Idaho National Engineering and Environmental Laboratory

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

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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*

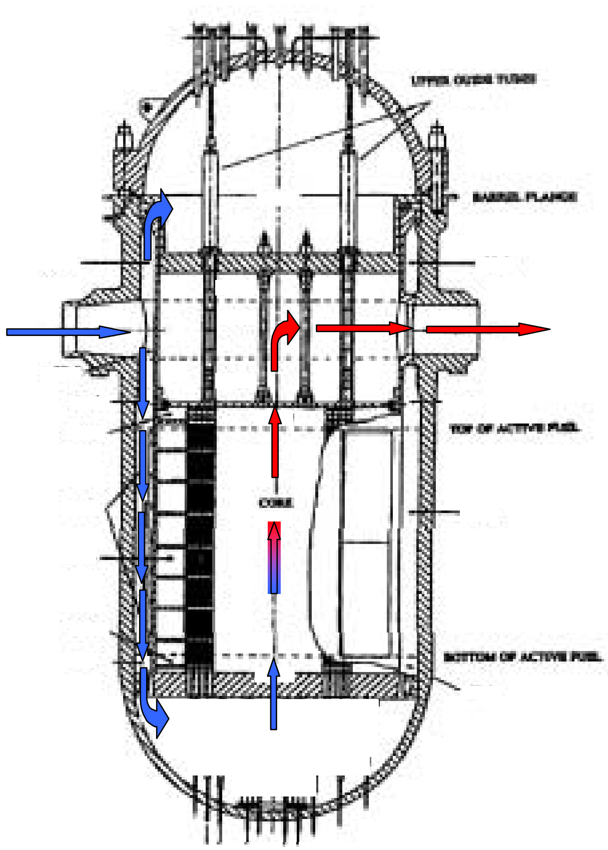
Introduction (continued)

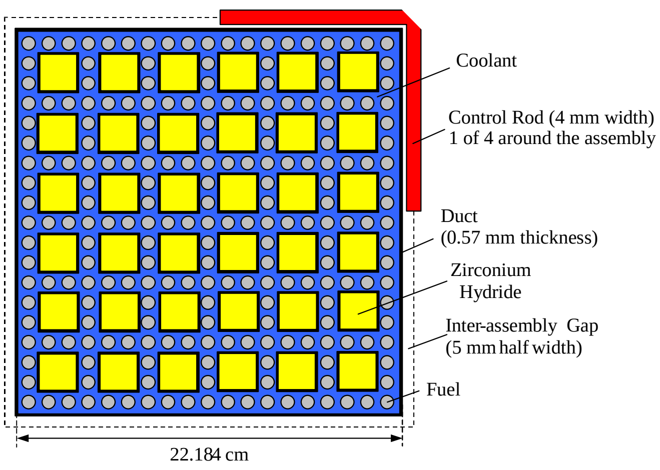
- *The analysis was performed using RELAP5-3D, which is being improved to support analysis of the SCWR.*
  - *Improvements have been made to the water properties, solution scheme in the supercritical region, and additional heat transfer and wall friction correlations applicable to supercritical conditions*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

