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Applicability Assessment with New Channel and Bundle-Power Limits for Limiting Condition for Operations of Wolsong Nuclear Power Plant

Sungmin Kim*, Dongwook Kho
Korea Hydro & Nuclear Power Co., Ltd., Yuseong-Gu, Daejeon, Korea
**Corresponding author: kimsungmin@khnp.co.kr)*

1. Introduction

Currently a single power limit for all 380 channels in the core (channel-power limit of 7.07 MW and bundle-power limit of 898 kW) is specified in the technical specifications [1] of heavy water reactors (HWRs) in Korea. This single channel and bundle-power limit was established to ensure the safety of high-power channels located in the central region of the core. Each fuel channel has its own power and flow intended to result in similar fluid conditions at all the outlets. Therefore, low-power channels have a lower flow and therefore should have a lower limit for channel-power and bundle-power

Channel-specific channel and bundle-power safety-analysis limits have been used in Canada since the 1990's. The application of a similar approach is also being considered in Korea. The rationale for the establishment of channel-specific channel and bundle-power safety limits, selection of single channels for detailed safety evaluation, and the results of Loss Of Coolant Accident (LOCA) analysis with established channel and bundle-power safety-analysis limits were analysed [2]. Based on this result, channel-specific channel and bundle-power safety-analysis limits are established, as shown in Figure 1 and Figure 2.Based on safety-analysis limits, we can establish new channel and bundle-power limits for Limiting Condition for Operation (LCO). This paper shows the establishment of new channel and bundle-power limits for LCO, and with it, the applicability assessment results.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	
A									4408	4702	4682	4681	4703	4407									A
B						4319	4743	5678	5836	5837	6011	6011	5836	5837	5677	4745	4317						B
C					4598	5086	5851	6343	6514	6863	6899	6898	6864	6514	6345	5849	5088	4597					C
D				4640	5398	5966	6542	7216	7300	7300	7300	7300	7300	7300	7215	6541	5964	5401	4638				D
E			4860	5367	6196	6740	7174	7300	7300	7300	7300	7300	7300	7300	7300	7172	6744	6192	5372	4855			E
F			5452	6142	6851	7225	7300	7300	7300	7300	7300	7300	7300	7300	7300	7300	7221	6857	6135	5459			F
G		5036	5897	6591	7195	7300	7300	7300	7300	7300	7300	7300	7300	7300	7300	7300	7300	7190	6595	5892	5044		G
H		5550	6433	7193	7300	7300	7300	7300	7300	7300	7300	7300	7300	7300	7300	7300	7300	7300	7193	6436	5549		H
J	4559	5742	6794	7300	7300	7300	7300	7300	7300	7300	7300	7300	7300	7300	7300	7300	7300	7300	7300	6797	5745	4559	J
K	4750	5963	6955	7300	7300	7300	7300	7300	7300	7300	7300	7300	7300	7300	7300	7300	7300	7300	7300	6957	5962	4754	K
L	5080	6236	7116	7300	7300	7300	7300	7300	7300	7300	7300	7300	7300	7300	7300	7300	7300	7300	7300	7115	6239	5080	L
M	5070	6201	7105	7300	7300	7300	7300	7300	7300	7300	7300	7300	7300	7300	7300	7300	7300	7300	7300	7105	6204	5071	M
N	4989	6076	6958	7300	7300	7300	7300	7300	7300	7300	7300	7300	7300	7300	7300	7300	7300	7300	7300	6958	6076	4991	N
O	4817	5828	6822	7168	7300	7300	7300	7300	7300	7300	7300	7300	7300	7300	7300	7300	7300	7300	7168	6824	5827	4817	O
P		5630	6675	7187	7277	7300	7300	7300	7300	7300	7300	7300	7300	7300	7300	7300	7300	7277	7185	6678	5627		P
Q		5046	5972	6888	7300	7284	7300	7300	7300	7300	7300	7300	7300	7300	7300	7300	7286	7300	6893	5966	5054		Q
R			5591	6297	7017	7227	7114	7300	7300	7300	7300	7300	7300	7300	7300	7117	7227	6991	6290	5598			R
S			4566	5487	5880	6524	6931	7139	7300	7300	7300	7300	7300	7300	7104	6929	6560	5876	5267	4563			S
T				4536	5141	5751	6230	6756	6848	6891	6890	6891	6890	6849	6791	6231	5720	5115	4534				T
U					3876	4504	5166	5893	5979	6226	6215	6215	6226	5978	5893	5165	4504	3875					U
V						3418	3962	4643	4768	4946	4938	4938	4945	4768	4641	3961	3417						V
W									3697	3794	3950	3950	3793	3695									W
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	

