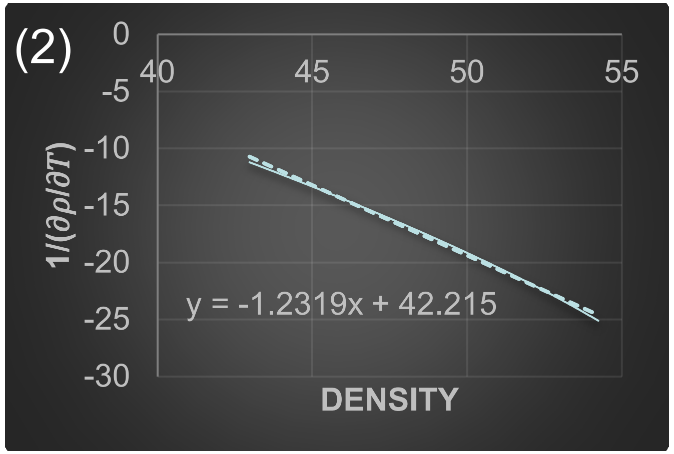
**(3)MDC**

Assume MTC=-0.01 \$/°F,

$$\mathrm{R} = 0.0061595\rho^2 - 0.42215\rho + 6.1823$$

(1)

| T(F) | density@2000psia(lbm/ft3) | drdt(lbm/ft3*F) | 1/drdt(ft3*F/lbm) |
|---|---|---|---|
| 599 | 42.97 | -0.08917 | -11.21463 |
| 590 | 43.75 | -0.08324 | -12.01351 |
| 580 | 44.55 | -0.07776 | -12.86027 |
| 570 | 45.3 | -0.07314 | -13.67151 |
| 560 | 46.02 | -0.06919 | -14.45287 |
| … | … | … | … |
| … | … | … | … |
| … | … | … | … |

