UET calculation for Kori Units 3 and 4 Power Uprate

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1. Introduction

Unfavorable Exposure Time (UET) refers to the portion of the operating cycle for which the natural reactivity feedback mechanisms of the reactor core are insufficient to ensure that peak system pressures are less than 3200 psig during an Anticipated Transient Without Scram (ATWS). In an ATWS, a heatup of the primary system occurs due to loss of normal feedwater or loss of load. It is assumed that reactor trip does not occur. As a result, the coolant inlet temperature increases and reactor power drops due to negative moderator feedback. In a core with a sufficient negative moderator temperature coefficient, the core power will decrease enough to ensure that the primary system limiting pressure of 3200 psig is not reached. In this study, the UET was calculated for Kori units 3,4 assuming 4.5% power uprate

2. Methods and Results

Transient Analysis (TA) team has generated Critical Power Trajectory (CPT) Curves which identify the power level required to reach 3200 psig as a function of coolant inlet temperature. (Actually, 3200 psia, instead of 3200 psig, is conservatively assumed to be the limiting pressure in the TA analysis) In an UET analysis for a given core design, critical powers are calculated by Nuclear Design (ND) team using 3-dimensional nodal code, ANC, as a function of burnup and inlet temperature for various ATWS scenarios. These critical powers are compared to the TA CPT curves. If, at a particular burnup, the ANC critical power at 3200 psia exceeds the TA CPT curve for any inlet temperature, then that burnup is considered unfavorable. The fraction of the operating cycle that is unfavorable is the UET for that particular ATWS scenario.

2.1 Critical Power Trajectory

TA team has identified four Loss of Normal Feed water(LONF) and four Loss of Load(LOL) ATWS scenarios for this analysis;

Case 1. LONF, three PORVs avaliable
Case 2. LONF, two PORVs avaliable
Case 3. LONF, one PORV avaliable
Case 4. LONF, no PORVs avaliable
Case 5. LOL, three PORVs avaliable
Case 6. LOL, two PORVs avaliable
Case 7. LOL, one PORV avaliable
Case 8. LOL, no PORVs avaliable

All eight scenarios assume full auxiliary feedwater capacity. The CPT curves are reproduced in the table below.

Table 1 CPT in Fraction of Power

	Fraction of Nominal Power							
TIN(F)	**Case1**	**Case2**	**Case3**	**Case4**	**Case5**	**Case6**	**Case7**	**Case8**
580	0.878	0.864	0.847	0.831	0.888	0.868	0.848	0.829
600	0.724	0.695	0.661	0.629	0.743	0.702	0.664	0.624
620	0.551	0.509	0.461	0.415	0.58	0.519	0.464	0.408
640	0.353	0.303	0.243	0.186	0.387	0.316	0.246	0.177
650	0.242	0.19	0.127	0.063	0.278	0.203	0.131	0.054
660	0.123	0.067	-0.002	-0.071	0.16	0.081	0.003	-0.081

Eight CPTs are calculated assuming an NSSS power of 2912 MWt. The uprated core power for Kori 3,4 is 2900 MWt while the pump heat is 12MWt, giving an NSSS power of 2912 MWt. In the UET evaluation, we are trying to demonstrate that the ANC power is less than the CPT power. This is the favorable condition
Note in the above table that the CPT power for some cases at 660F is negative. This, of course, is physically impossible. To calculate an upper bound inlet temperature for these cases, linear interpolation will be used to calculate the inlet temperature corresponding to a CPT equal to pump heat of 12MWt. The final CPTs in the unit of absolute power including upper bound inlet temperatures are presented in Table 2.

Table 2. CPT in Absolute Power

	NSSS Absolute Power (MWt)							
TIN(F)	**Case1**	**Case2**	**Case3**	**Case4**	**Case5**	**Case6**	**Case7**	**Case8**
580	2556.7	2516.0	2466.5	2419.9	2585.9	2527.6	2469.4	2414.0
600	2108.3	2023.8	1924.8	1831.6	2163.6	2044.2	1933.6	1817.1
620	1604.5	1482.2	1342.4	1208.5	1689.0	1511.3	1351.2	1188.1
640	1027.9	882.3	707.6	541.6	1126.9	920.2	716.4	515.4
650	704.7	553.3	369.8	183.5	809.5	591.1	381.5	157.2
653.7	-	-	-	-	-	-	-	12.0
654.4	-	-	-	12.0	-	-	-	
659.5	-	-	12.0		-	-	-	
660	358.2	195.1			465.9	235.9	12.0	

2.2 Critical Power

To calculate the UETs for these cases, critical power calculations at 3200 psia are performed in ANC at each burnup step in the full power depletion and at each inlet temperature. Table 3 shows Critical Powers(CP) in absolute power calculated by ANC.

