Transactions of the Korean Nuclear Society Autumn Meeting
Pyeongchang, Korea, October 30-31, 2014

Available Driving Head Following a Loss-of-Coolant Accident in the APR1400 Design

Jeong-kwan Suh[a*], Jae-yong Lee [a], Hae-jung Sung [b]
[a]*KHNP Central Research Institute, 1312-70 Yuseong-daero, Yuseong-gu, Daejeon 305-343, Korea*
[b]*KEPCO Nuclear Fuel, 989-242 Daedeok-daero, Yuseong-gu, Daejeon 305-353, Korea*
[*]*Corresponding author: jksuh@khnp.co.kr*

1. Introduction

The objective of in-vessel downstream effect (IDE) evaluation is to demonstrate that there is reasonable assurance that sufficient long-term core cooling (LTCC) is achieved with debris and chemical products which are postulated to be transported to the reactor vessel [1]. To maintain LTCC, it should be demonstrated that the available head to drive emergency core cooling (ECC) flow into the core is greater than the head loss across the core due to possible debris buildup.

In this paper, the available driving heads following a loss-of-coolant accident (LOCA) in the APR1400 design were presented.

2. Available Driving Head

The following relationship should be true to ensure that a sufficient flow is available to maintain LTCC :

$$dP_{avail} > dP_{debris} \quad (1)$$

The core flow is only possible if the manometric balance between the downcomer (DC) and the core is sufficient to overcome the flow losses in the reactor vessel (RV) downcomer, RV lower plenum, core, and loops at the appropriate flow rate [2, 3].

$$dP_{avail} = dP_{dz} - dP_{flow} \quad (2)$$

where dP_{avail} = total available driving head
dP_{dz} = pressure head due to liquid level between downcomer side and core
dP_{flow} = pressure head due to flow losses in the reactor coolant system (RCS)

The flow losses (dP_{flow}) for LOCA scenarios were based on the values provided in LOCA analyses data [4].

2.1 Available Driving Head at Hot-leg Break Condition

In the event of a hot-leg (HL) break, the driving force is the manometric balance between the liquid in the downcomer and core as shown in Fig. 1. If a debris bed begins to build up in the core, the liquid level will begin to build in the cold legs and steam generator (SG). As the level begins to rise in the SG tubes, the elevation head to drive the flow through the core increases as well. The driving head reaches its peak when the shortest SG tube has been filled with coolant.

2.1.1 Assumptions

1) Core voiding was neglected and the core liquid level was assumed to be at the bottom of the hot leg. This is conservative because it maximizes the static head of the liquid in the core region.
2) The downcomer liquid density was based on the sump liquid conditions. Since density is inversely proportional to liquid temperature, and a lower density will reduce the driving head from the downcomer, a conservatively high sump liquid temperature was selected. The liquid density is also a function of the containment pressure. The containment pressure is as high as 454.9 kPa (65.98 psia) early in the event and then continually decreases throughout the event [1]. A density corresponding to this saturation pressure is approximately 918.17 kg/m^3 (57.32 lbm/ft^3).
3) The core liquid density was set equal to the downcomer liquid density for conservatism.
4) The reactor vessel downcomer and lower plenum k/A^2 is small (typically << 0.1). Further, the liquid density is large (> 57.32 lbm/ft^3) and bulk velocity is low. Therefore, the losses in these regions can be neglected.

2.1.2 Calculations

$$dP_{dz} = dP_{DC} - dP_{core} \quad (3)$$
$$dP_{DC} = (Z_{so} - Z_{core\text{-}in}) \times \rho_{DC} \times g = 135{,}730\text{Pa}$$
$$dP_{core} = (Z_{brk} - Z_{core\text{-}in}) \times \rho_{core} \times g = 43{,}698\text{Pa}$$

The inputs are found from APR1400 drawings and evaluations. As stated in the assumptions, the flow losses in the downcomer, lower plenum and core are negligible. The loop losses were evaluated from LOCA analyses data. From the calculation, dP_{flow} was determined as follows :

$$dP_{flow} = 1{,}366.9 \text{ Pa} \quad (4)$$

From Eq. (2), (3), (4), the $dP_{available}$ is as follows:

$$dP_{avail} = dP_{DC} - dP_{core} - dP_{flow} = 90{,}666\text{Pa } (13.15\text{psi})$$