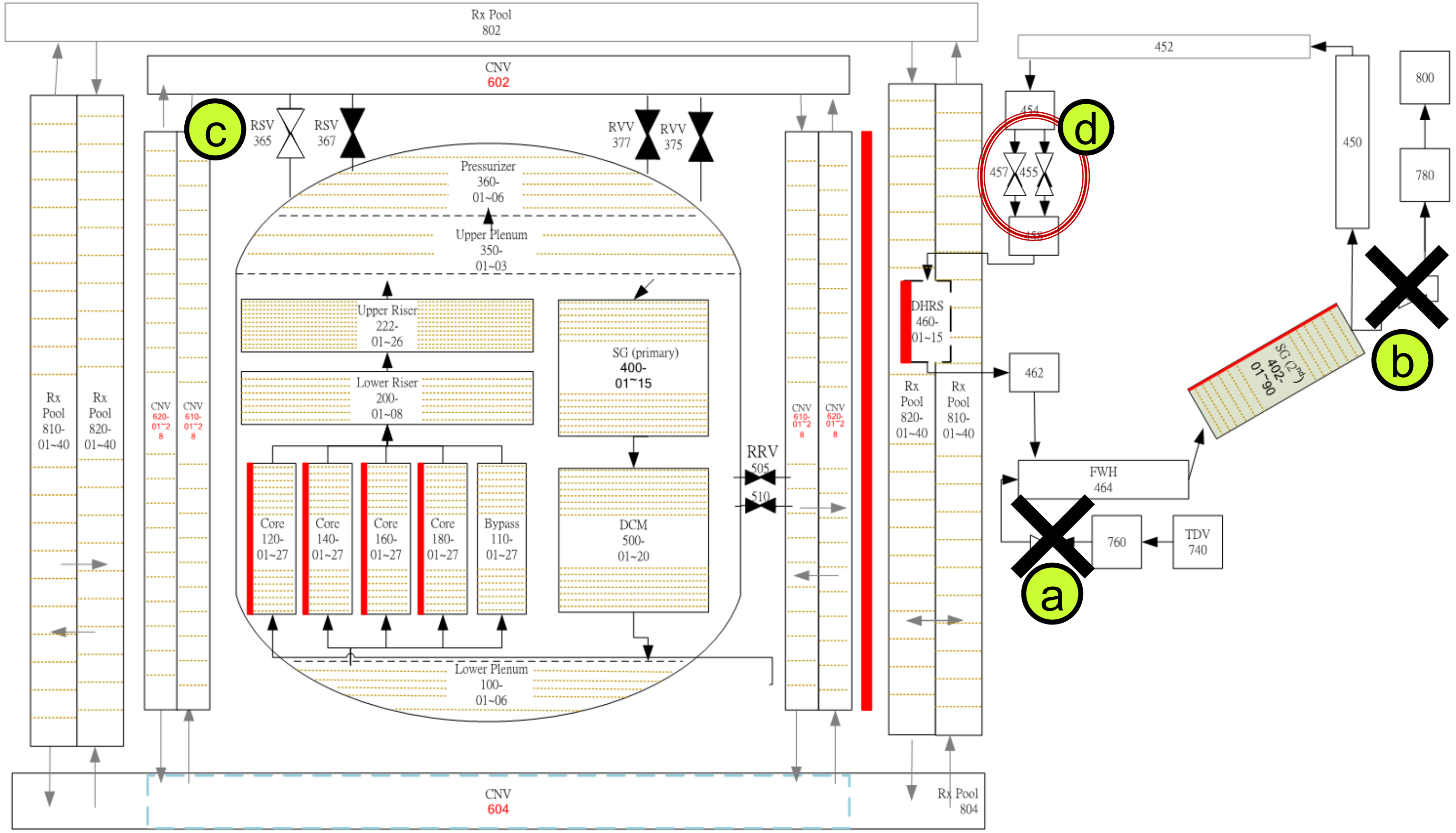



| *(3) | Density(lbm/ft3) | Reactivity(dollars) |
|---|---|---|
| 30000501 | 37.1 | -1.00148 |
| 30000502 | 45.53 | -0.26968 |
| 30000503 | 45.83 | -0.22750 |
| 30000504… | … | |
| 30000505… | … | |
| 30000506… | … | |

# Steady-State Results

| Parameters | FSAR | RELAP5-3D | Differ.(%) |
|---|---|---|---|
| Thermal power (MW) | 250.0 | 250.0 | 0.0 |
| Primary-side mass flow (lbm/s) | 1616.7 | 1622.9 | 0.4 |
| Primary-side pressure (psia) | 2000.1 | 1996.7 | -0.2 |
| Core inlet temperature (°F) | 481.0 | 479.8 | -0.2 |
| Core average temperature (°F) | 540.0 | 538.5 | -0.3 |
| Core outlet temperature (°F) | 599.0 | 597.3 | -0.3 |
| PZR water level (%) | 60.0 | 59.7 | -0.5 |
| Secondary-side mass flow (lbm/s) | 226.6 | 226.6 | 0.0 |
| SG outlet pressure (psia) | 475.0 | 475.5 | 0.1 |
| SG inlet temperature (°F) | 250.0 | 250.1 | 0.0 |
| SG outlet temperature (°F) | 536.0 | 545.0 | 1.7 |
| Core bypass flow (%) | 7.5 | 7.4 | -1.6 |

# Transient (Turbine Trip)




| Sequence of Event | Time(s) FSAR | Time(s) RELAP |
|---|---|---|
| (a)Event initiator - TT and loss of FW flow due to assumed LOOP | 0 | 0 |
| (b)Turbine stop valves fully closed (assumption) | 0 | 0 |
| Reactor trip, SSI and DHRS actuation, PZR heater trip (high PZR pressure 2100 psia) | 7 | 6(4+2) |
| (c)RSV lifts | 8 | NA |
| Peak RCS pressure | 9 | 7 |
| (d)DHRS actuation valves full open | 37 | 36 |

