Idaho National Engineering and Environmental Laboratory

An Evaluation of a Novel Safety Concept for the SCWR

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Outline

- *Safety characteristics of a once-through SCWR design is described*
- *A novel safety concept for the SCWR is proposed and evaluated*
  - *Concept developed and qualitatively evaluated by WEC*
  - *Concept quantitatively evaluated by INEEL for loss-of-flow events and loss-of-coolant accidents (LOCAs)*
- *Future work*
- *Conclusions*

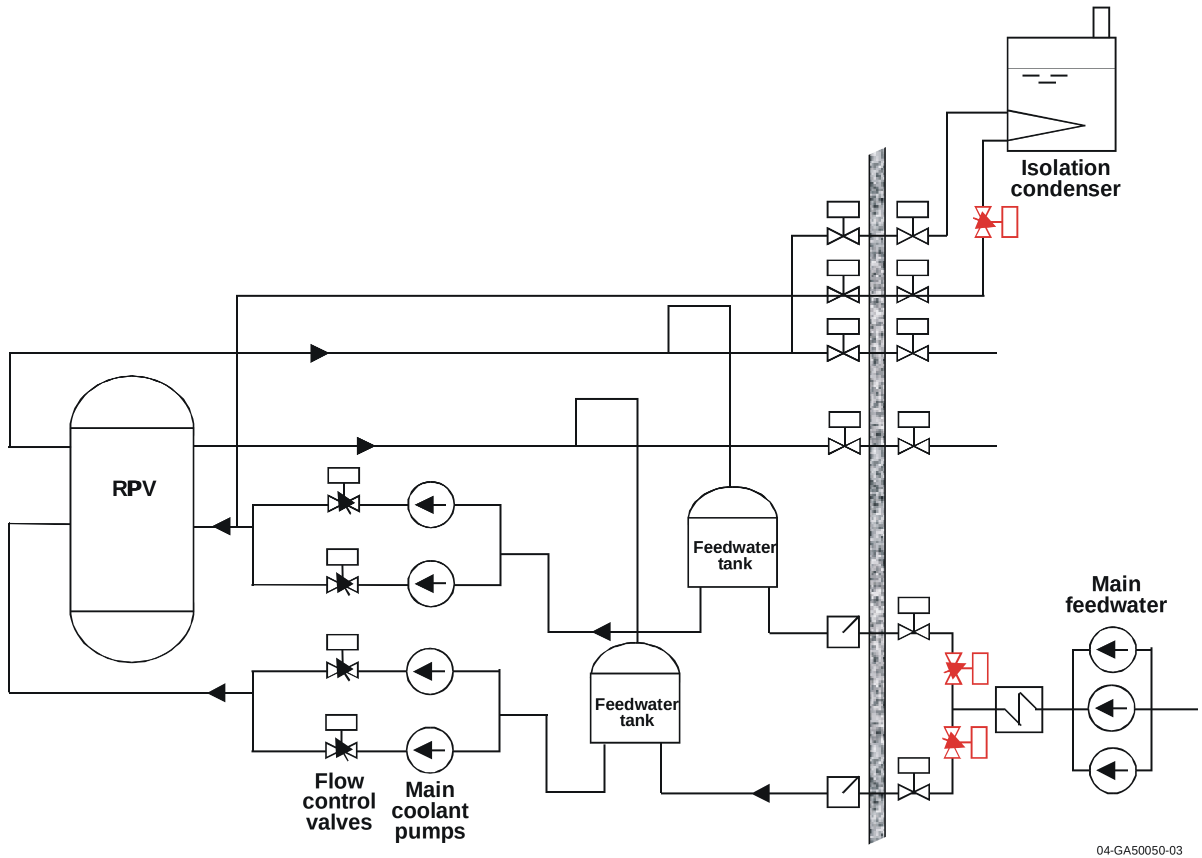
The once-through design was reviewed

- *The reference SCWR contains a once-through Reactor Coolant System (RCS)*
- *An evaluation of the design identified the loss of normal feedwater as a critical event that leads to a rapid loss of coolant flow through the core and rapid heatup of the cladding*
- *The feedwater and core flow systems are inherently coupled, so that loss of one function (i.e. loss of feedwater) leads to the loss of the other*
- *To cope with this sequence, improved reliability of the normal feedwater system (so to reclassify a loss of feedwater from a Condition II transient to a Condition III accident) and rapid actuation (within 5-10 seconds) auxiliary feedwater systems have been suggested*
- *It is our opinion that these two solutions would present significant technical (i.e. rapid alignment of the auxiliary feedwater system, a rapid reactor trip following any indication of a loss of feedwater) and licensing (i.e. reclassification of the event) challenges, and would have a significant cost due to the required improvements to the feedwater systems*
- *Thus, a novel approach to the SCWR safety was taken that utilizes a completely passive concept*

