Idaho National Engineering and Environmental Laboratory

Modeling of Supercritical Pressurized Water Reactors with SCDAP/RELAP5-3D

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Presentation Overview

- *Basic design of Supercritical Pressure Water Reactor (SCWR).*
- *Comparison of properties of Zircaloy fuel cladding and a candidate SCWR fuel cladding (Alloy MA956).*
- *Comparison of structural behavior of Zircaloy clad and Alloy MA956 clad fuel rods during heatup representative of post-blowdown period of LOCA.*
- *Comparison of cladding temperature behavior during flow reduction accident in SCWR using different models for convective heat transfer.*
- *Conclusions.*

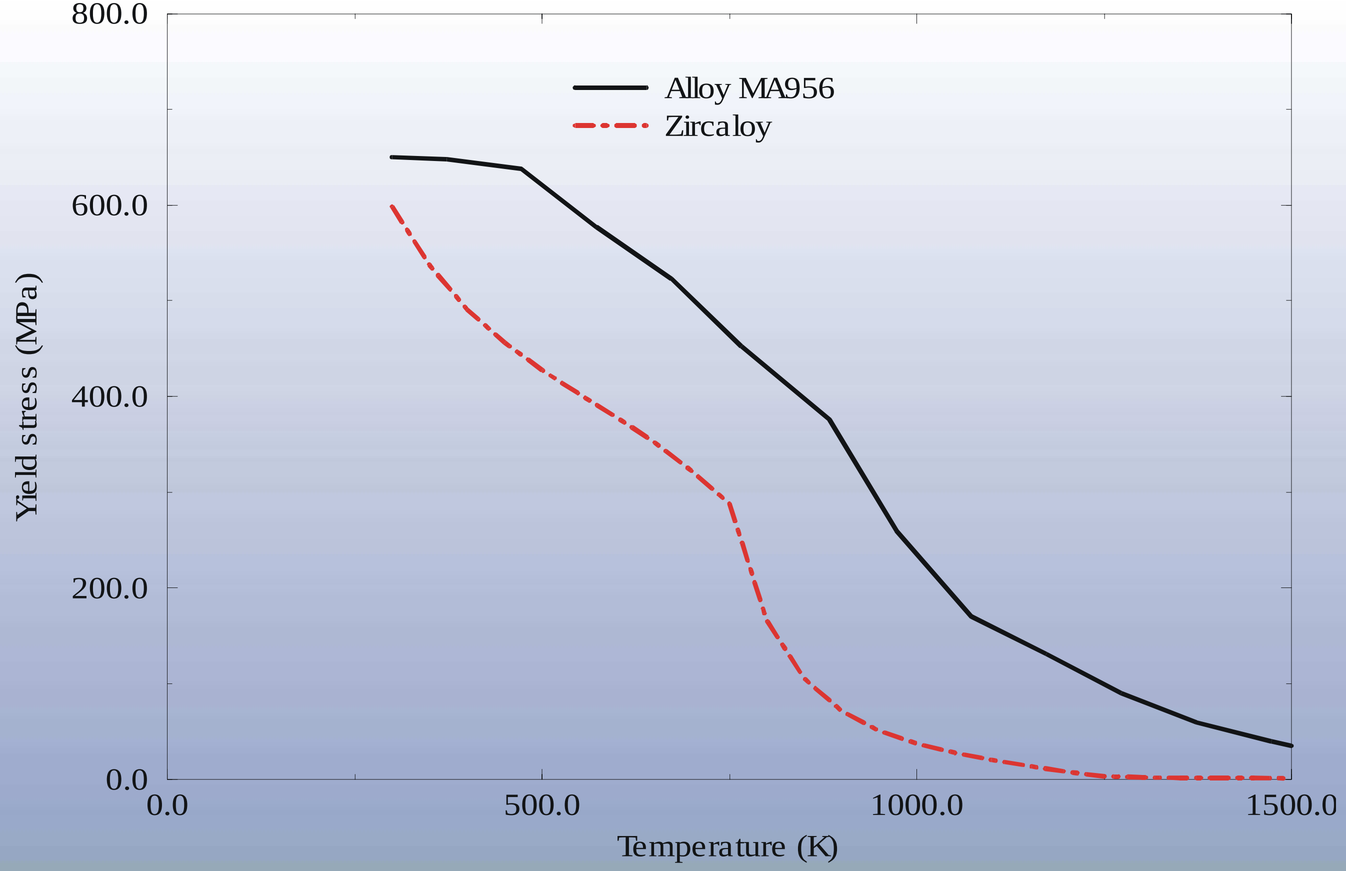
SCWRs differ from Generation III LWRs in several ways to achieve 25% greater thermal efficiency

- *Coolant pressure of 25.0 MPa instead of 15 MPa in PWR and 7 MPa in BWR.*
- *Coolant core exit temperature of 800 K instead of 560 K in SBWR.*
- *Cladding composed of high temperature alloys such Fe-based MA956 and Ni-based Inconel 718 instead of Zircaloy.*
- *Once-through direct flow of all coolant (working fluid) from main feedwater pumps to reactor core and no steam separators, dryers, or recirculation lines.*
- *Higher fill gas pressure.*

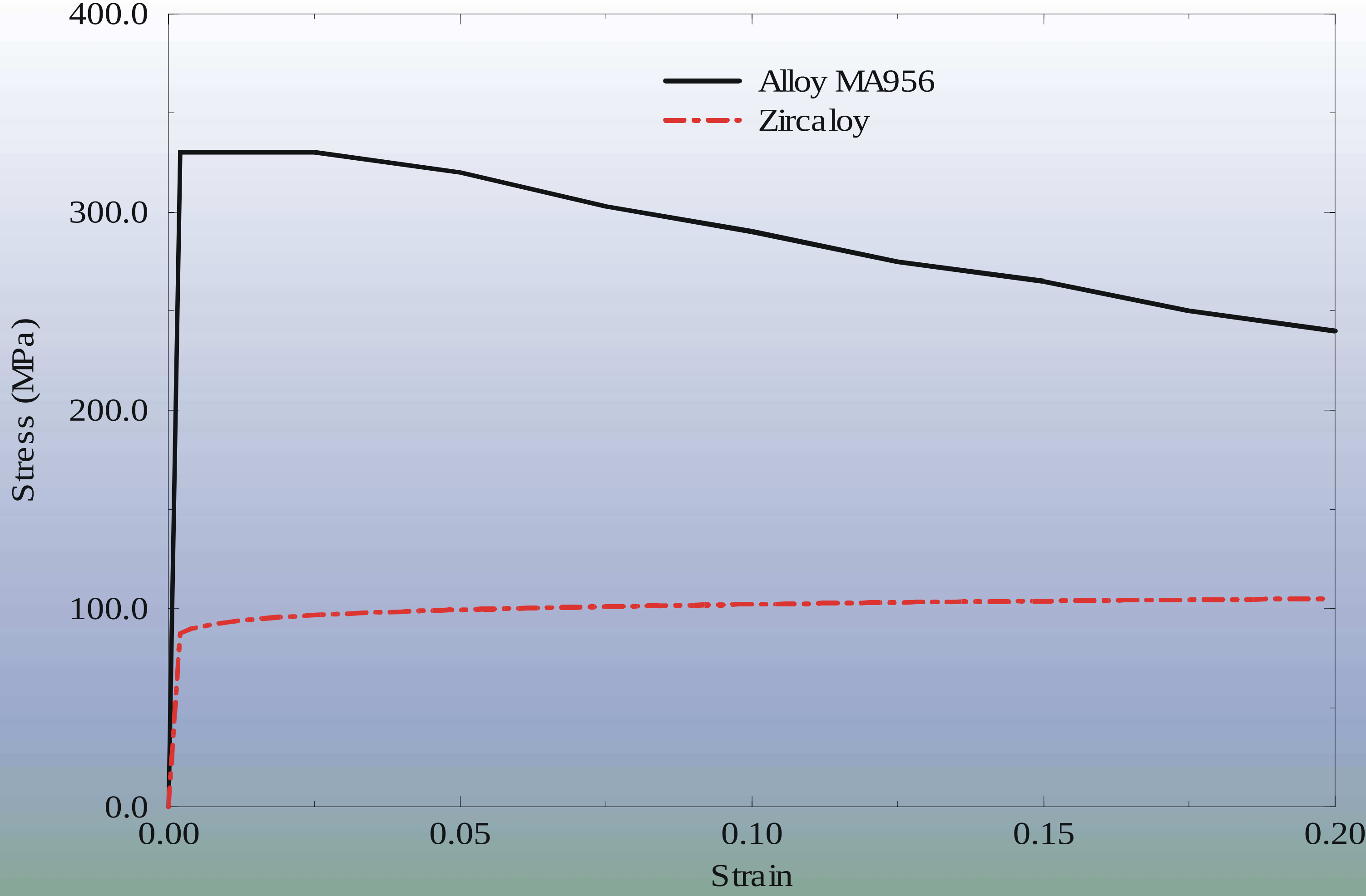
Proposed cladding materials for SCWRs have high temperature capability and oxidation resistance

