ANALYSIS OF LOCA/LOECC WITH A NON-STOP CATHENA SIMULATION

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ABSTRACT

This paper documents a new approach which simulates without interruption the blowdown and the post-blowdown portions of a LOCA/LOECC. The blowdown portion is simulated first with the pressures, enthalpies, and void fractions of the headers as boundary conditions. The transient inlet header flowrates are written to a file. The blowdown portion is then simulated again with the inlet header flowrates as boundary conditions. At the end of the blowdown, the flowrates are gradually changed to obtain the desired constant gas flowrate of the post-blowdown portion. This new approach was applied with CATHENA MOD3.5a Rev. 0 for a 20% reactor inlet header break coincident with a total loss of emergency core cooling injection. In summary, this paper shows a successful new approach where the blowdown and the post-blowdown portions of a large LOCA coincident with a total loss of emergency core cooling are simulated continuously.

1. INTRODUCTION

In previous analyses, three codes (for example FIREBIRD [1], HOTSPOT, CHAN [2]) have been used for the simulation of LOCA/LOECC. The methodology used asked for three steps where the blowdown and the post-blowdown portion of the transient where simulated separately, usually by different codes. This three-step approach has also been used with the CATHENA [3] code.

The new approach described in the present work simulates without interruption the blowdown and the post-blowdown portions of the transient with the thermalhydraulic code CATHENA [4]. There are many advantages to this non-stop approach: there is consistency in the conditions between the blowdown and the post-blowdown portion of the transient, this approach is less prone to errors since the data manipulation is minimized, and it avoids the extraction of data at the end of the second step which can be time consuming. This new approach was applied with CATHENA MOD3.5a Rev. 0 for a 20% reactor inlet header break coincident with a total loss of emergency core cooling injection.

2. THE CATHENA CODE

CATHENA is a one-dimensional, two-fluid thermalhydraulic computer code designed for the analysis of two-phase flow and heat transfer in piping networks. The CATHENA thermalhydraulic code was developed by AECL, Whiteshell Laboratories, primarily for the analysis of postulated accident conditions in CANDU reactors.

Heat transfer models are available to model conductive, convective and radiative heat transfer to and from pipe walls and fuel. The pressure tube deformation is modelled as well as the zirconium/steam reaction. Flexible system control models have been developed in the code to control its operation and the models it offers. All features of CATHENA are available through the input control file without the need to re-compile the code.

3. METHODOLOGY FOR THE SIMULATION OF LOCA/LOECC

3.1 Previous methodology

In previous analyses, three codes (for example, FIREBIRD [1], HOTSPOT, CHAN [2]) have been used for the simulation of large loss-of-coolant accident coincident with loss of emergency core cooling scenarios. The simulation of postulated LOCA/LOECC has been performed in three separate steps. In the first step, the blowdown portion of the transient is simulated with a circuit code that predicts the thermalhydraulic conditions in the channel. In the second step, these boundary conditions are used by a fuel code to predict the detailed fuel and channel behaviour during the blowdown portion of the transient. The boundary conditions for this second step are the pressures, enthalpies, and void fractions of the headers. The third step consists of a parametric survey of different steady gas flowrates (usually 5 g/s, 10 g/s, 20g/s and 100 g/s) using the results of the second step as initial conditions with specialized channel codes. It involves a change in boundary conditions from the second step since channel flowrates are specified instead of headers conditions. This change in boundary conditions imposes the last two steps mentioned above.

3.2 Proposed methodology

In the proposed methodology, the first step still requires the use of a circuit thermalhydraulic code to provide the appropriate boundary conditions to the second step. The blowdown portion is simulated first with the pressures, enthalpies, and void fractions of the headers as boundary conditions. The transient inlet-header-to-inlet-feeder flowrates are written to a file. The blowdown portion is then simulated again with the inlet header flowrates as boundary conditions. At the end of the blowdown, the flowrates are gradually changed to obtain the desired constant gas flowrate of the post-blowdown portion of the transient. There is no cut between the blowdown and the post-blowdown portions of the transient.

3.3 CATHENA methodology

When CATHENA is used to simulate transients, two steps are necessary. From the given boundary conditions (channel power, header pressure, etc...), the CATHENA simulation is performed until the converged solution for thermalhydraulic parameters is obtained. Then the transient is started using, as initial conditions, the results of the steady state.

4. CATHENA CHANNEL AND FUEL MODELLING

Channel O17 is chosen because it is a high powered channel (7.3 MW) which contains a bundle of 935 kW. The nodalization of channel O17 with its associated feeders is shown in Figure 1. Each horizontal and vertical section of the feeders are modelled independently. The channel is modelled by 12 thermalhydraulic nodes, one per bundle. Figure 2 shows the detailed fuel modelling. The bundle is modelled by 19 different pins because of the right-left symmetry. Radially, each pin is modelled by 6 nodes in the fuel, 3 nodes in the sheath and 1 node for zircaloy oxide resulting from the zircaloy-steam reaction at high temperature, as seen in Figure 3.

Thermal radiation between the fuel elements and the pressure tube is modelled as well as between the pressure tube and the calandria tube. The pressure tube ballooning at high temperature is modelled with the assumption that it retains its circular shape. The fuel-to-sheath heat transfer coefficient is kept constant at:

- 10.0 $kW/m^2/°C$ when the sheath temperature is below 700 °C,
- 1.0 $kW/m^2/°C$ when the sheath temperature is higher than 750 °C
- and is varied linearly in between.

The sheath emissivity is set at 0.7, the inside of the pressure tube at 0.7 and the outside of the pressure tube as well as the inside of the calandria tube is set at 0.3. The zircaloy-steam reaction is modelled with the Urbanic-Heidric correlation. The radial distribution of the heat generation in the fuel is constant in volume . The power pulse of the 20% RIH break with total loss of ECC is shown in Figure 4.