2.2 Available Driving Head at Cold-leg Break Condition

In the event of a cold-leg (CL) break, the driving force is the manometric balance between the liquid in the downcomer and core as shown in Fig. 2. The ECC water from each direct vessel injection (DVI) lines runs to the break, ensuring that the downcomer is full to at least the bottom of the CL nozzles. The $dP_{available}$ is established

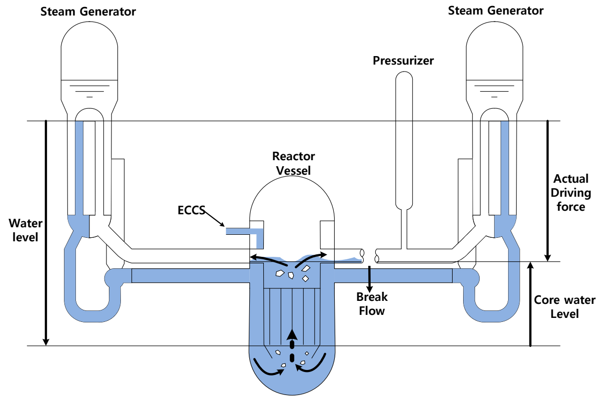

Fig. 1. Available Driving Head at HL Break Condition

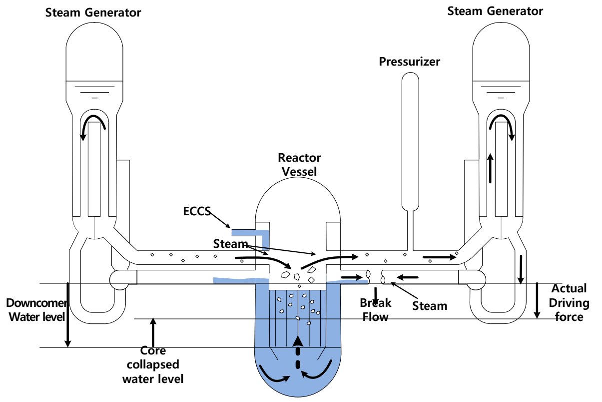

Fig. 2. Available Driving Head at CL Break Condition

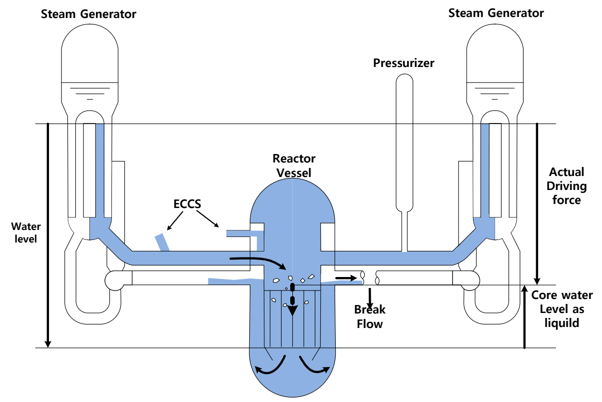

Fig. 3. Available Driving Head at CL Break after HLSO

by the manometric balance between the downcomer liquid level and the core liquid level considering pressure drop through RCS loops due to the steam flow.

2.2.1 Assumptions

1) The core void fraction (α) changes with time so a time dependent relationship was used as follows (WCAP-16793-NP Rev. 2 App. K, RAI #18 [2]).

$$\alpha_{core} = 1.1128 \times t^{-0.1183} \quad (5)$$

2) The assumptions used in HL break case (assumptions # 2, 3, and 4) were also applied to CL break case.