Table 3. CP in Absolute Power

	ANC Absolute Critical Power(MWt)							
TEMP. / BU	580	600	620	640	653.7	654.4	659.5	660
150	2465.4	1923.1	1357.6	766.0	333.9	310.7	142.5	128.0
1000	2448.0	1885.4	1308.3	708.0	270.1	246.9	81.6	64.2
2000	2430.6	1844.8	1244.5	621.0	171.5	148.3	12.0	12.0
3000	2416.1	1815.8	1195.2	560.1	101.9	78.7		
4000	2404.5	1789.7	1160.4	513.7	52.6	29.4		
6000	2390.0	1752.0	1105.3	447.0	12.0	12.0		
8000	2378.4	1725.9	1064.7	394.8				
10000	2366.8	1699.8	1027.0	336.8				
12000	2358.1	1682.4	1000.9	319.4				
14000	2346.5	1659.2	974.8	299.1				
16000	2346.5	1647.6	948.7	273.0				
18000	2337.8	1621.5	911.0	226.6				
19500	2329.1	1601.2	882.0	188.9				

2.3 UET calculation

The resulting ANC critical powers are used in an Excel spreadsheet to determine the fraction of the operating cycle for which the ANC critical power exceeds the TA CPT curve.

In the next part of the worksheet, entitled Unfavorable Power (NSSS power -CPT power) versus burnup and Temperature, the difference between the ANC absolute critical power and the CPT absolute power is calculated. If this difference is >0.0, then that time in life is unfavorable. If the difference is <0.0, then that time in life is favorable for that inlet temperature.

Table 4 shows the most unfavorable case.

Table 4. Unfavorable Power

	CP-CPT (MWt)				
TEMP. / BU	580	600	620	640	653.7
150	51.352	106.012	169.504	250.576	321.900
1000	33.952	68.312	120.204	192.576	258.100
2000	16.552	27.712	56.404	105.576	159.500
3000	2.052	-1.288	7.104	44.676	89.900
4000	-9.548	-27.388	-27.696	-1.724	40.600
6000	-24.048	-65.088	-82.796	-68.424	0.000
8000	-35.648	-91.188	-123.396	-120.624	
10000	-47.248	-117.288	-161.096	-178.624	
12000	-55.948	-134.688	-187.196	-196.024	
14000	-67.548	-157.888	-213.296	-216.324	
16000	-67.548	-169.488	-239.396	-242.424	
18000	-76.248	-195.588	-277.096	-288.824	
19500	-84.948	-215.888	-306.096	-326.524	

The UET is calculated by determining the total amount of unfavorable time. If all of the delta-power values are negative, then the entire cycle is favorable and the UET is 0%. If all of the delta-power values are positive, then the entire cycle is unfavorable and the UET is 100%. For Table 4, the highest temperature is limiting which means it gives the longest UET. The exact burnup step which UET ends can be obtained by extrapolation using Excel spreadsheet . The extrapolation sets the UET at 4824 MWD/MTU or 24.7% of the operating cycle. The calculated UETs are presented in Table 5.

Table 5. UET

Case		PORV Available	Cycle Length (MWD/MTU)	UET Start (MWD/MTU)	UET End (MWD/MTU)	Total UET (MWD/MTU)	UET (%)
LONF	1	3	19,500	-	-	-	0
	2	2	19,500	-	-	-	0
	3	1	19,500	0	1,973	1,973	10.1
	4	0	19,500	0	4,353	4,353	22.3
LOL	5	3	19,500	-	-	-	0
	6	2	19,500	-	-	-	0
	7	1	19,500	0	1,695	1,695	8.7
	8	0	19,500	0	4,824	4,824	24.7

3. Conclusion

UETs have been calculated for Kori Units 3 and 4 assuming 4.5% of power uprate. The cases with one and no PORV had UETs. For these cases, the maximum UET of 24.8% of the operating cycle was calculated.

REFERENCES

[1] Westinghouse, Westinghouse Anticipated Transients without Trip Analysis, WCAP-8330, 1974.

[2] Westinghouse, WOG Risk-Informed ATWS Assessment and Licensing Implementation Process, WCAP-15831-P, 2002.

[3] MOCIE, Mid Term Report for Power Uprate Technology Development for Operating Nuclear Power Plants(II), C02NJ03, 2005