Dispersion of Iodine-131 Radioactive Airborne in the Chemical Form of CH_3I, HOI and I_2 from Radioisotope Production Facility Stack to The Environment

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Abstract. The purpose of this research is to develop a method for measuring radioactive release I-131 in the stack of isotope production facilities and in the environment (outdoor) in the form of: organic Iodine methyl Iodide (CH_3I), elemental iodine (I_2) and inorganic hypoiodous acid iodine (HOI). Charcoal filters are used to adsorb organic Iodine methyl Iodide (CH_3I). Silver coated gauze is used to adsorb elemental Iodine (I_2). Glass fiber paper filters are used to adsorb inorganic hypoiodous acid iodine (HOI*)*. The discharge of I-131 activity concentrations on average from the stack and in seven outdoor places around the isotope production installation are still underneath the standard level within the air (530 Bq/m^3) based on controls of Nuclear Energy Supervisory Agency (BAPETEN) Head, No. 7/2013. The activity concentrations of I-131 in stack from large to small were CH_3I (63.03%), I_2 (30,27%) and HOI (7.70%) respectively. While average I-131 concentration in the outdoors were CH_3I (61.12%), I_2 (20.37%) and HOI (18.39%).

Keywords: I-131, Iodine-131, charcoal, stack, CH_3I, HOI, I_2, Methyl Iodide, Elemental Iodine, Hypoiodous acid.

1 Introduction

Radioisotope Production Facility at Serpong, produces and processes I-131 that can disperse to the housings (community) and the environment around the Serpong nuclear area (SNA). The Radioisotope Production Facility is surrounded by densely populated housings. The population in the 5 km radius from the facility in 2019 is around 241,821 people with a growth of 2.22 percent per year [1, 2, 3]. This has come to the attention of BATAN (National Nuclear Energy Agency) and BAPETEN (Nuclear Energy Regulatory Agency) to conduct radiation protection studies on the release of radionuclides in general, specifically Iodine-131 (I-131) from the nuclear installation stack which produces I-131.

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I-131 is produced routinely for medical purposes in hospitals and pharmacies, for both domestic and export. I-131 is a beta and gamma emitting radioactive material. Radioiodine (I-131) is one of the large enough radioactive substances to get attention, because of its volatile nature and can damage the thyroid gland from the people health. I-131 causes mutations and death to penetrated cells, and can cause thyroid cancer. I-131 is the largest radionuclides released from a nuclear accident. For example, the activity of I-131 radionuclide released from the nuclear accident in Chernobyl (Russia) on 1986 amounted to 1,850 PBq (1 PBq = 1.10^{15} Bq), and in Fukushima (Japan) on March 2011 amounted to 400 PBq [4, 5, 6, 7, 8, 9, 10]

The purpose of this study is to develop a method for measuring radioactive release I-131 in the stack of isotope production facilities and in the environment (outdoor) in the form of: organic Iodine methyl Iodide (CH_3I), elemental iodine (I_2) and inorganic hypoiodous acid iodine (HOI). Previous research only measured I-131 concentrations by using a charcoal (indirect method), without measured the chemical forms of CH_3I, I_2 and HOI [10]. The measurement method of I-131 in the stack and the environment is usually done only by using charcoal, while the development of the I-131 measurement method is done not only by using charcoal filters to measure CH_3I, but also using silver coated gauze to measure I_2 and glass fiber paper filters to measure HOI.

2 Methods

2.1 Description of Research Locations

This research was carried out within the seven yards of houses (outdoor), Serpong Nuclear Region, and within the stack of I-131 radioisotope production installation. The research was conducted as numerous as seven houses with five wind headings for 15 to 22 hours at the same time to product and discharge of I-131 radioactive to the stack. Research locations map at Serpong Nuclear region is shown on Figure 1. Seven research locations of the stack are at Sengkol (North and 0.8 km from the stack), BATAN Indah (North and 2.6 km from the stack), Jaletreng (North and 4.2 km from the stack), Puri Serpong (East and 2.2 km from the stack), Muncul (North East and 1.3 km from the stack), Pabuaran (South and 1.9 km from the stack), and Suradita (West and 3.2 km from the stack) [10].

