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Molten Fuel Mass Assessment for Channel Flow Blockage Event in CANDU6

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1. Introduction

In CANDU6, a fuel channel flow blockage causes a sudden reduction of flow through the blocked channel. Depending on the severity of the blockage, the reduced flow through the channel can result in severe heat up of the fuel, hence possibly leading to pressure tube and calandria tube failure. If the calandria tube does not fail the fuel and sheath would continue to heat up, and ultimately melting could occur.

Eventually, molten material runs down onto the pressure tube. Even a thin layer of molten material in contact with the pressure tube causes the pressure tube and calandreia tube to heat up rapidly. The thermal transient is so rapid that failure temperatures are reached quickly.

After channel failure, the contents of the channel, consisting of superheated coolant, fission products and possibly overheated of molten fuel, are rapidly discharged into the moderator. Fuel discharged into the moderator is quenched and cooled. The rapid discharge of hot fuel and coolant into the calandria causes the moderator pressure and temperature to increase, which may cause damage to some in-core components. Thus, the assessment results of molten fuel mass are inputs to the in-core damage analysis.

In this paper, the analysis methodology and results of molten fuel mass assessment for the channel flow blockage event are presented.

2. Methodology for Molten Mass Assessment

The mass of molten fuel and sheath material at the time of channel failure is required as input to the in-core damage assessment. The molten mass is calculated from the thermal-hydraulic analysis results. For the purpose of estimating the molten mass, the fuel and channel heatup is assumed to continue for an additional two seconds after the predicted time of channel failure. This is conservatively done by neglecting the channel failure during this additional 2 second period. The mass of molten material is overestimated since the highest fuel and sheath temperatures, which correspond to the top pins of each ring, are used; that is the assessment conservatively uses melting of the top fuel element of each ring to represent all of the fuel elements in that ring. The melting temperatures for Zircaloy sheath and UO_2 fuel are taken as 1760℃ and 2840℃ respectively. This overestimates the mass of molten material because fuel and sheath temperatures are highest for the top pins of each ring. For channel failure predicted to occur by the Shewfelt criterion, the molten mass assessment is based on the conditions at the time of channel failure. In addition to the molten mass of fuel and sheath material, and additional 5% of the fuel is assumed to interact with the molten sheath and form a molten eutectic, for all fuel elements in which sheath melting is predicted to occur.

3. Assessment Results

Molten mass estimates are based on fuel and sheath temperatures two seconds after the assumed time of channel failure to conservatively account for any additional heatup prior to ejection of molten material from the channel. For the sheath melting criterion case, Table 1 summarizes the maximum molten mass results for channels G5 and A9, along with the results for channel O6_mod.

Table 1. Summary of Maximum Molten Material Masses

	Fuel	Sheath Compound	Total
O6_mod	32.2	20.7	42.1
G5	3.8	17.4	17.4
A9	0.0	19.1	19.1

For flow rates less than 0.9 kg/s, the channel failure occurs later than sheath melting but earlier than fuel centreline melting. Therefore, only molten sheath compound (molten sheath and molten eutectic alloy) is available.

The 0.0 kg/s flow case has a longer period between sheath melting and channel failure and more sheath heating times and therefore, more molten materials than the 0.5 kg/s flow case. For flow rates between 1.2 kg/s and 1.5 kg/s, the channel failure occurs later than both sheath and fuel centerline melting, and therefore both molten sheath compound and molten UO_2 are available.

For the 1.5 kg/s flow case, stratified two phase coolant effectively cools the bottom pin sheath of the highest power bundles and delays their melting time (i.e., channel failure time), resulting in the maximum amount of molten materials For the 1.5 kg/s flow case, the channel failure occurs due to the Shewfelt failure criterion.

For flows higher than 2.0 kg/s, channel failure and sheath melting do not occur, but fuel centerline melting occurs. The amount of fuel melting decreases as flow increase, and therefore only molten UO_2 is available. The maximum amount of molten materials for the sheath melting criterion case is 42.1 kg of molten material consisting of sheath compound (9.9 kg) and UO_2 (32.2 Kg) for the 1.5 kg/s flow case.

The channel flow transients for the 5 reference cases for channel O6_mod are shown in Figure 1. The temperature transients of fuel centreline, sheath, coolant and pressure tube for the reference cases are shown in Figure 2.

