GASEOUS RELEASES EVALUATION AND SAFETY PERFORMANCE IMPROVEMENT OF KARTINI RESEARCH REACTOR VENTILATION SYSTEM

Syarip, Edy Triono BS
Staff of the Center for Technology of Accelerator and Material Process, BATAN, Yogyakarta.
Widyatmaka Susyanta, Hadi Kusuma
Staff of the Center for Reactor Technology and Nuclear Safety, BATAN, Serpong.
e-mail : ptapb@batan.go.id

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ABSTRACT

GASEOUS RELEASES EVALUATION AND SAFETY PERFORMANCE IMPROVEMENT OF KARTINI RESEARCH REACTOR VENTILATION SYSTEM. *The safety performance of Kartini research reactor related to the gaseous releases to the environment has been evaluated. The research covers an evaluation and improvement on the ventilation system and analysis of gas releases dissipating from the reactor building. The method used is calculation of reactor source term and direct measurement of gas release from the reactor stack. The source term analysis showed that the fission product accumulated in the reactor core at the start of operation was 4.838 $\times$ 10^6 Ci, after of 5 hours operation it became 3.614 $\times$ 10^8 Ci, and after 24 hours decay, the fission product became 4.727 $\times$ 10^6 Ci. The N^{16} activity inside the reactor building is 4.1 $\times$ 10^{-10} µCi/cm^3 and the Ar^{41} escaping to the atmosphere is 5.7 $\times$ 10^{-12} mCi/cm^3, which is lower than limit value for radiation worker of 2 $\times$ 10^{-6} µCi/cm^3. A sample case by using March 2009 data, the value of ground level concentration on variable distance x = 100 m to 5.000 m, was 9.726 $\times$ 10^{-19} rad/m^3, rise up to 6.303 $\times$ 10^{-14} rad/m^3 and tends to decrease to 1.598 $\times$ 10^{-15} rad/m^3 at distance 5,000 m. Whiles the direct observation on the upper reactor stack show that the radiation exposure is 2.33 $\times$ 10^{-9} rad/s, exit velocity of gas from stack is 8 m/s, absolute temperature effluent of gas is 26.2 °C, and outlet diameter of stack, d = 1 m and actual stack height 31.75 m. Based on safety limit criteria from national regulation (BAPAETEN), the values of radiation exposure, ground level concentration combined with atmosphere stability and demography factor was very safe for the actual condition of Kartini reactor site.*

Keywords: safety performance, Kartini reactor, source term, ventilation system.

INTRODUCTION

Kartini reactor is a TRIGA Mark II type research reactor operated by Center for Accelerator and Material Process Technology (CAMPT) of Indonesian National Nuclear Energy Agency (BATAN). Head of the CAMPT is fully responsible for conducting safe operation and utilization of the research reactor. He shall report to the Head of BATAN and to the Regulatory Body (BAPETEN) in operating and utilizing the research reactor safely. Kartini adopted a ventilation system which was specifically designed for IRT-2000, a Russian reactor. This adoption raises a need of performance validation of the system, which estimates the possibility of radiological consequences to the environment. It was suspected that Ar^{41} and N^{16} gases unexpectedly leaked from the building. It is essential that the leakage of this release is assured by in-situ evaluation and computer calculation.

This research is sponsored by the IAEA through a Technical Cooperation Project granted for the period of 2008 – 2009. This paper is a part of the progress report of the IAEA Technical Cooperation Project, Number *RC-13772-R1: "Safety evaluation for the performance to gaseous releases calculation from research reactor system ventilation"* [1]. The research contract has been successfully conducted involving the reactor operator and maintenance personnel of Kartini Reactor. Some of calculations for re-design of Kartini Reactor ventilation system has been done as well as the follow up of the re-design result, i.e., modification of ventilation system.

The research activities cover data acquisition of population, ecological variable, mathematical modeling of gas releases dissipating from the reactor building, ventilation system evaluation, and the source term analysis which is based on Kartini Reactor Design Base Accident. As well as in refer to the Safety Analysis Report (SAR), the Postulated Initiating Events (PIE), and other safety related documents [2].

