18th International Conference on Structural Mechanics in Reactor Technology (SMiRT 18)
Beijing, China, August 7-12, 2005
SMiRT18-P02-2

THE FEASIBILITY STUDY OF AN IN-VESSEL RETENTION STRATEGY DURING SEVERE ACCIDENTS FOR A 700 MWe PHWR

S.Y. Park
Korea Atomic Energy Research Institute
150 Dukjin, Yusong, Daejon, Korea
305-353 Phone: 82-42-868-8298,
Fax: 82-42-868-8256
E-mail: sypark@kaeri.re.kr

Y.H Jin
Korea Atomic Energy Research Institute
150 Dukjin, Yusong, Daejon, Korea
305-353 Phone: 82-42-868-2756,
Fax: 82-42-868-8256
E-mail: yhjin@kaeri.re.kr

S.D.Kim
Korea Atomic Energy Research Institute
150 Dukjin, Yusong, Daejon, Korea
305-353 Phone: 82-42-868-2658,
Fax: 82-42-868-8256
E-mail: sdkim2@kaeri.re.kr

Y.M. Song
Korea Atomic Energy Research Institute
150 Dukjin, Yusong, Daejon, Korea
305-353 Phone: 82-42-868-2663,
Fax: 82-42-868-8256
E-mail: ymsong@kaeri.re.kr

ABSTRACT

This paper presents an 'In-vessel Retention Strategy' during severe accident of typical 700 MWe CANDU-type reactor. It includes some design characteristics of the reactor, computer code calculation results for a typical station blackout scenario and a large loss of coolant scenarios, and the brief discussion about in-vessel retention strategy. As a results, the "In-vessel Retention Strategy' might be very effective means for the Wolsong plant severe accident management. It results from the design features ; (1) Calandria vault is always flooded during normal operation, (2) Negligible metal layer, (3) No insulation structure, (4) Low decay power due to the slow accident progression, (5) Large calandria bottom area to transfer the corium decay heat into the calandria vault water, etc.

Keywords: In-vessel Retention, External Vessel Cooling, Severe Accident Management, Heavy Water Reactor .

1. INTRODUCTION

Severe accident management strategies have been developed for the Wolsong plant. The plant is a 700 MWe pressurized heavy water reactor. There are seven individual accident management strategies One of the key accident management strategies is to inject water into the calandria vault to retain the relocated corium within the calandria vessel through an external vessel cooling during severe accident scenarios, which is so-called an in-vessel retention for a light water reactor. This study focuses on the feasibility of an in-vessel retention strategy in the Wolsong heavy water reactor.

2. DESIGN FEATURES OF REFERENCE PLANT

Fig 1 illustrates a schematic of the fuel channels, a calandria, vessel and a calandria vault. of a reference plant. The reference plant is a CANDU heavy water-moderated, natural uranium-fuelled pressurized heavy water reactor with a thermal output of about 2,060 MWth. The CANDU design comprises a cylindrical stainless steel assembly (the calandria vessel) housed within a light-water filled, a steel-lined concrete structure (the calandria vault) which provides a thermal shielding and cooling. The calandria vessel contains a heavy water (D2O) moderator, reactivity control mechanisms and three hundred and eighty fuel channels that contain fuel bundles through which pressurized D2O coolant flows. Thus CANDU reactors possess two inherent supplies of water close to the fuel: the moderator which surrounds the fuel channels, and the shielding water which surrounds the calandria. And the plant has two independent heat transport loops. This design feature can contribute to a delay in an accident progression. For example, even if a loss of coolant occurs at one loop, the other loop is still intact by isolating the relevant valves. Then the decay heat can be removed through the intact SG.