5. RESULTS

5.1 Circuit simulation

The circuit simulation of a 20% RIH break with total loss of emergency cooling was performed by the SOPTH-G2 code for the blowdown portion of the transient and the beginning of the post-blowdown portion (the code was stopped after 260 seconds). The pressures, enthalpies and void fractions at the headers were written to a file. A pre-processor calculated the gas and liquid enthalpies needed by CATHENA from the mixture enthalpies calculated by SOPHT.

5.2 Steady state results

The SOPHT circuit simulation gave a inlet header to outlet header pressure drop of 1.22 MPa at steady state. The steady-state flowrate calculated by CATHENA in channel O17 was 21.8 kg/s.

5.3 Transient results

5.3.1 Flowrate results (blowdown portion)

Figure 5 shows the comparison between the flowrate calculated by two CATHENA simulations of the blowdown. The full line shows the predicted flowrate at the inlet of the channel for the first CATHENA simulation (where the boundary conditions are pressures, enthalpies and void fractions at the headers). The dotted line shows the predicted flowrate for the simulation using the flow boundary conditions at the inlet header. The results are almost identical showing that new approach is valid and give results almost identical to the traditional approach in the blowdown portion of the transient.

The results presented in the following sections are for the blowdown and post-blowdown portions.

5.3.2 Hydrogen production results

Figure 6 shows the CATHENA predictions of hydrogen production in the channel for the first 1000 seconds. These results are for single channel O17 and steam starvation is used in CATHENA. To have an idea of the total hydrogen production, the maximum amount must be multiplied by 380, which gives approximately 57 kg. This number is well below the value used in safety analysis. One of the reason is that the assumptions for this analysis were made as to maximize the fuel elongation and not the hydrogen production.

5.3.3 Fuel and Sheath Temperature Results

Figure 7 shows the top pin sheath temperatures at bundle 3. Bundle 3 was chosen because it experienced the highest sheath temperatures. The highest temperatures occurred for the 5g/s case. The peak occurred earlier in the 5g/s case than in the other cases because there is less cooling. The decline in temperature after the peak is due to the fact that all the available zirconium have been oxidized and no zirconium is left for the continuation of the steam/zircaloy reaction which produces heat. Figures 8 and 9 show the surface and center fuel temperature at the same location. These plots are very similar to Figure 7 because the gap heat transfer coefficient is kept constant.

5.3.4 Fuel elongation results

Figure 10 shows the CATHENA prediction of fuel elongation at land edge relative to the time of accident. The land edge is chosen because this is where the highest elongation occurs. The 5g/s case has the highest elongation at about 37 mm. This is well below the available space for fuel expansion at Gentilly-2. Note that the timing of the highest fuel elongation does not always correspond to the timing of the highest fuel temperatures because the total elongation depends on the temperatures of each bundle. The sheath temperature of each bundle reaches its peak at different time due to the exhaustion of the zirconium/steam reaction.

5.3.5 Pressure Tube Temperature Results

Figure 11 shows the CATHENA predictions of top pressure tube temperatures at bundle 6 to 8 for the blowdown portion of the transient. These are the three axial segments which experienced contact with the calandria tube before 100 seconds. Table 1 summarizes the contact parameters for all segments which contacted during the blowdown phase of the transient. Due to the moderator subcooling, the calandria tube did not experience dryout after the contact with the pressure tube.

6. DISCUSSION AND CONCLUSION

The comparison between the inlet channel flows of two methodologies for the blowdown period (Figure 5) shows that the results with the flowrate as a boundary condition are identical to those where the pressure and enthalpies are taken as boundary conditions. This allows the whole transient of a large LOCA with loss of ECC to be simulated without interruption by CATHENA. The pressure tube deformation is calculated continuously during the transient as well as all the other parameters. This methodology can be applied to other codes like the coupled code CATHENA-ELOCA [5]. There are many advantages to this non-stop approach: there is consistency in the conditions between the blowdown and the post-blowdown portion of the transient, this approach is less prone to errors since the data manipulation is minimized, and it avoids the extraction of data at the end of the second step which can be time consuming. It was applied to a 20% RIH break with total loss of ECC and was shown to give reasonable results, consistent with previous results. In summary, this paper shows a successful new approach where the blowdown and the post-blowdown portions of a large LOCA coincident with a total loss of emergency core cooling are simulated continuously.

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4. D.J. Richards, B.N. Hanna, H. Hobson and K.H. Ardron, "CATHENA: A Two-Fluid Code for CANDU LOCA Analysis, (renamed from ATHENA)", Presented at the 3rd International Topical Meeting on Reactor Thermalhydraulics, Newport, Rhode Island, 1985.
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TABLES

Table 1. Pressure-tube to calandria tube contact parameters, 20% RIH break with total loss of ECC, blowdown portion of the transient

bundle	time of contact	temperature	pressure
	s	C	MPa
7	62.3	795	1.78
8	64.7	794.1	1.63
6	74.4	823.9	1.21
9	105.2	837.1	0.49
5	158.2	1010.4	0.39