Figure 1. Channel-Specific Channel-Power Safety Limits (kW)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	
A									564.4	602.0	599.5	599.3	602.1	564.4									A
B						553.2	597.4	695.3	734.4	724.1	757.7	764.2	722.9	741.4	697.7	601.4	553.1						B
C					589.5	628.9	718.0	791.9	834.5	862.4	876.6	880.1	869.8	834.4	797.7	718.4	632.3	589.3					C
D				594.7	654.9	726.8	803.7	898.1	921.3	935.0	935.0	935.0	935.0	928.4	900.7	807.8	726.0	658.6	594.4				D
E			622.7	640.2	780.2	841.5	908.5	935.0	935.0	935.0	935.0	935.0	935.0	935.0	935.0	909.6	847.2	782.1	644.4	621.9			E
F			668.7	775.7	849.2	885.7	935.0	935.0	935.0	935.0	935.0	935.0	935.0	935.0	935.0	935.0	884.5	856.9	777.3	673.9			F
G		635.6	741.0	836.1	890.2	926.7	932.8	935.0	935.0	935.0	935.0	935.0	935.0	935.0	935.0	929.4	933.7	892.4	843.0	742.6	641.3		G
H		710.7	805.6	894.8	912.5	931.1	932.4	935.0	935.0	935.0	916.7	917.1	935.0	935.0	935.0	935.0	929.1	919.1	897.3	813.0	710.4		H
J	583.8	698.7	840.1	913.7	935.0	935.0	935.0	935.0	935.0	935.0	917.1	910.8	935.0	935.0	935.0	935.0	935.0	935.0	920.6	840.9	703.0	583.8	J
K	593.3	721.3	847.2	922.0	935.0	935.0	935.0	935.0	935.0	935.0	909.4	910.5	935.0	935.0	935.0	935.0	935.0	935.0	919.0	851.4	719.4	597.4	K
L	611.3	772.9	863.6	935.0	935.0	935.0	935.0	935.0	934.3	935.0	904.0	896.5	935.0	934.7	935.0	935.0	935.0	935.0	935.0	860.4	779.6	611.3	L
M	637.2	773.9	865.4	935.0	935.0	935.0	935.0	932.8	925.7	916.0	910.5	910.7	916.8	925.1	933.4	935.0	935.0	935.0	935.0	867.2	772.2	640.1	M
N	638.8	759.9	841.8	935.0	935.0	935.0	933.9	925.4	893.9	893.5	883.2	883.0	894.0	893.7	927.7	935.0	935.0	935.0	935.0	838.6	763.8	639.1	N
O	616.7	729.2	817.8	884.3	935.0	935.0	931.4	907.5	885.1	874.6	863.0	862.3	875.5	884.7	909.9	933.8	929.2	935.0	879.8	820.4	728.8	616.7	O
P		711.7	820.2	874.4	931.8	935.0	928.1	909.2	879.0	868.9	862.1	862.2	868.4	880.6	909.1	928.5	935.0	931.9	878.2	823.4	717.4		P
Q		630.7	733.4	832.0	899.5	914.4	911.5	901.7	882.2	881.8	877.0	876.0	881.9	882.1	901.5	910.6	913.0	907.6	834.5	738.8	632.2		Q
R			675.2	774.1	858.4	895.4	905.3	909.1	896.6	898.0	906.0	905.7	897.3	897.5	908.1	904.1	902.5	862.4	780.8	678.1			R
S			590.5	707.2	768.5	815.1	859.8	892.3	915.6	935.0	935.0	935.0	935.0	915.4	892.2	862.0	815.7	774.8	710.0	590.3			S
T				611.4	652.3	746.7	782.7	848.6	865.4	891.6	902.3	904.2	890.2	863.4	852.6	780.6	752.7	653.4	611.2				T
U					539.9	605.9	693.2	784.4	795.7	827.3	824.7	831.3	829.9	801.5	787.5	692.2	604.6	539.0					U
V						478.2	548.0	631.7	650.2	682.0	687.4	686.2	680.9	649.3	630.3	547.1	477.3						V
W									522.4	538.4	561.6	561.0	538.0	521.6									W
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	

