An Evaluation of Calandria Vault Makeup Models in ISAAC 2.0 Code

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1. Introduction

The previous version of the ISAAC (Integrated Severe Accident Analysis Code in CANDU) 1.0 [1] was developed in 1995. Since then, a few new features were added to the ISAAC 2.0 code [2], including a simple coolant makeup model into calandria vault (CV). The developed model will be used as a calculational aid to generate support tables for the "coolant makeup into CV" as an accident management strategy that is needed to make CANDU-specific severe accident management guidance. This table will help operators to find an optimum light water supply rate or timing into CV when severe core damage has happened in Wolsong plants.

2. Model Characteristics and Assumptions

The major model requirements, characteristics and assumptions are as follows:

– When the CV water level decreases, the makeup water is injected from the holdup tank using a gravitational force

– When the water level in the holdup tank becomes too low, the operator can provide water to the holdup tank using the demineralized water supply system [3]

– The CV makeup model calculates mass flow rates of water/steam/non-condensable gases through the relief valves, and the corresponding rates of energy exchange

– External makeup flow to the CV is modeled through an external event flag to calculate mass flow rates of water (assuming that the makeup water is light water with an infinite source) and the following user input parameters are needed

- Desired water level in the calandria vault to control water makeup flow
- Makeup flow into the calandria vault
- Water temperature of makeup flow

3. Methods and Results

This section describes analysis methods and results of the coolant makeup model into the CV (CMM) developed in ISAAC 2.0 code.

3.1 Analyzing Scenarios

The calandria vault and end shields protect the fuelling machine operating areas from direct radiation from the reactor and as a result, nuclear heat is accumulated within shields. After reactor trip, heat is added to the water in the CV by conduction through the calandria walls from the moderator and the heat from these sources is removed by circulating light water through the end shield cooling system (ESC) [4]. When heat exchangers in the ECS fail to remove the heat and the coolant becomes saturated, the CV rupture disks located in the relief vent piping system open (setpoint = 69 kPa(g) (= 10 psig)) and steam is relieved into the boiler room with the water level decrease in the CV (normal level = 115.17m ± 0.15m).

As the CV water level becomes lower than the water level in the holdup tank (normal level =114.33m) that is connected with the CV, the makeup water is gravitationally provided. When the holdup tank inventory that is very small (≈3 tons) is depleted, the operator provides the demineralized water from the storage tank with very large inventory (unlimited external sources). Therefore, the makeup rate into the CV is limited only by the demineralized water supply rate into the holdup tank that is between 5.5 l/sec to 9.9 l/sec according to the characteristic curve for the demineralized water supply pumps.

From these, the coolant makeup analysis into the CV is conservatively made with the minimum water supply rate provided just after the rupture disks open. For a sensitivity study, 4 cases (no makeup, makeup ends at the desired water level of 3.0m, 3.3m and 4.0m) are analyzed. The target plants are Wolsong 2/3/4 units.

3.2 Accident Progression

For the reference sequence, a large LOCA is analyzed for the bounding calculation that is a transient sequence initiated by a guillotine break in the reactor outlet header (ROH) with an area of 0.259 m^2 in one loop. It was assumed that the emergency core cooling system injection, moderator cooling function, shield cooling function for the calandria vault and end shields, containment dousing spray system, and the containment local air coolers (LAC) were not available. The feedwater is initially provided but no main or auxiliary feedwater is available after a reactor shutdown that is assumed to occur at 0.87 seconds following the FSAR results [5]. The main steam safety valves (MSSVs) are initially closed but, after the LOCA signal is received at 3.5 seconds (when primary pressure reaches 5.56 MPa), are manually opened at 33 seconds from a crash cooldown operation. Major accident progression is shown in the Tab.1 and a detailed trend of the important variables for the thermal hydraulics can be referred to from the Wolsong level 2 PSA final reports [6].