Passive safety systems are proposed

- *Active, non-safety systems have passive, safety-related back-ups to perform nuclear safety functions*
  - *Safety functions automatically actuated, no reliance on operator action*
  - *Passive features actuated by stored energy (batteries, compressed air)*
  - *Once actuated, their continued operation relies only on natural forces (gravity, natural circulation) with no motors, fans, diesels, etc.*
- *Common approach with the most advanced LWR concepts proposed by the main NSSS vendors:*
  - *Westinghouse AP600/AP1000 and IRIS, Framatome-ANP SWR-1000, and GE ESBWR*
- *Design goal: Achieve a degree of safety at least comparable to the more advanced plant concepts currently being proposed*

Proposed SCWR RCS



The proposed RCS contains

- *A reactor vessel*
- *Two feedwater and steam lines and their isolation valves (MFIVs and MSIVs)*
- *Two feedwater tanks (FWTs)*
- *Four main coolant pumps (MCPs) and flow control valves (FCVs)*
- *One isolation condenser (IC) (eventually two if increased reliability becomes necessary)*
- *Pressure balance lines (PBLs) between the steam lines and the FWTs*

Normal response to loss of feedwater events

- *The level in the FWTs will decrease, but the remainder of the system will not be immediately affected*
- *As the level in the FWTs decreases, the Low Level Reactor Trip Setpoint will be reached*
- *On this signal, the reactor will be shut down, and the Startup Feedwater System (SFW, NON SAFETY GRADE) will be actuated to control the level*
  - *If the SFW is available, the plant will be maintained at hot zero power conditions and ready to restart*
  - *The SFW has standard characteristics, and is designed to be actuated within 45 seconds (including diesel startup and alignment)*

Safety response to loss of feedwater events

- *If SFW is not available, the level in the FWTs will decrease until reaching the safety actuation setpoint when*
  - *Feed and steam lines are isolated*
  - *MCPs are tripped*
  - *The IC is aligned to remove decay heat*
- *This approach allows a mild response to a loss of normal feedwater event, similar to that of current LWRs.*
  - *Loss of normal feedwater does not lead to an immediate loss of core flow*

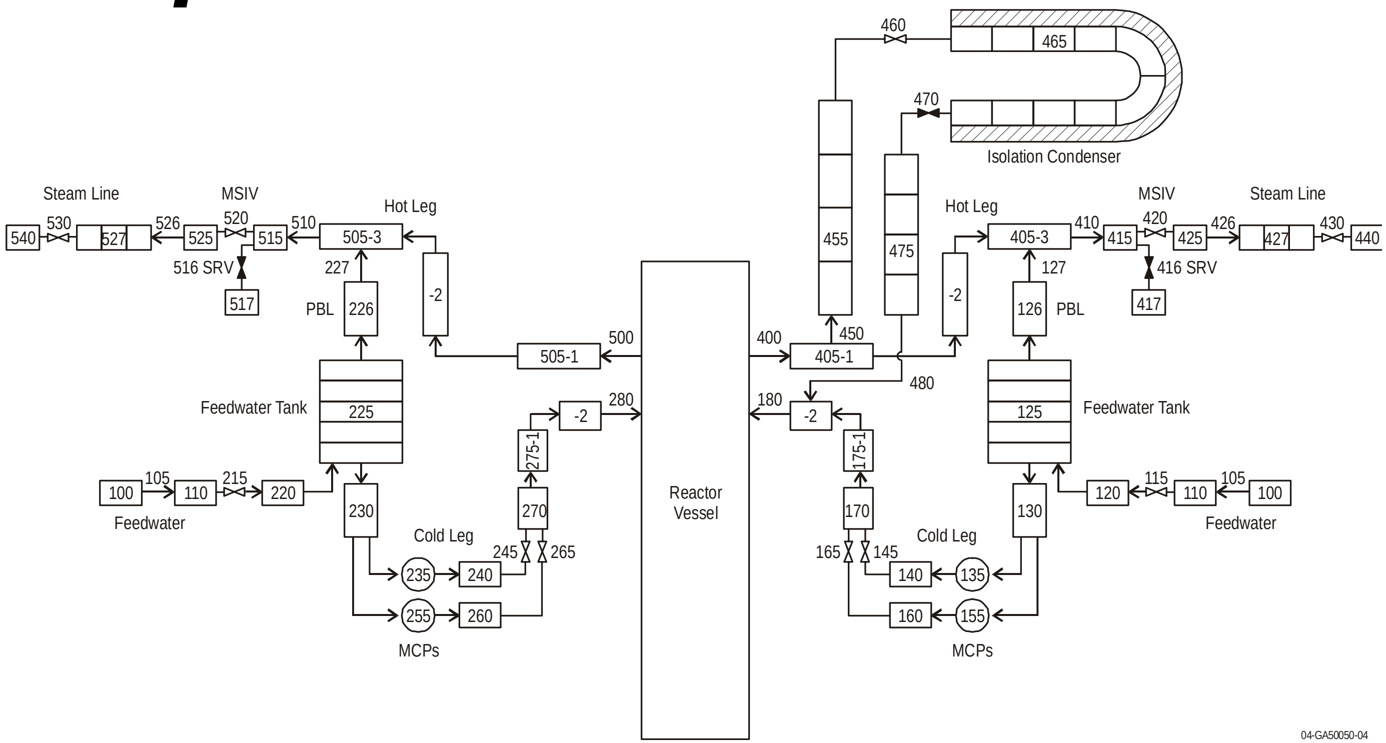
Short-term response to loss of flow events