2.2 I-131 concentration Measurement Method

I-131 Concentrations Measurement Method in the Stack. I-131 concentrations measurement method of in the stack has been explained in detail in my paper, 2017 [10]. Basically, the measurement method for I-131 on the stack is explained in Figure 2. The difference between the development method and the previous method is that the development method is modified from the previous method where the concentration of I-131 is measured using a charcoal filter, silver plated gauze and glass fiber paper filter. Previous research method only measured I-131 concentrations by using a charcoal (indirect method), without measured the chemical forms of CH_3I, I_2 and HOI [10]. Charcoal filters are used to adsorb organic Iodine methyl Iodide (CH_3I-131). Silver coated gauze is used to adsorb elemental Iodine (I_2 -131). Glass fiber paper filters

are used to adsorb inorganic hypoiodous acid iodine (HOI-131). Grade of the standard quality level of radioactivity in the air is 530 Bq / m^3 based on the direction of PERKA BAPETEN No. 7/2013 [11].

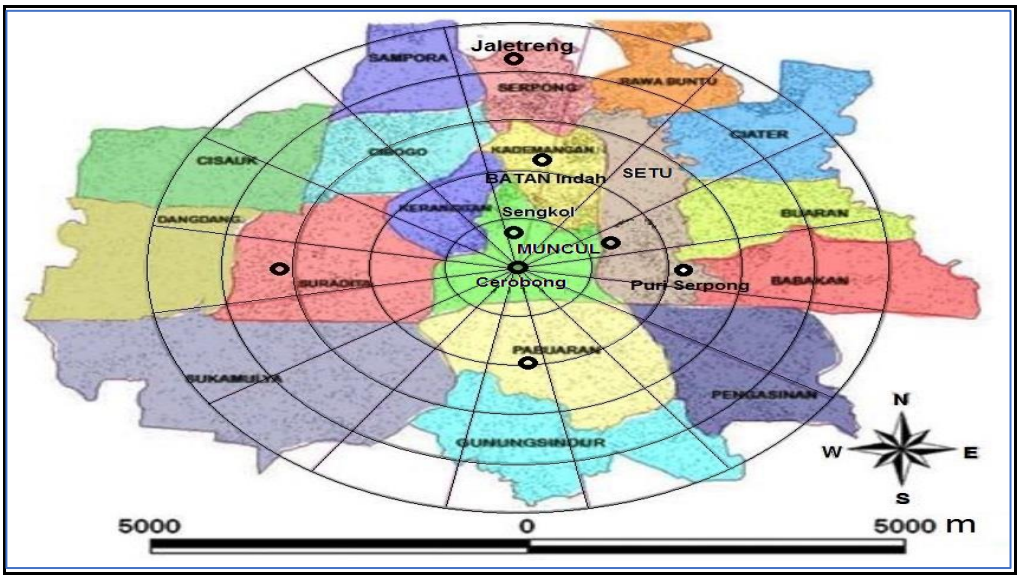

Fig. 1. Research locations map at Serpong Nuclear Area.

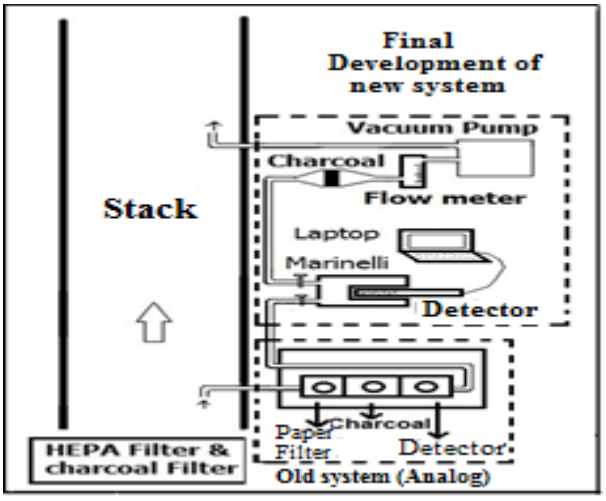

Fig. 2. I-131 concentration measurement system within radioisotope production stack.

