# Development of a Safety Analysis Code for a Supercritical Water Cooled Reactor (SCWR)

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## 1. Introduction

Supercritical water-cooled reactor (SCWR) has been selected by GIF (Generation IV International Forum) as one of the promising nuclear reactor for the future and research activities are going on worldwide. SCWR design is considerably simple compared with current light water reactor (LWR) designs and consequently results in capital cost reduction. Also, very high thermal efficiency up to about 45% is possible in SCWR due to high core outlet temperature.

In this paper, a computer code, TASS/SCWR is presented for the safety analysis of a SCWR. It is based on TASS/SMR[1] that is a safety analysis code for the SMART reactor. Relevant mathematical models are implemented for the application to supercritical water. Several test calculations have been carried out for the validation of TASS/SCWR.

Since the coolant density change in the core is large for SCWR compared to that of the conventional PWR, a passive safety system driven by gravity force is possible. A passive residual heat removal system (PRHRS) is proposed for the SCWR. The core flow after the feedwater trip is supplied by the PRHRS instead of the active safety systems such as reactor core isolation cooling (RCIC) and auxiliary feedwater systems (AFS).

## 2. Mathematical Models

The reactor coolant system thermal-hydraulic model is formulated with five one-dimensional conservation equations of two-phase flow. The conservation equations are the following.

Conservation of mixture mass:

$$\frac{dM}{dt} = \sum_i W_i \qquad (1)$$

Conservation of liquid mass:

$$\frac{dM_l}{dt} = \sum_i (1 - x_i)W_i + W_{cond} \qquad (2)$$

Conservation of mixture energy:

$$\frac{dE}{dt} = \sum_i h_i W_i + Q \qquad (3)$$

Conservation of steam enthalpy:

$$\frac{dH_s}{dt} = \sum_i x_i W_i h_{s,i} + Q_{stm} - W_{cond} h_s \qquad (4)$$

Conservation of mixture momentum:

$$\frac{1}{g}\frac{L}{A}\frac{dW}{dt} = (P_{up} - P_{down}) - K_f \frac{W|W|}{2\rho g A^2} + \Delta P_{elev} \qquad (5)$$

The summations in the above equations are over all momentum paths connected to each given node. After the integration of the conservation equations, pressure is calculated using the equation of state considering the node thermal-hydraulic state (i.e. subcooled/saturated liquid, superheated/saturated steam).

Thermodynamic properties of supercritical water or steam are calculated using IAPWS-IF97[2] formulation. The fission power input to the fuel is found from the reactor kinetics equations with six delayed neutron groups. ANS73 decay heat curve has been incorporated into the database. Heat transfer correlations and conduction equations are modeled for the calculation of heat generation in the core and heat removal in the PRHRS.

## 3. Analysis Results

### 3.1 Validation

A set of test calculations is performed to validate the numerical models implemented in the TASS/SCWR. The node and flow path geometry is shown in Fig. 1.
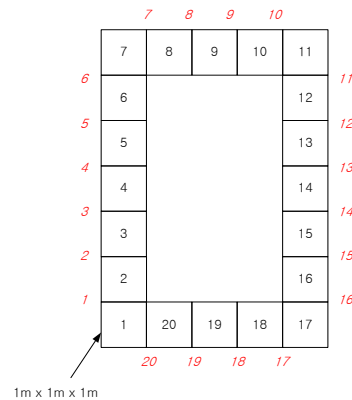


Figure 1. Test geometry of TASS/SCWR

For the first case, heat is removed at a rate of 20 MW during 100 seconds. Initial fluid temperature is 500 °C at 25 Mpa. In this calculation, the conservation of physical properties and numerical instability is tested when the system pressure drop below the critical pressure. Figures 2 and 3 show a good conservation and stable results.

Above the supercritical pressure, the specific heat is very large near 380 °C called pseudo-critical point. For the second case, the natural circulation is simulated when the fluid average temperature change near the pseudo-critical point. The flow rate shows a minimum value near 380 °C in Fig. 4. The calculated specific heat well agrees with the exact value in Fig. 5.