- *Alloy MA956 has excellent strength at high temperatures due to dispersion of yttrium oxide (Y_2O_3).*
- *Composition of MA956: 74.5wt% Fe, 20wt% Cr, 4.5wt%Al, 0.5wt% Y_2O_3.*
- *Composition of Inconel 718: 52.6wt% Ni, 18wt%Cr, 24wt% Fe, 3wt% Mo.*
- *Other Ferritic-Martensitic steels; T91 (9Cr-1Mo-V), A-21 (9Cr-TiC), new stainless steels; HT-UPS*

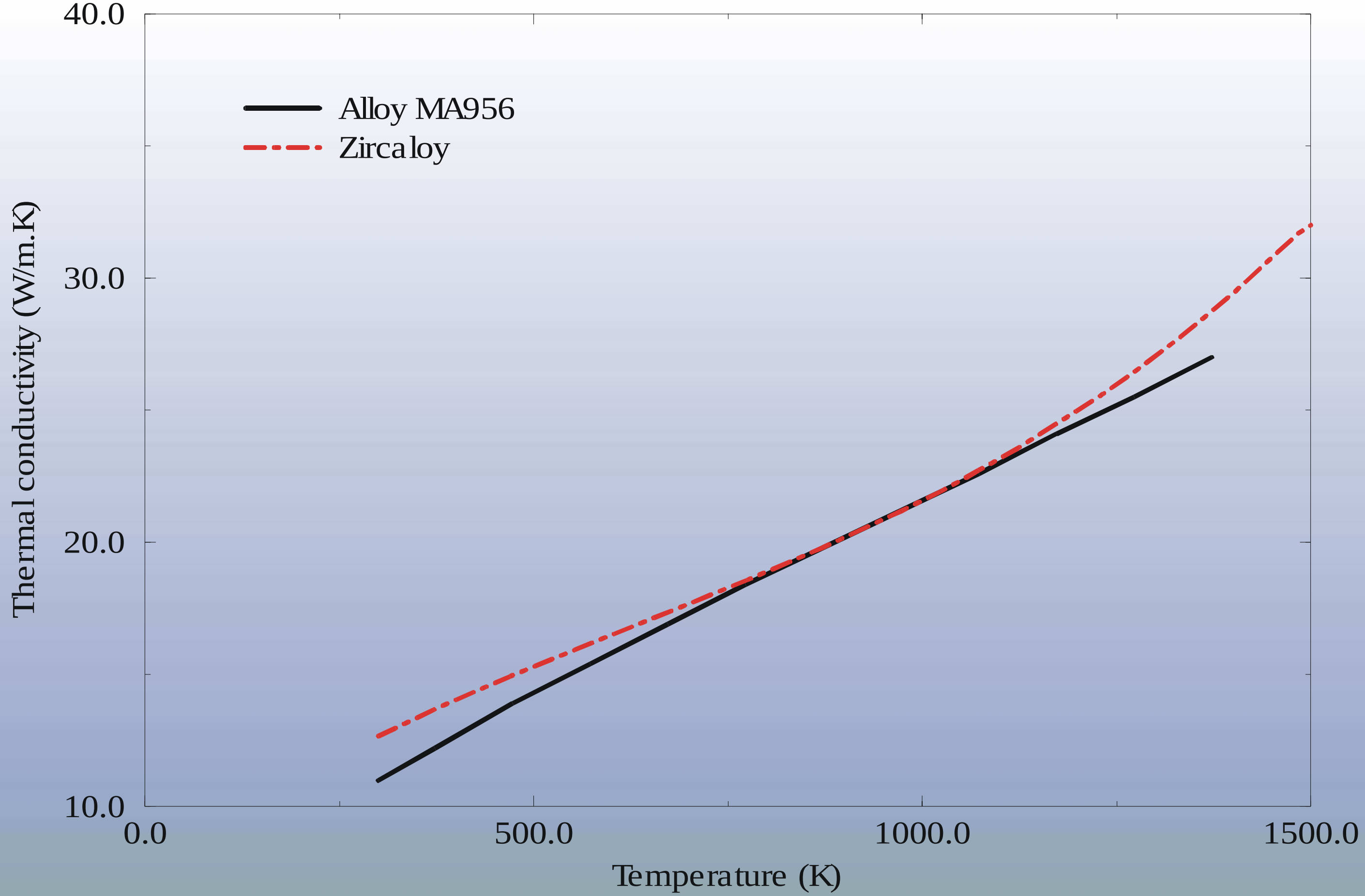
MA956 has small decrease in strength as temperature increases from 300 K to 500 K