METHODOLOGY

The method used for evaluating gaseous release covers the theoretical overview, data collecting, and experiments or measurements. The research activities are as follows:

1. Collecting data of Kartini reactor components and system for risk analysis, especially related to the ventilation systems up to emergency preparedness system;
2. Evaluation on retrofitting of ventilation system
3. Performance test of retrofitted ventilation system
4. Source term calculation using ORIGEN-2;
5. Activation of Ar^{41} and Ni^{16} calculation;
6. Referred to SAR and PIE documents
7. Experimental methods coverings:

Overview of the whole Kartini reactor data as a preparation for risk analysis calculation propagated from source term analysis following a Design Bases Accident (DBA) of Kartini Reactor (2,9).

Assessment of meteorological data including Pasquil stability and the present population distribution around reactor from 1 - 5 km radius (2,8,10).

Calculation and direct measurement of radioactive emission rate from stack and effective height of stack due to meteorology parameters, such as wind velocity, direction, temperature.

Description of Kartini Reactor Ventilation System (2)

Kartini Reactor ventilation system comprises blower unit, filter, ducting and stack. The main purpose of reactor ventilation system is to circulate the air in order to get fresh and clean air and to prevent the accumulation of contaminated air in the reactor building. The reactor building volume is 4.419 m^3. The ventilation system is also intended to maintain the temperature in the reactor building at a constant operation temperature as well as to prevent temperature increase and heat accumulation. The air exchange frequency in the reactor building is maintained 6 times per hour, with the air outflow rate 396.3 m^3/minute. The air flow through ventilation holes is designed to be distributed equally through every part of containment, via primary outlet containing pre filter and absolute filter, before it goes to blower and to the 31.75 m height of reactor's stack. Control room ventilation system as a part of reactor ventilation system is installed to control the air circulation inflow and outflow from the control room.

The ducting is constructed from rectangular plates where the intersections are connected by bolt flanges. The ducting ends at the channel under the stack. The primary channel is installed at the height of 9 m. The ducting is divided into two branches up to the end of the channel at the height of 0.25 m. Two units of blower which run alternately are installed as redundant system. Blower I and blower II are equipped with interlock systems. Two blowers are used for air absorption and compression into the stack. To adjust the amount of the airflow, a damper is installed at the inlet side and the outlet side of each blower. Filter housing is equipped with a manometer to monitor the dirt of air filter based on pressure distinction between air flows before and after entering the filter building.

When the reactor is in operation condition, some Ar^{41} is assumed to release due to the Ar^{41} gas content of the air that dissolves in water. When it is activated by neutrons then it becomes an active Ar^{41} gas, which can escape to the reactor room. The reactor core, which is submerged by water during reactor operation, becomes Ar^{41} gas producer where this gas will travel from the core to the reactor room. The gas type of radioactive waste is treated directly by filtration using pre-filter "*Farr HEPA Filter*", and absolute filter called: "*Farr Hi flow Filter*" for filtration of gas which contains particles size of 1 – 15 µm.

The dirty air removed from the reactor through gas stack, is passed through a filter system. The filter system consists of a pre-filter and an absolute filter of VILAIR brand. The purpose of the combination of two pre-filters of P15/500 and PA/500 types is to hold the dirt/dust entering the ducting. The combination will absorb dust up to 10 µm in diameter. It is assumed that 85% of the dust can be absorbed by this pre-filter. This type of filter, P15/500, can be cleaned by washing it using only plain water, at a washing power of 15-20 times. Air filter of

PA/500 type is able to hold refined dust up to less than 1 μm in diameter. Since this filter cannot be rewashed then it should be disposed after once usage.

Since the environmental safety requirements for contamination are very strict, in a sense that the permitted amount of radioactive dust or gas going out of the reactor room is very low, then an absolute filter is installed. The filter chosen is N type of LUWA, where this type can hold back molecules of up to less than 0.3 μm in diameter. The total dust that can be filtered is up to about 99.99%. The pre-filter and the absolute filter are installed in such that they can be easily replaced and removed for maintenance. The air filter system can hold up molecules to less than 0.3 μm in diameter, but Ar^{41} and N^{16} can still pass through it. It is therefore necessary to provide a stack of 31.75 m high in order to reduce the concentration of the air contamination to make the reactor operation reach the environmental safety requirements.