For the last case, a natural circulation condition is simulated using the TASS/SCWR and MARS[3] codes and the results are compared. Initial pressure and temperature is 25 Mpa and 300 °C respectively. 10 MW power is supplied to node 2 and removed from node 12. Figures 6 and 7 compare fluid density and temperature calculated by TASS/SCWR and MARS, which show a good agreement.
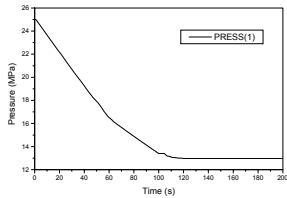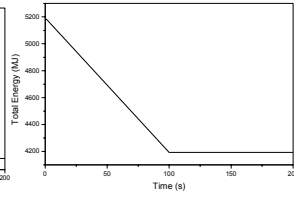


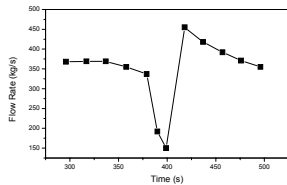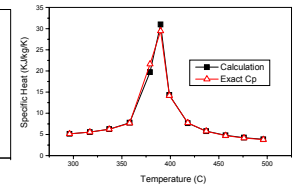Figure 2. Pressure



Figure 3. Total Energy



Figure 4. Flow rate
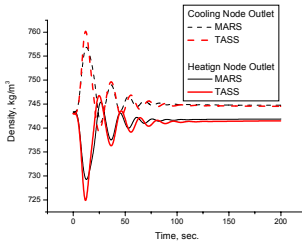


Figure 5. Specific Heat
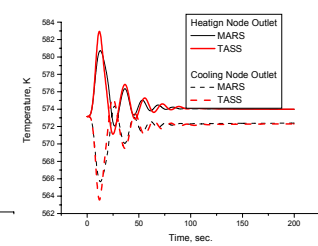


Figure 6. Fluid density



Figure 7. Temperature

*3.2 A Passive Safety System for the SCWR*

A passive safety system has been proposed for the SCWR. It is composed of PRHR heat exchanger, PRHR tank, and compensation tank. Feasibility study on the passive safety system without compensation tank had been performed[4], and the results showed that the core cooling was important just after the feedwater loss. In the present study, compensation tanks are installed at the upstream of PRHR heat exchanger to mitigate initial core heat-up. Figure 8 shows the nodalization of TASS/SCWR for the SCWR with PRHRS. The safety analysis for the current design is now in progress.

## 4. Conclusion

A safety analysis code TASS/SCWR has been developed for the application to a SCWR. A set of test calculations has been carried out for the developed models. Any mathematical and numerical problems are not found in the test calculation and the results of TASS/SCWR and MARS codes showed a good agreement. TASS/SCWR will be applied to the safety analysis of the SCWR with PRHRS.
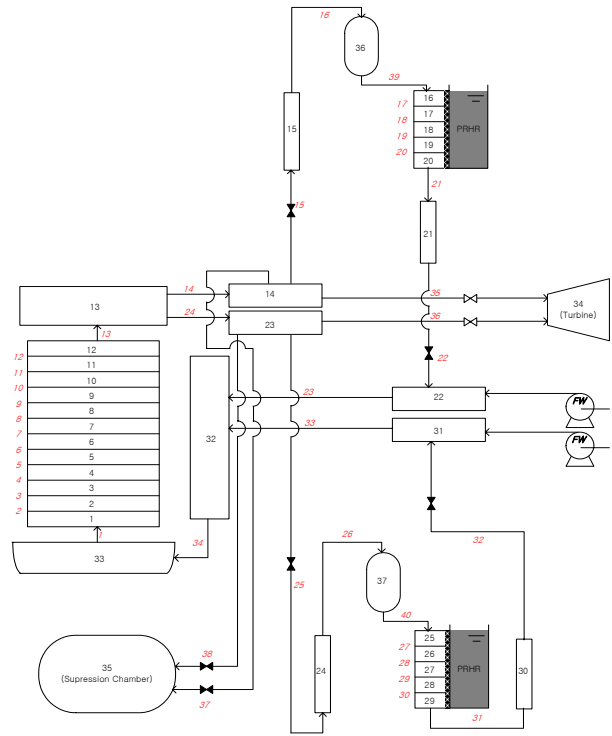


Figure 8. Nodalization of TASS for SCWR

## REFERENCES

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[3] B. D. Chung et al., MARS3.0 Code manual input requirements, KAERI/TR-2811/2004, Korea Atomic Energy Research Institute, 2004.

[4] H. Y. Yoon and Y. Y. Bae, Feasibility Study of a Passive Safety System for a Supercritical Pressure Water Cooled Reactor, GENES4/ANP2003, Sep. 15-19, 2003, Kyoto, JAPAN.