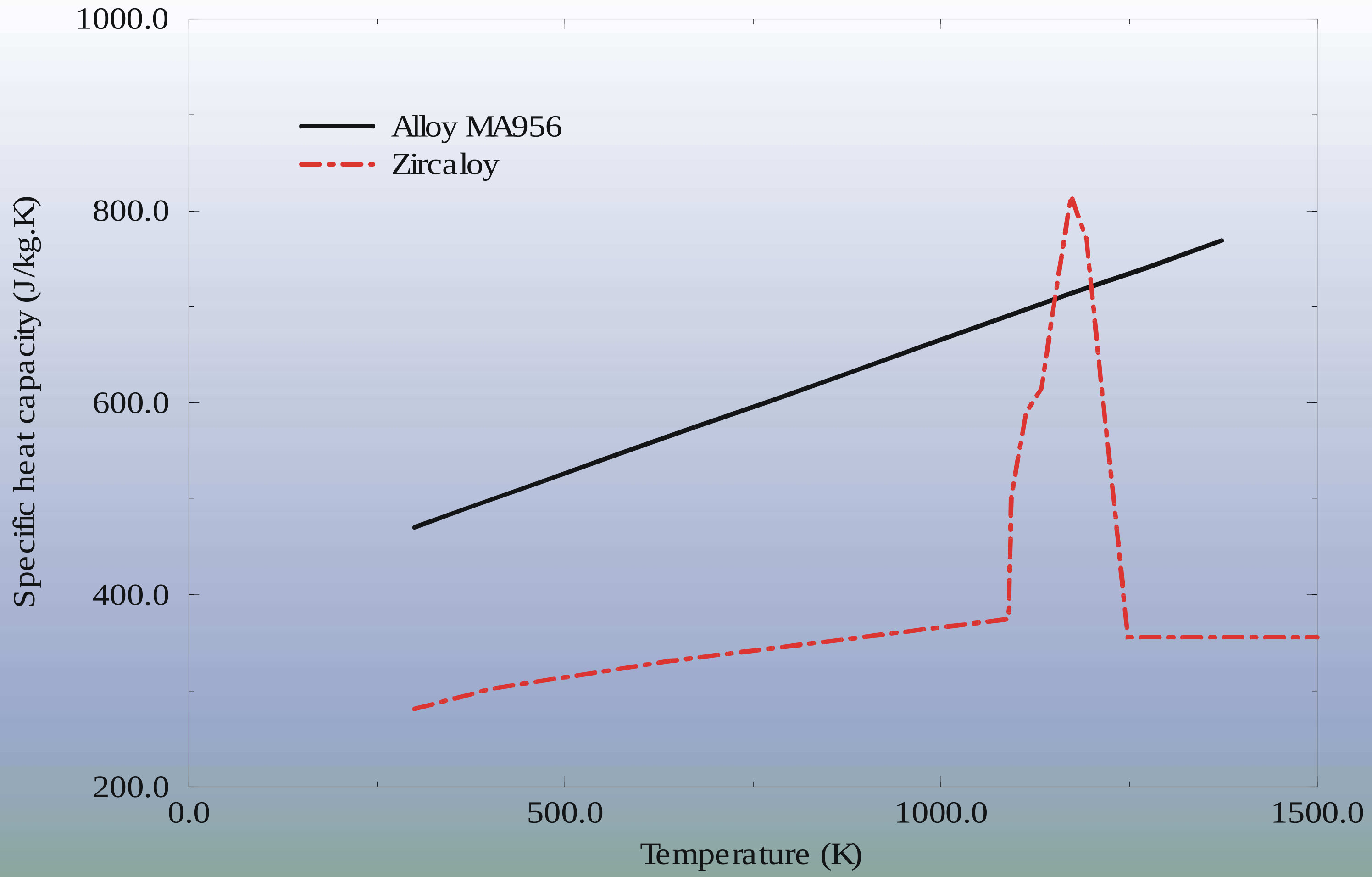
MA956 at 873 K has about three times the strength of Zircaloy and similar ductility



Thermal conductivities of MA956 and Zircaloy are similar



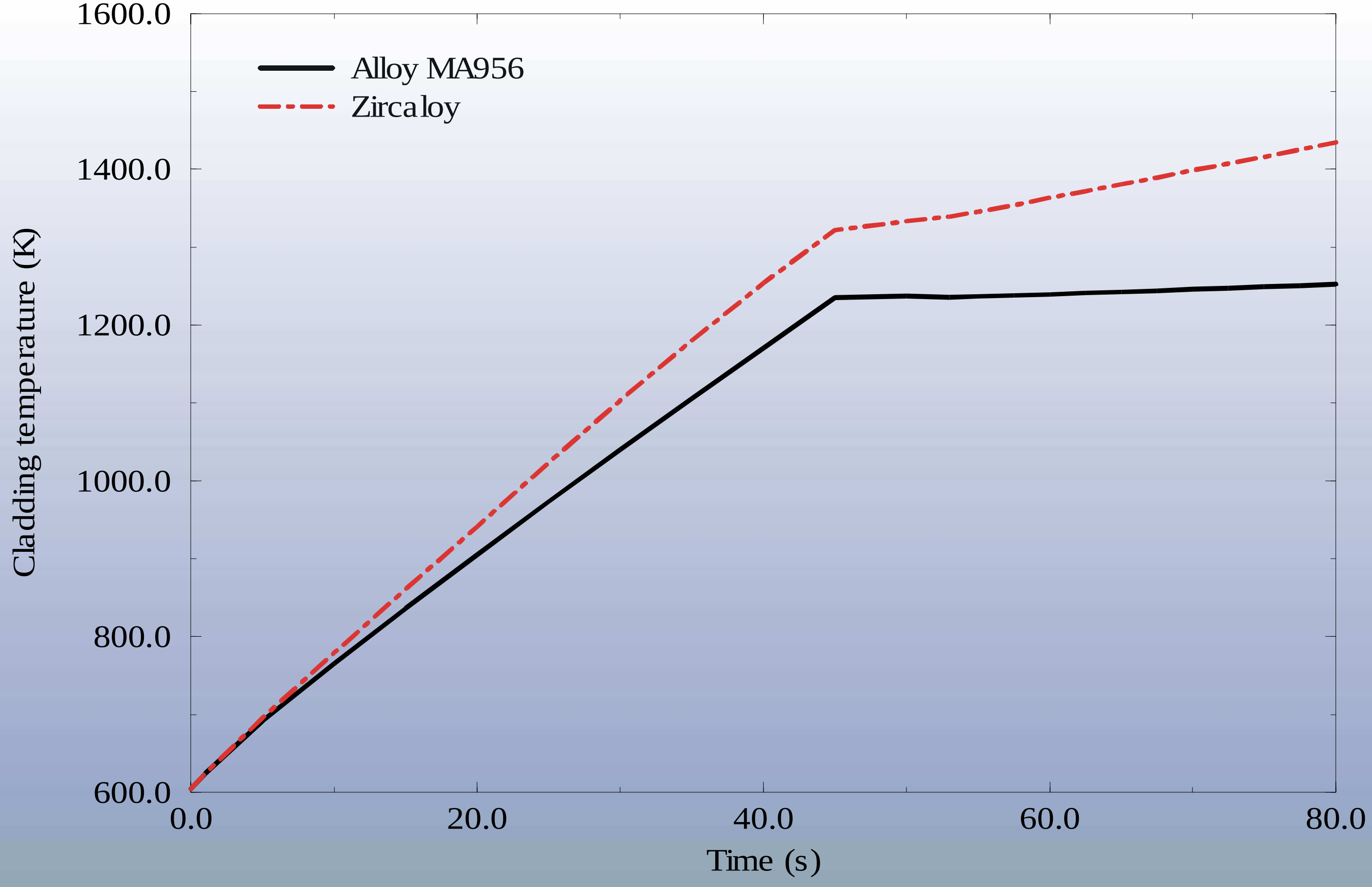
Stored energy of MA956 cladding is greater than that of Zircaloy cladding