The design under consideration

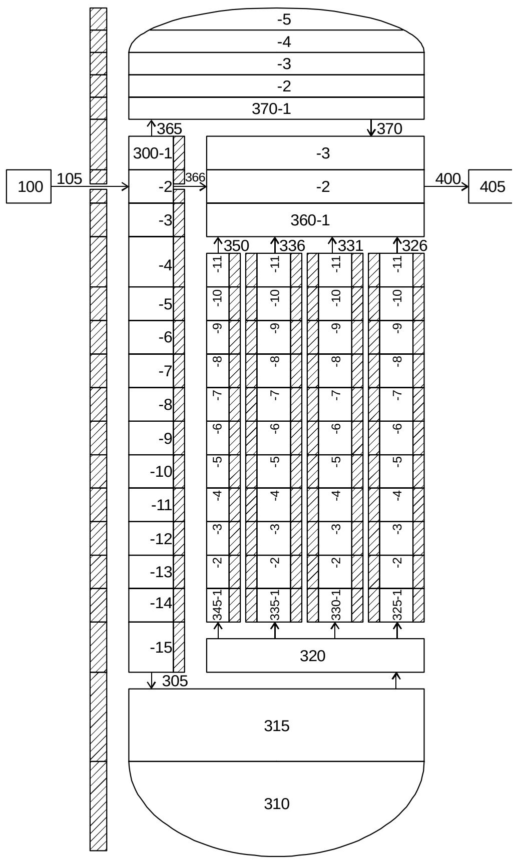
- *Utilizes a once-through direct cycle with a conventional reactor vessel*
- *Contains 157 square canned fuel assemblies that each contain 217 fuel rods and 36 moderator boxes*
- *Utilizes conventional UO2 fuel*
- *Achieves thermal neutron spectrum with moderator boxes that contains solid zirconium 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



