Perspective on the audit calculation for SFR using TRACE code

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1. Introduction

Korean Sodium Cooled Fast Reactor (SFR) is being developed by KAERI. The Prototype SFR will be a first SFR applied for licensing. KINS started research programs for preparing new concept design licensing recently. Safety analysis for the certain reactor is based on the computational estimation with conservatism and/or uncertainty of modeling.

For the audit calculation for sodium cooled fast reactor (SFR), TRACE code is considered as one of analytical tool for SFR since TRACE code have already sodium related properties and models in it and have experience in the liquid metal coolant system area in abroad. Applicability of TRACE code for SFR is pre-checked before real audit calculation. In this study, Demonstration Fast Reactor (DFR) 600 steady-state conditions [1] is simulated for identification of area of modeling improvements of TRACE code.

2. DFR-600 geometry modeling

KAERI developed DFR-600 st.-st input decks for MARS-LMR code and used for component analysis and system transient analysis.[1] Based on the MARS-LMR's input deck provided by KAERI, overall geometry of DFR-600 is modeled with TRACE ver.5 Patch 3[2] include 6-channel reactor core, hot and cold reactor pool, IHX, DHX, SG and AHX etc. Material properties are also used the exact value of the designer's.

2.1 Sodium Related models of TRACE code

Sodium properties and Equation of State (EOS) of liquid sodium has already implemented in TRACE codes as well as heat transfer correlation for liquid metal coolants including lead-bismuth.

TRACE code uses Lyon-Martinelli heat transfer correlation for sodium coolant [3] and sodium properties such as density, thermal conductivity and viscosity has compared with MARS-LMR's[5] and ANL's [4] value and have nearly similar values. However enthalpy vs. temperature shows about 10% discrepancies with respect to the designer's and lower heat transfer correlation.

Enthalpy equation difference could give higher or lower temperature calculation for heat transfer regions in core and heat exchangers. Otherwise, the thermal conductivity gives minor difference during steady-state calculations. During transient calculations, other properties including thermal conductivity variations are need to be considered for more precise prediction.

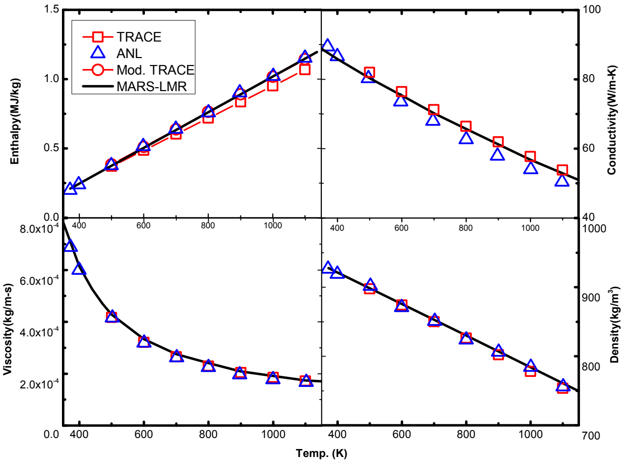

Fig. 1. Sodium properties comparison between TRACE, MARS-LMR and ANL correlation.

2.2 Modeling descriptions

Overall geometry of DFR-600 is modeled with TRACE code. Core composed with 6 channels representing inner/outer/hot core, control rods, reflectors and internals. PHTS modeled with core, hot pool and cold pool, 4-IHXs, 2-DHXs, 2 Primary Pumps. IHTS is modeled with tube side of IHX, piping and shell side of 2 SGs. RHRS is composed with 2 PDRCs and 2 ADRCs in the design. In modeling, one PDRC and one ADRC with double heat transfer capability.
PDRC has equipped with FDHX with blower and damper and ADRC with AHX. These feature also modeled but it is limited st.-st. condition for normal operation to heat transfer to RHRS.
MARS-LMR code have special model for friction factor for wire-wrapped fuel. Core friction factors are re assigned for TRACE modeling in each channel.

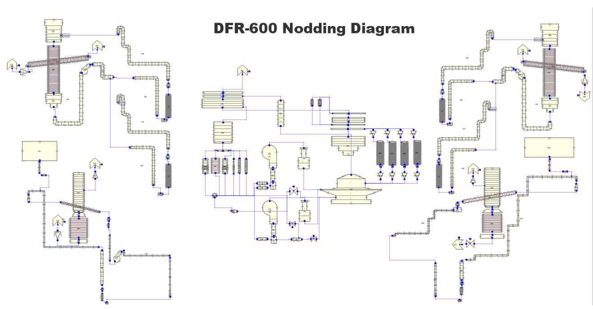

Fig. 2. TRACE nodding diagram for DFR-600.