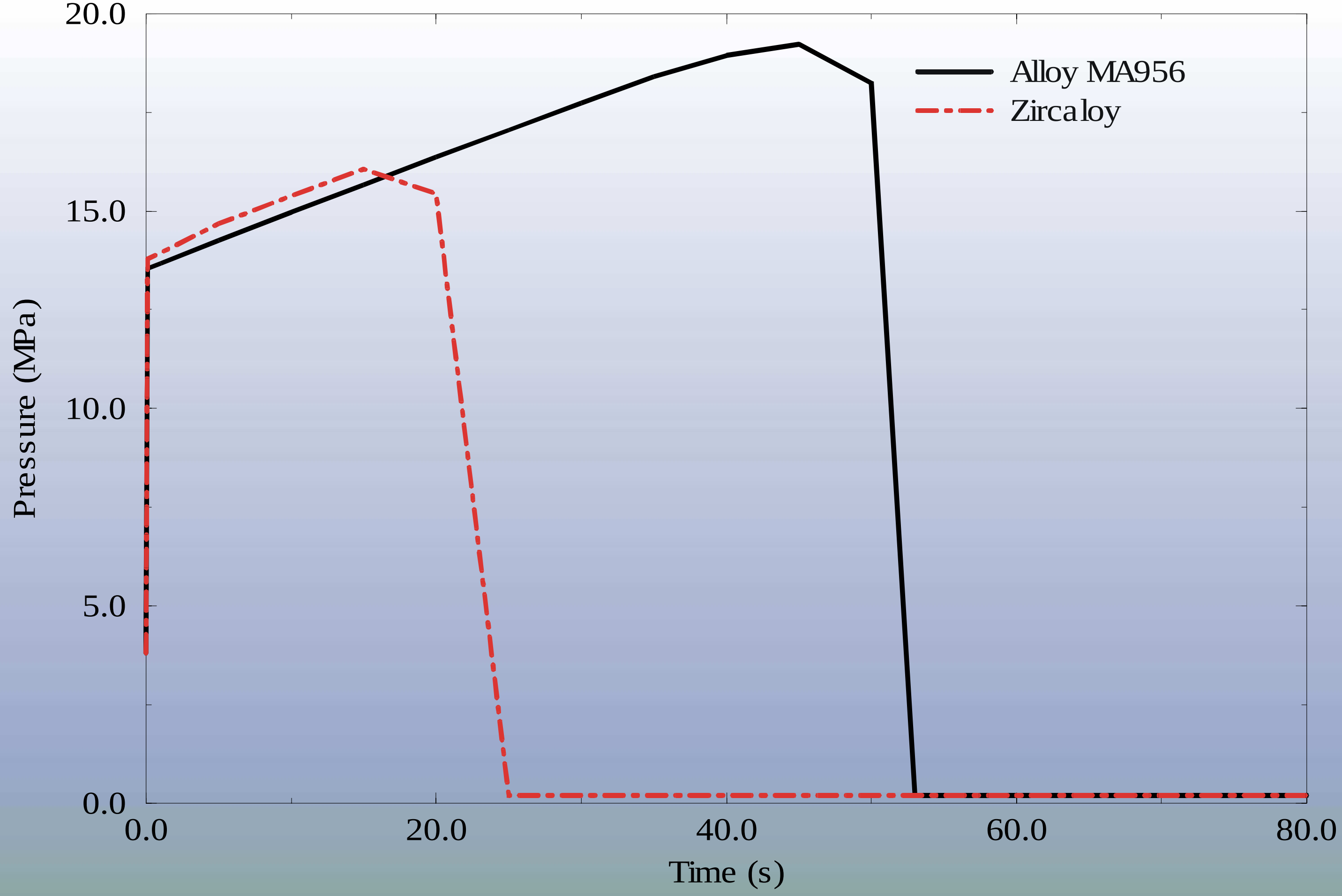
Coolant conditions similar to post-blowdown phase of LOCA used to compare deformation behavior of MA956 and Zircaloy

- *Fuel rod power corresponding with decay heat a few seconds after rector scram.*
- *Coolant pressure of 0.2 MPa.*
- *Steam flow rate of 0.054 kg/m^2.s.*
- *Temperature of steam at inlet to fuel bundle of 500 K.*

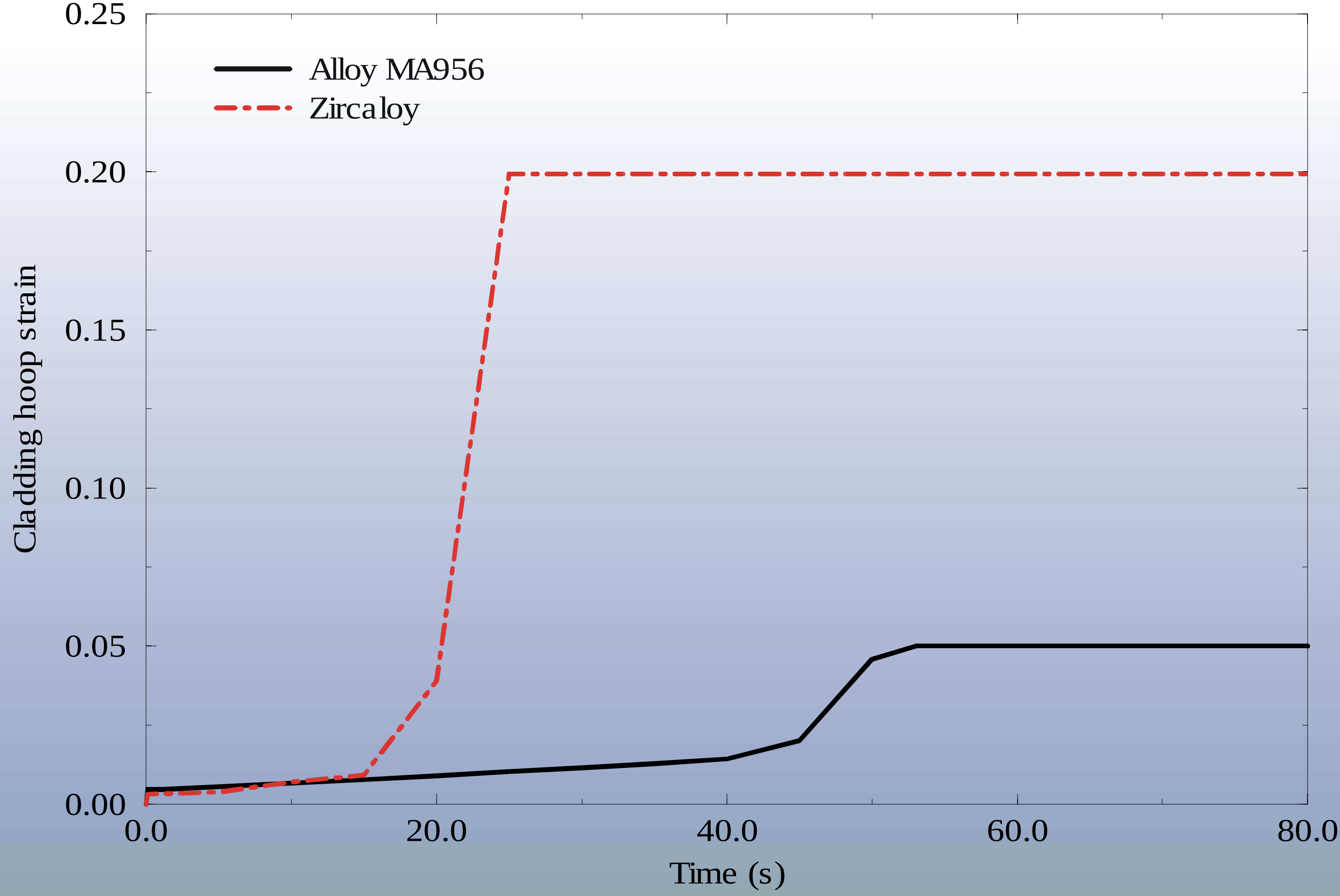
Temperature of Zircaloy cladding during heatup period of LOCA greater than that of MA956 due to oxidation