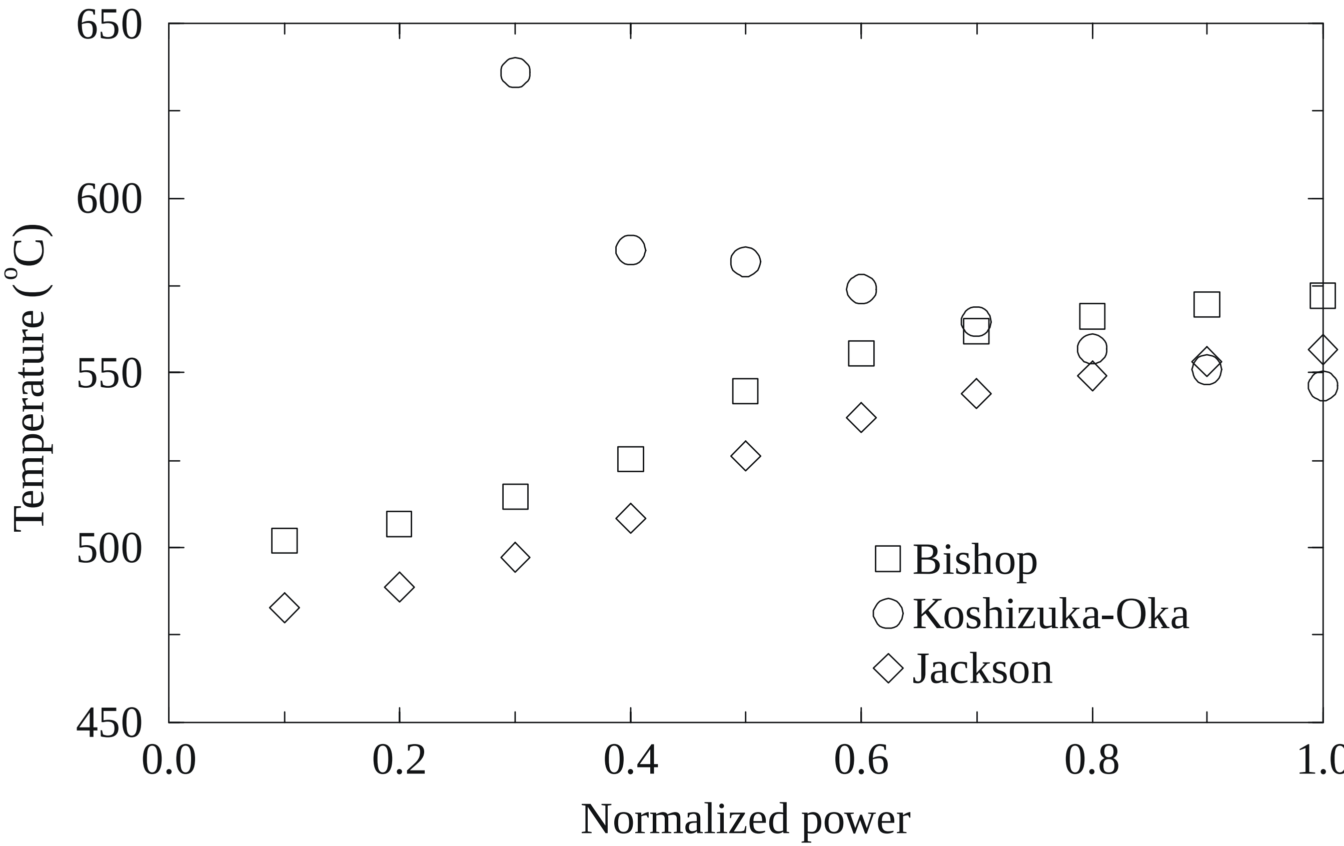


The RELAP5 model has features similar to PWRs and BWRs



- 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

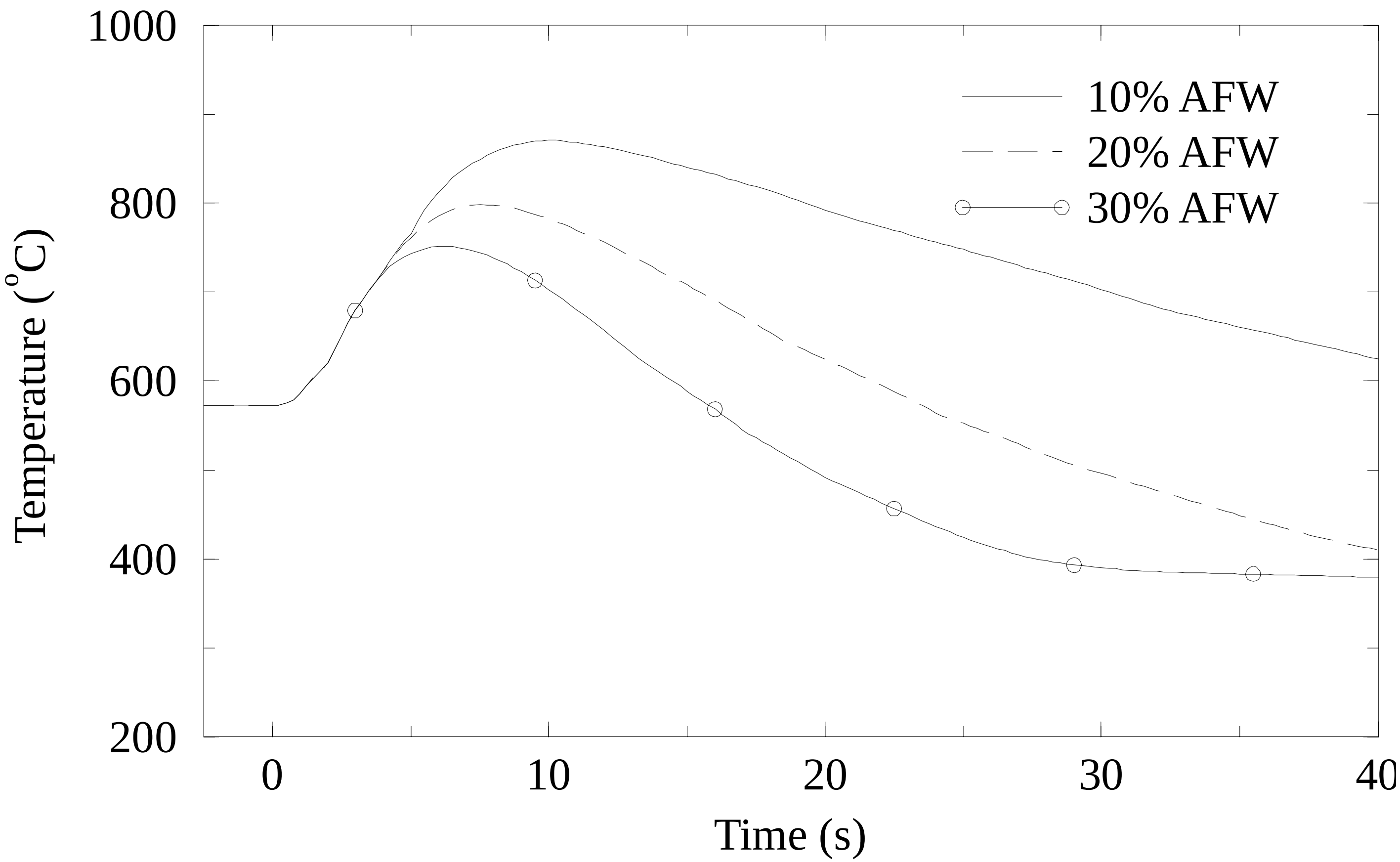
- *SCWR is a once-through direct cycle without coolant recirculation in the reactor vessel*
  - *Loss of feedwater is important because*
    - *It results in rapid undercooling of the core*
    - *It is a moderate-frequency (Condition II) event that must not result in any significant damage to the fuel*
- *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)**

