ANALYSIS OF CANDU6 REACTOR STATION BLACKOUT EVENT CONCOMITANT WITH MODERATOR DRAINAGE

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Consequences of CANDU 6 station blackout concomitant with moderator drainage event is analyzed in the present paper. The SCDAPSIM/RELAP5 mod 3.4 code was used to perform this analysis. The results obtained are compared with the case where calandria vessel is filled with the water until moderator boiloff occurs.

Keywords: CANDU, station blackout, SCDAPSIM/RELAP5.

1. Introduction

One of distinct feature of CANDU reactor towards light water reactor is represented by the moderator system which is a separate system from the reactor cooling system. Therefore, outside the fuel channels there is the heavy-water, low temperature, low-pressure moderator contained in the calandria vessel (CV). This heavy-water inventory represents an inherent safety characteristic of the CANDU reactors and can play an important role in severe accident prevention and mitigation by passively remove decay heat from the fuel for many hours after an accident providing time and opportunity for operator intervention [1].

Although it is a very low probability event, an earthquake initiating a station blackout event can potentially led to concomitant main moderator system pipe break, as moderator system is not seismically qualified. The moderator outlet nozzles are located on the bottom of the calandria vessel, as shown in Figure 1. As a result, after a pipe break in the main moderator system, the moderator will drain from calandria vessel and the capability of moderator to act as a heat sink will be lost.

The paper presents the analysis of the consequences of such severe accident, a station blackout (SBO) event concomitant with moderator drainage. The results were compared with the case where the moderator water remains available. The SCDAPSIM/RELAP5 mod 3.4 code [2] was used to perform this severe accident analysis.

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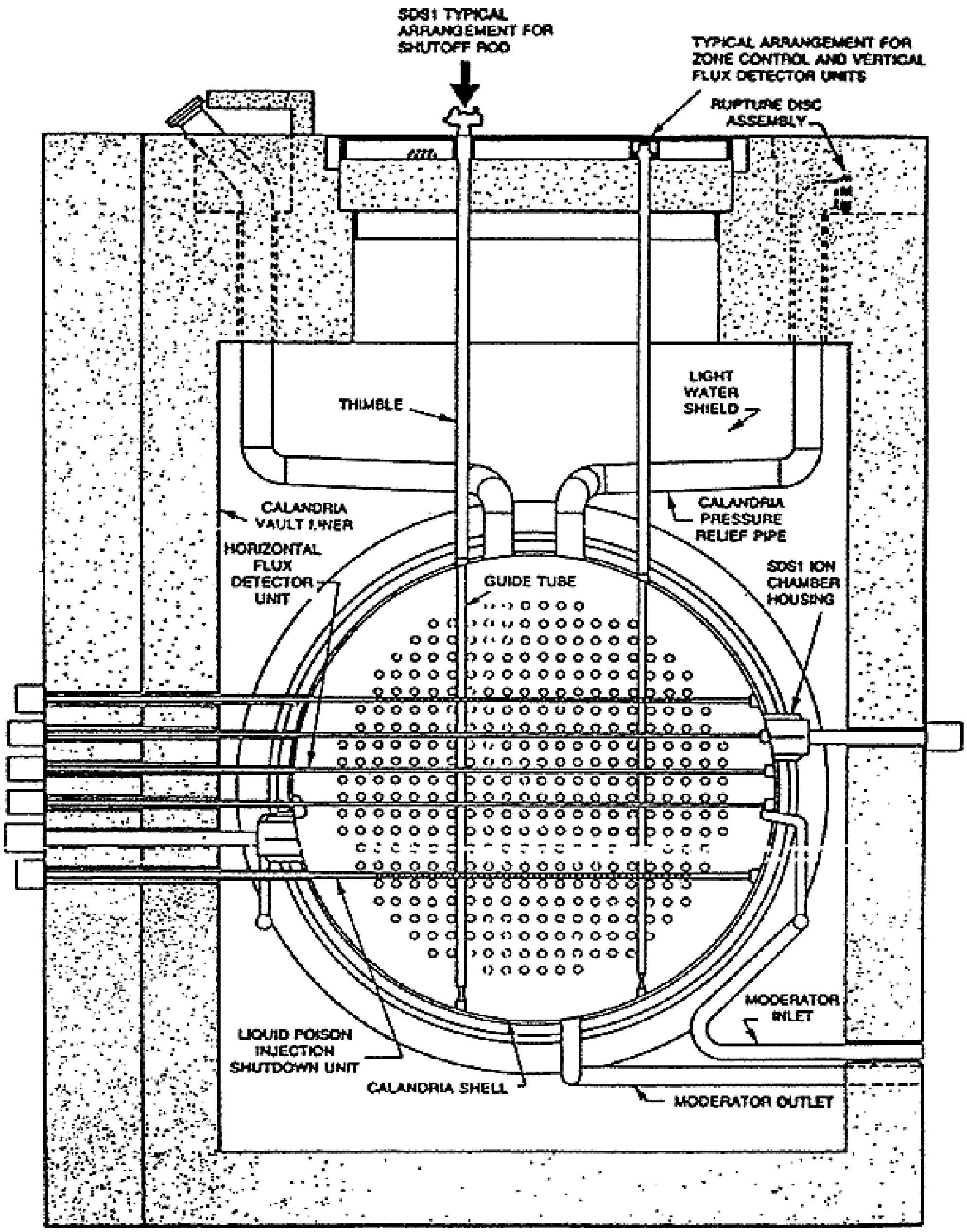