Initial pressure in SCWR fuel rods expected to be near EOL internal pressure in LWR fuel rods



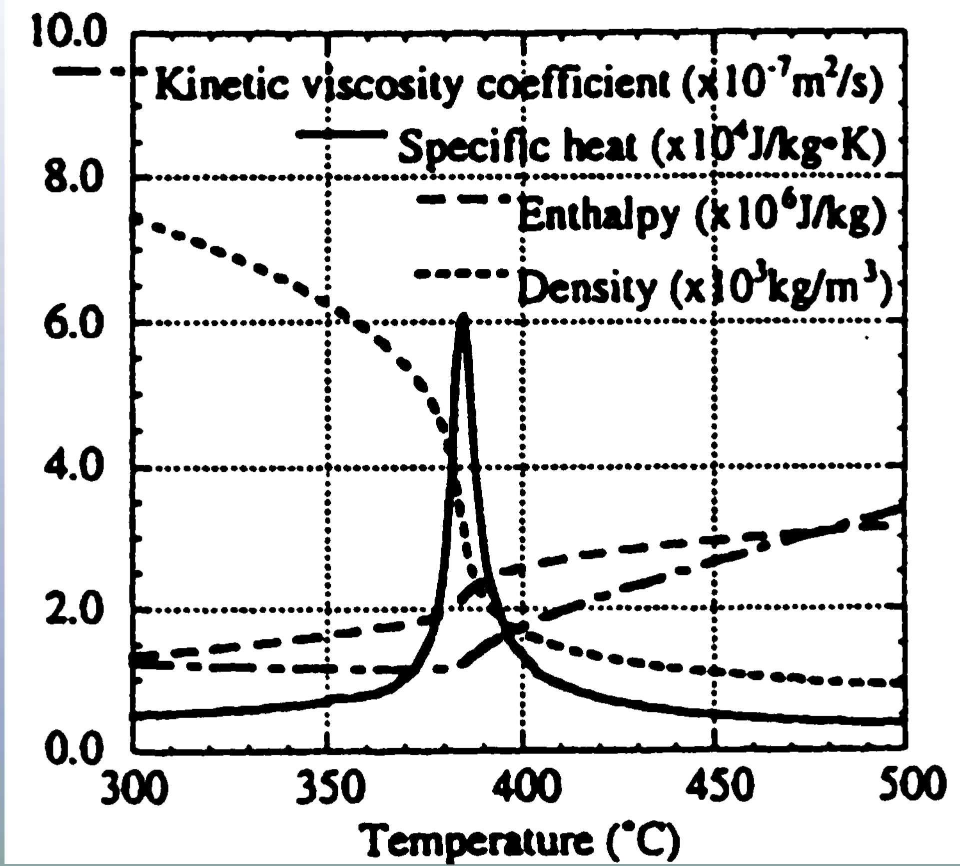
SCWR fuel rods during LOCA may not balloon as much as LWR fuel rods



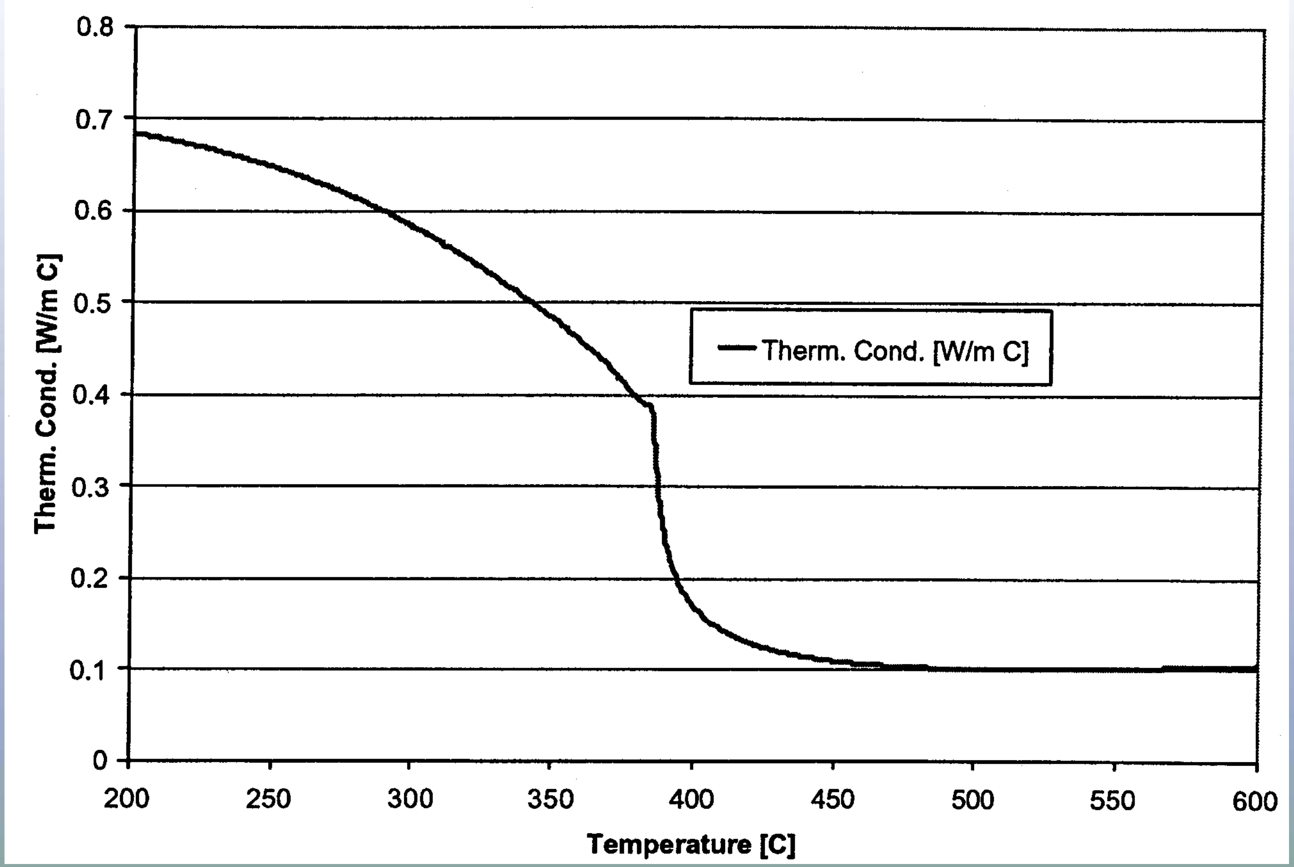
Convective heat transfer in SCWR investigated using Power-Coolant Mismatch transient

- One bundle of fuel rods modeled.
- Power in bundle representative of hot bundle steady state power (peak linear power of 46.8 kW/m).
- Coolant pressure of 25 MPa.
- Coolant inlet temperature of 553 K.
- Steady state mass flow rate of 2700 kg/m^2.s.
- Coolant flow decreased to 50% of steady state coolant flow while power remains constant.