2.3 Steady-state calculation with original TRACE model

With the designed primary/secondary flow rate and inlet sodium temperature, core power, and heat transfer to RHRS, original TRACE calculated higher core outlet temperature and intermediate heat exchanger outlet temperature. This estimation caused by enthalpy difference at certain temperature elevation between codes. With the modification of enthalpy equation of TRACE code to the MARS-LMR's and ANL's value, the designed temperature difference between inlet and outlet was achieved.

Another finding during heat exchanger modeling is that node size effect is bigger than expected. Most of the sodium to sodium heat exchanger is based on counter current flow and high temperature change within heat exchangers. This needs finer node size than LWR system modeling. It was also pointed out in DFR-600 simulation with MARS-LMR code.[1] Therefore node size effect could be a check point for SFR modeling with system codes.

3. DFR-600 St.-St calculation result with modified TRACE code

Checking for the plant system energy balance and other parameter predictability, st.-st. conditions of DFR-600 is simulated with TRACE model with modified enthalpy equation. Major design parameters [1] are compared with TRACE calculation result as below

Table I: TRACE code St.-St calculation result

	DESGIN (K/MW/kg/s/,m)	TRACE prediction
CORE		
I/O T.	638.15/783.15	637.92/784.08
Power	1548.2	1548.2
m. flow	8366.1	8365.8
IHX		
I/O T.	578.55/775.15	580.43/778.94
Power	387.5	386.3
m. flow	3073	3072.98
SG		
Power	775	772.37
m. flow	344.7	344.7
DHX power	4.7	3.02

Major object of this study is applicability and identification of model improvements for TRACE code to SFR system. Possibility of simulation of st.-st. condition of DFR-600 concept design is first stage goal with TRACE code especially primary pool and intermediate loop.

Residual Heat Removal System specific design feature during normal operation is presented with power only. Assumptions are used to adjust heat removal by DHX such as RHRS coolant mass flow/temperature, AHX air mass flow/temperature and piping. Another assumption is used the power of primary and intermediate pumps is not modeled. So, IHX and SG power estimation is lower than design value.

With considering above assumptions, TRACE calculation results showed good agreement with design parameters such as power, mass flow and temperatures.

One of special merit of TRACE code is use of SNAP combined animation. SNAP animation could enhance efficiency of modeling and analysis of new design. In addition to the TRACE code input deck for DFR-600, animation model for the system also developed and utilized during st.-st. calculation. It would be used future analysis work for transient analysis.

4. Conclusions

TRACE code input deck and SNAP animation model for DFR-600 is developed. Steady State calculation shows that TRACE code can be used as a system analysis tool to evaluate SFR system and identify uncertain area during calculation.

In the system modeling with the system code, material property including sodium coolant and heat transfer correlation, needs to be validated with experiment evidence and validation effort and nodding and reasonable use of K-factor is another checking point for system evaluation. All of these are being issued even in LWR system evaluations.

For the transient analysis, component based evaluation and validation is needed. Most important component for SFR system analysis is RHRS because residual heat removal only relies on this passive system.

Based on the modeling for DFR-600 for st.-st., analytical model and component based research and transient analysis is planned for further SFR research on thermal-hydraulic area.

DFR-600 based calculations are aimed to prepare audit calculation of safety analysis for the prototype sodium cooled reactor so called "MIRERO" Modeling and analysis for the MIRERO will followed with DFR-600 study with TRACE code.

REFERENCES

[1] G.S. Ha, et at. Safety Evaluation for Transients of Demonstration SFR, KAERI/TR-4288/2011/, Feb. 2011
[2] TRACE V5.0 Theory Manuel, USNRC, 2010
[3] Konstantin Mitkityuk, Heat transfer to liquid metal: Review of data and correlations for tube bundles, Nuclear Engineering and Design, Vol.239, p. 680-687, 2009.
[4] C.B. Davis. Applicability of RELAP5-3D for Thermal-Hydraulic Analyses of a Sodium-Cooled Actinide Burner Test Reactor, INL/EXT-06-11518, July 2006
[5] G.S. Ha, et at. Development of MARS-LMR and steady-state Calculation for KALIMER-600, KAERI/TR-3418/2007, May 2007