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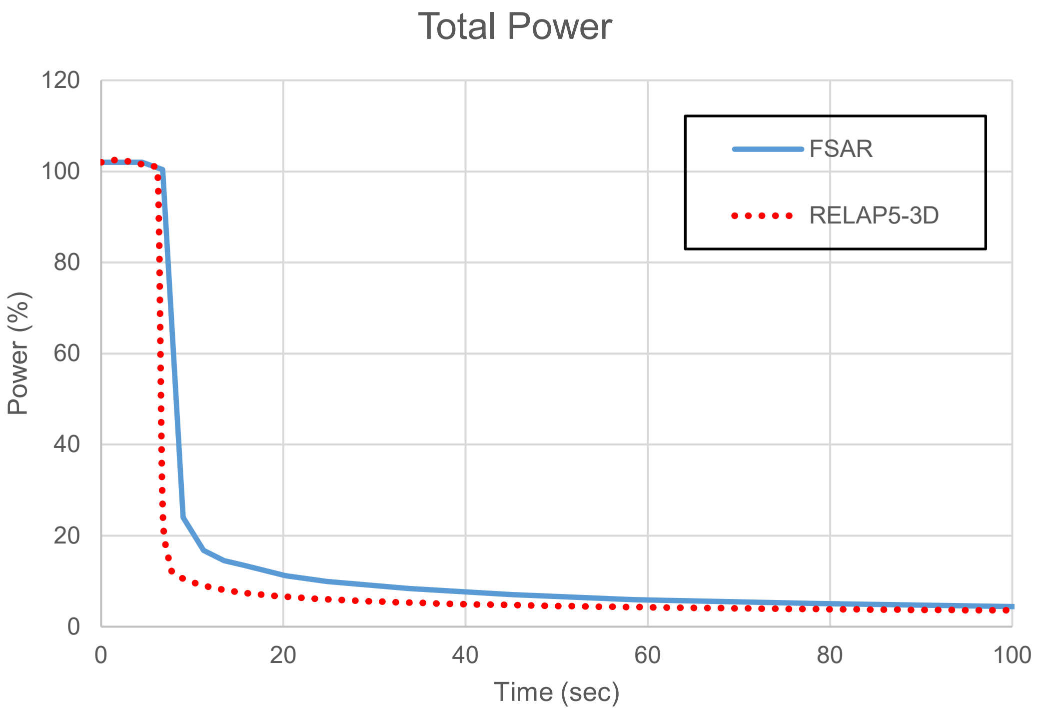