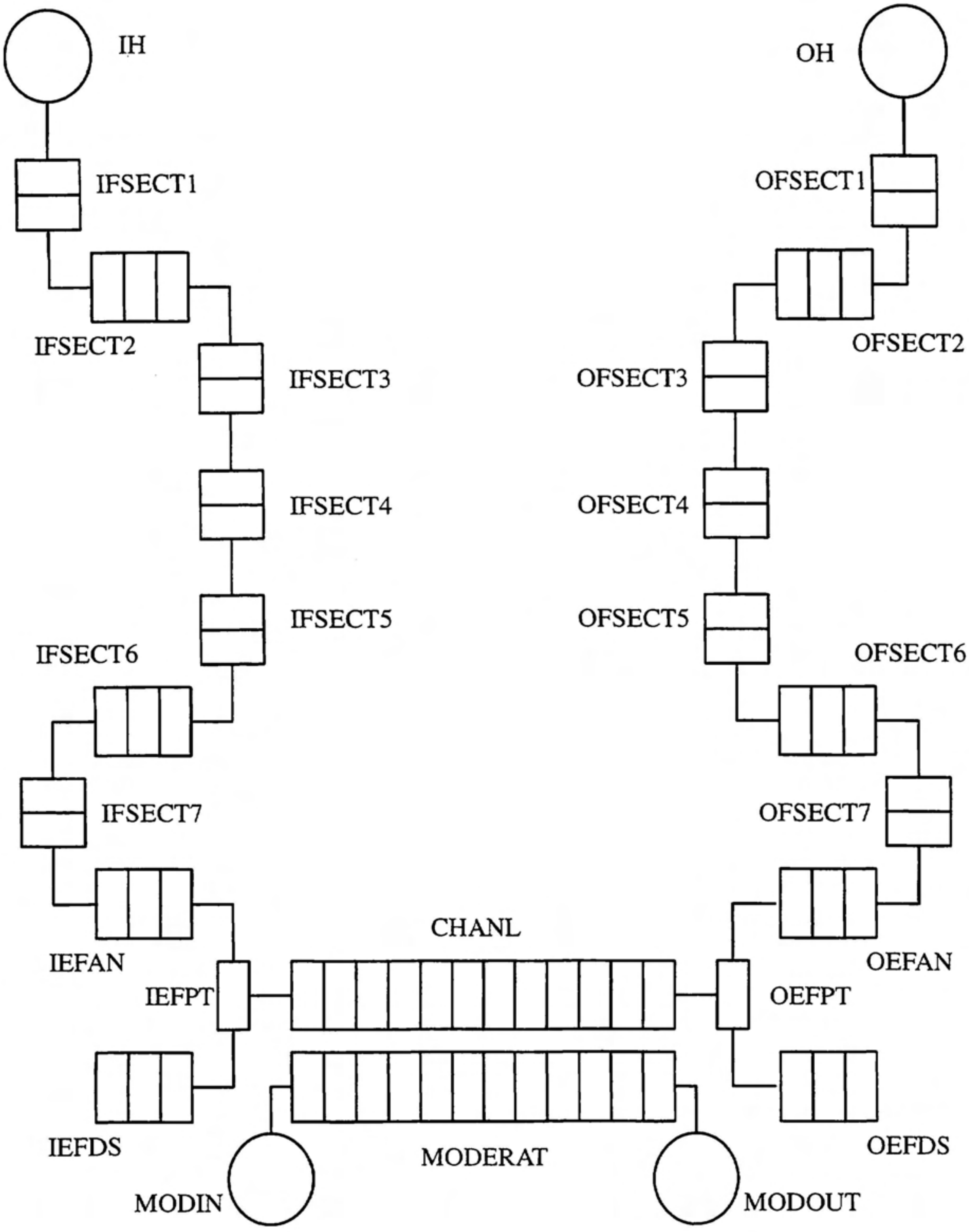

Figure 1. CATHENA thermalhydraulic node/link representation

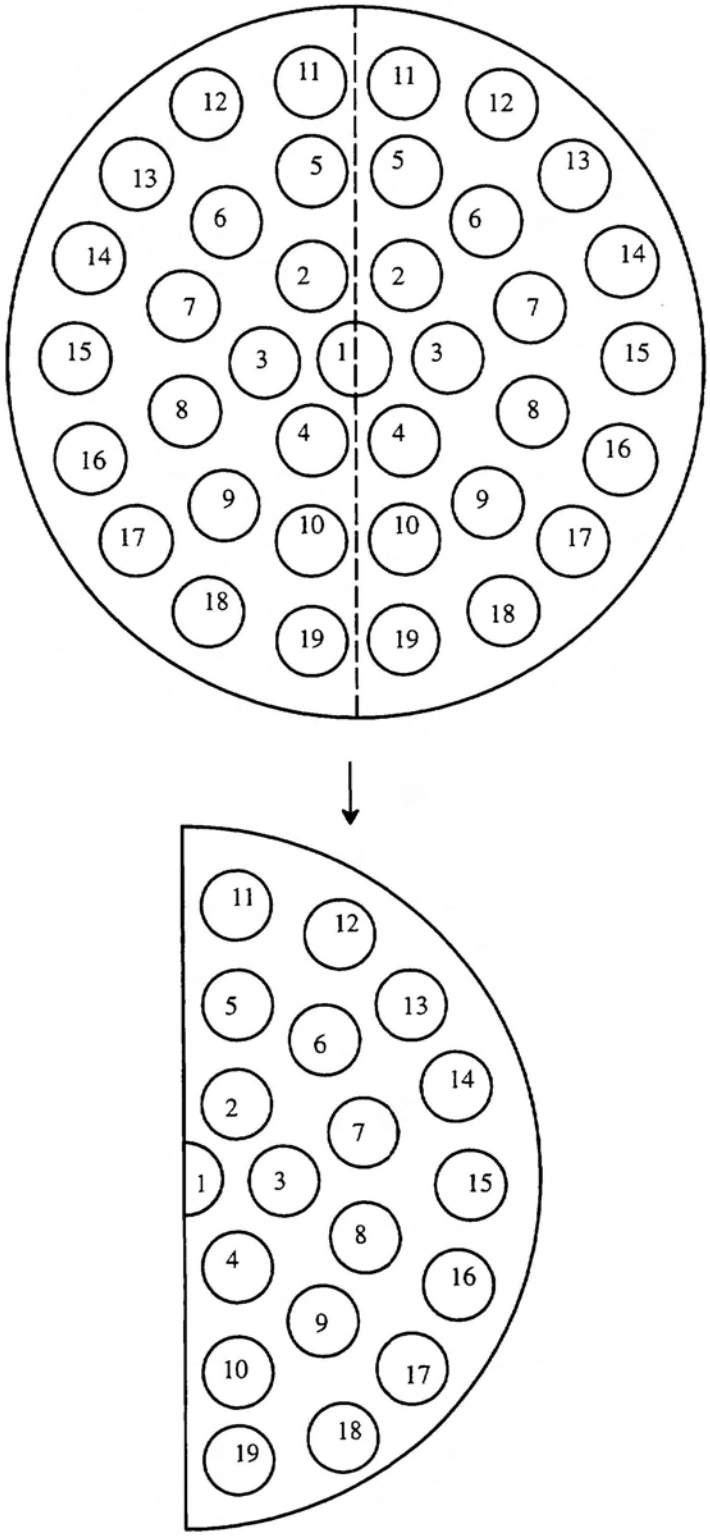

Figure 2. CATHENA detailed fuel modelling