Time [sec]				Event
N/A	3.0	3.3	4.0	
0.0				LOCA occurs in ROH HPI/MPI/LPI fail Moderator cooling & ESC fail MSIV close Dousing/LAC fail
0.87				RX trip, MFW/AFW fails
20.7				Loop 1 core uncovers
33.4				SG MSSV (broken loop) manual open
4226				CT rupture disc fails
7603				Loop 1 PT fail
7953				Loop 2 core uncovers
8981				Loop 2 PT fail
32316				CV rupture disc fails
115055		115075	N/A	CT fail
132907	N/A			CCI starts in CV
360000 (= 100 hr)				End calculation

Tab.1 Major Accident Progression

3.3 Calculational Results

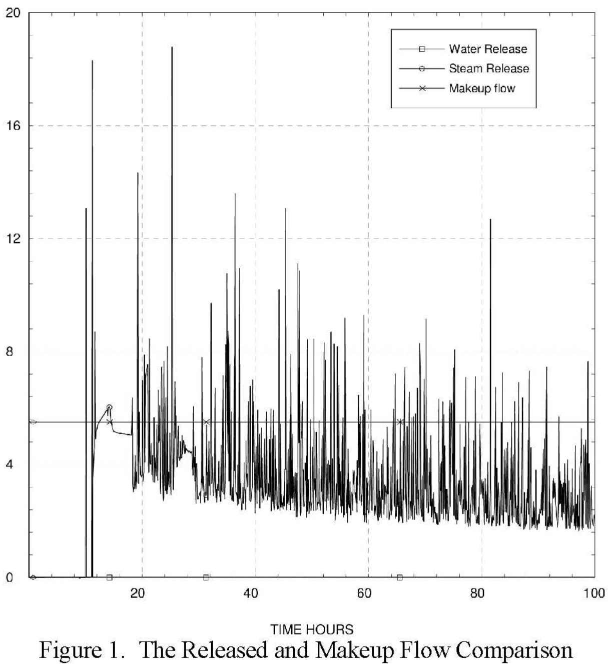

Figure 1. The Released and Makeup Flow Comparison

The CV makeup is possible as the water level becomes about 1 m lower from the normal water level after the rupture disks open. The released mass flow through the relief valves is made by water in the first beginning and by steam only thereafter and the released mass flow calculated was smaller than the minimum makeup rate (=5.5 l/sec) as shown in the Figure 1. Therefore, the water level recovery time in the CV depends mainly on the demineralized water supply rate into the holdup tank. If no makeup is available, the water level in the CV decreases continuously due to the external cooling effect of the calandria walls and the calandria failure occurs finally at about 32 hours into the accident. But the calandria failure is prevented as far as the CV makeup (water temperature = 26 C) starts at least 1 m higher than the calandria failure height according to the sensitivity study on the makeup start water level (see Figure 2).

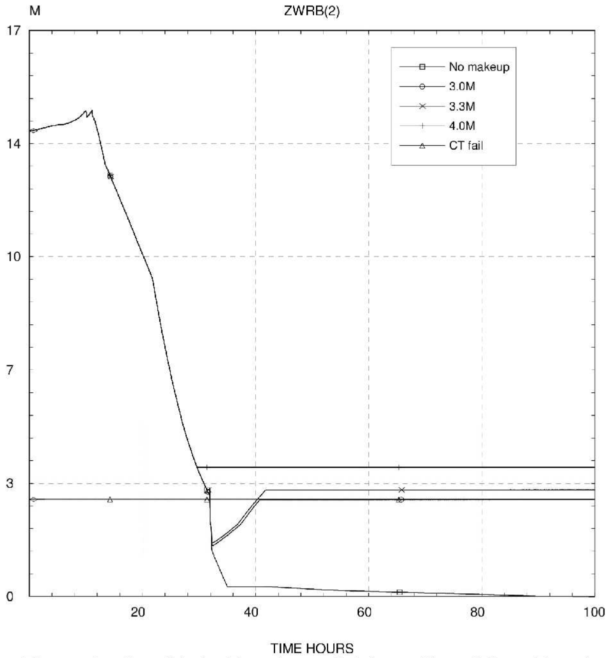

Figure 2. Sensitivity Results on Makeup Start Water Level

4. Conclusion

Though more sensitivity studies are needed for various accident scenarios, the accident management strategy using the water makeup into the CV is judged to be effective. Especially, if the makeup begins at least 2 hours (which corresponds to about 1 m higher water level) before the calandria failure, the accident progression can be stopped inside the calandria.

ACKNOWLEDGMENTS

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