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Comparison of Atmospheric Dispersion Models Between PHWR and PWR

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1. Introduction

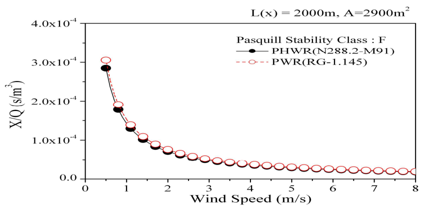
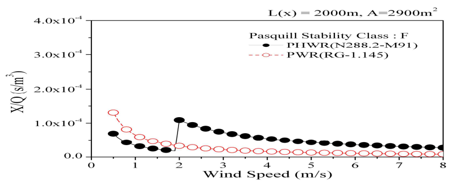
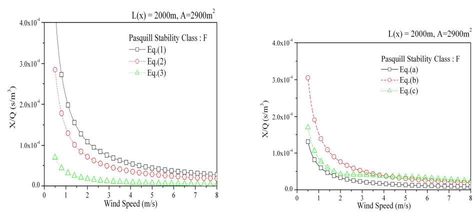
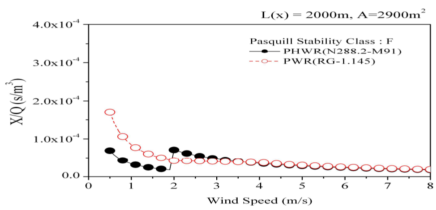
The radiation dose and the atmospheric dispersion for Pressurized Heavy Water Reactors (PHWR) are based on the CAN/CSA N288.2-M91 standards [1]; for Pressurized Water Reactor (PWR) on the NRC Regulatory Guide 1.145 [2]. There are some differences between in the methodologies used in the standards, including the atmospheric dispersion model, the release height, the temperature lapse rate, the cutoff condition. This paper reports on a comparison of standards for atmospheric dispersion models of PHWRs and PWRs in order to determine which one is the more conservative. The comparison between PHWR and PWR for atmospheric dispersion factors and radiation doses confirms that there are no big differences.

2. Atmospheric dispersion and radiation dose

2.1 Model comparing PHWR and PWR

PHWRs and PWRs use the Gaussian dispersion model, which employs dispersion parameters determined empirically by field experiments, and is used for calculating atmospheric dispersions. ADDAM (Atmospheric Dispersion and Dose Analysis Method) is a computer program developed to calculate statistical distributions of radiation doses for an individual or for a population following the release of airborne radioactive material into the atmosphere under hypothetical accident conditions at a PHWR. ADDAM introduces a theoretically more rigorous way of analyzing weather data compared with previous methods [3]. ADDAM was developed to improve on current accident analyses, which use the PEAR computer program. ADDAM has interpreted AECB-1059 to signify the worst dose existing at most 10% of the time or, conversely, the 90% cutoff on a cumulative frequency distribution of dose calculated for the release occurring at any time during the meteorological data collection period. This obviates the need for PEAR to perform a deterministic dispersion and dose calculation on a single set of meteorological inputs. The following are PHWR/PWR modeling differences.