RESULTS AND DISCUSSION

The PIE was overviewed and it comprises 8 events, 3 of which are: the failure of transfer cask, loss of coolant water, and the failure of scram system causing radioactive releases to environment. The influence on atmosphere stability, temperature, rainfall, humidity, air pressure and velocity, and other factors such as population density, age, sex ratio of population and total population, was evaluated to determine the suitability of reactor. Atmosphere stability uses Pasquil-Gillford equation, which has six stability classes from extremely stable A to moderately stable F, is calculated to determine effective stack height H, and ground level concentration $\chi(x,y)$ [3,4]. Data of Kartini reactor component and system such as fuel elements, core, cooling water, building, ventilation, environmental variables and emergency preparedness have been acquired.

The environment monitoring at reactor site from January 2007 up to December 2008, shows that the rainfall in Kartini reactor site is 6.21 mm, air pressure around reactor site is 1 atmosphere, humidity is 78.44%, and daily temperature average is 26.36 °C. The average maximum temperature is 31.43 °C, while minimum temperature is 22.82 °C, during 2 years data. The wind direction is presented in Figure 1 for 2007 and Figure 2 for 2008. All of the figures show wind directions tend to point 240° direction. For wind velocity, Figure 3, and 4 show similar with the previous data and time.

Verification of ventilation system components to assure which components should be modified and replaced-caused by ageing, has been conducted. The components such as rolling door, fan wheel housing and motor blower, air duct from reactor building to blower housing, have been improved. Comparison between formerly existing ventilation system and modified ventilation system is shown in Table 1, and the picture is shown in Figure 5. It is shown that modified system give a higher air pressure at the inlet and outlet air filter than before modification, whiles, air pressure different between inside reactor building and outside air is the same. This indicates that the new filter system is working more effective. The retrofitting of the blower system gives more space in the filter and fan wheel housing, and makes a maintenance program easy. Duct retrofitting decreases the air leakage possibility in the ventilation system.

The source term calculation using ORIGEN-2 has been done to estimate the ultimate goal of gaseous release to the environment, and the result is shown in Table 2. The source term analysis showed that the fission product accumulated in the reactor core at the start of operation was 4.838×10^{6} Ci, it became 3.614×10^{8} Ci after 5 hours operation (time period of daily operation), and after reactor shut-down of 24 hours decay the fission product became 4.727×10^{6} Ci. The activation product in the reactor coolant i.e. Ar^{41} and Ni^{16} was calculated and the calculation results show that N^{16} activity inside the reactor building is 4.1×10^{-10} μCi/cm^3 and the Ar^{41} escaping to the atmosphere is 5.7×10^{-12} mCi/cm^3, which is lower than limit value for radiation worker of 2×10^{-6} μCi/cm^3.

Ground level concentration and effective stack height is calculated using Equation A-1 and A-2 (see Appendix A), and the plume of gas releases calculated using data of March 2007, March 2008 and March 2009 are shown in Figure 6, Figure 7, and Figure 8. Direct observation on the upper stack show that the radiation exposure is 2.33×10^{-9} rad per second, exit velocity of gas from stack is 8 meters per second, absolute temperature effluent of gas is 26,2 °C, and outlet diameter of stack, d = 1 meter and actual stack height 31.75 meters.