I-131 Concentration Measurement Method at Outdoor. The method of measuring the I-131 concentration at outdoor has also been explained in detail in my paper, 2017 [10]. Basically, the measurement method for outdoor I-131 is explained in Figure 3. The difference with the previous method is that in this study concentration of I-131 was measured using indirect methods in charcoal filters, silver coated gauze and glass fiber paper filters. Charcoal filters are used to adsorb organic Iodine methyl Iodide (CH_3I-131). Silver coated gauze is used to adsorb elemental Iodine (I_2 -131). Glass fiber paper filters are used to adsorb inorganic hypoiodous acid iodine (HOI-131).

Measurement of I-131 concentration at outdoor coincides with production of I-131 radioisotope at the Radioisotope Production Facility. Thus, measurement of I-131 concentration in the form of CH_3I-131, HOI-131 and I_2-131 in stack and outdoors was carried out at the same time during 24 hours.

Fig. 3. Air sampling at outdoor by using charcoal, silver coated gauze and glass fiber paper filters.

Elemental Iodine Sampling Method (I_2). Elemental Iodine (1_2-131) needs attention, because elemental iodine with a very small diameter (ultrafine) will be very easy to enter the body and

can interfere with health. In addition, the concentration in the air at a nuclear facility is quite large, ranging from 17.3% to 66.1% [12].

Elemental iodine is present in the atmosphere in the form of vapors or aerosol particles with a diffusion coefficient of 0.08 cm^2 / second. This diffusion coefficient is used to determine the diameter of the elemental Iodine aerosol particles, it is known that based on the calculation of the diameter of the elemental Iodine aerosol particles is 0.835 nm [13, 14]. There are various types of elemental Iodine sampling that are commonly used, namely:

a. Cadmium Iodide on cromosorb [14]. This sample has high efficiency, but is not durable, expensive and only one-time use.

b. Silver plated silica gel (AgS) [15]. The efficiency is quite high, but only one use.

c. Sampling gauze shape (copper or silver) [13]. This sample has a high efficiency, is durable, and can be decontaminated.

Iodine gas (I_2) is produced from stable KI crystals (20 mg) which are activated neutrons in the reactor. After activation, KI crystals is taken into a glove box, then a chemical reaction takes place producing I2 gas. The chemical reaction equation for I_2 production is as follows: [16]:

$$2KI + 2KNO_2 + 2H_2SO_4 \longrightarrow I_2\uparrow + 2\ NO\uparrow + 2H_2O + 2K_2SO_4$$

Elemental Iodine sampling (I_2) used in this research was silver coated gauze type. I-131 in the form of I_2 adsorbed silver coated gauze is affixed to charcoal with a 25 lpm vacuum pump flow rate. This silver coated (Ag) gauze is best contaminated and durable, so that it is economically quite cheap [17]. Elemental iodine that passes through silver-plated brass gauze will be adsorbed on the gauze with Van der Walls bonds and react chemically to form covalent bonds between I_2 and Ag. The chemical reaction is:

$$2\ Ag\ (s) + I_2\text{-}131\ (g) \longrightarrow 2\ AgI\text{-}131$$

Measurement of the concentration of the element iodine (I_2) in the gauze sample was carried out with a gamma spectrometer system using an in-situ NaI(Tl) detector. I-131 concentration in gauze (C) is calculated by equation (1), in this case Nt is the I-131 count of gauze. Concentration of I-131 in charcoal is counted utilizing the following formula:

$$C = \frac{(N_t - N_{Bg}}{Y.t.\eta.(ts.F)} \quad (1)$$

Information:

C: Concentration of I-131 (Bq/m^3)

η: Counting efficiency of calibration standard source with gamma detector of NaI(Tl) (cps/Bq)

Nt: I-131 radionuclide counts in charcoal at 364 keV energy(counts)

N_{Bg}: background (no sample) counts without I-131 radionuclide counts (counts)

t: duration of measuring (s)

ts: length of sampling (s)

F: sampling flow rate (m^3/s)

Y: plenitude of I-131 in nature (81.21%)

Organic Iodine Sampling Method (CH_3I). Iodine (I-131) in form of organic methyl iodide (CH_3I-131) is produced in radioisotope production facilities can penetrate aerosol filters. Sampling is done by pulling the sample stream through an aerosol filter containing an Iodine filter material, such as activated charcoal, silver zeolite or other material with a vacuum pump on flow rate of 25 lpm. Increasing the efficiency of organic methyl iodide (CH_3I-131) sampling Iodine is done by mixing activated charcoal and a chemical called tri ethylene diamine (TEDA). The efficiency of CH_3I sampling is influenced by physical parameters, such as air temperature, water vapor, organics and time. Efficiency will decrease, if sampling is done for a long time (aging). Warming air flow to reduce water content in charcoal is an effective method for collecting organic iodine [18]. The charcoal extracting cartridge is shown in Figure 4. Methyl Iodide (CH_3I) is produced by mixing TEDA and Dimethyl Sulfate ($(CH_3O)_2SO_2$) according to the following equation:

$$\text{TEDA-I-131} + (CH_3O)_2SO_2 \longrightarrow CH_3I\text{-131} + \text{TEDA-}CH_3SO_4$$

The CH_3I-131 concentration in charcoal (C) is calculated to be equal to equation (1), while Nt is the I-131 count in the form of CH_3I in charcoal (counts).

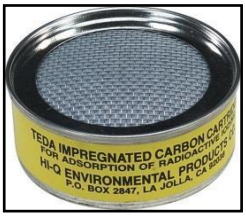

Fig. 4. Charcoal filter used in this study contains TEDA

Inorganic Iodine Sampling Method (HOI). The filter paper used for air sampling is Whatman GF / A fiber glass. This filter has Dioctyl Phthalate (DOP) sampling efficiency at a diameter of 0.3 um of 99.99%. This paper filter is used to adsorb I-131 in the form of inorganic Iodine Hypoiodic Acid (HOI). HOI is formed from the chemical process elemental Iodine (I_2) which undergoes a process of hydrolysis with water (H_2O). The chemical reaction for HOI formation is [19]:

$$I_2\text{-131} + H_2O \longrightarrow \text{HOI-131} + I^- + H^+$$

Concentration of I-131 within the shape of HOI in-filter paper (C) is calculated equal to equation (1), while Nt is the count of I-131 in the form of HOI in-filter paper (counts).

3 Results

The results of measurements and calculations of I-131 activity concentrations within radioisotope production stack are shown in Figures 5, 6, 7, 8, 9, 10 and 11. Overall the order of

concentrations of CH_3I, HOI and I_2 with activity concentrations of large to small within stack, namely CH_3I, I_2 and HOI respectively.

The highest total activity concentration of the measurement system on December 11-12, 2013 in the stack was 470.35 Bq/m^3 on time of 19.00 to 20.00 (Figure 5). The total activity concentration was high on time of 19.00 to 20.00, because at those times the method of changing the phase from the solution phase to the gas phase amid the disintegration handle of Mo-99 into I-131 gas. There was an I-131 gas that get away through the sidelines of the elastic connector to the stack during this gas phase, so that the concentration of the I-131 movement rises quickly between 19.00 and 20.00. I-131 measurement was done every 1 hour. Overall the average concentration of I-131 activity (103.03 Bq/m^3) were still underneath the quality standard of the I-131 radioactivity level in the air which is 530 Bq/m^3 based on PERKA BAPETEN control of No. 7/2013 [11].