Properties of supercritical water vary sharply around pseudo-critical temperature (p=25 MPa)



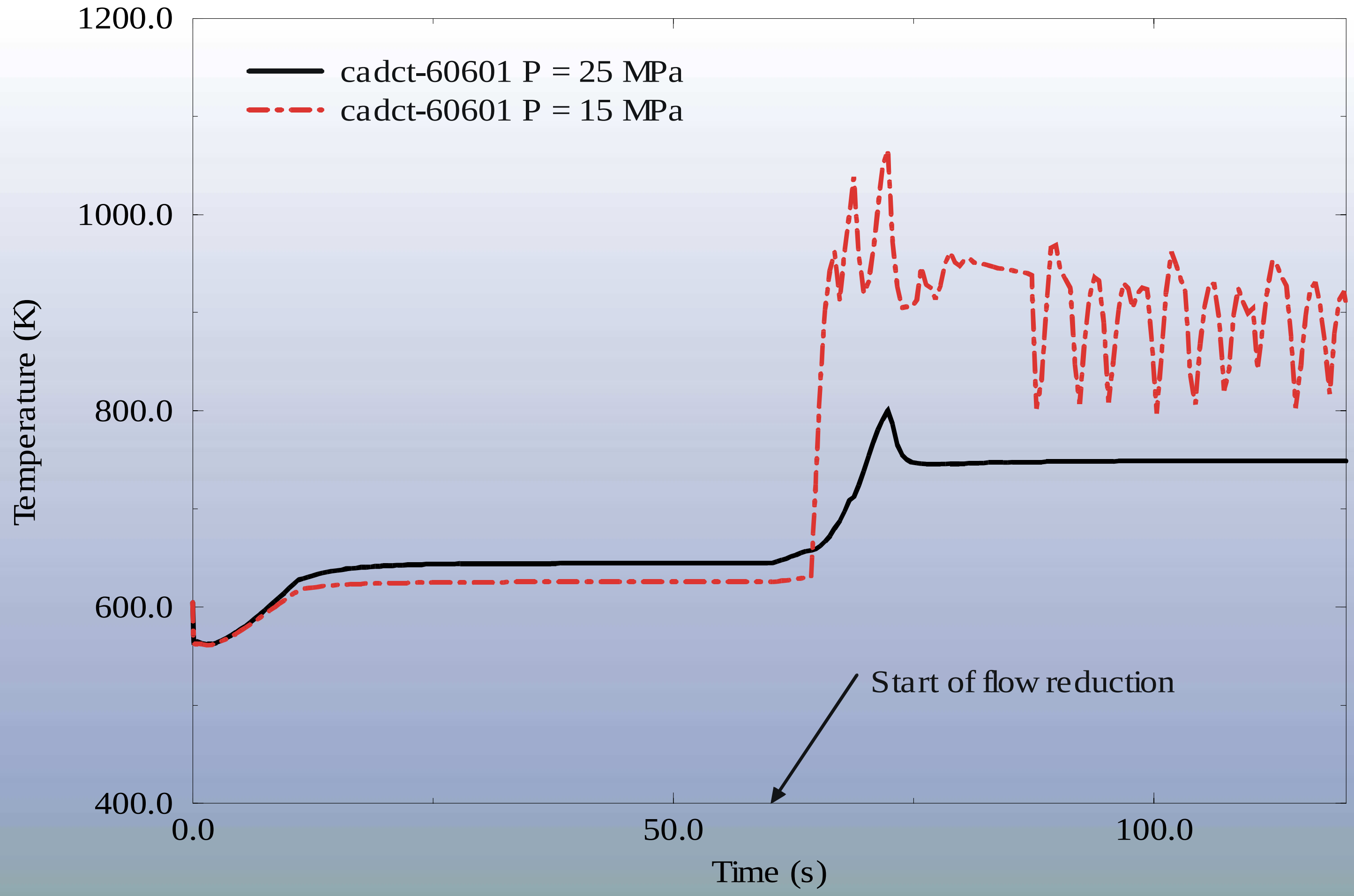
Variation in thermal conductivity with respect to temperature (p=25 MPa)



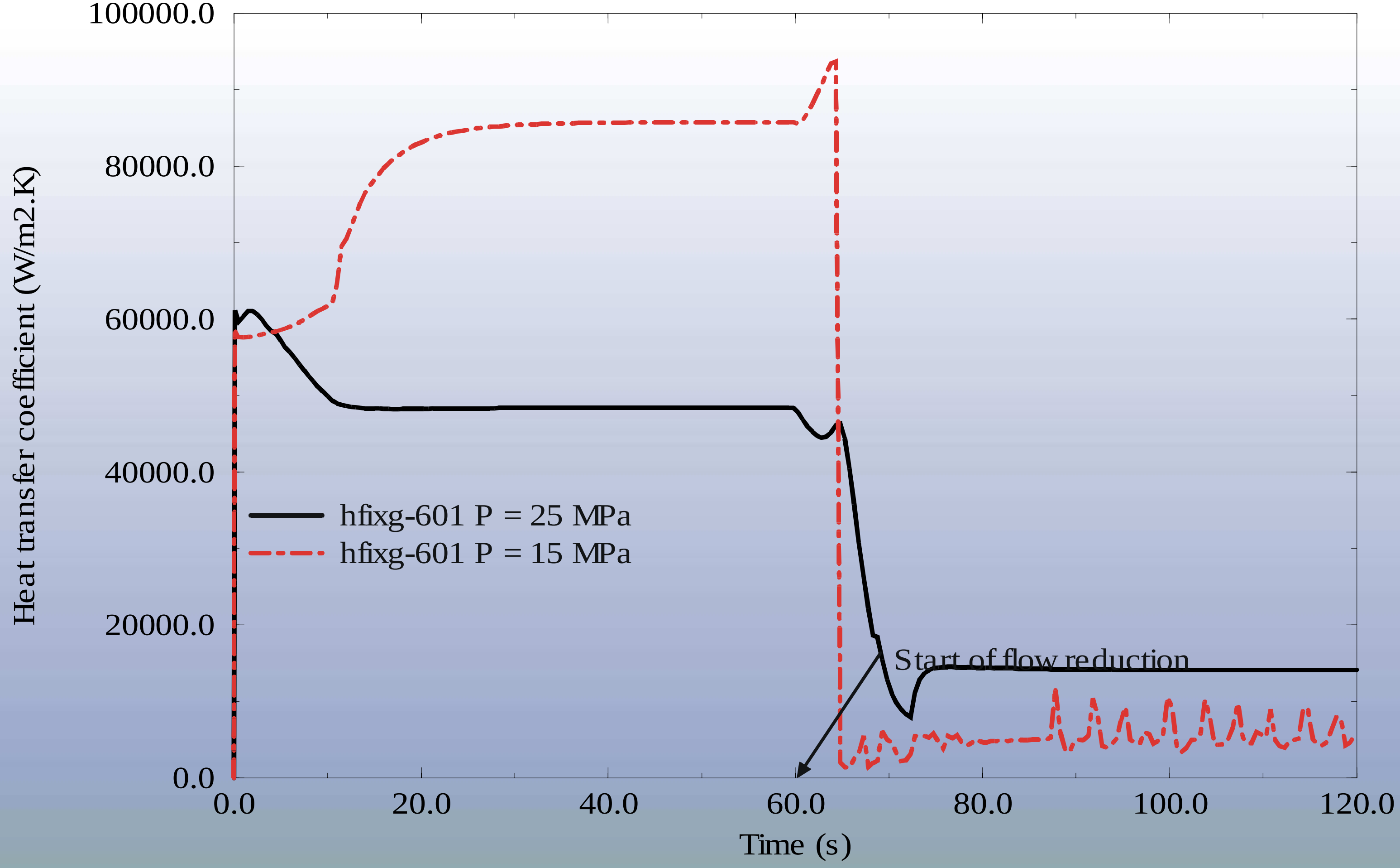
Convective heat transfer correlations for supercritical water are summarized by Cheng et al.