Table 1. PHWR/PWR modeling differences

	PHWR : CAN/CSA N288.2-M91	PWR : NRC RG 1.145
Basic Eq.	$\chi/Q=\frac{1}{\pi\bar{U}_{10}(\sigma_y\sigma_z)}$ (1)	$\chi/Q=\frac{1}{\pi\bar{U}_{10}(3\sigma_y\sigma_z)}$ (a)
	● No building wake/meander effect ● $\sigma_y\sigma_z$ are similar to PWR's ● $\sigma_y\sigma_z$ are modeled one time ● Atmospheric Dispersion Factor is three times that of PWR	● $\sigma_y\sigma_z$ are modeled three times
Basic Eq. + Building Wake Effect	$\chi/Q=\frac{1}{\pi\bar{U}_{10}\Sigma_y\Sigma_z}$ (2)	$\chi/Q=\frac{1}{\pi\bar{U}_{10}(\sigma_y\sigma_z+\frac{A}{2\pi})}$ (b)
	 Fig. 1 Atmospheric dispersion factor with basic equation and building wake effect for PHWR/PWR	
	● Building wake is reflected in Eq. (1) ● PHWR's and PWR's are almost the same	● Building wake is based on Eq. (b) ● Use the higher value of Eq.(a) and Eq. (b)
Basic Eq. + Meander Effect	$\chi/Q=\left(\frac{2}{\pi}\right)^{1/2}\frac{1}{\bar{U}_{10}(x\theta_L)\Sigma_z}$ (3)	$\chi/Q=\frac{1}{\pi\bar{U}_{10}\Sigma_y\sigma_z}$ (c)
	 Fig. 2 Atmospheric dispersion factor with basic equations and meander effect for PHWR/PWR	
	● Meander effect is reflected in Eq. (2) ● Meander effect is considered to be 2m/s ● Meander effect is reflected in $\Sigma_y=x\theta_L$. ● It is lower than PWR's, because wake effect is included in vertical atmospheric dispersion coefficient (Σ_z).	● Meander effect is based on Eq. (c) ● Meander effect is considered to be 6m/s ● Meander effect is reflected in Σ_y.
Basic Eq. + Building Wake Effect + Meander Effect	 Fig. 3. Each of the atmospheric dispersion factors for PHWR/PWR  Fig. 4 Final atmospheric dispersion factor for PHWR/PWR	
	● Below 2m/s: calculate with Eq. (3) Over 2m/s: Use Eq. (2) ● Meander effect is considered regardless of atmospheric stability.	● Use the higher value of Eq.(a) and Eq. (b) ● Use the lower value of Eq. (c) and the above result ● Meander effect is not considered in classes A, B, and C, in which

		atmospheric conditions are unstable.

where,

X/Q : atmospheric dispersion factor

$\bar{U}_{10}$: mean wind speed measured at a height equal to 10 m

σ and Σ : basic plume spread and plume spread with meander effects and building wake effects.

θ_L : angle used for the prolonged and long-term releases, defining a sector within which the effluent concentration is constant

A : the smallest vertical plane cross sectional area of the reactor building.

Below 2m/s wind speed, we found that PHWRs are not conservative. In order to solve this problem, we checked PHWR models and found that if we reduced θ_L from 22.5 degrees to 7.5 degrees, we achieved a more conservative atmospheric dispersion model than that of PWRs (Fig. 5).

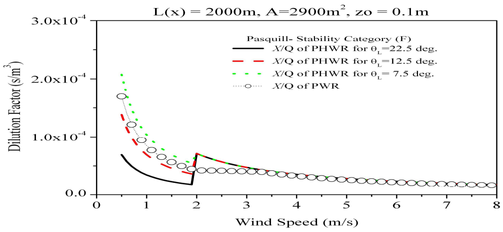


Fig. 5. 5 Change of atmospheric dispersion factor for PHWR with θ_L change

2.2 Results of atmospheric dispersion factors(X/Q) and radiation doses for Wolsong#1 NPP with PHWR and PWR methods

PWRs have only one atmospheric dispersion factor X/Q value, which is first selected with a given cutoff frequency and then applied to all accidents for radiation dose calculation; but for PHWRs, radiation doses are calculated with a given cutoff data. ADDAM considers it as possible that there are several atmospheric dispersion factors in the same event, because this method uses different energies based on different release heights; ADDAM subdivides the transient release into intervals of constant user specified duration (Table 2).

The dose calculation was performed for the two methods for Wolsong#1 NPP. One method was based on Ministry of Education, Science and Technology (MEST) notice No. 2009-37 with the ADDAM code. This method applied the PHWR method with atmospheric dispersion factors, the building wake effect, the meander effect, and the dose calculation for 30 days; however, the g r o u n d - l e v e l of release, the dose conversion factor, and the cutoff frequency (99.5 percentile) followed MEST notice No. 2009-37 [4]. The other method follows the PWR approaches for two hours of dose calculation. The following are the results of the comparison of PHWR and PWR methods of assessment of atmospheric dispersion factors and the dose calculations for Wolsong#1 NPP.