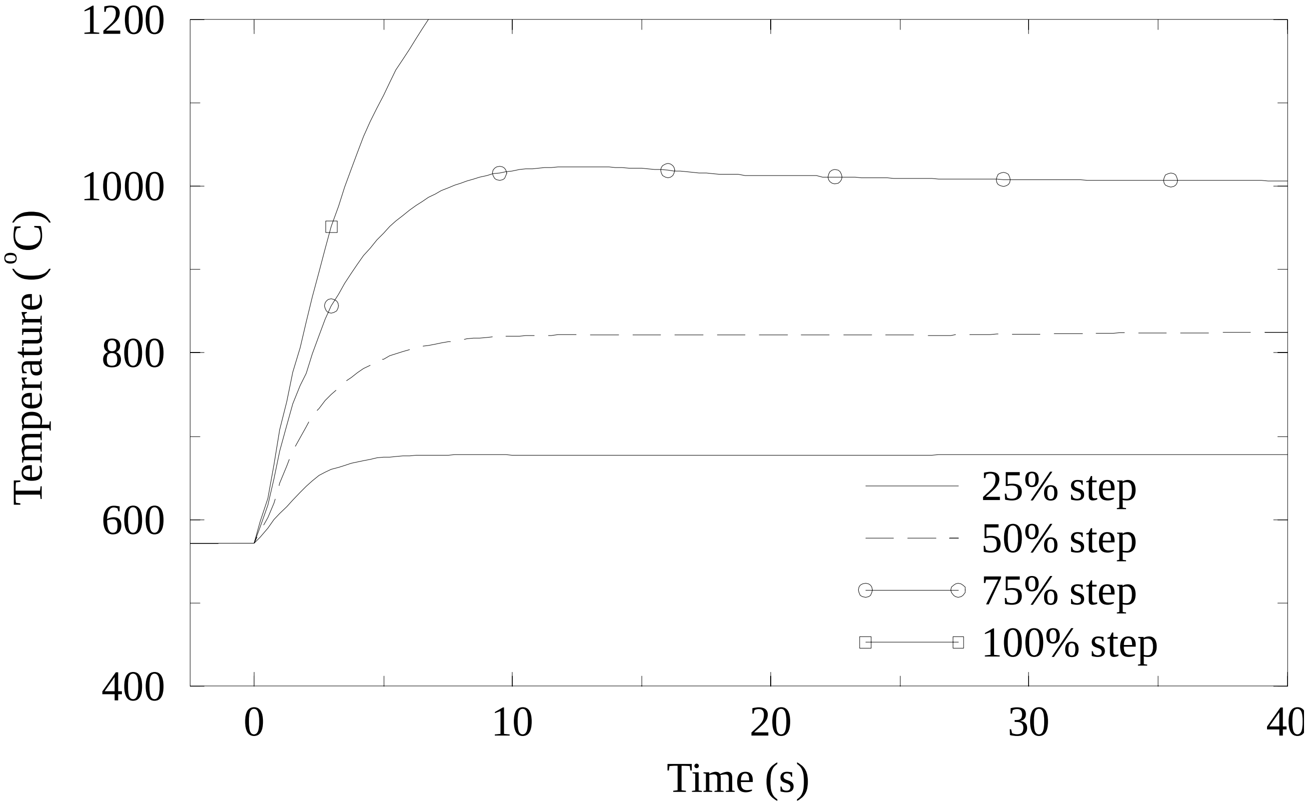
** Described in paper*

Transient temperature limit met when AFW flow exceeded 15%



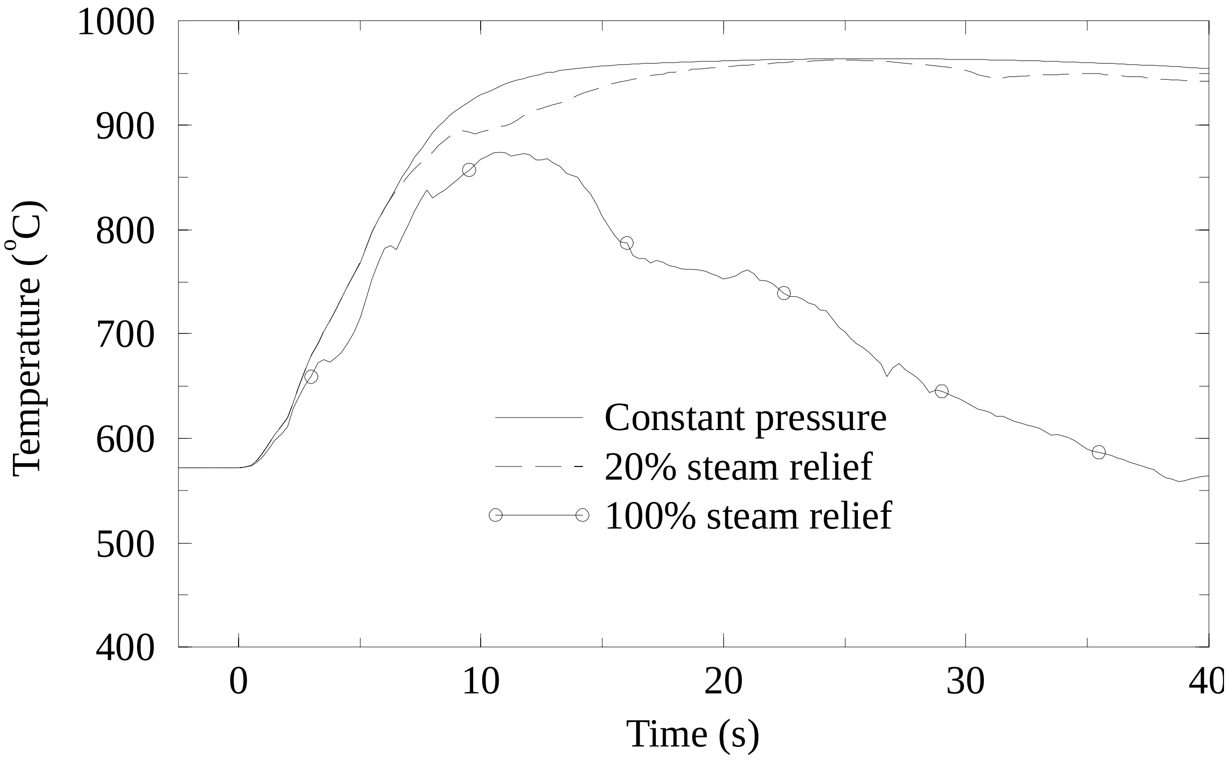
- 5-s MFW coastdown
- Scram
- Constant pressure