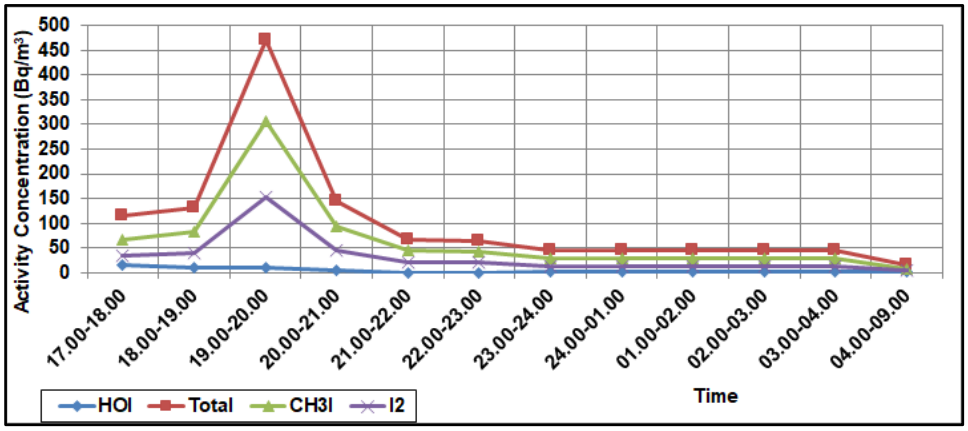

Fig. 5. Measurement results of I-131 activity concentrations within stack on December 11 to 12, 2013

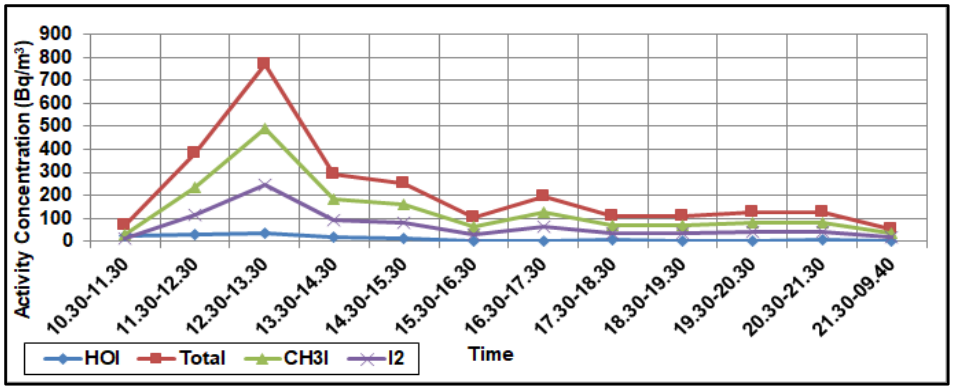

Fig. 6. Measurement results of I-131 activity concentrations within stack on December 18 to 19, 2013

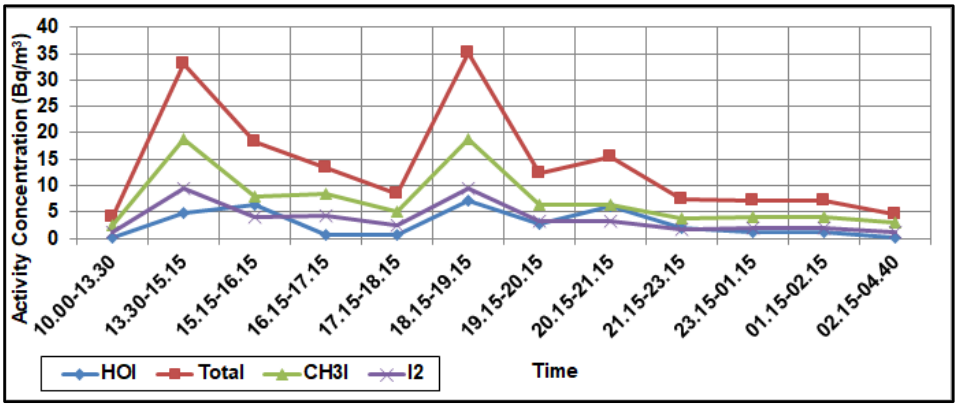

Fig. 7. Measurement results of I-131 activity concentrations within stack on December 27 to 28, 2013