For example, using March 2009 data, the value of ground level concentration on x and y coordinates, χ(x,y), is shown in Appendix A, with variable distance x = 100 meters to 5,000 meters, while ordinate of y is taken from 32 meters and 50 meters, the effective height of stack is obtained 38.55 meters. Initially the value of χ(x,y) for x =100 meters and y = 32, and 50 meters shows 9.726×10^{-19} rad/m^3, rise up to 6.303×10^{-14} rad/m^3.and tends to decrease 1.598×10^{-15} rad/m^3 at distance 5,000 meters. Table-3 shows some values of emission rate Q from stack (rad/s) measured directly, the average value is used to calculate ground level concentration, χ(x,y). The above values are acceptable according to safety requirements [5]. The radioactive release or gas effluent from reactor stack was measured by gamma spectrometry, and the result shown that the radioactive element was detected as K^{40} (as natural radioactivity). The above calculated and measured values were far below the limit value determined by the regulatory body i.e. 6×10^{-7} μCi/cm^3 [6,7,8]. While the measurement result of airborne radioactivity in the reactor stack by using HI-Volume Air Sampler shows the average gross beta radioactivity is 6.15×10^{-8} Bq/cm^3, this value is far below the limiting value stated in SAR of Kartini reactor i.e. 4×10^{-5} Bq/cm^3 [2], and conform with the requirements for research reactor in general [11,12].