Fig. 1. The CANDU 6 reactor – End view

2. CANDU6 plant model

The plant model includes the representation for the two loops, fuel channels, inlet headers, feeders and end fittings, outlet headers, feeders and end fittings, associated reactor coolant pumps, pressurizer, steam generators and a simplified model for balance of plant systems. In general, all plant components are modelled using RELAP5 components, except for the fuel and fuel channel thermal response which are modelled using SCDAP components and the debris bed modelled by the COUPLE module. Details of the SCDAPSIM/RELAP5 model of CANDU 6 plant, analysis methodology, assumptions and failure criteria used can be found in ref. [3-6].

Calandria vessel is modelled as two parallel pipe components with three sub-volumes having vertical orientation. Each pipe component simulates half of the calandria volume representing the moderator surrounding fuel channels of one PHTS loop. The analogous volumes of the two parallel pipes are connected through cross flow junctions. The four calandria pressure relief ducts are modelled as pipe components with three sub volumes having vertical orientation. Calandria over pressure rupture disk (OPRD) is modelled as a trip valve and connects CV with containment. The main moderator system pipe break is modelled as a trip valve with an open area of 0.1412 m^2, as shown in Figure 2.

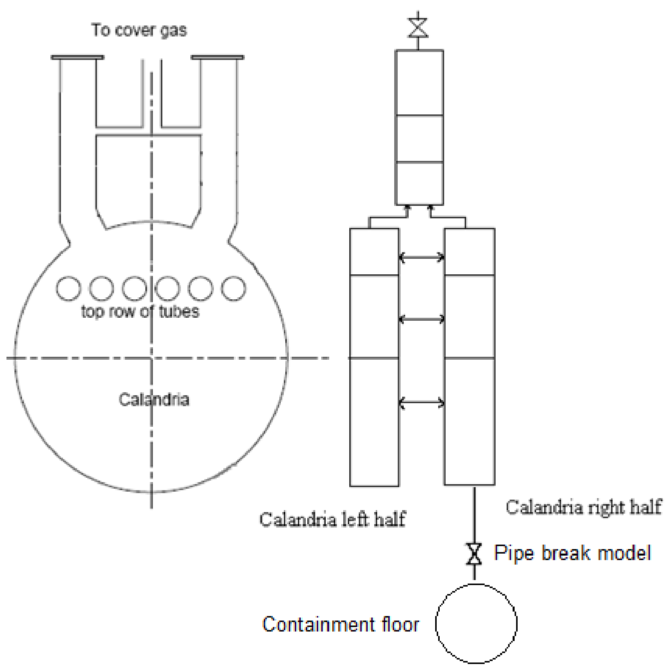

Fig. 2. Calandria vessel model

3. Results

The accident phenomenology and timing of the main events during the CANDU 6 SBO event is well described in ref. [4]. Thereafter only the differences between the two cases, the moderator water remains available until boiloff (the reference case), and without water in calandria vessel will be pointed out.