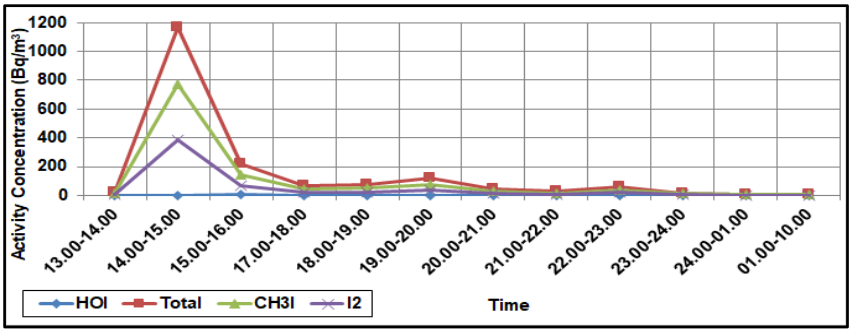

Fig. 8. Measurement results of I-131 activity concentrations within stack on January 22 to 23, 2014

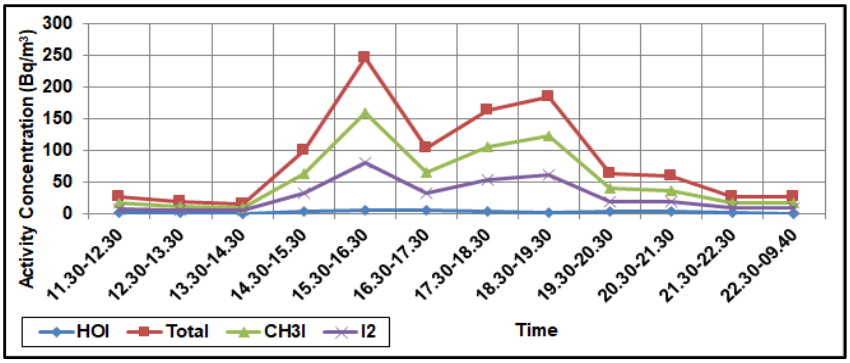

Fig. 9. Measurement results of I-131 activity concentrations within stack on Feb 5 to 6, 2014

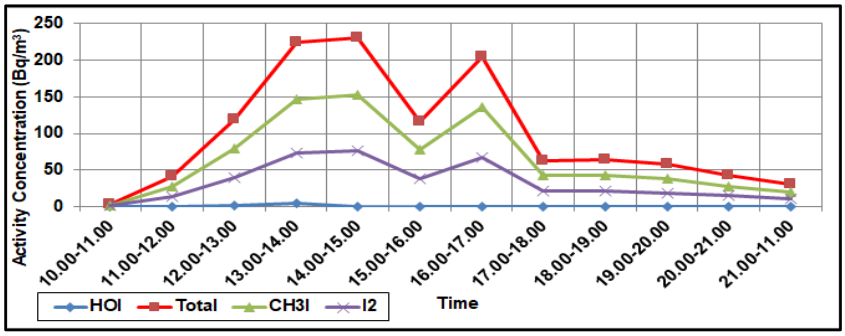

Fig. 10. Measurement results of I-131 activity concentrations within stack on February 19 to 20, 2014