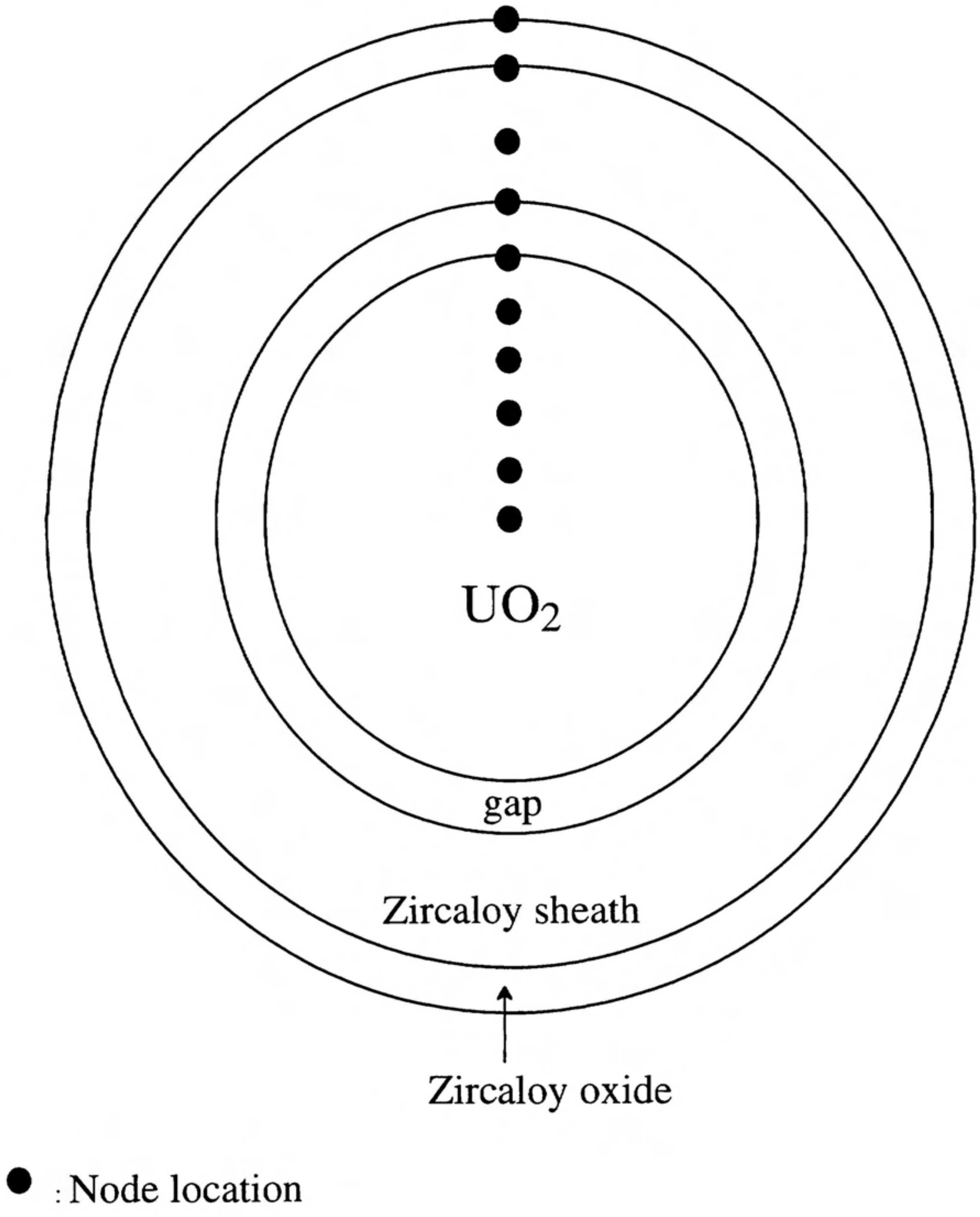

Figure 3. CATHENA fuel element radial nodes and region

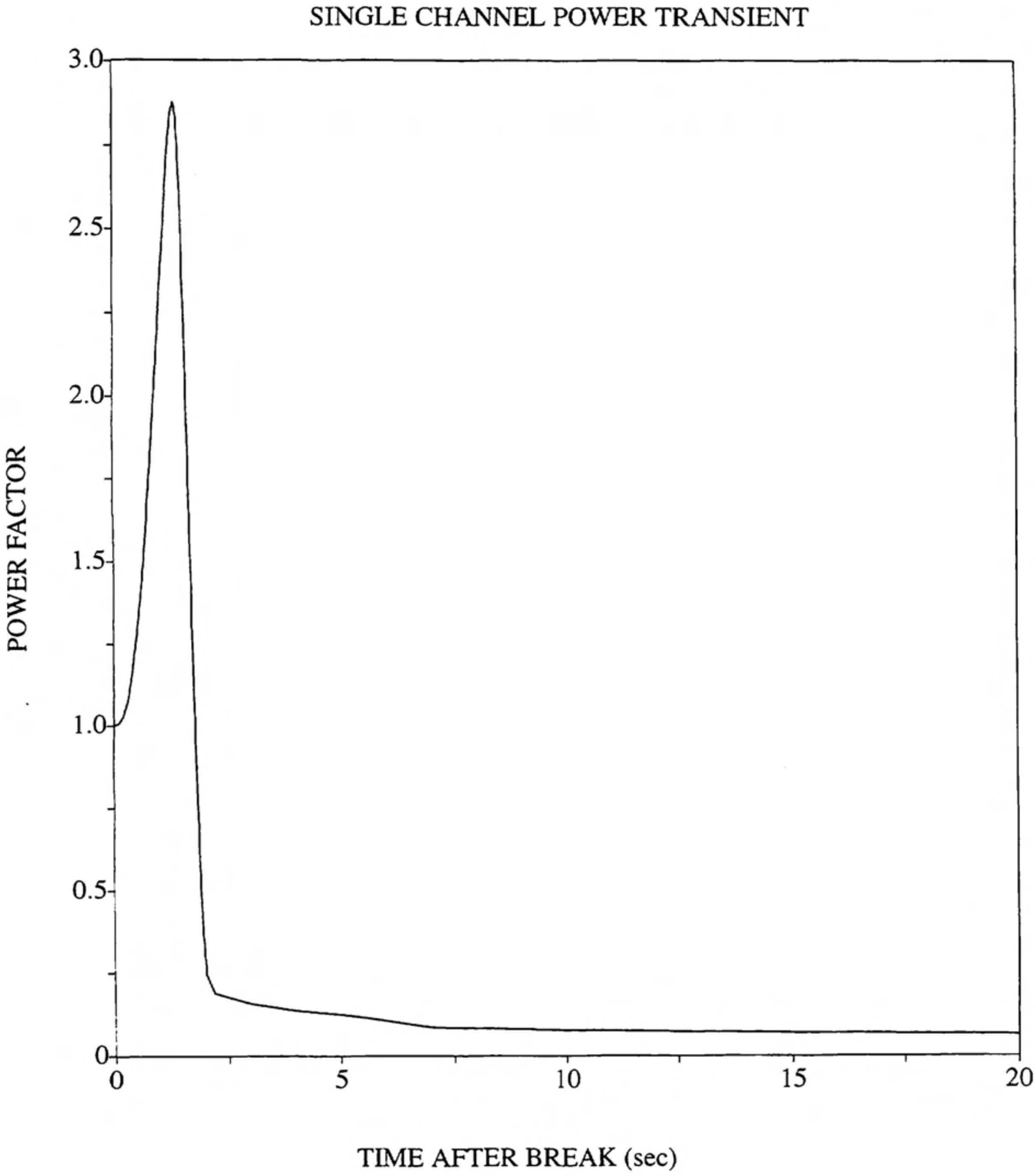

Figure 4. 7.3 MW channel power transient (20% RIH break