Figure 2. Channel-Specific Bundle-Power Safety Limits (kW)

2. Establishment of LCO

Two sigma uncertainties of channel and bundle power for Wolsong Nuclear Power Plants (WSNPPs) are 3.2% and 4.1%. These come from comparing Reactor Fuelling Simulation Program (RFSP) physics program calculation results, and measurements [3]. Channel-specific channel and bundle-power limits for LCO were established RFSP based as below and shown in Figure 3 and Figure 4.

$$LCOC_i = SLC_i/1.032 \quad (1)$$

$$LCOB_i = SLB_i/1.041 \quad (2)$$

Where,
LCOCi = Chanel powers for LCO 1~380
LCOBi = Bundle powers for LCO 1~380
SLCi = Channel powers of safety analysis limit 1~380
SLBi = Bundle powers of safety analysis limit 1~380

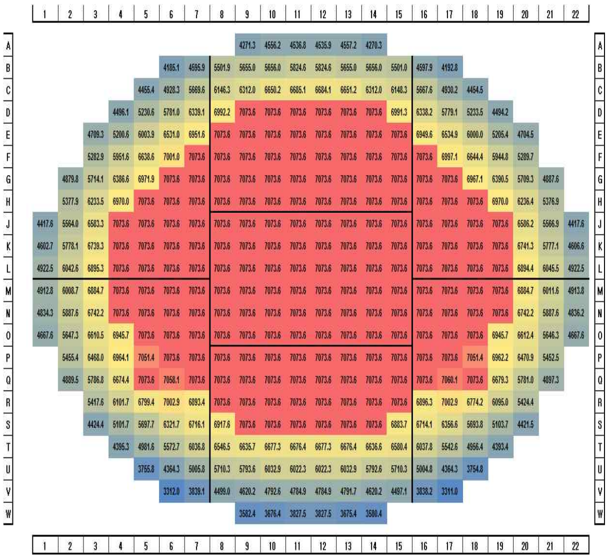

Figure 3. Channel-Specific Channel-Power LCOs(kW)

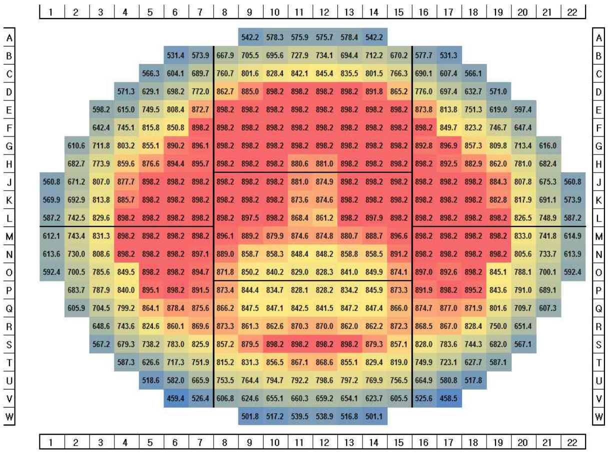

Figure 4. Channel-Specific Bundle-Power LCOs (kW)

WSNPPs will be checked two times per week with new channel-specific channel and bundle-power limits for LCO by surveillance intervals. Before application to WSNPPs of the new channel-specific channel and bundle-power limits for LCO, we need to confirm their applicability.

3. Applicability Assessment with New LCO

For the preparation of licensing applications, the WSNPP#1 safety analysis and reactor operational-support-code system have been changed from PPV/MULTICELL/RFSP 2-17 to the Canadian Industry Standard Toolset (IST)-based WIMS/DRAGON/RFSP-IST in an attempt to resolve the Generic Action Items (GAI) issued by the Canadian Nuclear Safety Commission (CNSC). In accordance with this, WSNPP#1 simulations have been performed using the newly acquired WIMS/DRAGON/RFSP-IST code suite. In the future, all CANDU in Korea will be used with RFSP-IST.