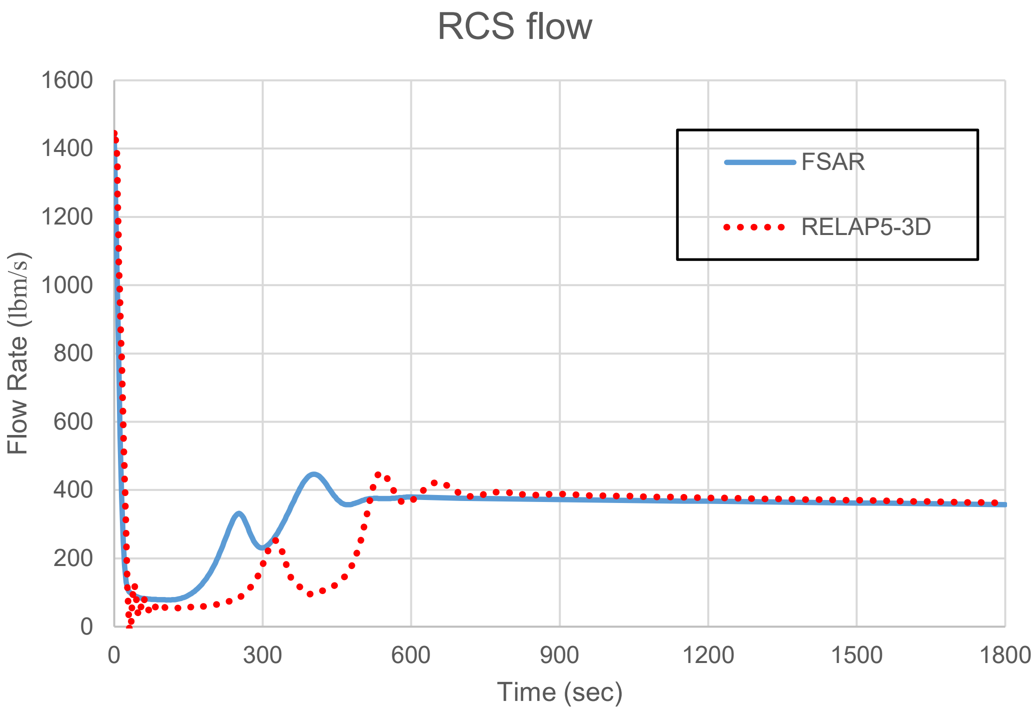

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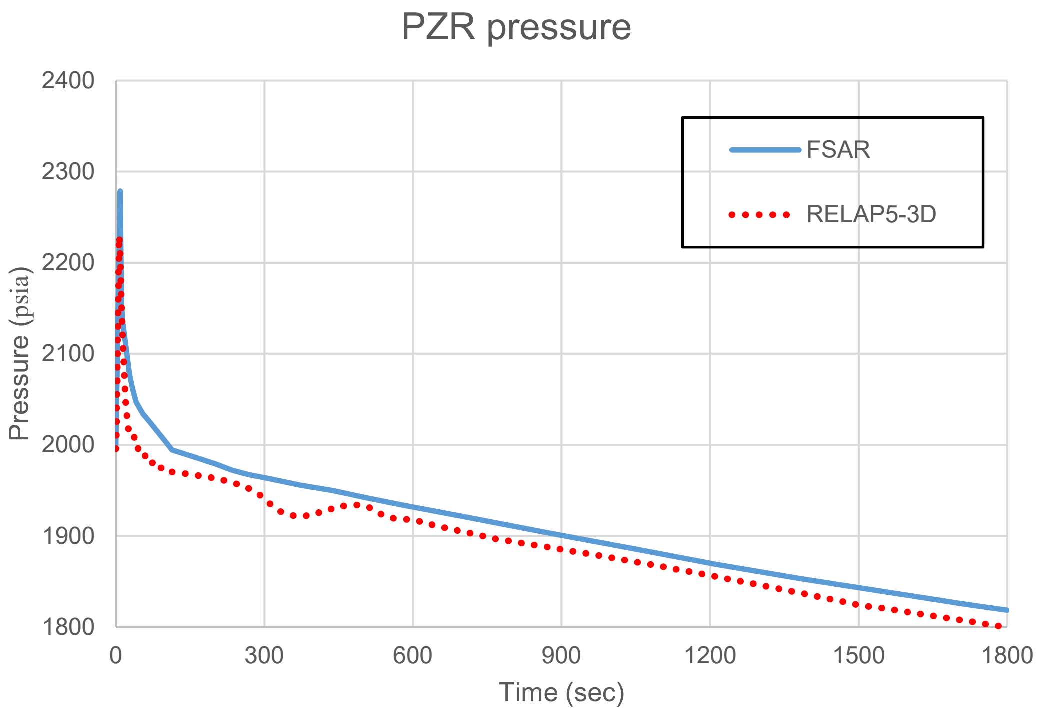
