Assessment of the thermal margins during the planned outage

Hae Cheol Oh, Myung Ki Kim, Bag Soon Chung, Jeong Heon Ha, Sung Yull Hong
Korean Electric Power Research Institute., 103-16.,Moonjidong., Yusung-Gu., Daejeon, haech@kepri.re.kr

1. Introduction

KEPRI is developing the defense-in-depth model ,which is called the ORION model, to monitor risk during the planned outage. The defense-in-depth is measured by number, redundancy and diversity of systems, structures, and components (SSCs) which are needed to mitigate challenges to the safety functions. To complete qualitative defense-in-depth model, also additional deterministic information such as thermal margin when a loss of residual heat removal event occurs during outage is required. The relationship between the expected decay heat levels and the time until RCS boiling, core uncovery, and core damage is described and the estimation result of the thermal margin during the specific refueling outage of reference plant is presented in this paper.

2. Thermal Margin Estimation During Outage

The risk due to accidents during shutdown is strongly dependent upon the time available from the start of the event to the onset of RCS boiling or core damage. Lower decay heat levels translate into longer time periods between the start of an accident and RCS boiling and core uncovery or core damage. In turn, an increase in the available response time suggests an increased chance of successful accident recovery. Therefore, it is important that the operators or maintenance staff during the planned outage get the exact information of thermal margin. The ORION (Outage Risk Indicator of Nuclear Power Plants) model can capture and show the thermal margin automatically through two variables: the reactor condition (i.e., RCS level and temperature) and shutdown days. In this section, the assumptions, and the approach used to calculate the time until RCS boiling, core uncovery and core damage as a function of the varying decay heat levels are discussed.

2.1 Assumptions

The following assumptions are used in the calculation of the times to boil and core uncovery in the ORION model.
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- The time to boil and time to core damage calculations are appropriate for conditions of RCS vented and maintained at atmospheric pressure.
- For the time to boil calculations all decay heat is transferred to the coolant within and above the reactor vessel, to the fuel and clad within the core region, and to the core support assembly
- The calculation of decay heat levels and times to boiling and core damage nominally apply to conditions prior to refueling. After refueling, the decay heat in the core is reduced by the simple fraction of spent fuel transferred to the fuel pool.

2.2 Thermal margin equations

1) Time to boil

The time required for the vessel water to reach the boiling temperature is represented by the following equation.

$$t_b = \{[(V/v) + MCp_{structure}]*(T_{sat} - T_{ini})\} / P_s$$

Where: P_s = decay heat level
V = volume of water that heats uup to the saturation temperature (ft^3)
v = specific volume of water at T_{ini}
T_{sat} = 212 ^oF
T_{ini} = initial RCS temperature

2) Time to Core Uncovery

The time to core uncovery is the sum of the time required to bring the full heated water volume to saturation and the time to boil an equivalent volumes of water that lies above the core.

$$t_{cu} = t_b + (E_{boiloff} / Ps)$$

Where: $E_{boiloff} = V_b / v_{sat} * (h_{fg})$
Vb= equivalent volume of water that must vaporize
v_{sat} = specific volume of water at 212 ^oF
h_{fg} = heat of vaporization at 212 ^oF

3)Time to Core Damage

The time to fuel failure (i.e., gap release) can be derived in the model based on information reported in SECY-93-190. It was noted that the time to gap release could be estimated by assuming that gap release occurs one hour after core uncovery one day after shutdown.

$t_{cd} = t_{cu} + 1.0 * P_{s1} / Ps$

Where: P_{s1} = the decay heat level at one day after shutdown

Ps = the current decay heat

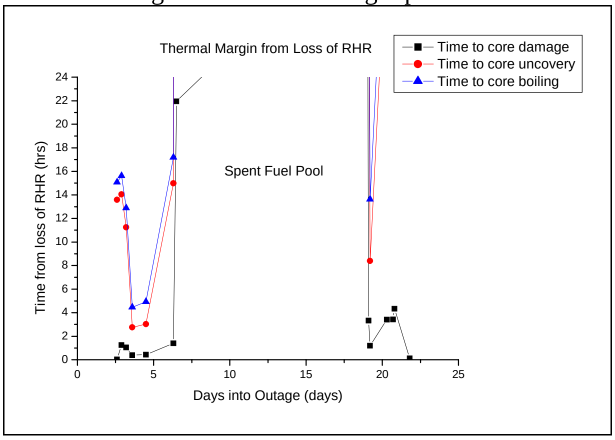
2.3 Results of thermal margin evaluation

This approach was applied to the specific outage schedule of reference plant. The change of RCS level per POS(Plant Operating States)is shown in Figure 2.and the results of thermal margins (i.e., time to boil, time to uncovery, and time to core damage) for this schedule are shown in Table 1 and Figure 1.