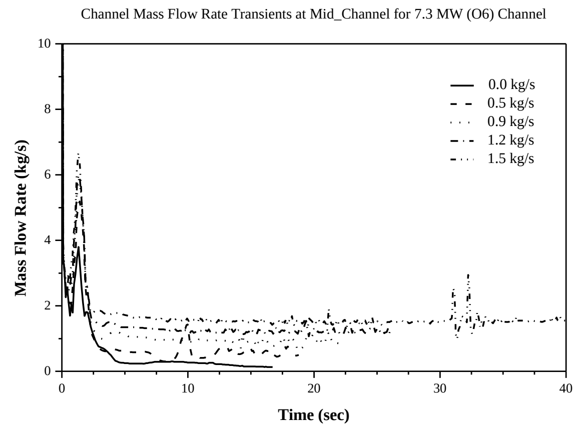

Figure 1. Channel Mass Flow Rate Transients at Mid-Channel for 7.3 MW Channel (O6_mod)

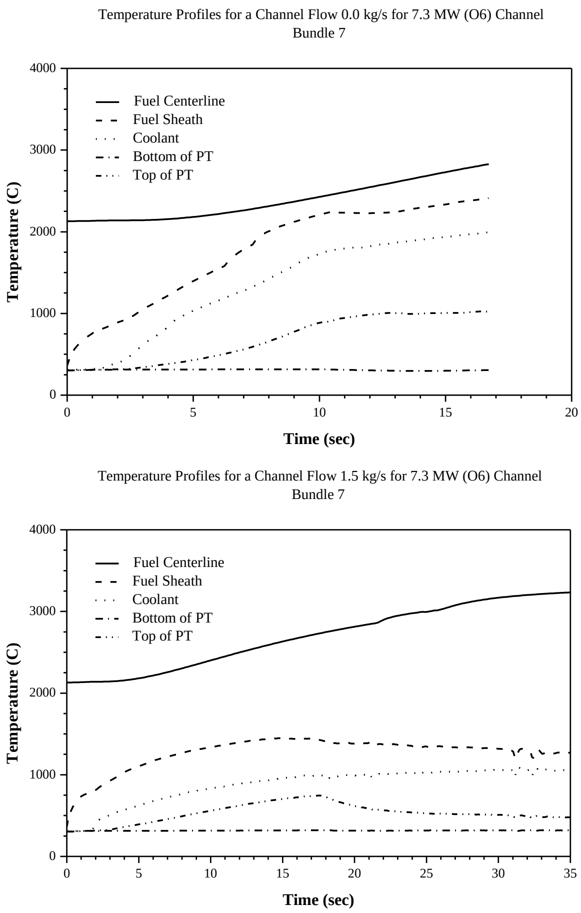

Figure 2. Temperature Profiles for a Channel Flow of 0.0 and 1.5 kg/s for 7.3 MW Channel (O6_mod)

Figure 3 shows the predicted trend of molten masses versus time for the O6_mod cases. The maximum amount of molten materials of 42.1 kg is to be input to the in-core damage analysis.

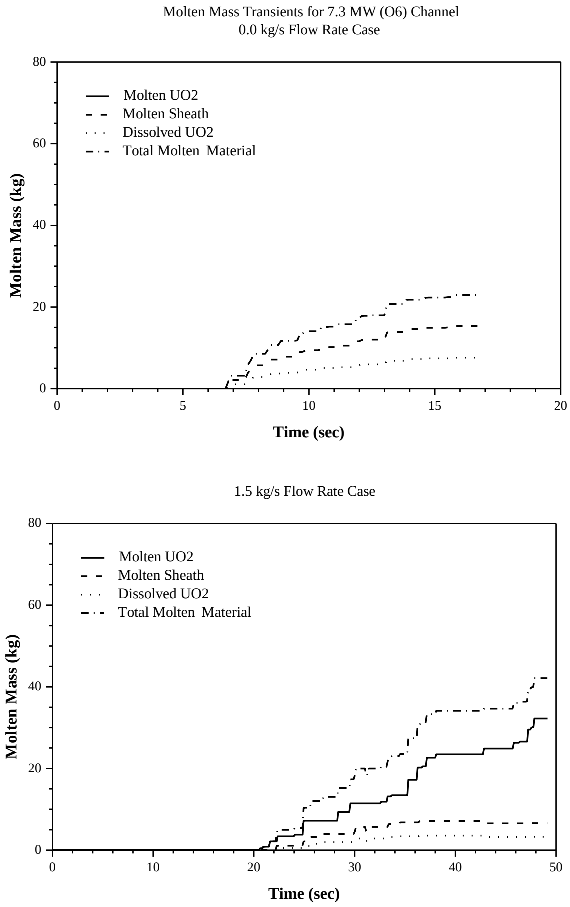

Figure 3. Molten Mass Transients for 0.0 and 1.5 kg/s Channel Flow (O6_mod)

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