To confirm the applicability, we used about three years of data from WSNPP#1, #2, and #4. The WSNPP#1 data was initial core and two kinds of simulation data, which used RFSP 2-17 and RFSP-IST. WSNPP#2, #4 data were equilibrium core using RFSP 2-17. They are representative of all CANDU core life.

The applicability of the current WNPP#1, #2, and #4 is shown in Table 1 and in Figures 5–9. If we apply the new channel and bundle-power limits for LCO of WSNPPs, we can keep our new LCO.

After re-tubing, the initial fresh core of WSNPP#1 was loaded with 160 depleted uranium (^{235}U 0.52 at.%) fuel bundles in the central 80 channels at bundle positions #8 and #9 and 4,400 natural uranium fuel bundles at the rest of the bundle positions in the core. The depleted fuel bundles are used to achieve power flattening in the central region of the core until the burnup distribution in the core has reached equilibrium. Due to depleted uranium effects, the WSNPP#1 core has a much greater margin than WSNPP#2 and #4, at the initial core. As shown Figure 5, the margins are decreased until the burnup distribution in the core has reached equilibrium. Compared with RFSP 2-17 and RFSP-IST for margin of LCO, the two versions of the physics code results are in very good agreement. This means during normal operating status, there are no differences.

The core status of WSNPP#2 and WSNPP#4 is the equilibrium burnup state. WSNPPs maintain about 2–4% margins for channel power and 6–8% margins for bundle power with comparable LCO, as shown in Figure 6 and 7. Figure 8 and 9 show the minimum margin position of channel-specific channel and bundle power. The expected position is also shown. Those are far locations of reactivity control devices.

Table 1. Channel and Bundle-Power Margins for WSNPPs

Unit		Minimum Margin	Average Margin	Remark
WSNPP1	Channel	1.24% (O-17)		Initial Core
	Bundle	1.0% (P-12)		
	Channel	0.09% (M-06)		ITS
	Bundle	1.0% (P-12)		
WSNPP2	Channel	0.65% (N-16)	3.07%	
	Bundle	0.93% (E-04)	6.42%	
WSNPP4	Channel	0.23% (P-16)	2.67%	
	Bundle	2.47% (P-12)	7.09%	

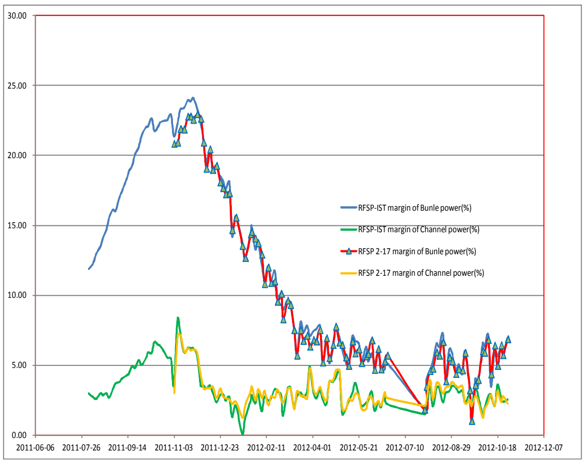

Figure 5. Margin Trend of Channel and Bundle Power of WSNPP#1 (%)

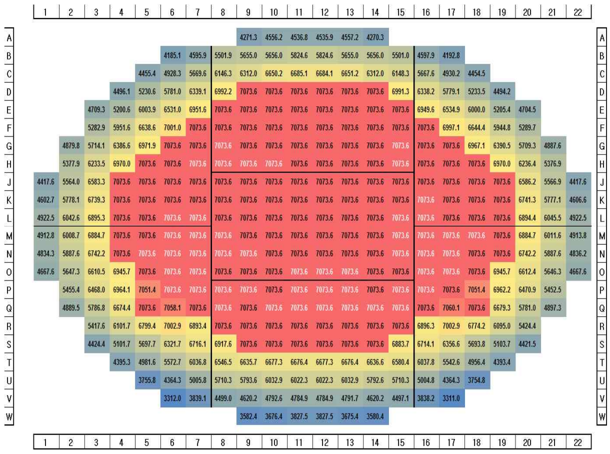

Figure 8. Minimum Margin Locations of Channel Power of WSNPP#4 at Each Calculation (White numerals)

