A Parametric Study of the Thermal-Hydraulic Response of SCWRs During Loss-of-Feedwater and Turbine-Trip Events

Cliff B. Davis
Jacopo Buongiorno
Philip E. MacDonald

2003 RELAP5 International User’s Seminar
West Yellowstone, Montana

August 27 - 29, 2003
Introduction

• The INEEL is studying the feasibility of a thermal-spectrum reactor cooled by light water for electric power production because of the potential for improved economics compared to current light-water reactors.

• The purpose of this analysis was to perform simple parametric calculations of a preliminary design of a supercritical water reactor (SCWR) to characterize the response to various transients so that the required response times and capacities for various safety systems could be determined.

• The results from the analysis are being used in the design of various safety systems.
**Introduction (continued)**

- The analysis was performed using RELAP5-3D, which is being improved to support analysis of the SCWR.
  - Improvements have been made to the water properties, solution scheme in the supercritical region, and additional heat transfer and wall friction correlations applicable to supercritical conditions
- Used a cladding temperature limit of 840°C to evaluate transient response
- This work was funded through a DOE Nuclear Energy Research Initiative project
The design under consideration

- Utilizes a once-through direct cycle with a conventional reactor vessel
- Contains 157 square canned fuel assemblies that each contain 217 fuel rods and 36 moderator boxes
- Utilizes conventional UO2 fuel
- Achieves thermal neutron spectrum with moderator boxes that contain solid zirconium hydride
- Utilizes Ni based Alloy 718 for the fuel rod cladding
- Has the potential for improved economics because of plant simplification (lack of steam generators, pressurizer, steam separators) and high thermal efficiency
Illustration of the SCWR design
The RELAP5 model has features similar to PWRs and BWRs

- Contains 3 parallel core channels
- Represents 3 core bypass paths
- Uses inlet orifices to balance the flow
- Boundary conditions are used to represent the feedwater and main steam systems
- Transient reactor power calculated with a best-estimate point kinetics model
Additional heat transfer data are required to analyze the SCWR during off-normal operation and transients. 

- Maximum cladding temperature
- Steady state
- Power-to-flow ratio held constant
- Used popular SCW heat transfer correlations
- Extrapolation for normalized power < 0.7 - 1.1
The loss-of-feedwater and turbine-trip transients were evaluated because

- SCWR is a once-through direct cycle without coolant recirculation in the reactor vessel
  - Loss of feedwater is important because
    - It results in rapid undercooling of the core
    - It is a moderate-frequency (Condition II) event that must not result in any significant damage to the fuel
- Average coolant density is low in the SCWR core and pressurization events result in significant positive reactivity insertion
  - Turbine trip without steam bypass has the potential to cause a significant increase in reactor power
Parametric calculations for loss of feedwater investigated the effects of

- Main feedwater (MFW) coastdown time (0 to 10 s)*
- Scram (with and without)*
- Auxiliary feedwater (AFW) flow rate (10-30% of rated feedwater)
- Steam relief (20-100% capacity)
- Step changes in MFW flow rate (25-100%)
- Coolant density reactivity feedback (nominal and high)*

* Described in paper
Transient temperature limit met when AFW flow exceeded 15%

- 5-s MFW coastdown
- Scram
- Constant pressure
Temperature limit met for 50% step change in MFW flow

- No scram
- No AFW
Fast-opening 100%-capacity turbine bypass system helps significantly

- 5-s MFW coastdown
- Scram
- No AFW
Parametric calculations of a turbine trip without steam bypass investigated the effects of

- Scram

- Safety relief valve (SRV) capacity (0 - 90%)
Pressure response following a turbine trip is acceptable

- Instant control valve closure
- Continued MFW at rated flow
- Required SRV capacity reasonable
Small increase in reactor power following turbine trip

- Instant control valve closure
- Continued MFW
- Comparable event in BWR4 resulted in a 170% power increase
Conclusions

• SCWR with solid moderator rods can tolerate a 50% step change in MFW flow without scram

• Transient temperature limit can be met following a total loss of MFW if AFW flow exceeds 15% of initial MFW flow

• AFW flow requirements can be reduced by
  – Fast-opening 100%-capacity turbine bypass
  – Higher feedback coefficients typical of designs with water rods

• Acceptable pressure response following turbine trip without steam bypass if the SRV capacity is greater than 90%

• Power increase following turbine trip without steam bypass and with full MFW flow is much smaller than in comparable BWRs