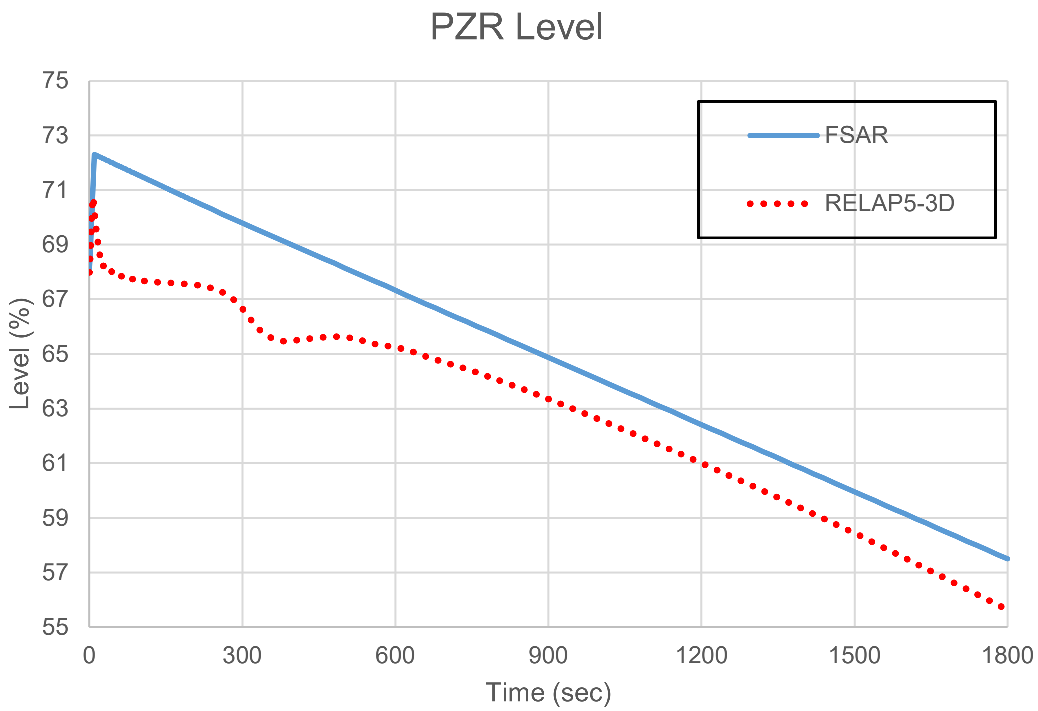
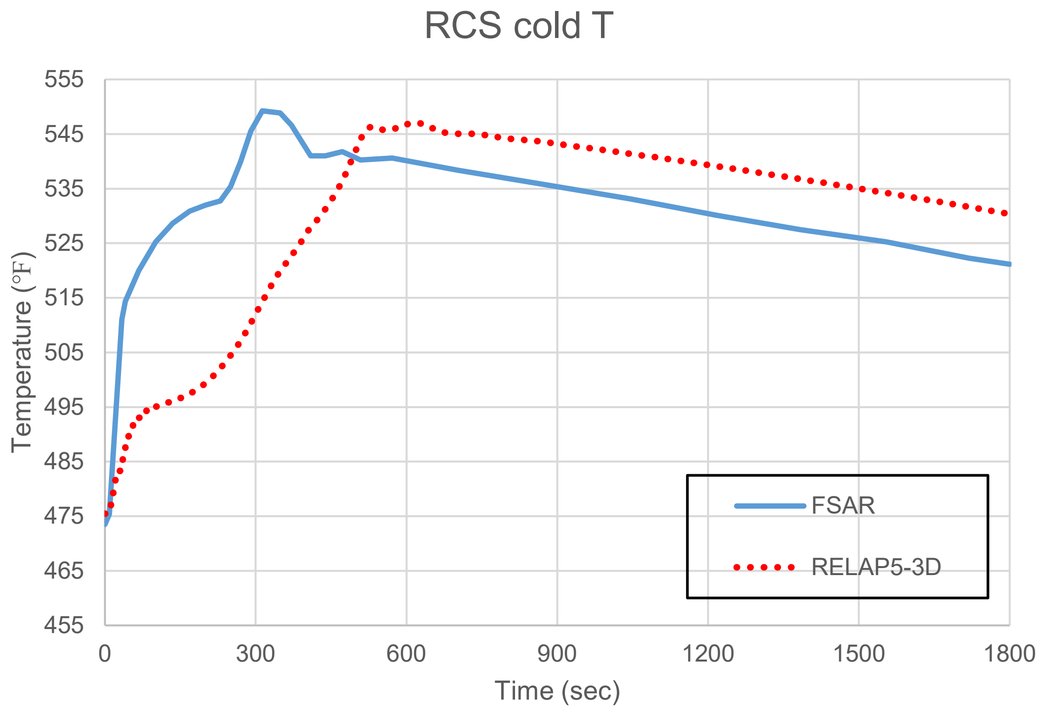
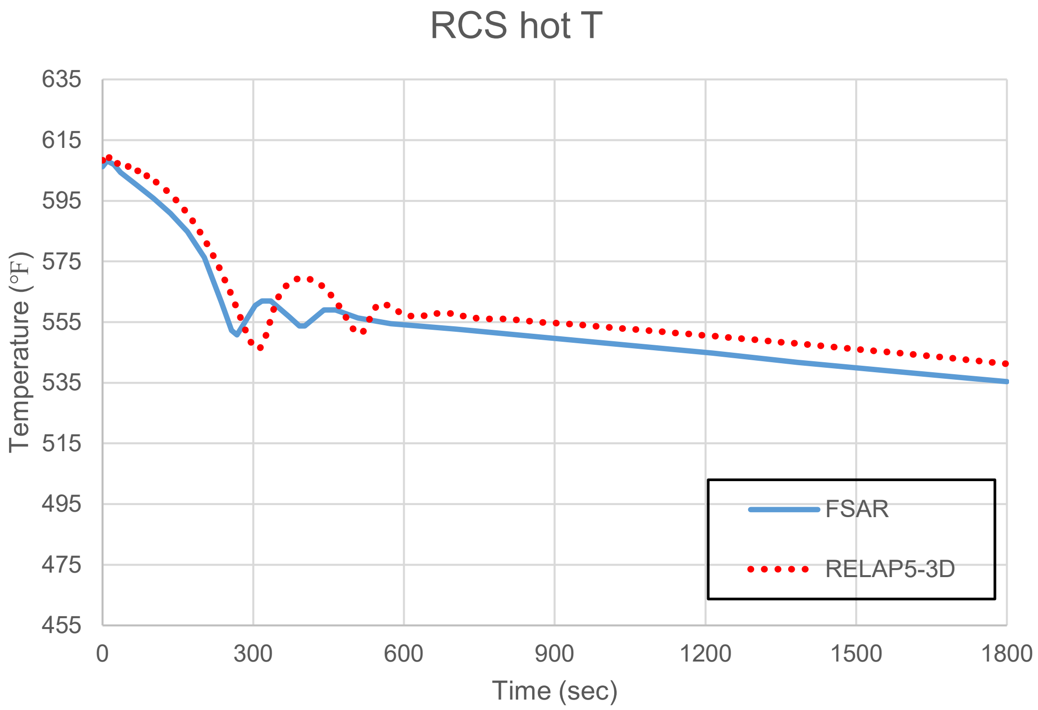