- Without meander effects, the difference of atmospheric dispersion model between PHWR and PWR is about 10%.
- Below 2 m/s wind speed, the atmospheric dispersion model for PHWRs is less conservative than the PWR's; for wind speeds higher than 2 m/s, the results are similar to each other.
- The radiation doses for some events affecting atmospheric dispersion factors of PHWRs have higher values than those for PWRs; some events have lower values for PHWRs than for PWRs. Each event of the safety analysis for the Wolsong#1 NPP is lower than the dose limit [5], even using the atmospheric dispersion factor of PWRs.

Table 2. Results of atmospheric dispersion factors and radiation doses for Wolsong#1 NPP

PWR Atmospheric dispersion factor 5.05E-04 s/m^3

FSAR SECTION	Accident	Dose(mSv) Dose limit Thyroid	Dose limit Whole body	PHWR (P99.5) Thyroid	PHWR (P99.5) Whole body	PWR (P99.5) Thyroid	PWR (P99.5) Whole body	Atmospheric dispersion factor (99.5 percentile) Maximum wind direction	s/m^3
15.2.1.1	Safety System Available (A)	30	5	1.5	0.4	0.9	0.0	SE	2.238E-04
Large LOCA +	Full loss of R/B isolation (B)	2500	250	25.5	5.6	82.6	15.3	ESE	5.430E-04
	Veltillation inlet open	2500	250	17.3	3.8	60.7	10.5	ESE	5.268E-04
	Veltillation outlet open	2500	250	16.5	3.7	55.1	13.6	SE	4.929E-04
	R/B Personal airlock seal break	2500	250	15.1	3.4	63.1	17.2	SE	6.473E-04
	R/B equipment airlock seal break	2500	250	14.7	3.2	51.3	3.5	ESE	7.147E-04
	R/B Personal airlock open	2500	250	64.7	13.2	222.9	15.2	ESE	5.983E-04
	R/B equipment airlock open	2500	250	299.2	58.1	1037.2	48.4	ESE	6.601E-04
	Minimum detectable hole	2500	250	3.0	0.8	8.8	4.1	SE	4.624E-04
	Full loss of dousing	2500	250	1.2	0.3	1.5	0.5	SE	2.982E-04
	Full loss of local air cooler	2500	250	1.1	0.3	1.3	0.4	ESE	4.011E-04
	Imparement of ECC (C)	2500	250	302.2	58.7	936.5	14.3	ESE	3.999E-04
Large LOCA+Loss of CL Ⅳ power +	Safety System Available (D)	2500	250	22.4	8.7	12.8	14.1	ESE	3.429E-04
	Full loss of R/B isolation (E)	2500	250	236.6	81.6	578.7	146.8	SSE	3.047E-04
	Imparement of ECC (F)	2500	250	92.3	20.1	18.8	5.2	ESE	3.380E-04

3. Conclusion

The details of the comparison between PHWRs and PWRs for atmospheric dispersion factors and radiation doses are given in Table 2; these data confirmed that there are no big differences. It can be concluded based on the comparison results using dose calculation against the PWR method that the newly adopted code ADDAM is justified for use in carrying out safety analyses at the Wolsong#1 NPP.

REFERENCES

[1] CAN/CSA-N288.2-M91, "Guidelines for Calculating Radiation Doses to the Public from a Release of Airborne Radioactive Material under Hypothetical Accident Conditions in Nuclear Reactors", 1991 April.

[2] Regulatory Guide 1.145 "Atmospheric Dispersion Models for Potential Accident Consequence Assessments at Nuclear Power Plant", 1982 November. And Regulatory Guide 1.23 "Meteorological Monitoring Programs For Nuclear Power Plants" Rev.1, 2007 March.

[3] CW-111090-225-002 Revision 0. "ADDAM Version 1.0 Theory Manual", 2003 June.

[4] Ministry of Education, Science and Technology notice No. 2009-37.

[5] Wolsong #1 NPP FSAR Chapter 15, 2009 December.