Rhode Island Nuclear Science Center Transient Analyses
Revised Jan. 20, 2016 by Arne P. Olson, ANL

13.7 Section 13.2.2 of the SAR states that ANL performed a PARET analysis of reactivity insertions, but there is no reference provided for the PARET analysis. Provide a copy of the referenced calculation, including initial conditions and assumptions used in the analysis. If available, provide a copy of the PARET input deck.

The following text is based on the Fourth Response to RAI Dated April 13, 2010 Submitted September 8, 2010. Input parameter changes were provided by Jeff Davis on January 8, 2016.

For these RAI, four reactivity insertion transients were re-analyzed for forced convection cooling mode, and one reactivity insertion was analyzed for natural convection mode using the PARET/ANL Version 7.5 code.

PARET/ANL Version 7.5 solves the point-kinetics equations for reactor power versus time, while computing thermal-hydraulic conditions in one or more fuel channels. Feedback from the thermal-hydraulic solution is continuously fed back into the point-kinetics equations. The reactor is modeled using two hydraulic channels: a hot channel, and an average channel. The hot channel represents conditions in the coolant channel between fuel plates that is most limiting. This channel typically has fuel plates having the highest power density adjacent to it. The average channel represents all other coolant channels adjacent to fuel plates. Reactivity feedback from fuel heatup (Doppler Effect), water heatup, and water density change, are accounted for using feedback coefficients derived from the neutronics models. The input to the PARET model consists of several categories of information:

1. geometry of the channels (fuel meat, clad, coolant)
2. delayed neutron kinetics data
3. reactivity insertion definition
4. control system response
5. initial operating conditions of power and flow
6. solution options such as time step sizes and edit selection.

The neutronics codes used to generate input for the PARET models were:

WIMS/ANL for multi-group neutron cross sections; REBUS-PC (which includes DIF3D as the neutronics solver) for power density information, and VARI3D (which also includes DIF3D as the neutronics solver for real and adjoint flux), to provide the reactor kinetics delayed neutron fractions, decay constants, and prompt neutron lifetime. Data on reactor power distribution is provided in Reference 2, and data on the reactor kinetics parameters and reactivity feedback coefficients is provided in RAI 4.10.
***** this paragraph is the original; not as updated per January 9, 2016, from J. Davis *****

The forced convection transients are assumed to take place under the following assumptions [Technical Specifications, Revised Section 2.1.1 in RAI 14.36, "Safety Limits in the Forced Convection Mode]:

Measured Parameter	Limiting Trip Value	Safety Limit
P	2.3 MW	2.4 MW
m	1740 gpm	1580 gpm
H	23' 9.1"	23' 6.5"
T_o	123 F	125 F

***** the above paragraph is the original; not as updated per January 9, 2016 *****

The natural convection transients are assumed to take place under the following assumptions [Technical Specifications, Revised Section 2.1.2 in RAI 14.52, "Safety Limits in the Natural Convection Mode]":

Measured Parameter	Limiting Trip Value	Safety Limit
P	125 kW	200 kW
H	23' 9.1"	23' 6.5"
T_o	128 F	130 F

The period trip at 4 seconds is assumed to fail. The power trip is functional. The time delay for control blades to begin to move after a trip is assumed to be 100 ms. The time to full insertion is the maximum allowed of 1.0 second [TS 3.2.3].

Case 1: Rapid Insertion of 0.6% Δk/k Reactivity From Very Low Power

The reactor is initially operating at 10 watts, 125 °F coolant inlet temperature, and 1500 gpm. There is a water head of 23' 6.5" above the top of the fuel meat, which provides a pressure of 1.708×10^5 Pa. Then 0.6% Δk/k reactivity, the total reactivity worth of all experiments [TS 3.1.3], is inserted as a very short ramp of 0.1 second duration, starting at 0.0 seconds. The reactor power rises rapidly. The power trip at 2.5 MW is actuated at 10.504 s. Since no actual negative reactivity from the control system occurs for 100 ms after the trip, the reactor power continues to rise from the trip level of 2.5 MW to a maximum of 2.610 MW at 10.606 s. The control blades are inserted starting at 10.606 sec and are fully inserted at 11.506 sec. The reactor power drops rapidly to shutdown conditions.

Peak temperatures for fuel meat centerline, clad surface, and coolant are: 87.1 °C; 86.2 °C; and 68.0 °C, respectively, at 10.60 s. These peak fuel and clad surface temperatures are far below the maximum temperature of 530 °C for LEU silicide fuel that the NRC finds acceptable as fuel and clad temperature limits not to be exceeded under any conditions of operation (See NUREG-1537, Part I, Appendix 14.1 and NUREG-1313). The peak coolant temperature is well below the saturation temperature of 115.3 °C.

Case 2: Slow Insertion of 0.02 % Δk/k /Second Reactivity From Very Low Power

The reactor is initially operating at 10 watts, 125 °F coolant inlet temperature, and 1500 gpm. There is a water head of 23' 6.5" above the top of the fuel meat, which provides a pressure of 1.708×10^5 Pa. Then a long, slow ramp reactivity insertion begins at a ramp rate of 0.02 % Δk/k / s (TS 3.2.4), continuing for 100 s. Power rises slowly. The power trip at 2.5 MW is actuated at 32.386 s. Since no actual negative reactivity from the control system occurs for 100 ms after the trip, the reactor power continues to rise from the trip level of 2.5 MW to a maximum of 2.690 MW at 32.486 s. The reactor power drops rapidly to shutdown conditions.