- *The MCPs will coast down following loss of power to the pump buses*
- *A reactor trip will be generated on a undervoltage, underfrequency or low flow setpoints*
- *At zero power, decay heat will be removed by natural circulation, with the feedwater system (main or startup) maintaining tank level.*
  - *If feedwater is not available, the sequence is identical to the one discussed previously*

Quantitative analyses were performed using RELAP5

- *The short-term response to a complete loss-of-flow transient was evaluated to determine requirements for MCP inertia*
- *The long-term response to a complete loss-of-feedwater (LOFW) transient was evaluated to size the IC*
- *Large-break LOCAs were simulated without LOCA mitigation systems*
  - *Used for input to containment design*
  - *Used to determine the time available for the LOCA mitigation systems to respond*

The RELAP5 model of the SCWR loops is shown below:



- The model contains two nearly identical external loops, with MCPs, FWTs, and MSIVs
- One loop contains the IC

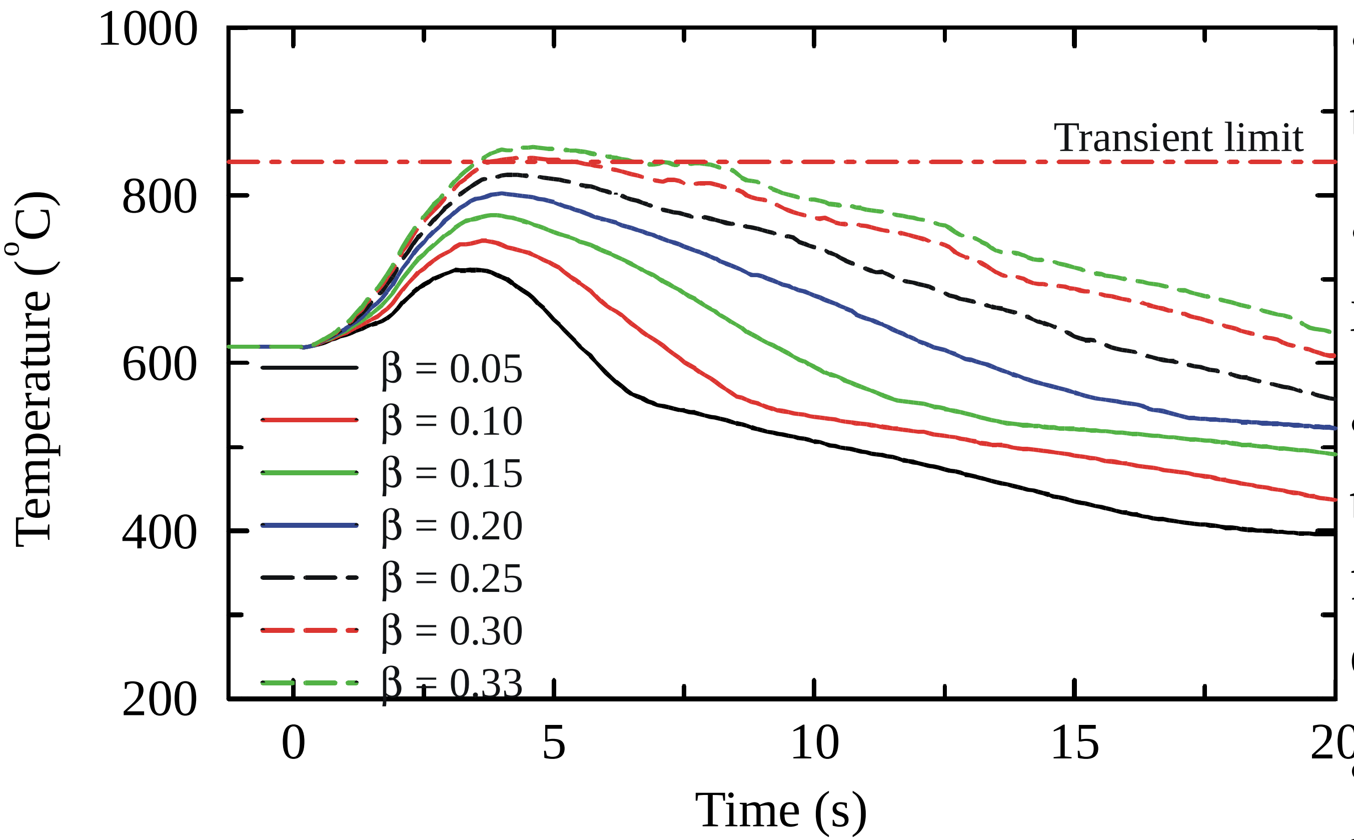
The short-term response to a complete loss-of-flow transient was evaluated

- *The purpose of the evaluation was to determine pump coastdown requirements*
  - *The pump speed was calculated parametrically as $\alpha = 1/(1 + \beta t)$ where α = speed ratio, β = input parameter, t = coastdown time in seconds*
  - *β was varied from 0.05 to 0.33*
  - *The time required to reach 50% speed varied from 20 to 3 s*
- *The model was initialized at rated operating conditions and the power of the hot rod adjusted so that its maximum operating temperature was equal to the steady-state operating limit, 620ºC*

The short-term response to a complete loss-of-flow transient was evaluated (2/2):

- *The transient was initiated by an instantaneous loss of feedwater and a simultaneous MCP trip*
- *The reactor and turbine trips occurred at 1.5 s*
- *Safety relief valves (SRVs) began opening at 2.9 s to control steam line pressure*
- *Sensitivity calculations were performed to account for uncertainty in reactivity feedback*
- *Results were compared with a transient limit of 840ºC*

β < 0.29 provides acceptable transient results



- Maximum clad temperature
- Transient initiated at 0 s
- Use of 80% of the best-estimate feedback provides conservatism
- β < 0.20 with no feedback