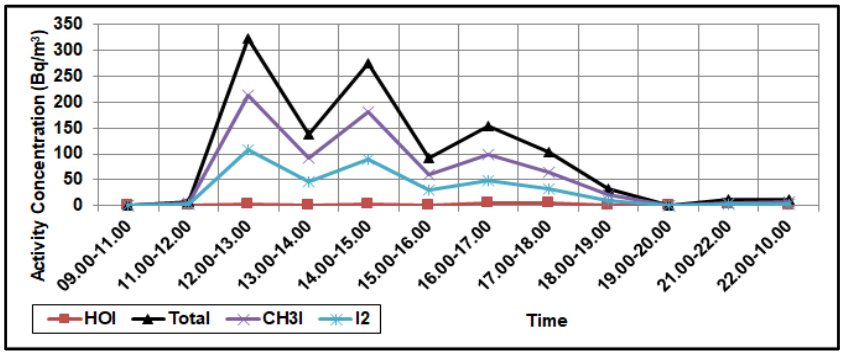

Fig. 11. Measurement of I-131 activity concentrations within stack on March 13 to 14, 2014

Measurement results of the overall I-131 activity concentrations in radioisotope production stack are shown on Table 1 and Table 2. Total activity concentrations of measurement system on December 27-28, 2013 were low, compared to the values of the activity concentrations in the stack on December 11-12 and 18-19, 2013. These cases were due to the fact that during the radioisotope production process were instrument damage, so that the production of I-131 was not optimal. The activity concentrations of CH_3I-131, I_2-131, HOI-131 and the highest total average in the stack on December 18-19, 2013 were 136.24; 68.12; 12.89 and 217.24 Bq/m^3 respectively. Concentrations measurement of I-131 activity in radioisotope production stack on 18-19 December 2013 were at the same time measured concentrations of I-131 activity at outdoor BATAN Indah housing. By and large concentrations of the I-131 activity on normal within the stack were still underneath the quality standard of the I-131 radioactivity level in the air which is 530 Bq/m^3 based on PERKA BAPETEN control of No. 7/2013 [11].

The measurement results of I-131 activity concentrations at outdoor Puri Serpong housing on December 11 to 12, 2013 are shown on Figure 12. The order of I-131 activity concentration in the form of CH_3I, HOI and I_2 from large to small at outdoor Puri Serpong housing were CH_3I, HOI and I_2 respectively. The arrange of I-131 concentrations at outdoor were diverse in arrange with the I-131 concentrations within the stack. The order of I-131 concentrations within the stack from huge to little were CH_3I, I_2 and HOI. These differences prove elemental Iodine aerosol particles (I_2) in the stack during dispersion to the housing undergo a chemical process that is the process of hydrolysis with water (H_2O) in the air to form inorganic Iodine Hypoiodic Acid (HOI) with chemical reactions as follows [19]:

$$(I_2)\text{-}131 + H_2O \longrightarrow HOI\text{-}131 + I^- + H^+$$

Table 1. Summary of measurements result from CH_3I dan I_2 activity concentration in Stack

No.	Location Direction-distance of	Date I-131 production time	Concentration (Bq/m3) and Time in Stack					
			CH_3I			I_2		
			Minimum	Maximum	Average	Minimum	Maximum	Average
1	Puri Serpong	11-12 Des 2013	2.59	16.99	8.98	0.86	5.66	2.99
	E, 2,2 km	17.00-05.00	17.40-18.40	19.45-20.45	17.40-07.50	17.40-18.40	19.45-20.45	17.40-07.50
2	BATAN Indah	18-19 Des 2013	8.79	36.21	20.65	2.93	12.07	6.88
	N, 2,6 km	11.30-21.40	11.30-12.30	21.20-22.25	11.30-01.40	11.30-12.30	21.20-22.25	11.30-01.40
3	Muncul	27-28 Des 2013	2.60	18.87	7.70	1.30	9.43	3.85
	NE, 1,3 km	13.30-05.00	13.30-14.30	21.45-22.45	13.30-06.40	13.30-14.30	21.45-22.45	13.30-06.40
4	Sengkol	22-23 Jan 2014	2.56	20.49	12.02	0.85	6.83	4.01
	N, 0,8 km	14.00-01.30	06.00-07.50	18.25-19.25	14.10-07.50	06.00-07.50	18.25-19.25	14.10-07.50
5	Pabuaran	5-6 Feb 2014	7.22	20.93	13.23	2.41	6.98	4.41
	S, 1,9 km	12.30-21.30	06.30-08.30	16.45-17.45	15.15-08.30	06.30-08.30	16.45-17.45	15.15-08.30
6	Suradita	19-20 Feb 2014	0	19.50	8.90	0	6.50	2.97
	W, 3,2 km	11.00-21.00	14.05-16.30	23.35-24.35	14.05-09.00	14.05-16.30	23.35-24.35	14.05-09.00
7	Jaletreng	13-14 Mar 2014	0	21.60	10.77	0	7.20	3.59
	N, 4,2 km	11.00-21.00	15.10-16.10	02.00-03.20	15.10-09.00	15.10-16.10	02.00-03.20	15.10-09.00