Lower power -> lower pressure-> lower water level

# Transient (Turbine Trip)



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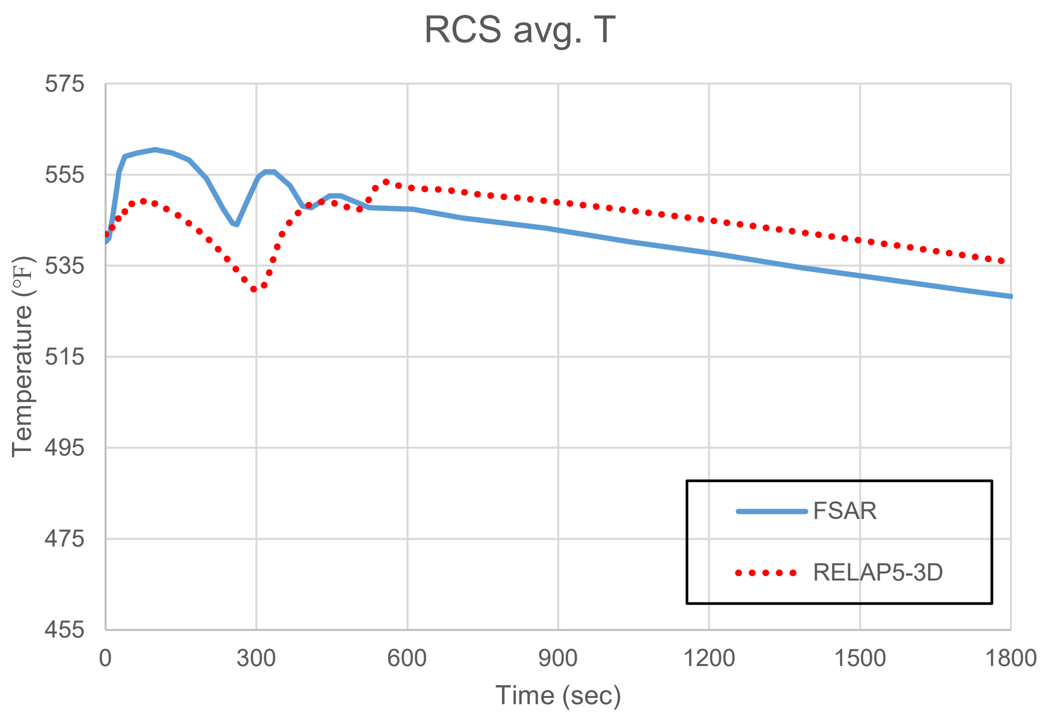