After main moderator system pipe break, the water level inside the calandria vessel starts to decrease gradually. The steam generators (SG) are the main heat sink during the early phase of the accident. Combined with the fact that there is still heat transferred from fuel channels to the remaining CV water, the SG dryout practically occurs at the same time for the both cases, as shown in Figure 3.

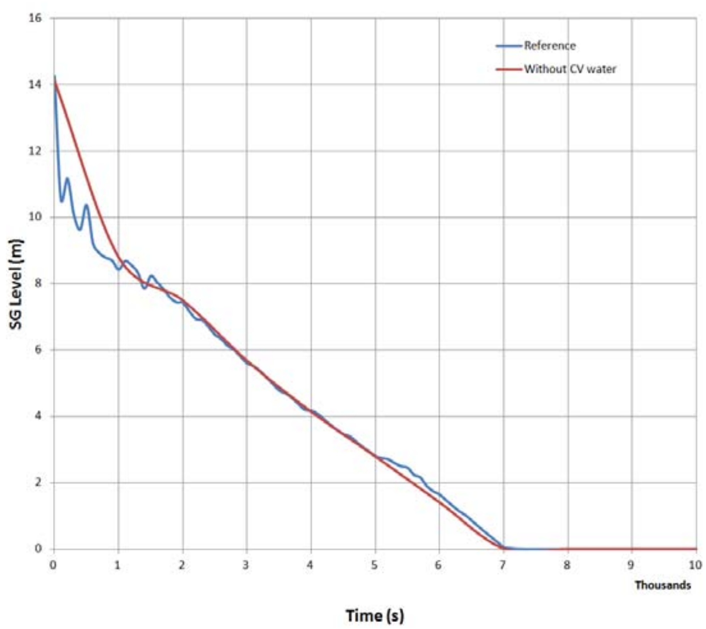

Fig. 3. Steam generator water level

However, when SG dryout occur, calandria vessel is almost empty. Consequently, after this point the loss of moderator as heat sink causes an adiabatic heat up of the fuel channel. As a result, for the case where moderator is drained, the pressure tube (PT) rupture occurs earlier (the fuel channel is considered to fail when the PT temperature became greater than 1000 K [4]). For the reference case, the PT rupture occurs at about 3.17 h (11400 s), whereas for the case without water in CV, the PT rupture occurs at about 3.63 h (13068 s).