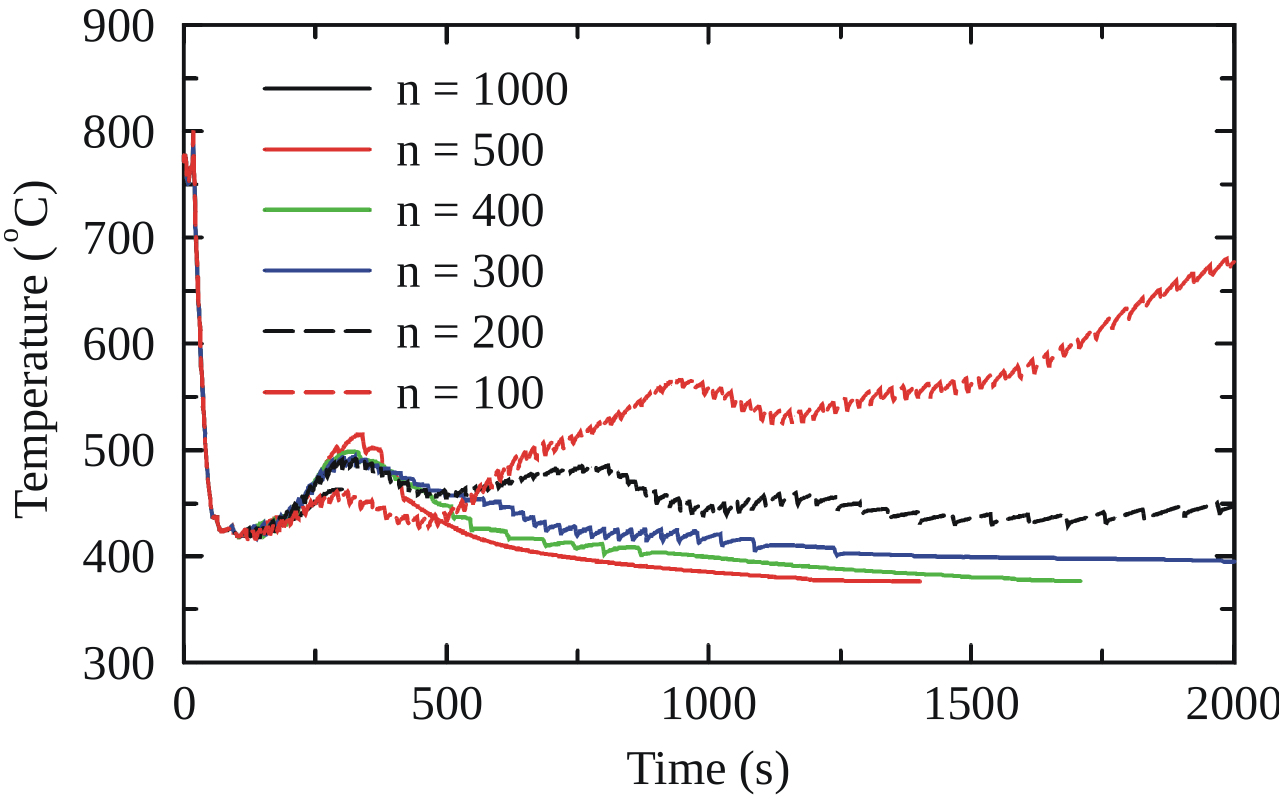
The long-term response to a complete LOFW transient was evaluated

- The purpose of the calculations was to size the IC
- The IC is located 10 m above the hot leg
- The tubes have an ID of 0.012 m and a length of 10 m
- The number of tubes was varied between 100 and 1000
- Conservative initial and boundary conditions were applied
  - 102% of initial rated power
  - 95% of rated flow
  - Feedwater temperature was increased 2ºC
  - Decay power was increased by 20%
  - The water rods were not insulated to maximize the stored energy in the reactor vessel

The long-term response to a complete LOFW transient was evaluated (2/2):