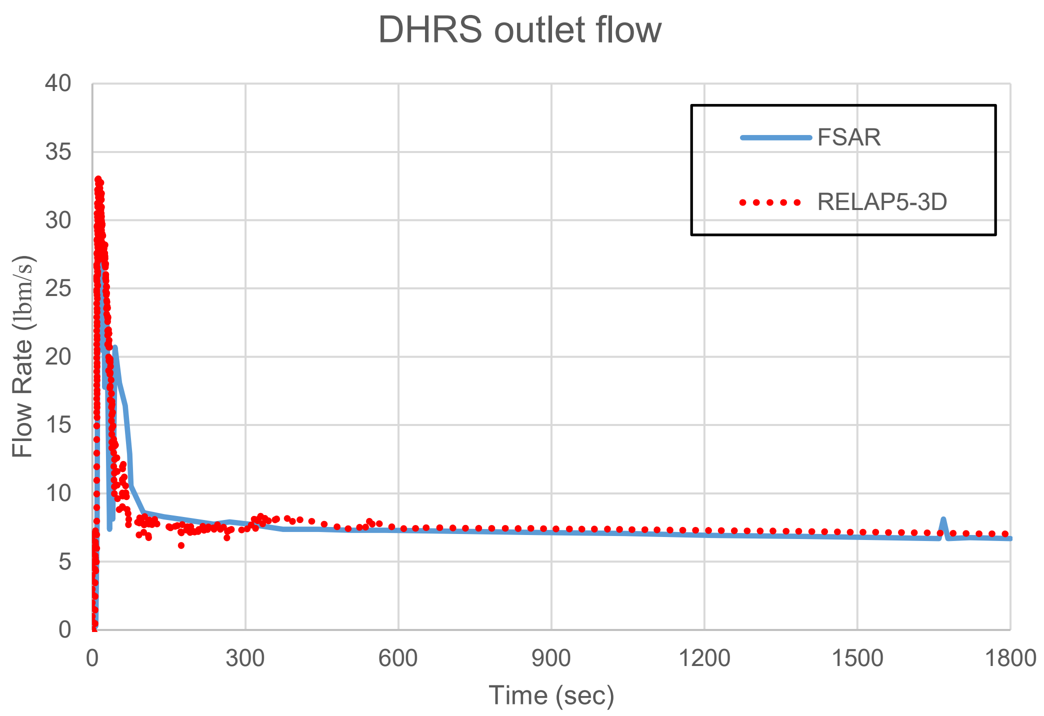

# Transient (Turbine Trip)

## Result discussions:

- Lack of the exact “SCRAM curve ” for the safety analysis.
- FSAR using NRELAP5 which has “HCSG” model.
- This case can benchmark the DHRS flow.

# Future Work

- Sensitivity Analysis, ex: nodalization refinement , scram delay time
- Extension of transient behavior, including LOCA, SBO, etc.
- Combined with VIPRE to calculate MCHFR.
- Other types of SMR.

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National Atomic Research Institute

# Thank You for Your Attention

# Q&A

# Reference


- NuScale Power, LLC, "Standard Design Approval Application, Part 2 – Final Safety Analysis Report," SDA-101, Rev. 1, Nov. 2022. [Online]. Available: NRC ADAMS Accession No. ML22365A006.
- P. Freitag, “Transient Thermal-hydraulic Simulation of a Small Modular Reactor in RELAP 5,” M.S. thesis, Dept. of Mechanical, Industrial and Systems Engineering, University of Rhode Island, 2018.
- K. Skolik, C. Allison, J. Hohorst, M. Malicki, M. Perez-Ferragut, L. Pieńkowski, and A. Trivedi, “Analysis of loss of coolant accident without ECCS and DHRS in an integral pressurized water reactor using RELAP/SCDAPSIM,” *Progress in Nuclear Energy*, vol. 134, Art. no. 103648, 2021, doi: 10.1016/j.pnucene.2021.103648