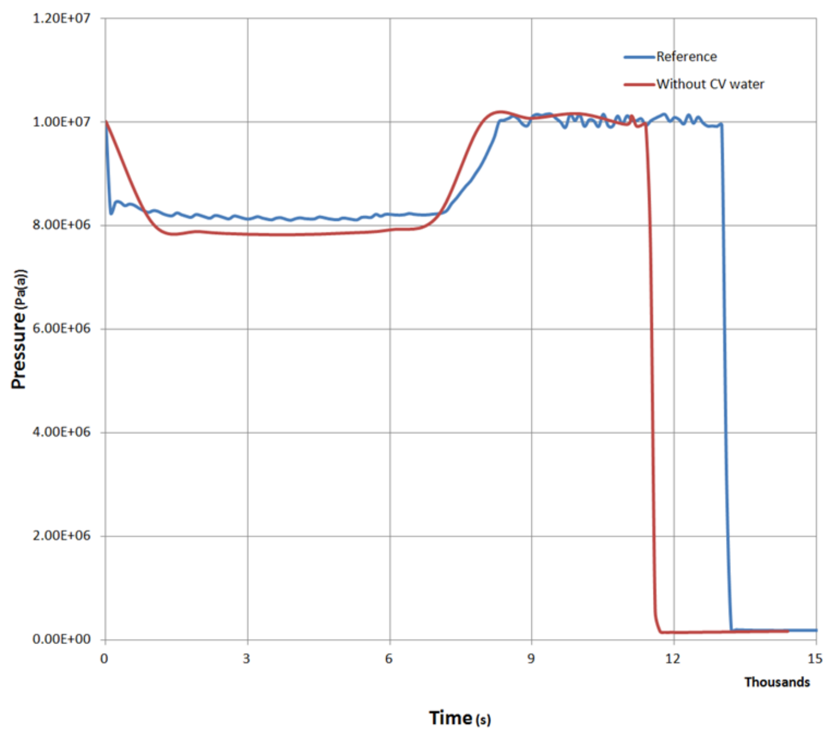

Fig. 4. Reactor outlet header pressure

The rupture of the pressure tube and calandria tube of fuel channels in each loop generates a rapid blow-down from the PHTS into the CV, and the pressure in the Heat Transport System (HTS) decrease rapidly, as shown in Figure 4. When PHTS inventory is discharged into CV, the pressure inside the calandria vessel increases rapidly and reaches the set point of the rupture disk. For the reference case, when the rupture disks open, a rapid decrease in the CV water level occurs. At this time, the fuel channels located on the upper side of calandria vessel becomes uncovered whereas the fuel channels located on the lower side of calandria vessel are still submergen in water. After the initial rapid moderator expulsion, the moderator continues to discharge gradually into the containment as a result of continued moderator boil-off due to the heat transfer from the core [4].

Contrary to the reference case, in the moderator drainage case at the moment of the CV rupture disks open, there is no water in calandria vessel. Hence, all fuel channels are uncovered and heat-up similarly. Accordingly, core collapse occurs much earlier, soon after PT rupture, at 3.6 h whereas this occurs at 7.8 h for the reference case.

The hydrogen generated during this stage of the accident in the moderator drainage case is much less: 44 kg compared to 306 kg generated in reference case, as shown in Fgure 5. This happen due to the absence of the steam from boiling of CV water, and consequently only 2 % of core Zirconium oxidation compared to 40 % in the reference case.

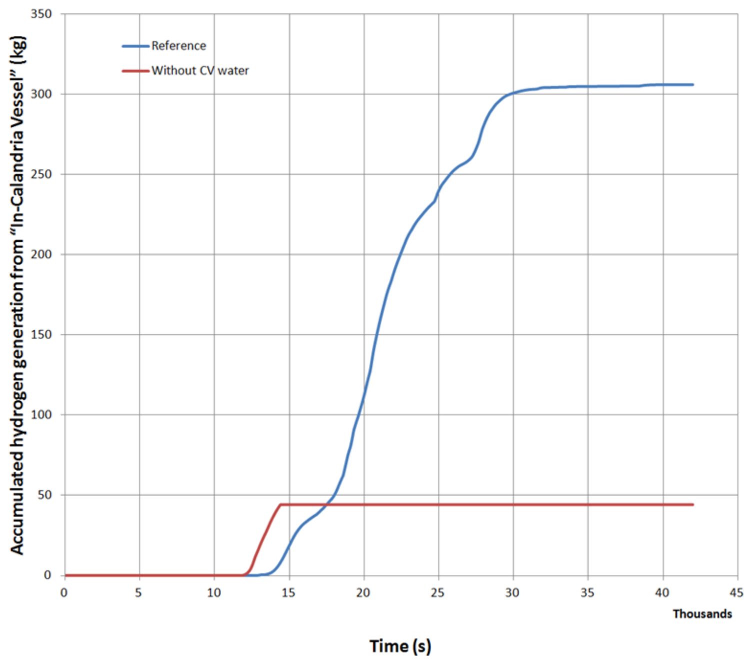

Fig. 5. Hydrogen generated until core collapse

As no water is present in calandria vessel when core collapse occurs, heat-up of the debris bed at the bottom of calandria vessel starts much earlier: 3.6 h compared to 11.58 h for the reference case.