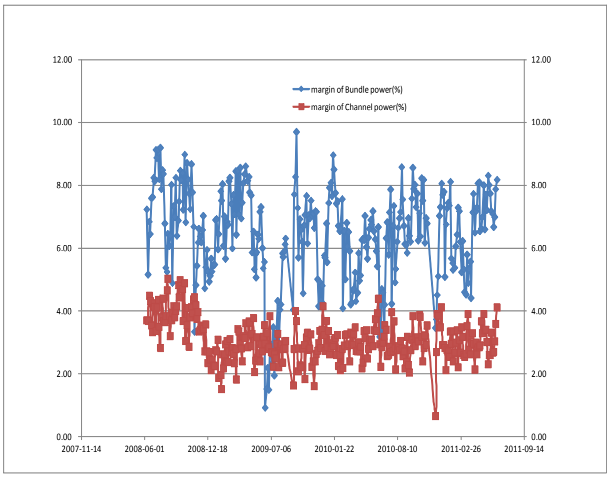

Figure 6. Margin Trend of Channel and Bundle Power of WSNPP#2 (%)

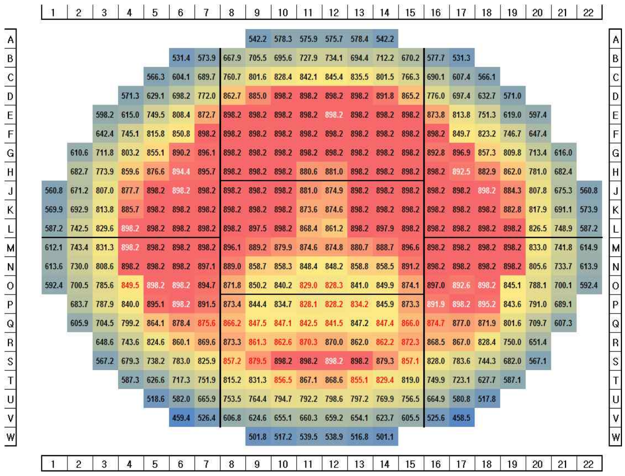

Figure 9. Minimum Margin Locations of Bundle Power of WSNPP#4 at Each Calculation (White and red numerals)

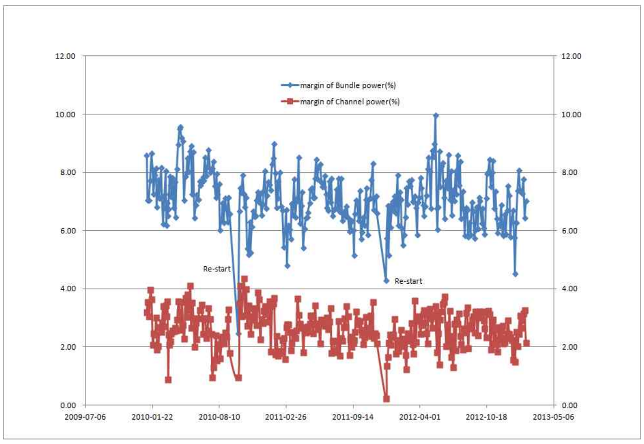

Figure 7. Margin Trend of Channel and Bundle Power of WSNPP#4 (%)

4. Conclusion

Channel-specific channel and bundle-power limits for LCO in WSNPPs are established based on safety analysis limits. To confirm the applicability with the new LCO, we used about three years of data from WSNPP#1, #2, and #4. WSNPP#1 data is initial core and two kinds of simulation data, which include RFSP 2-17 and RFSP-IST. WSNPP#2 and #4 data are equilibrium core using RFSP 2-17. They are representative of all CANDU core life.

WSNPPs can keep their LCO. When at equilibrium, WSNPPs maintain about 2–4% margins for channel power and 6–8% margins for bundle power. However, sometimes there are very small margins for operation, and they need careful fuel management.

Providing WSNPP channel-specific channel and bundle powers to establish LCO has several effects, such as enhancing safety and relieving the regulatory burden.

REFERENCES

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[2] J.H. Choi, and S.M. Kim et al. “Establishment of Channel Specific Channel and Bundle Power Limits”, 2015 CNS, 2015 June.
[3] 86-63710-DM-001, Rev 5 “Overall Plant Control Design Manual”, Wolsong NPP 1, 1998 Dec.