Table 1. Thermal margin per POS

POS	Days into Outage	Time to boil (hrs)	Time to core uncovery (hrs)	Time to core damage (hrs)
D	2,6	0,03	13,58	15,08
E	2,9	1,25	14,05	15,62
F	3,2	1,04	11,24	12,88
G	3,6	0,39	2,75	4,47
H	4,5	0,43	3,03	4,92
I	6,3	1,39	14,99	17,18
J	6,5	21,94	280,79	282,99
K	11	27,53	352,42	355,19
L	14,8	Spent Fuel Pool		
K2	18,8	34,53	441,9	445,37
J2	19	51,93	664,71	669,92
I2	19,1	3,32	35,88	41,12
H2	19,2	1,19	8,39	13,63
G2	20,3	3,41	36,86	42,24
F2	20,7	3,43	37,12	42,53
E2	20,8	4,33	48,7	54,12
D2	21,8	0,11	49,97	55,51

Figure 1. Thermal margin profiles



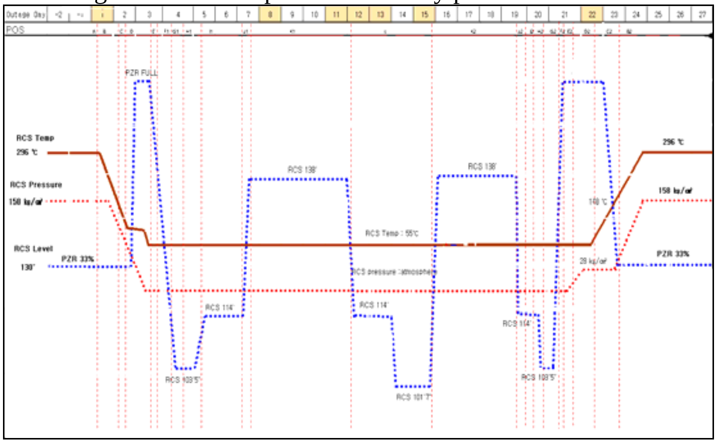
3. Conclusions

The approach of thermal margin estimation during the outage was introduced and the evaluation example with real one was presented. After the completion of this ORION model development, an easy thermal margin review with this tool can be done prior to each outage, and before each major change of state in the outage.. Also the contingency plan such as the preferred alternate cooling mechanism and flow rate needed to maintain subcooling can be provided based on this information.

REFERENCES

[1]NSAC-176L, Safety Assessment of PWR Risk During Shutdown Operations, 1992
[2]SECY-93-190,"Regulatory Approach to Shutdown and Low Power Operations, 1993
[3]TMI PSSA Appendix C "Thermal hydraulic Analysis, 1999

Figure 2. Th RCS parameter history per POS



- <u>Description of POSs</u>

A : Separate Main Unit from Grid, Turbine/Reactor manual trip
B : Start RCS cooldown using SGs
C : Continue cooldown using SCS, Entry into Mode 5
D : Pressurizer Solid
E : RCS Draindown (to PZR Level 50%)
F: RCS Draindown (Flange Level)
G : RCS Draindown (Level at 103.5 feet)
H : Install nozzle dam of SG
I : RCS at Flange Level(114 feet)
J : Cavity Flooded to 138 feet
K : Core Off load
L : Reactor defueled
K2 : Refueling complete
J2 : Drain to Cavity Level 125 feet
I2 : CEA Insertion
H2 : Drain to Cavity Level 116 feet
G2 : Postrefueling Mid loop operation (Level at 103.5feet)
F2 : Fill to PZR Level 50%
E2 : Fill to PZR Level 100%
D2 :Entry into Mode 4
C2 : Stop Shutdown Cooling System
B2 : RCS Heatup to NOP/NOT