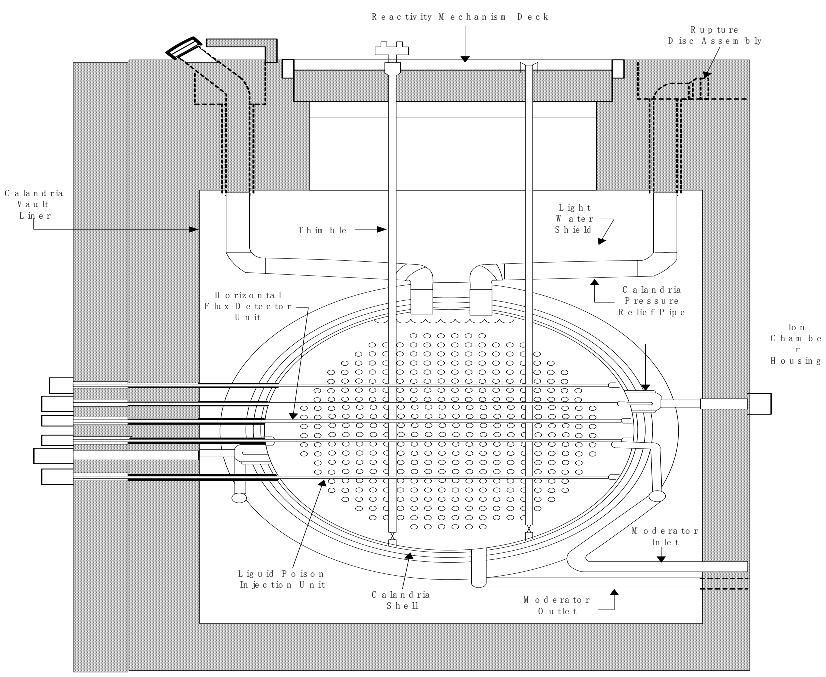

Figure 1.   A schematic of Fuel Channels, a Calandria, vessel and a Calandria Vault

.

3. FEASIBILITY STUDY

Several limiting factors can be considered in studying the feasibility of an in-vessel retention for a light water reactor. These factors include the choking limit for a steam venting due to the insulation structure of the reactor cavity, the critical heat flux for a downward facing boiling on the vessel outer surface(F.B.Cheung, 2003), the focusing effect by a thin metal layer on the top of the molten corium in the lower plenum of the reactor vessel, and the two-phase flow instabilities in the natural circulation loop within the flooded cavity due to the thermal insulation structure around the reactor vessel (J.H.Song, 2002).

In the typical light water reactor design, there is a bottleneck between the reactor vessel lower head and the insulation structure. When a high rate of vapor is generated on the vessel lower surfaces under severe accident conditions a choking can occur at the bottleneck, which may increase the vessel wall temperature and finally result in a vessel failure. Wolsong plants, however, have no thermal insulation structure around the calandria vessel. Hence the choking limit for a steam venting through the bottleneck or the two-phase flow instabilities in the natural circulation loop within the flooded calandria vault can not be limiting factors in Wolsong plants.

There is no considerable steel material in the core of the Wolsong plant, and as a result only a negligible metal layer can be formed on the corium of the calandria vessel bottom. This means that we need not take into account the limiting factor of the focusing effect from the metal layer.

The corium from this plant has a lower volumetric decay heat power when compared with the same powered light water reactor. This results from the fact that the plant uses natural uranium and that the severe accident progression occurs slower than that of a light water reactor. Table 1 and Table 2 compare the accident progressions of the Wolsong plant with that of typical Korean standard nuclear power plant(KSNP) which is a 1000 MWe light water reactor. The selected scenarios are a typical station blackout sequence without any recovery action and a large loss of coolant accident. ISAAC(Integrated Severe Accident Analysis Code for CANDU Plants) computer program (KAERI, 1995) and MAAP(FAI, 1994) have been used in the calculation. Calculation results show that the times of a corium relocation, calandria vessel water depletion, and calandria vessel failure for the Wolsong plant are much later than the times for a KSNP.

One of the major different design features of the Wolsong plants from other light water reactor is a calandria vessel. The calandria vessel is always submerged in water because the calandria vault is flooded during a normal operation. And the molten corium in the bottom of the calandria vessel has a very large heat transfer area to the outside water of the calandria vault through the vessel wall. As a result, the critical heat flux is not exceeded on the caldaria vessel wall surface. Figure 2 shows the total heat transfer rate from the calandria vessel to the caldaria vault shield water for two maximum heat flux limits. When the maximum heat flux is limited artificially to 0.1 MW/m^2, the vessel wall fail at about 12 hours after the accident initiation. If the maximum heat flux is increased to 0.2 MW/m^2 , the vessel wall does not fail as long as the wall is submerged in water. The vessel failed only after the bottom wall was uncovered. Based on the above discussion, the in-vessel retention strategy seems to be very effective for the Wolsong plant.