Peak temperatures for fuel meat centerline, and clad surface are: 86.1 °C; 85.2 °C. The peak coolant temperature of 67.0 °C is reached at 32.60 s. These peak fuel and clad surface temperatures are far below the maximum temperature of 530 °C for LEU silicide fuel that the NRC finds acceptable as fuel and clad temperature limits not to be exceeded under any conditions of operation (See NUREG-1537, Part I, Appendix 14.1 and NUREG-1313). The peak coolant temperature is well below the saturation temperature of 115.3 °C.

The safety limit on power of 2.4 MW is exceeded (the power briefly reaches 2.690 MW). However, the safety limit on power does not apply to transients. In this case, the fuel meat and cladding reach peak temperatures of about 86 C, far below the maximum allowed temperature of 530 °C

Case 3: Slow Insertion of 0.02 % Δk/k / Second Reactivity From 1.8 MW Power

The reactor is initially operating at 1.8 MW, 125 °F coolant inlet temperature, and 1500 gpm. There is a water head of 23' 6.5" above the top of the fuel meat, which provides a pressure of 1.708×10^5 Pa. Starting from this initial condition, a long, slow ramp reactivity insertion begins at a ramp rate of 0.02 % Δk/k / s [TS 3.2.4], continuing for 100 s. Power rises slowly. The power trip at 2.5 MW is actuated at 8.269 s. Since no actual negative reactivity from the control system occurs for 100 ms after the trip, the reactor power continues to rise from the trip level of 2.5 MW to a maximum of 2.516 MW at 8.369 s. The reactor power drops rapidly to shutdown conditions.

Peak temperatures for fuel meat centerline, and clad surface are: 88.6 °C; 87.8 °C; and 69.6 °C. The peak coolant temperature of 69.6 °C is reached at 8.40 s. These peak fuel and clad surface temperatures are far below the maximum temperature of 530 °C for LEU silicide fuel that the NRC finds acceptable as fuel and clad temperature limits not to be exceeded under any conditions of operation (See NUREG-1537, Part I, Appendix 14.1 and NUREG-1313). The peak coolant temperature is well below the saturation temperature of 115.3 °C.

Case 4: Slow Insertion of 0.02 % Δk/k /second Reactivity From 2.2 MW Power

The reactor is initially operating at 2.2 MW, 125 °F coolant inlet temperature, and 1500 gpm. There is a water head of 23' 6.5" above the top of the fuel meat, which provides a pressure of 1.708×10^5 Pa. Starting from this initial condition, a long slow ramp reactivity insertion begins at a ramp rate of 0.02 % Δk/k / s [TS 3.2.4], continuing for 100 s. Power rises slowly. The power trip at 2.5 MW is actuated at 4.647 s. Since no actual negative reactivity from the control system occurs for 100 ms after the trip, the reactor power continues to rise from the trip level of 2.5 MW to a maximum of 2.5112 MW at 4.747 s. The reactor power drops rapidly to shutdown conditions.

Peak temperatures for fuel meat centerline, and clad surface are: 88.8 °C; 87.9 °C; and 69.6 °C. The peak coolant temperature of 69.6 °C is reached at 4.700 s. These peak fuel and clad surface temperatures are far below the maximum temperature of 530 °C for LEU silicide fuel that the NRC finds acceptable as fuel and clad temperature limits not to be exceeded under any conditions of operation (See NUREG-1537, Part I, Appendix 14.1 and NUREG-1313). The peak coolant temperature is well below the saturation temperature of 115.3 °C.

Case 5: Rapid Insertion of 0.6% Δk/k Reactivity From 100 kW Under Natural Convection Cooling

The reactor was brought up to 100 kW under natural convection conditions with a maximum inlet temperature of 130 °F. There is a water head of 23' 6.5" above the top of the fuel meat, which provides a pressure of 1.707×10^5 Pa. Power and flow are allowed to stabilize out to 360 s, at which time the power is 100.08 kW. Then a very short reactivity ramp of 0.6% Δk/k is inserted over 0.1 s, starting at 360.00 s. The power trip at 125 kW is actuated at 360.036 s. The reactor power continues to rise from the trip level of 125 kW to a maximum of 369.3 kW at 360.140 s. The reactor power drops rapidly to shutdown conditions.

Peak temperatures for fuel meat centerline (78.9 °C) and clad surface (78.9 °C) occur at 360.18 s, whereas the peak coolant temperature (75.7 °C) occurs at 54.1 s during the rise to power. These peak fuel centerline and clad surface temperatures are far below the maximum temperature of 530 °C for LEU silicide fuel that the NRC finds acceptable as fuel and clad temperature limits not to be exceeded under any conditions of operation (See NUREG-1537, Part I, Appendix 14.1 and NUREG-1313). The peak coolant temperature is well below the saturation temperature of 115.3 °C.

The safety limit on power of 200 kW is exceeded (the power briefly reaches 369 kW). However, the safety limit on power does not apply to transients. In this case, the fuel centerline and clad surface reach peak temperatures of about 79 °C, far below the maximum allowed temperature of 530 °C.

Reference

1. A. P. Olson, A USERS GUIDE TO THE PARET/ANL V7.5 CODE, May 1, 2010, GTRI-Conversion Program, Nuclear Engineering Division, Argonne National Laboratory Internal Memorandum, May 1, 2010.

2. Memo dated 3 September 2010 from Earl E. Feldman to James E. Matos entitled "Steady State Thermal Hydraulic Analysis for Forced Convective Flow in the Rhode Island Nuclear Science Center (RINSC) Reactor"