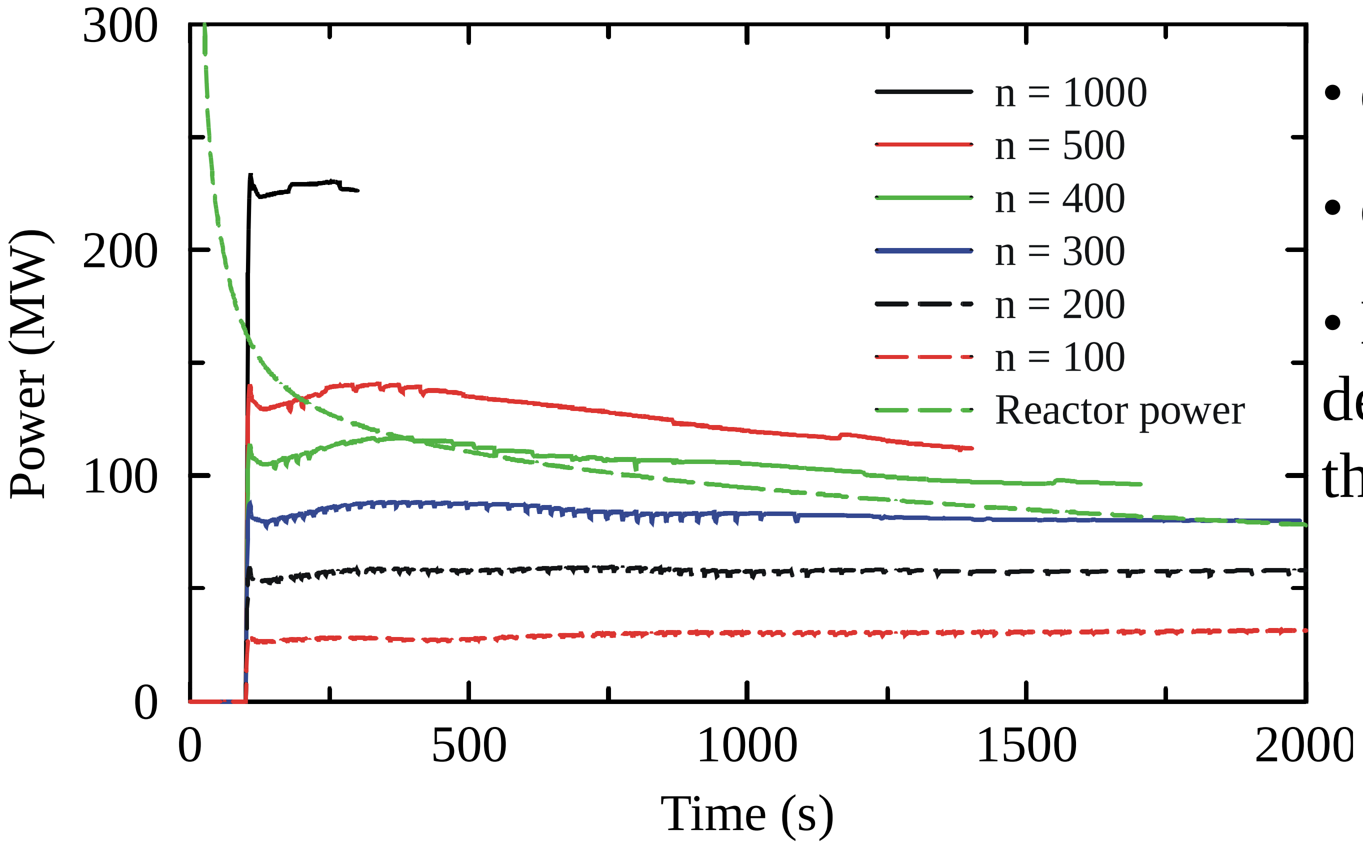
- *The transient was initiated by an instantaneous LOFW*
- *The reactor, turbine, and MCPs ($\beta = 0.20$)were tripped at 16.4 s (2 s after the level in the FWTs reached 1.7 m)*
- *The SRVs controlled pressure after the turbine was tripped*
- *The IC was actuated at 101 s (2 s after the level in the FWTs reached 0.65 m)*
- *IC actuation caused the MSIVs to close*

300 tubes provide adequate long-term cooling



- Maximum clad temperature
- 100 tubes does not provide adequate cooling
- 200 tubes might be acceptable