with total loss of ECC), channel O17

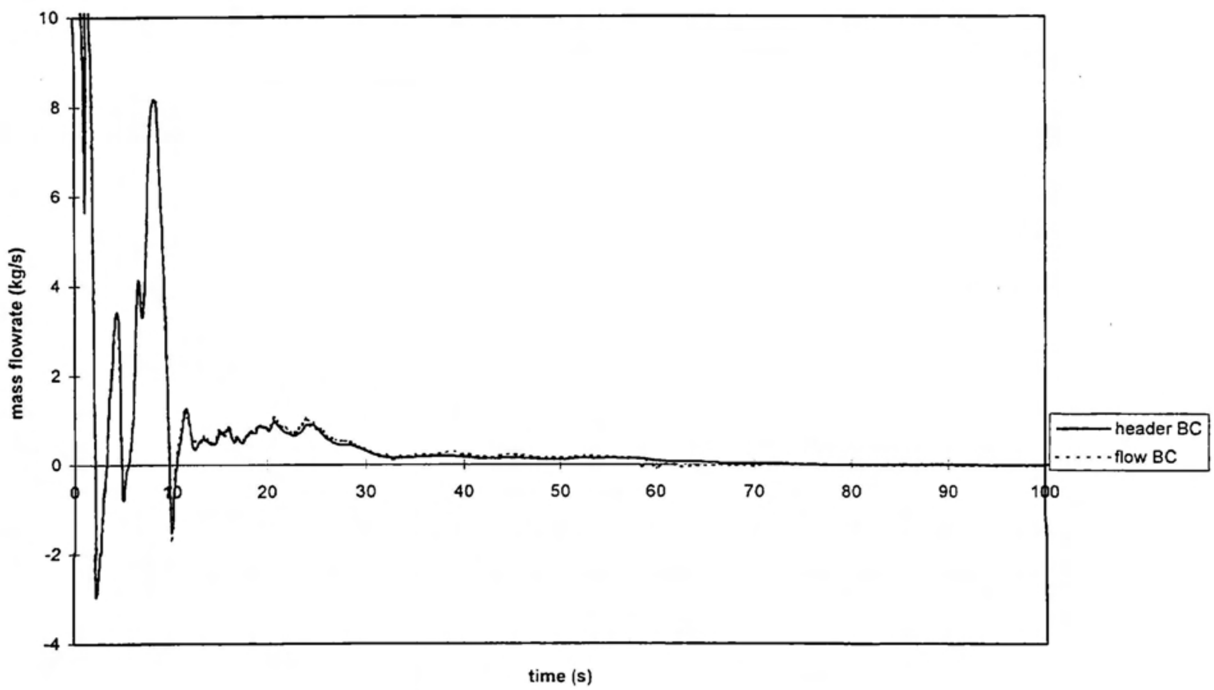

Figure 5. Comparison of CATHENA predicted inlet channel mass flowrate for a 20% RIH break with total loss of ECC