2.2.2 Calculations

$$dP_{dz} = dP_{DC} - (1-\alpha_{core})\, dP_{core} \quad (6)$$

$$dP_{DC} = (Z_{brk} - Z_{core\text{-}in}) \times \rho_{DC} \times g = 45{,}127\text{Pa}$$

$$dP_{core} = (Z_{core\text{-}out} - Z_{core\text{-}in}) \times \rho_{core} \times g = 34{,}267\text{Pa}$$

$$\alpha_{core} = 1.1128 \times 700^{-0.1183} = 0.5126$$

The dP_{avail} for a CL break is dependent upon the time at which the value is calculated. Therefore, the inputs described here can be used to calculate the expected dP_{avail} as a function of time. Since, the boiloff rate decreases with time, the minimum dP_{avail} for a CL break was calculated at the recirculation start time (700sec, [1]).

The loop losses were evaluated using LOCA analyses data. From the calculation, dP_{flow} was determined as follows :

$$dP_{flow} = 8{,}257 \text{ Pa} \quad (7)$$

From Eq. (2), (6), (7), the $dP_{available}$ is as follows:

$$dP_{avail} = dP_{DC} - (1-\alpha_{core})dP_{core} - dP_{flow} = 20{,}170 \text{ Pa (2.93 psi)}$$

2.3 Available Driving Head at CL Break after HLSO Condition

In the event of a CL break after HL switchover (HLSO) operation, the driving force is the manometric balance between the liquid in the downcomer and core as shown in Fig. 3. If a debris bed begins to build up in the core, the liquid level will begin to build in the HLs and SGs. As the level begins to rise in the SG tubes, the elevation head to drive the flow through the core increases as well. The driving head reaches its peak when the shortest SG tube has been filled with coolant.

2.3.1 Assumptions

1) The assumptions used in HL break case (assumptions # 2, 3, 4) were also applied to CL break after HLSO case.
2) The flow losses in RCS were based on the values in LOCA analyses data.

2.3.2 Calculations

$$dP_{dz} = dP_{DC} - dP_{core} \quad (8)$$

$$dP_{DC} = (Z_{so} - Z_{core\text{-}in}) \times \rho_{DC} \times g = 135{,}730\text{Pa}$$

$$dP_{core} = (Z_{brk} - Z_{core\text{-}in}) \times \rho_{core} \times g = 45{,}068\text{Pa}$$

The inputs are found from APR1400 drawings and evaluations. The loop losses were evaluated using LOCA analyses data. From the calculation, dP_{flow} was determined as follows :

$$dP_{flow} = 1.291\text{Pa} \quad (9)$$

From Eq. (2), (8), (9), the $dP_{available}$ is as follows:

$$dP_{avail} = dP_{DC} - dP_{core} - dP_{flow} = 90{,}660\text{Pa (13.15psi)}$$

3. Conclusions

The available driving heads of the APR1400 design were calculated in case of HL break, CL break, and CL break after HLSO operation at the recirculation start time (700 seconds after ECC start).

Each calculation results are summarized as follows;

- dP_{avail} at HL break condition : 90,666 Pa (13.15 psi)
- dP_{avail} at CL break condition : 20,170 Pa (2.93 psi)
- dP_{avail} at CL break after HLSO : 90,660 Pa (13.15 psi)

The voiding in the steam generator tubes by the secondary side heating will be considered in the following study. In addition, the break size spectrum will be analyzed to calculate the available driving head when the loop seal reformation happens after a small break LOCA.

REFERENCES

[1] APR1400-E-N-NR-13001-P Rev.0, “APR1400 Design Features to Address GSI-191,” October 2013.
[2] WCAP-16793-NP Rev.2, “Evaluation of Long-Term Cooling Considering Particulate, Fibrous and Chemical Debris in the Recirculating Fluid,” October 2011.
[3] USNRC, “Final Safety Evaluation by the Office of Nuclear Reactor Regulation: Topical Report WCAP-16793-NP, Revision 2,” April 2013.
[4] APR1400-F-A-TM-14004-P, Rev.0, “Pressure Drop Through a Loop Following Loss Of Coolant Accidents,” July 2014.
[5] APR1400-F-A-NR-12002-P, Rev.0, “Post-LOCA Long Term Cooling Evaluation Model,” September 2012.