Temperature limit met for 50% step change in MFW flow



- No scram
- No AFW

Fast-opening 100%-capacity turbine bypass system helps significantly



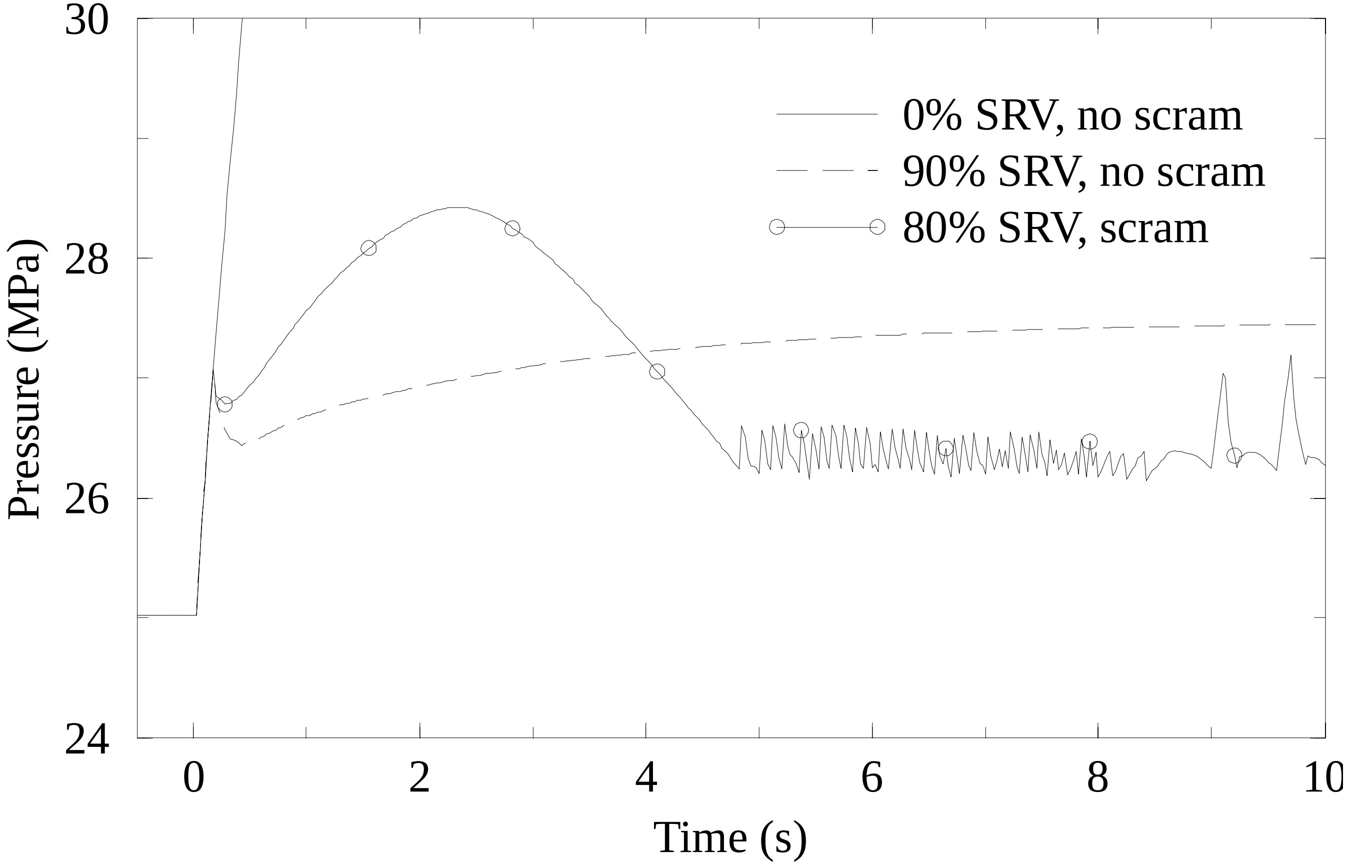
- 5-s MFW coastdown
- Scram
- No AFW

Parametric calculations of a turbine trip without steam bypass investigated the effects of