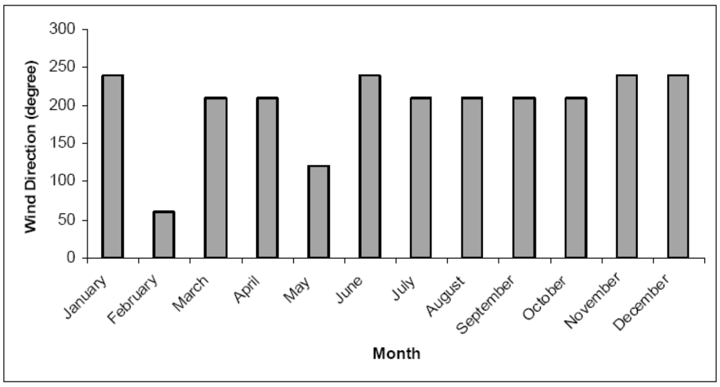


Figure 1. Wind direction at reactor site in 2007

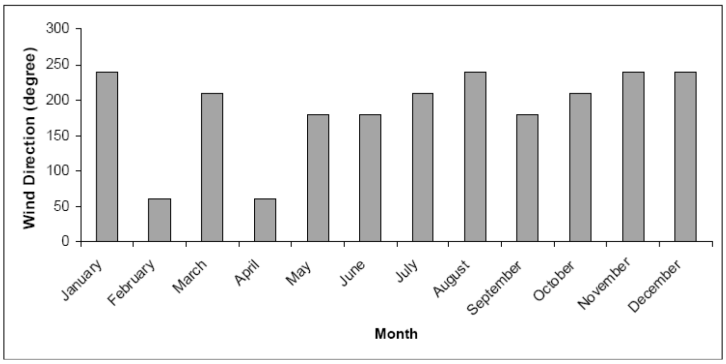


Figure 2. Wind direction at reactor site in 2008

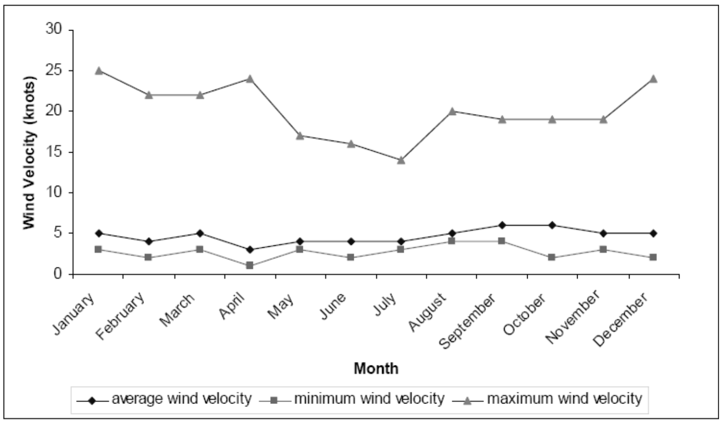


Figure 3. Wind velocity at reactor site in 2007

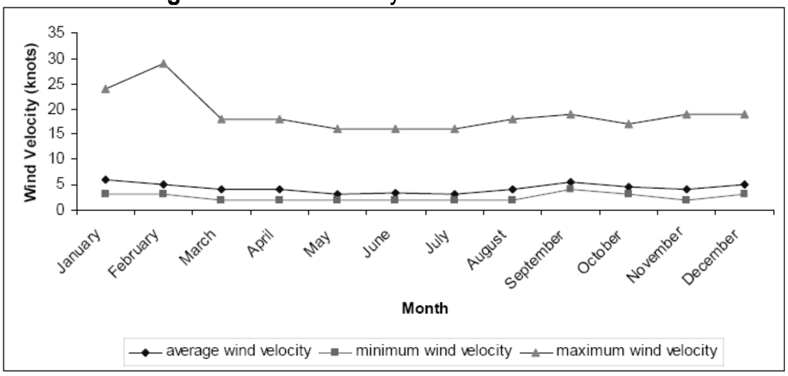


Figure 4. Wind velocity at reactor site in 2008

Table 1. Technical Specification of the Ventilation System before and after Retrofitting

No	Component's name	Technical Specification	
		before	**after**
1	Blower unit & capacity	2 units, each 40 kW	2 units, each 30 kW
2	Blower motor type	3 phases, 50 Hz, Cos φ = 0.85	MEZ, 3 phases f = 50 Hz Cos φ = 0.80
3	Damper	Available	Available
4	Fan wheel dimension	Ø = 1.22 m, h = 0.61 m	Ø = 1.2 m, h = 1.2 m
5	Pulley dimension	Ø1 = 0.4 m , Ø2 = 0.62 m	Ø1 = 0.26 m, Ø2 = 0.34 m
6	V-belt dimension	Length = 4.829 m	Length = 2.06 m
7	Air pressure, IN and OUT-filter	IN- filter = 0.16 inch H_2O OUT-filter = 0.7 inch H_2O	IN-filter = 0.35 inch H_2O OUT-filter = 2.05 inch H_2O
8	Type of air filter	HEPA, LUWA type N	HEPA, LUWA type N
9	Room volume	4.450 m^3	4.418 m^3
10	Ducting dimension	1.693 m^2	1.693 m^2
11	Charcoal filter	Available	available
12	Air pressure difference reactor building	$\Delta p \leq 0.2$ cm H_20	$\Delta p \leq 0.2$ cm H_20

Table 2. Fission product activity of irradiated fuel elements calculated using ORIGEN-2

No	Legend	Total fission product radioactivities (Ci/fuel rod)	Radioactivities (Ci/core)
1	Start operation	7.011×10^{04}	4.838×10^{06}
2	After 5 hours operation	5.238×10^{06}	3.614×10^{08}
3	3 hours decay	4.561×10^{05}	3.147×10^{07}
4	6 hours decay	2.444×10^{05}	1.686×10^{07}
5	9 hours decay	1.593×10^{05}	1.099×10^{07}
6	12 hours decay	1.172×10^{05}	8.087×10^{06}
7	15 hours decay	9.495×10^{04}	6.552×10^{06}
8	18 hours decay	8.213×10^{04}	5.667×10^{06}
9	21 hours decay	7.413×10^{04}	5.115×10^{06}
10	24 hours decay	6.850×10^{04}	4.727×10^{06}

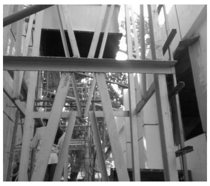
Table 3. The value of emission rate from reactor stack, Q

No.	Emission rate (rad per second)
1	2.33×10^{-09}
2	2.29×10^{-09}
3	2.26×10^{-09}
4	2.40×10^{-09}
5	2.38×10^{-09}

No.	Emission rate (rad per second)
6	2.33×10^{-09}
7	2.29×10^{-09}
8	2.27×10^{-09}
9	2.30×10^{-09}
10	2.26×10^{-09}

No.	Emission rate (rad per second)
11	2.35×10^{-09}
12	2.35×10^{-09}
13	2.44×10^{-09}