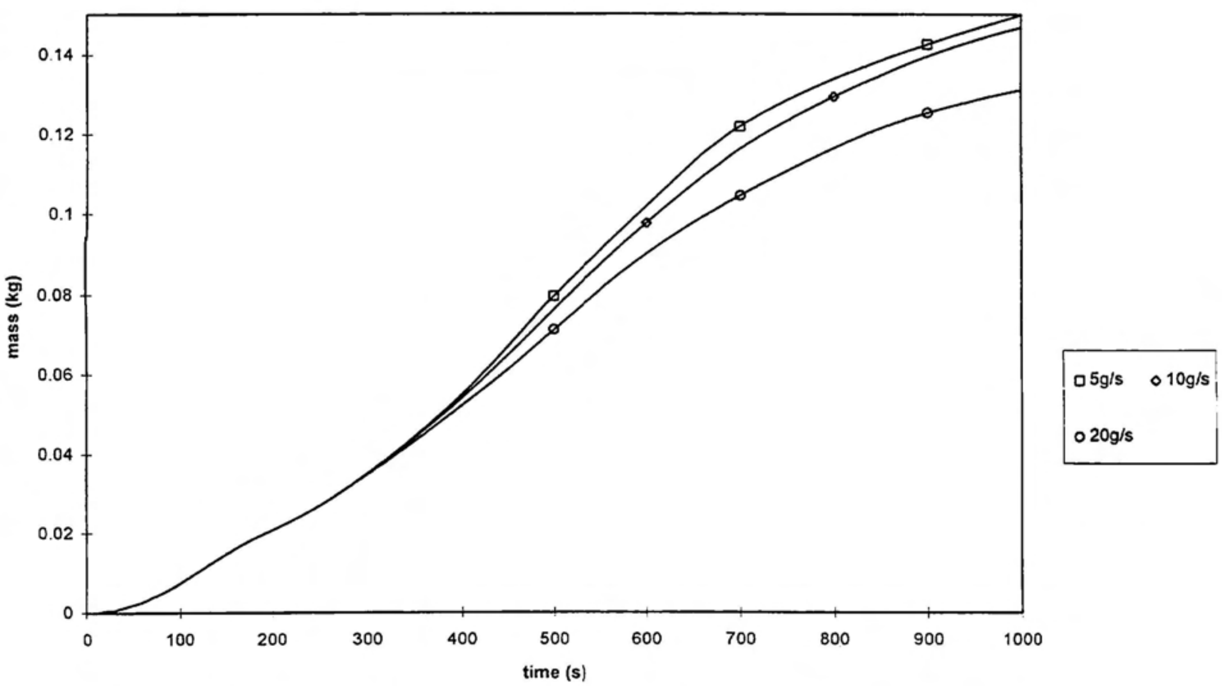

Figure 6. CATHENA prediction of hydrogen produced in the channel, 20% RIH break with total loss of ECC

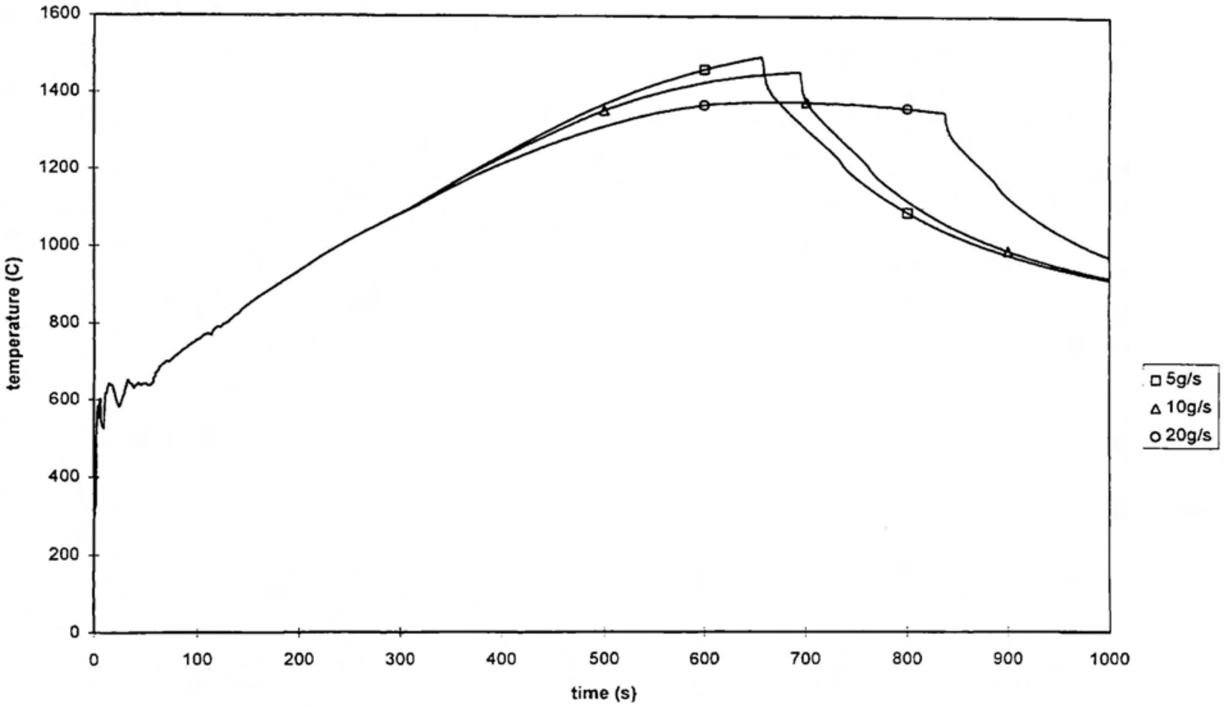

Figure 7. CATHENA predictions of top pin sheath temperature at bundle 3, 20% RIH break with total loss of ECC