Table 1. Comparison of the accident progression of the Wolsong plant with KNGR for SBO

Accident Progression	Wolsong plant (hours)	KNGR (hours)
SG dryout	2.3	1.3
LRV(PSV) open	1.5	0.9
Core uncovery start	2.8	1.8
Loop 1&2 fuel channel rupture	3.8	N/A
Core melt start	N/A	2.8
Corium relocation	6.7	4.2
Calandria vessel(RV) dryout	12.7	4.5
Calandria tank(RV) fail	40.7	4.5

Table 2. Comparison of the accident progression of the Wolsong plant with KNGR for LOCA

Accident Progression	Wolsong plant (hours)		KNGR (hours)
	LOOP 1	LOOP 2	
SG dryout		0.9	
LRV(PSV) open		1.8	
Core uncovery start	early	2.2	early
Loop 1&2 fuel channel rupture	2.3	3.1	
Core melt start			0.9
Corium relocation	2.3		1.5
Calandria vessel(RV) dryout	9.0		1.6
Calandria tank(RV) fail	35.3		2.6

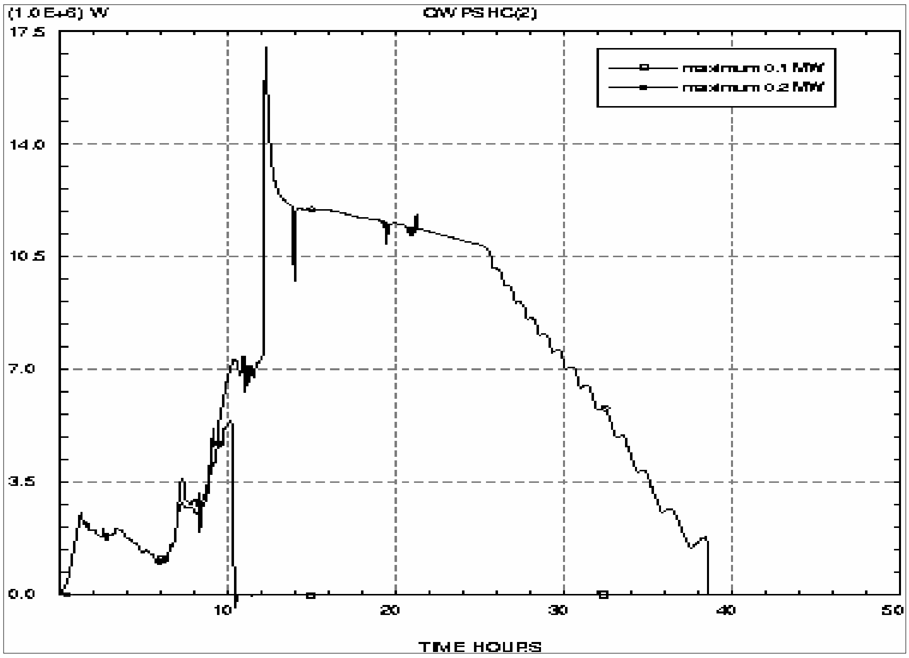

Figure 2. Total heat transfer rate from Calandria vessel to Calandria vault water

5. CONCLUSIONS

The results of feasibility study show that the times for corium relocation, calandria water depletion and calandria failure of the Wolsong(700MWe CANDU) are much later than those for the KSNP. It results from design differences. Wolsong design features are; (1) Duel primary heat transport system, (2) Large amount of cooling water in the calandria vessel, (3) Calandria is always submerged in the water. It provides the operator much available time to recover the accidents. And the In-vessel Retention Strategy' might be very effective means for the Wolsong plant severe accident management. The reasons can be; (1) Calandria vault is always flooded during normal operation, (2) Negligible metal layer, (3) No insulation structure, (4) Low decay power due to the slow accident progression, (5) Large calandria bottom area to transfer the corium decay heat into the calandria vault water, (6) Easy raw water supply from the expansion tank into the calandria vault for an external vessel cooling.

ACKNOWLEDGEMENTS

This study has been carried out under the nuclear R&D program planned by the Korean Ministry of Science and Technology(MOST).

REFERENCES

[1] FAI, (1994), "Modular Accident Analysis Program", May.

[2] F.B.Cheung, (2003), "Limiting Factors for External Reactor Vessel Cooling", The 10th International Topical Meeting on Nuclear Reactor Thermal Hydraulics, Seoul, Korea, October 5-9.

[3] J.H.Song, S.B.Kim, and H.D.Kim,(2002), "An analysis of the External Cooling of the Reactor Vessel during Severe Accidents", Nuclear Technology, Vol.138(1),pp79-89, April.

[4] KAERI/RR-1573/95,(1995), " Development of Computer Code for Level 2 PSA of CANDU Plant ", December.