Average: 2.33×10^{-09}

No	Name	Before	After
1	Rolling door		
2	Fan wheel housing and motor blower		
3	Air duct from reactor building to blower housing		

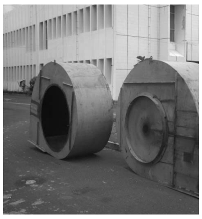
No	Name	Before	After
4	Fan wheel housing		

Figure 5: Comparison of Kartini reactor ventilation systems before and after improvements

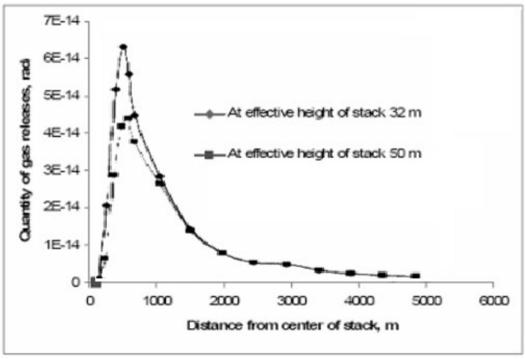


Figure 6. Plume in March 2007

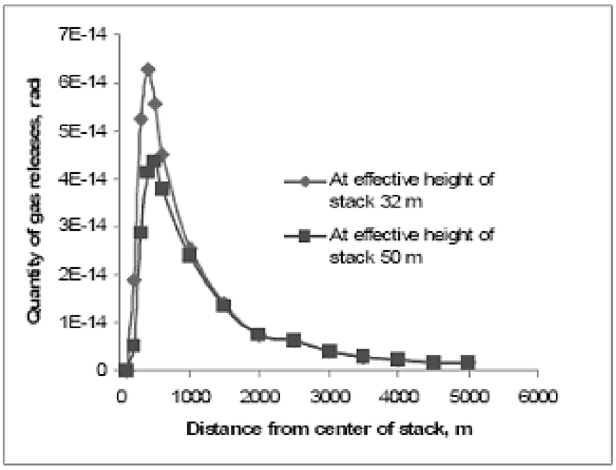


Figure 7. Plume in March 2008

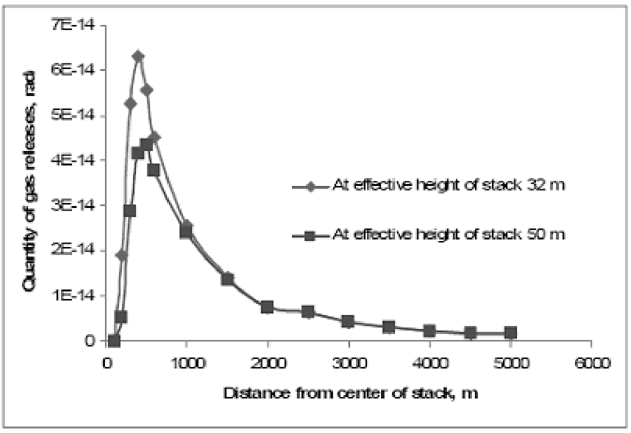


Figure 8. Plume in March 2009

While, a survey on the demography and population conditions surrounding the Kartini reactor site was done for 2003 – 2008 period. The projected population of the survey area shows that the total population in 2008 within 5 km radius was 660,191 people. While in 2003 the total population in the same area was 637,352 people. The population growth rate of the survey area is about 1.04% and relatively stable.