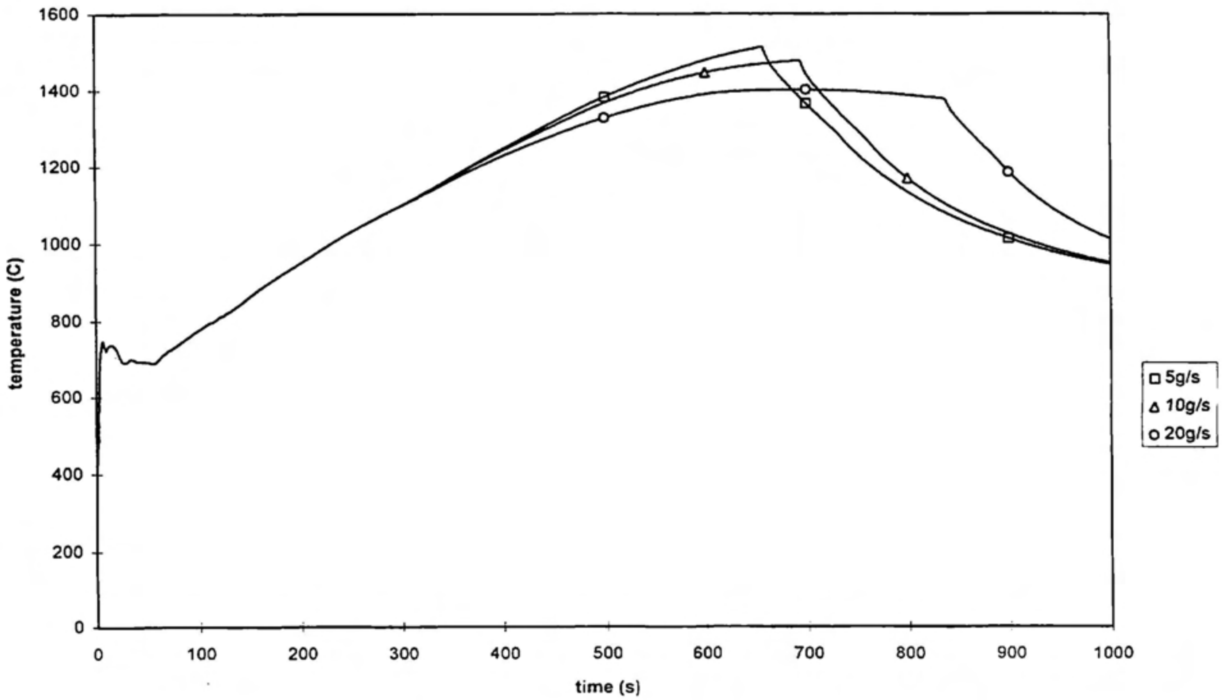

Figure 8. CATHENA predictions of top pin fuel surface temperature at bundle 3, 20% RIH break with total loss of ECC

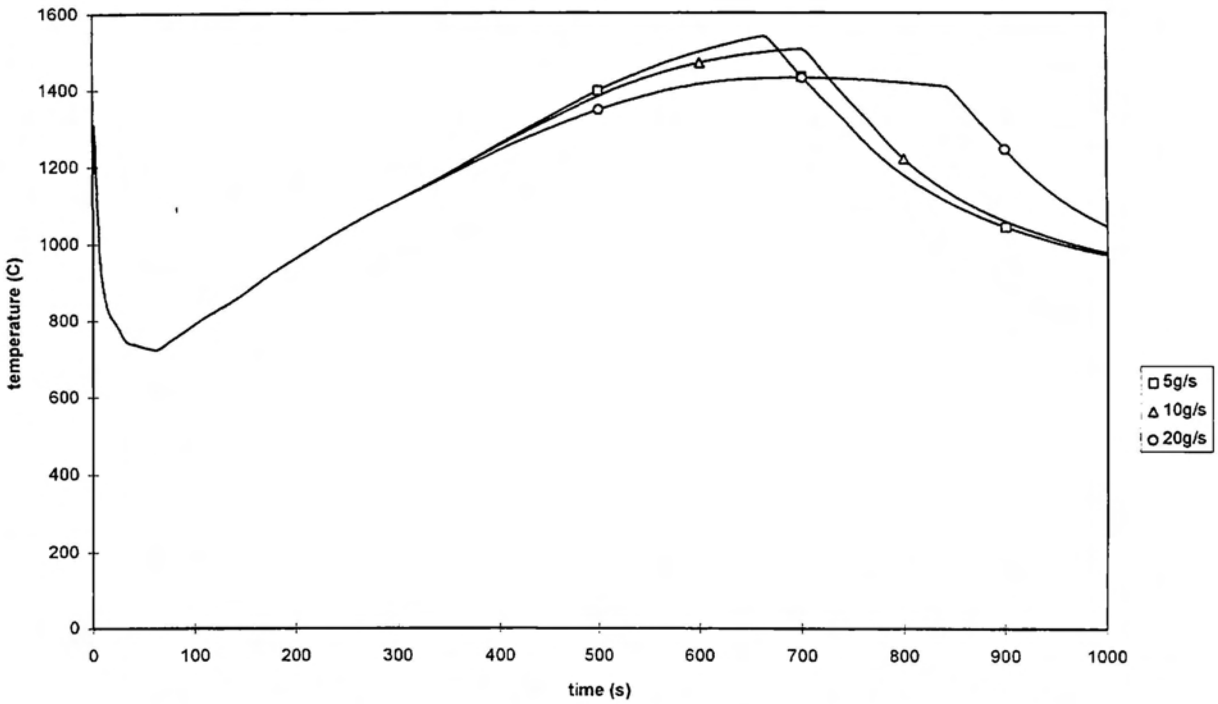

Figure 9. CATHENA predictions of top pin center fuel temperature at bundle 3, 20% RIH break with total loss of ECC