- *Scram*

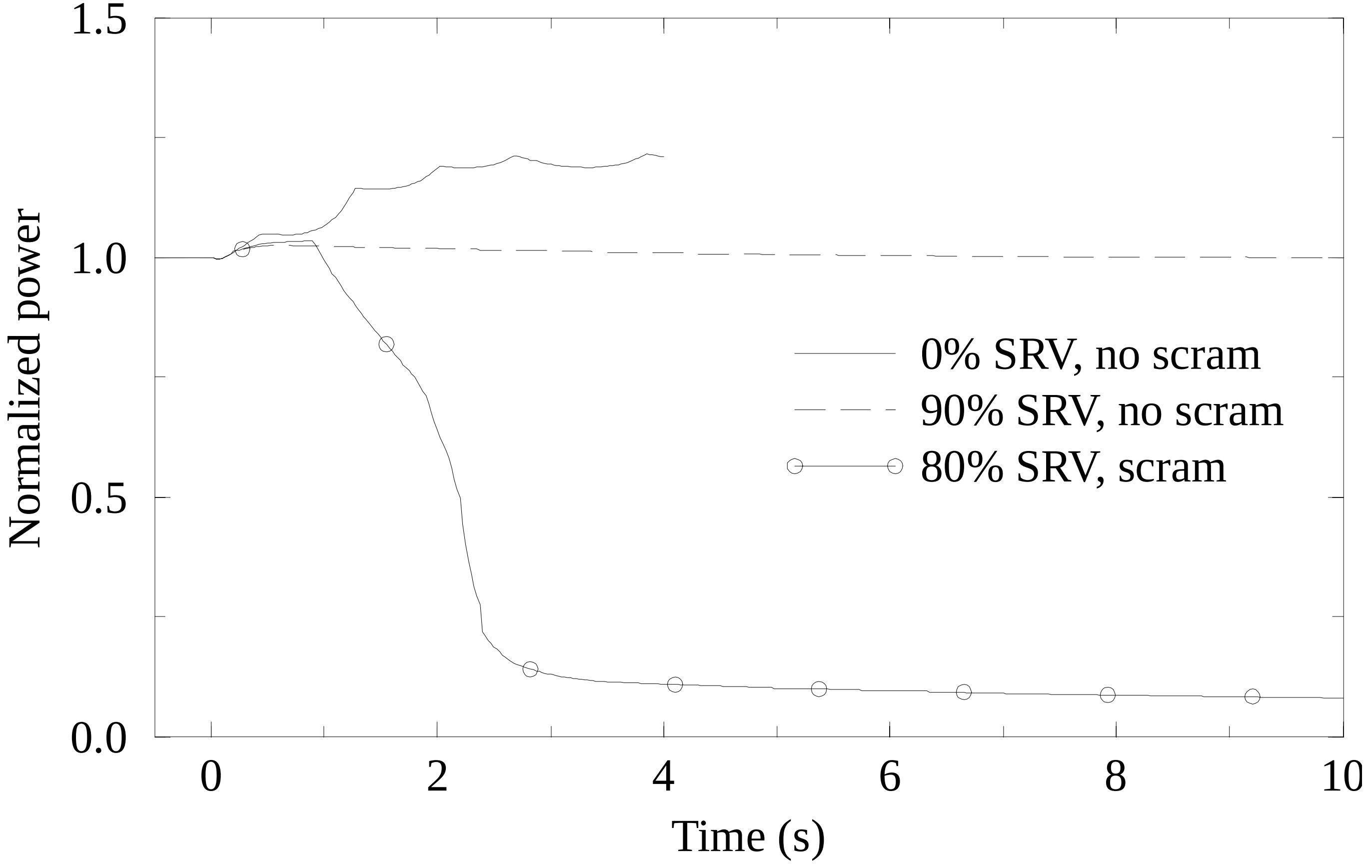
- *Safety relief valve (SRV) capacity (0 - 90%)*

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