The water in the reactor vault (RV), surrounding the calandria vessel, acts as a heat sink and cools the CV wall, maintaining the calandria vessel integrity. The maximum value calculated for the heat flux is lower than the critical heat flux (300 kW/m^2 [7]), as shown in Figure 6. However, as heat is transferred from the debris, reactor vault water reaches the saturation temperature and starts to boil. Consequently, the reactor vault water level begins to decrease and eventually, the water level in the RV falls below the CV bottom level. Subsequent to this moment, the CV bottom heats up rapidly and fails due to creep. Failure of calandria vessel occurs about 20 hours earlier in the case of moderator drainage: 31.26 h compared to 50.55 h for the reference case. Two main factors contribute to this: earlier core collapse and debris bed heat-up, thus a higher debris power density (about 1MW/m^3 compared to 0.62 MW/m^3 for the reference case), and as less Zirconium oxidation occurs, the molten debris contain more metallic Zirconium with higher thermal conductivity, this increase the heat transfer from molten debris to the RV water.

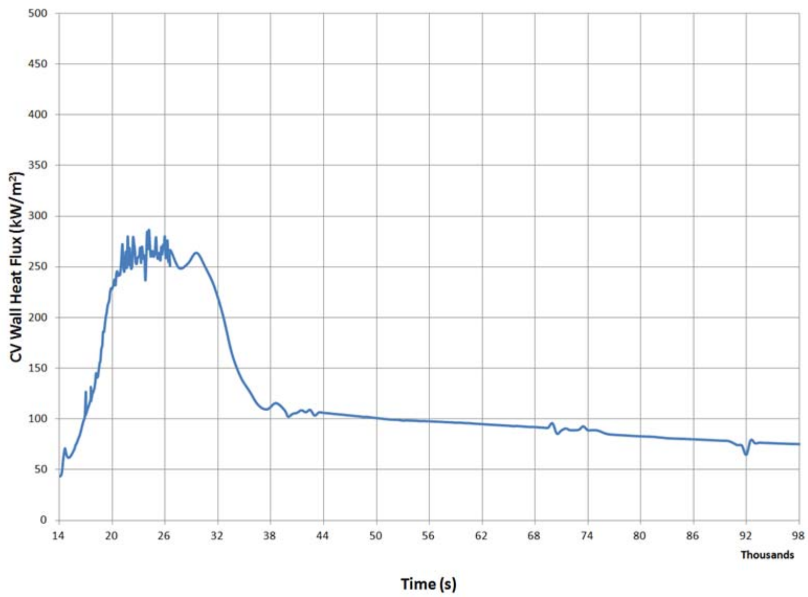

Fig. 6. Maximum calandria vessel wall heat flux

The main results obtained are summarized in the Table 1.

Table 1

List of Significant Differences in Timing of Events for Station Blackout Scenario

Event	SBO-reference scenario Event timing [h]	SBO concomitant with moderator drainage Event timing [h]
Class IV and Class III Power loss	0	0
SG secondary sides are dry	2.08	2.08
Pressure and calandria tubes are ruptured	3.63	3.17
Calandria vessel rupture disks #1-4 open	3.63	3.17
Core collapse	7.8	3.6
Start of debris heat-up	11.58	3.6
Calandria vessel failed	50.55	31.26

4. Conclusions

The SCDAPSIM/RELAP5 mod 3.4 code was used to perform the analysis of the consequences of a station blackout (SBO) event concomitant with moderator drainage. The main results of this study can be summarized as it follows:

- The timing of events for the early phase of the accident is similar for both cases; in particular, the steam generators are dry at the same moments.
- For the remaining phases of the accident, all the events occur much faster in the moderator drainage case. As a result, calandria vessel fails 20 h earlier
- The maximum value calculated for the heat flux is lower than the critical heat flux, confirming the heat removal capability from the calandria vessel wall by the reactor vault water, as long as the liquid phase is present in the reactor vault
- Few amount of hydrogen is generated in the moderator drainage case due to the lack of steam to react with Zirconium.
- Presence of water in calandria vessel significantly delays the progression of the severe accident that provides time and opportunity for operator intervention to restore the reactor vault water supply.

R E F E R E N C E S

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