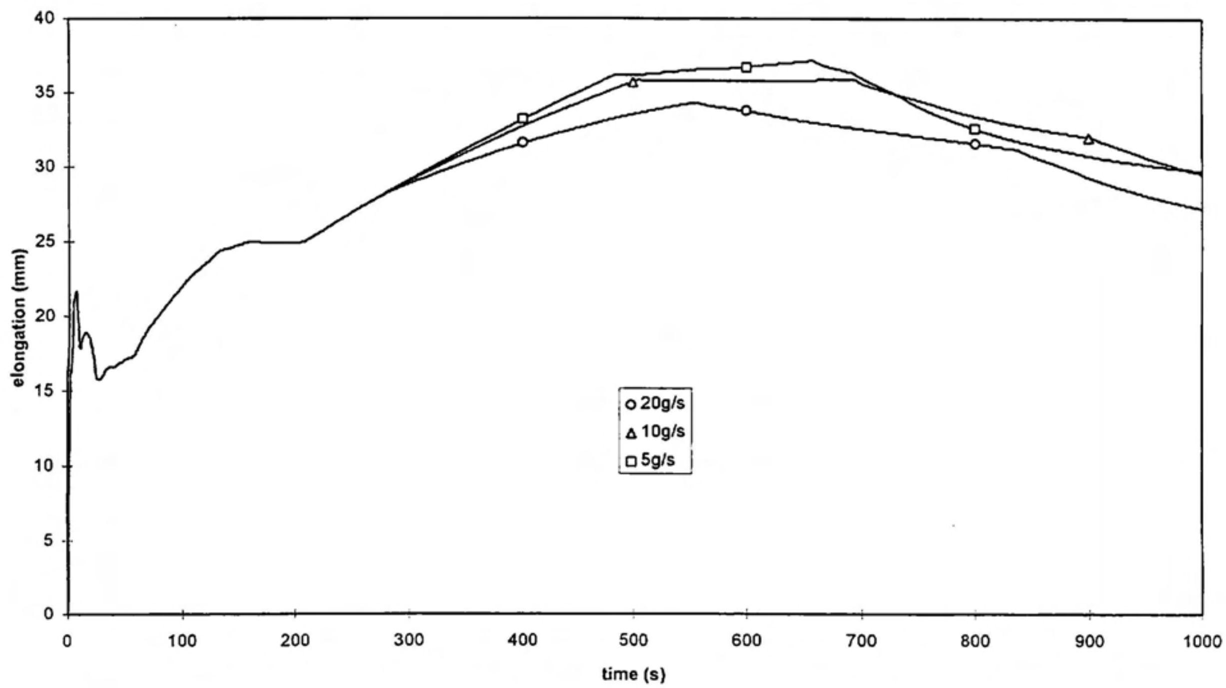

Figure 10. CATHENA prediction of fuel elongation at land edge relative to time of accident, 20% RIH break with total loss of ECC

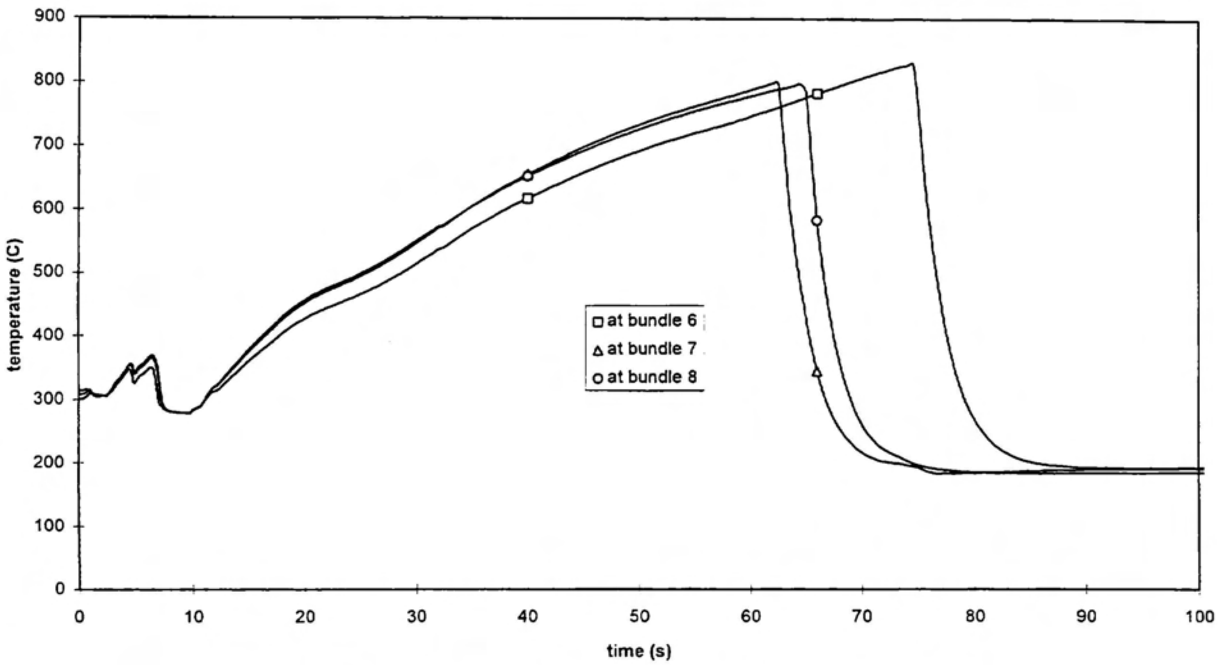

Figure 11. CATHENA predictions of top pressure tube temperatures at bundle 6 to 8, 20% RIH break with total loss of ECC (blowdown portion of the transient)