- *Reference: "Thermal-Hydraulic Analysis of Supercritical Pressure Light Water Reactors," International Congress on Advanced Nuclear Power Plants (ICAPP), Hollywood, Florida, June 9-12, 2002.*
- *Bishop correlation : A A. Bishop, R. O. Sandberg, and L. S. Tong, WCAP-2056-P, Part III-B, February 1964.*
- *Koshizuka correlation based on numerical analysis: "Numerical Analysis of Deterioration Phenomena in Heat Transfer to Supercritical Water", Int. J. Heat Mass Transfer 38, 3077-3084 (1995).*
- *Dittus-Boelter:* $Nu=0.023Re^{0.8}Pr^{0.333}$
- *Further experimental work required to identify and improve best correlation and reduce uncertainty in correlation.*

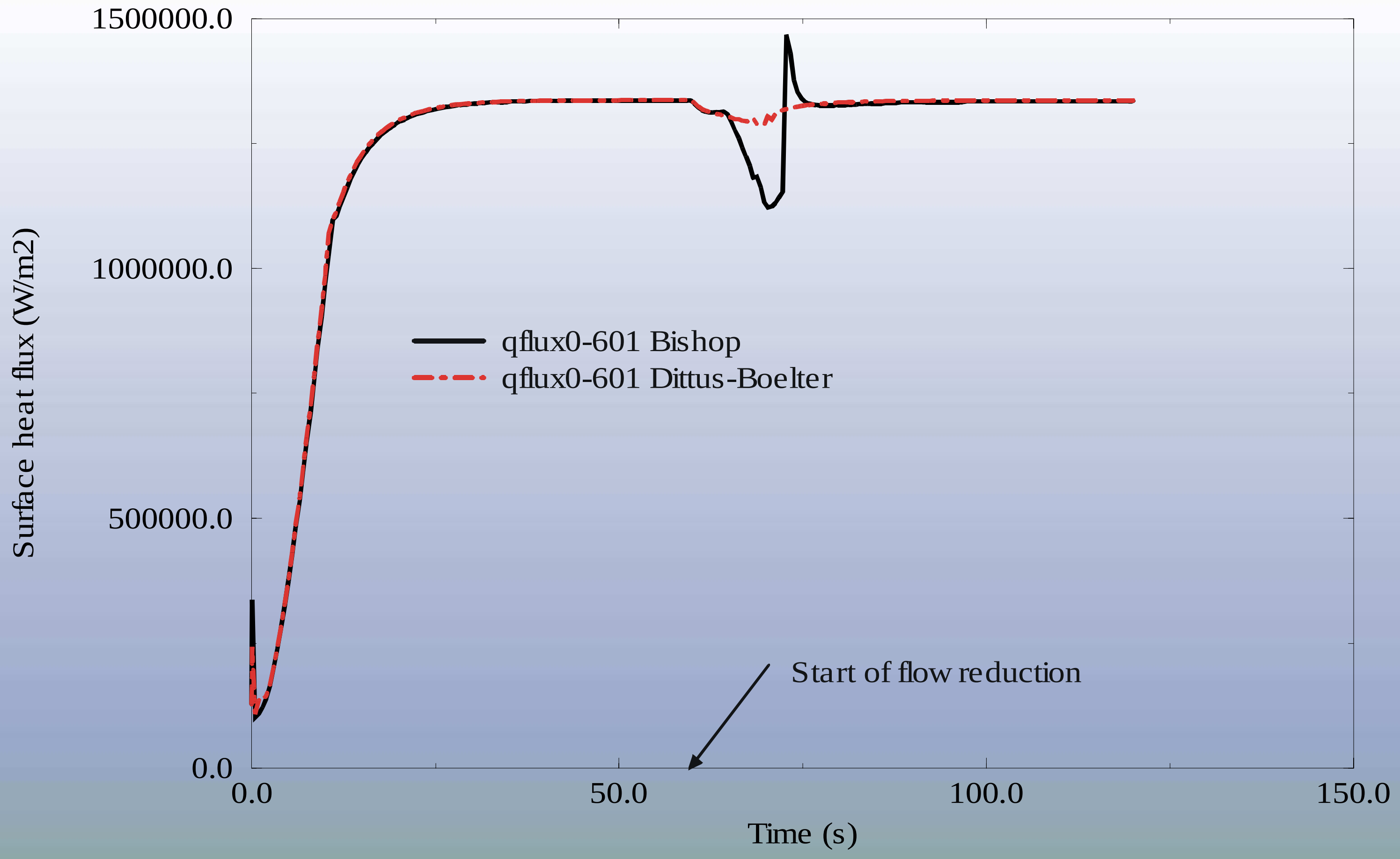
Greater cladding temperature increase after flow reduction for coolant pressure of 15 MPa than 25 MPa