CONCLUSIONS

From the above evaluation and the source term analysis can be drawn the conclusion that the fission product accumulated in the reactor core at the start of operation was 4.838×10^6 Ci, after of 5 hours operation it became 3.614×10^8 Ci, and after 24 hours decay, the fission product became 4.727×10^6 Ci. The N^{16} activity inside the reactor building is 4.1×10^{-10} µCi/cm^3 and the Ar^{41} escaping to the atmosphere is 5.7×10^{-12} mCi/cm^3, which is lower than limit value for radiation worker of 2×10^{-6} µCi/cm^3. A sample case by using March 2009 data, the value of ground level concentration on variable distance x = 100 m to 5,000 m, was 9.726×10^{-19} rad/m^3, rise up to 6.303×10^{-14} rad/m^3 and tends to decrease to 1.598×10^{-15} rad/m^3 at distance 5,000 m. Whiles the direct observation on the upper reactor stack show that the radiation exposure is 2.33×10^{-9} rad/s, exit velocity of gas from stack is 8 m/s, absolute temperature effluent of gas is 26.2 °C, and outlet diameter of stack, d = 1 m and actual stack height 31.75 m. Based on safety limit criteria from national regulation, the values of radiation exposure, ground level concentration combined with atmosphere stability and demography factor was very safe for the actual condition of Kartini reactor site. Therefore, the emergency preparedness program stated that if there is an accident, the evacuation is only for workers.

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APPENDIX A

In this model, the contaminant is assumed to be normally distributed around the central axis of the plume, and that atmospheric stability and wind speed determine the atmospheric dispersion characteristics of the contaminant in the downwind direction. This model is described by the Pasquill-Gifford equation:

$$\chi(x,y) = \frac{Q}{\pi\ \sigma_y \sigma_z \mu} \exp\left[-\frac{1}{2}\left(\frac{y^2}{\sigma_y^2} + \frac{H^2}{\sigma_z^2}\right)\right] \qquad \text{(A-1)}$$

where, $\chi(x,y)$ = ground level concentration in rad per cubic meter at point x, y.

x = downwind distance on plume center line, m

y = cross-wind distance, m

Q = emission rate, rad/s

σ_y, σ_z = horizontal & vertical standard deviation of contaminant concentration in the plume, m

μ = mean wind speed at level of plume center line, meters per second

H = effective stack height, meters

If the effluent gas has a significant exit velocity, or if it is at high temperature, it will rise to a level higher than the stack. The effective stack height, therefore, is the sum of the actual stack height, plus a factor that accounts for the exit velocity and the temperature of the effluent gas:

$$H = h + d\left(\frac{v}{\mu}\right)^{1.4}\left(1 + \frac{\Delta T}{T}\right) \qquad \text{(A-2)}$$

where: h = actual stack height, meters

d = stack outlet diameter, meters

v = exit velocity of gas, meters per second

μ = mean wind speed, meters per second

ΔT = difference between ambient and effluent gas temperatures

T = absolute temperature of effluent gas

The calculation of ground level concentration using Pasquil-Gifford modeling atmospheric stability for sample data of March 2009 is shown in Table A, below:

Table A. Calculation Result of Ground Level concentration

x (m)	y (m)	σ_y (m)	σ_z (m)	H	χ (Rad/m^3)
100	32	12	8	38.548198	9.726×10^{-19}
100	50	12	8	38.548198	5.784×10^{-21}
200	32	24	16	38.548198	1.894×10^{-14}
200	50	24	16	38.548198	5.261×10^{-15}
300	32	35	22	38.548198	5.252×10^{-14}
300	50	35	22	38.548198	2.875×10^{-14}
400	32	42	28	38.548198	6.303×10^{-14}
400	50	42	28	38.548198	4.148×10^{-14}
500	32	55	36	38.548198	5.568×10^{-14}

500	50	55	36	38.548198	4.363×10^{-14}
600	32	65	42	38.548198	4.511×10^{-14}
600	50	65	42	38.548198	3.788×10^{-14}
1000	32	105	65	38.548198	2.558×10^{-14}
1000	50	105	65	38.548198	2.392×10^{-14}
1500	32	150	90	38.548198	1.399×10^{-14}
1500	50	150	90	38.548198	1.354×10^{-14}
2000	32	200	125	38.548198	7.545×10^{-15}
2000	50	200	125	38.548198	7.407×10^{-15}
3000	32	300	175	38.548198	4.031×10^{-15}
3000	50	300	175	38.548198	3.998×10^{-15}
4000	32	400	220	38.548198	2.235×10^{-15}
4000	50	400	220	38.548198	2.225×10^{-15}
5000	32	480	250	38.548198	1.603×10^{-15}
5000	50	480	250	38.548198	1.598×10^{-15}