300 tubes are sufficient to remove decay heat within a reasonable time

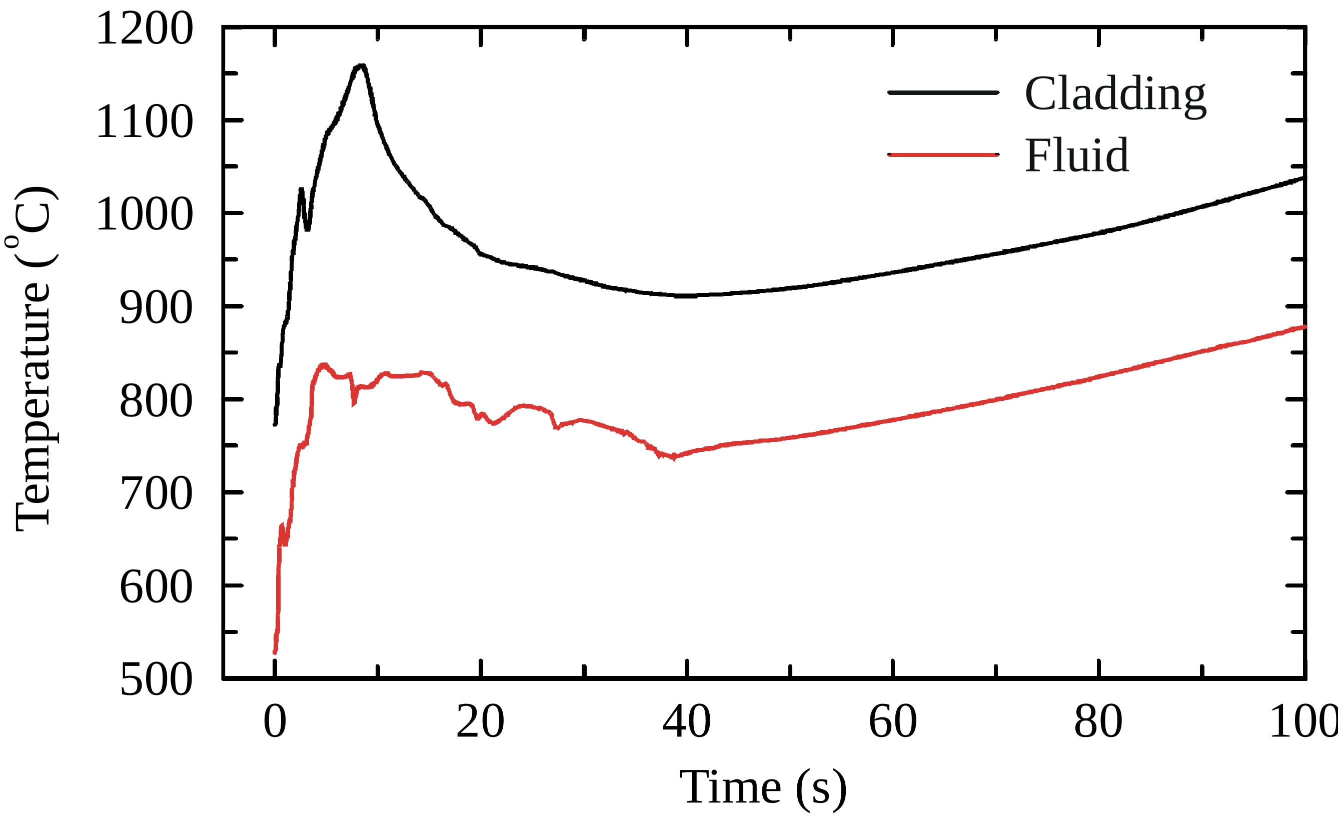


- $q_{max} < 0.8$ MW/m^2
- $q_{CHF} > 1.2$ MW/m^2
- Margin to CHF decreases with thinner tubes

The response of the SCWR to LOCAs was determined

- *The purpose of the calculations was to help size the containment and to determine the amount of time available for the LOCA mitigation systems to respond*
- *LOCAs initiated by large breaks were simulated*
  - *200% cold leg break (between MCPs and vessel)*
  - *200% hot leg break (between vessel and PBL)*
  - *200% steam line break (between PBL and MSIV)*
- *Conservative initial and boundary conditions were applied*
- *The 200% cold leg break resulted in the most severe cladding temperature*

The cladding thermal response is similar to that of a PWR



- 200% cold leg break
- The maximum temperature is relatively high, but the SCWR limit should be higher for a PWR
- Temperature decrease after 9 s was not observed last year with a once-through design

The LOCA mitigation strategy is being developed

- *Preliminary results obtained without mitigation systems result in much more time available than obtained last year for the once-through design*
- *The LOCA mitigation systems will have an ample amount of time to respond to limit the "reflood" temperature peak*
- *A passive system, relying on gravity injection from the containment and automatic depressurization, is being designed*

Conclusions and future work

- *A novel safety concept that features a state of the art safety approach has been developed*
  - *Preliminary analyses confirm the potential of the design*
  - *Preliminary component sizing has been completed for the MCPs and the IC*
- *The FWTs and MCPs provide adequate short-term protection for complete loss-of-flow transients*
  - *MCP coastdown characterized by $\beta < 0.29$ is acceptable for 80% of the best-estimate feedback, $\beta < 0.20$ for no feedback*

Conclusions and future work (2/3):

- *The IC provides adequate long-term decay heat removal following a complete loss of feedwater*
  - *Acceptable results obtained with 300 or more tubes*
  - *CHF must be considered in designing the tube thickness*
  - *Experiments are probably required to validate the design because of the large temperature difference across the IC tubes, the uncertainty in bundle CHF, and the uncertainty in heat transfer coefficients in supercritical water*

Conclusions and future work (3/3):

- *The blowdown peak cladding temperature during the cold leg break is relatively high, and may require additional analysis, but the limit for the SCWR should be greater than the limit for pressurized water reactors*
- *Without LOCA mitigation systems, the proposed RCS design results in much lower cladding temperatures after the blowdown peak during than the once-through design evaluated last year*
- *A LOCA mitigation strategy is being finalized, and will be completed by the end of this program*