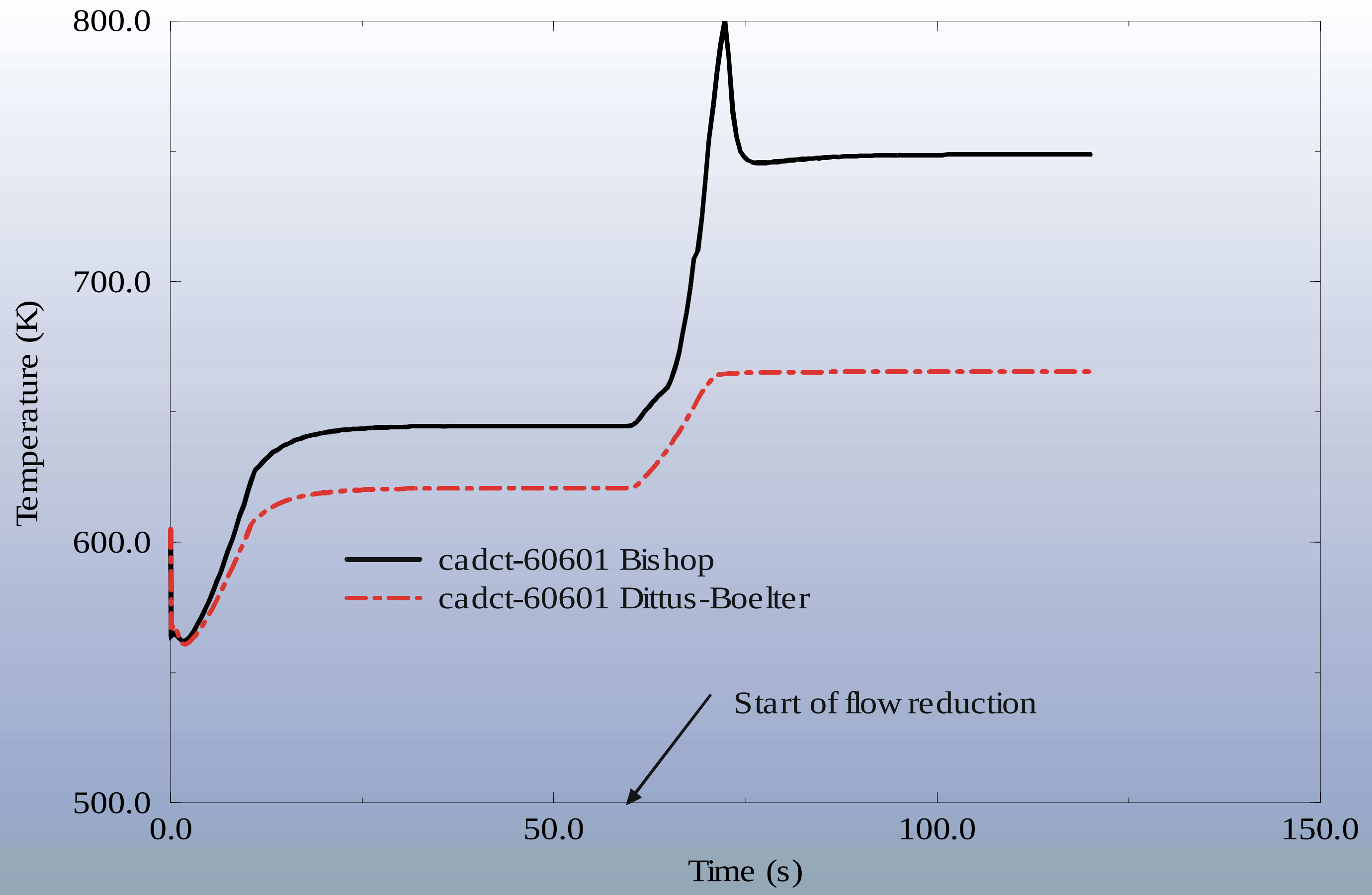
After flow reduction, convective heat transfer coefficient at 25 MPa coolant pressure is double that at 15 MPa



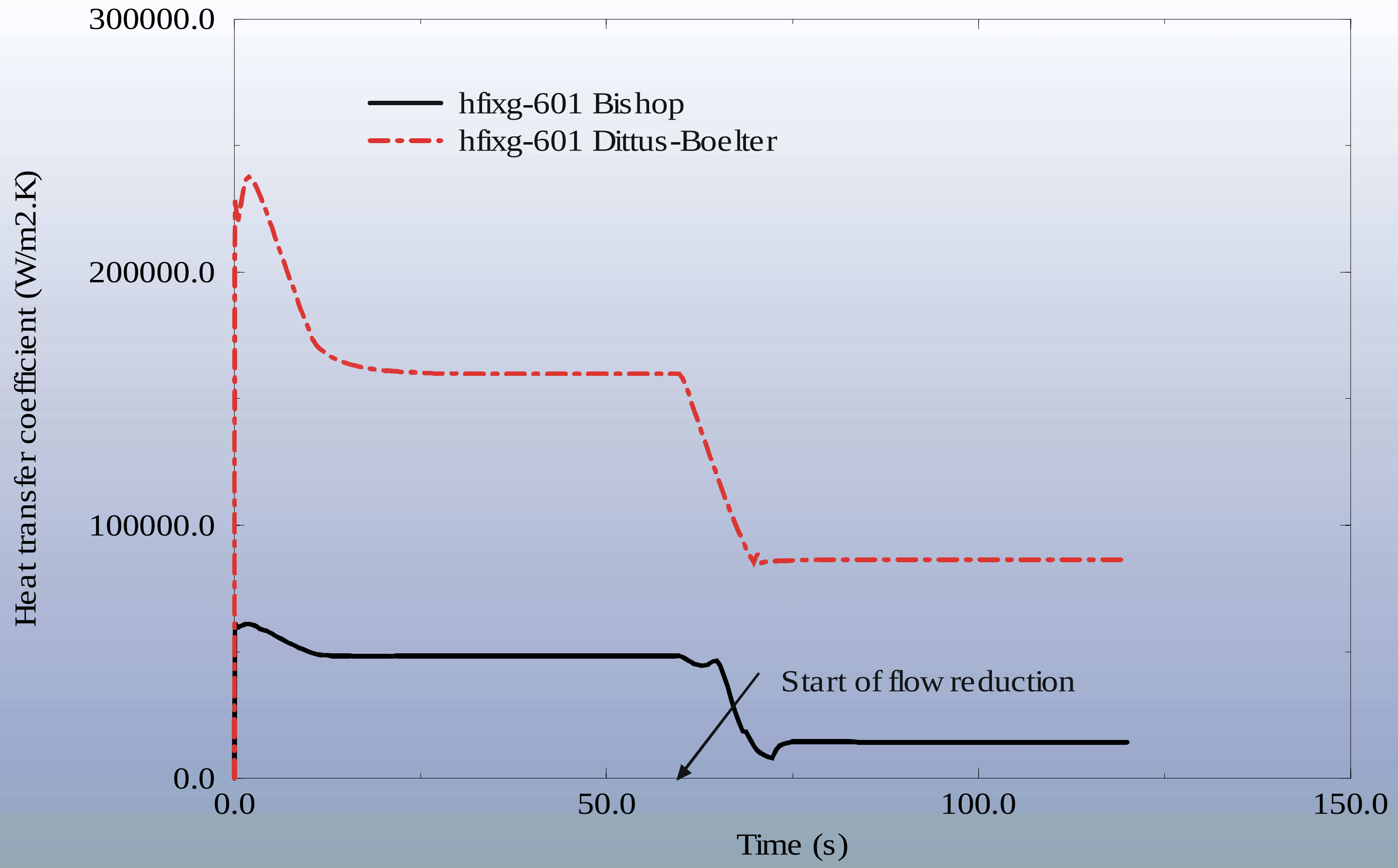
Bishop correlation predicts greater heat flux deterioration following flow reduction than Dittus-Boelter correlation



Higher cladding temperature calculated using Bishop correlation than Dittus-Boelter correlation



Bishop correlation calculates more than factor of two smaller heat transfer coefficient than Dittus-Boelter



Conclusions

- *SCDAP/RELAP5-3D has been extended to analyze behavior of fuel rods in SCWRs.*
- *Ballooning in SCWR fuel rods delayed and less extensive due to greater strength and less ductility of MA956 cladding at high temperatures.*
- *Temperature increase in SCWR fuel rods during flow reduction less severe than in LWR.*
- *Significant uncertainty in models for convective heat transfer in supercritical water.*