The highest total concentration of I-131 activity at outdoor Puri Serpong housing measured at 30.14 Bq/m^3 was on time of 19.45 to 20.45. Most of the total concentration which 56% concentration came of Methyl Iodide (CH_3I), 25% concentration of HOI and 19% concentration of I_2. The highest I-131 activity concentrations of CH_3I, HOI and I_2 were 16.99 Bq/m^3 on 19.45-20.45, 8.52 Bq/m^3 on time of 24.35 to 01.35 and 5.66 Bq/m^3 on time of 19.45 to 20.45. Decreased concentration of I-131 activity occurred on time of 22.10 to 23.10. This decrease is due to high wind speeds of around 3.1 m/s during those times.

Table 2. Summary of measurements result from HOI and Total activity concentration in Stack

No.	Location Direction-distance of stack	Date I-131 production time	Concentration (Bq/m3) and Time in Stack					
			HOI			Total		
			Minimum	Maximum	Average	Minimum	Maximum	Average
1	Puri Serpong	11-12 Des 2013	0.22	14.90	4.67	15.31	470.35	103.03
	E, 2,2 km	17.00-05.00	22.00-23.00	17.00-18.00	17.00-09.00	04.00-09.00	19.00-20.00	17.00-09.00
2	BATAN Indah	18-19 Des 2013	1.98	33.45	12.89	55.67	771.96	217.24
	N, 2,6 km	11.30-21.40	21.30-09.40	12.30-13.30	10.30-09.40	21.30-09.40	12.30-13.30	10.30-09.40
3	Muncul	27-28 Des 2013	0.28	10.21	5.67	3.70	40.68	19.31
	NE, 1,3 km	13.30-05.00	10.00-13.30	18.15-19.15	10.00-04.40	10.00-13.30	18.15-19.15	10.00-04.40
4	Sengkol	22-23 Jan 2014	0.14	6.64	1.96	5.83	1163.92	152.14
	N, 0,8 km	14.00-01.30	01.00-10.00	15.00-16.00	13.00-10.00	24.00-01.00	14.00-15.00	13.00-10.00
5	Pabuaran	5-6 Feb 2014	0.14	5.93	2.92	14.73	246.24	86.51
	S, 1,9 km	12.30-21.30	22.30-09.40	15.30-16.30	11.30-09.40	13.30-14.30	15.30-16.30	11.30-09.40
6	Suradita	19-20 Feb 2014	0.07	4.04	0.65	3.55	230.52	107.73
	W, 3,2 km	11.00-21.00	21.00-11.00	13.00-14.00	11.00-10.00	10.00-11.00	14.00-15.00	11.00-10.00
7	Jaletreng	13-14 Mar 2014	0	5.07	1.71	0	323.84	95.69
	N, 4,2 km	11.00-21.00	09.00-11.00	16.00-17.00	11.00-10.00	09.00-11.00	12.00-13.00	11.00-10.00

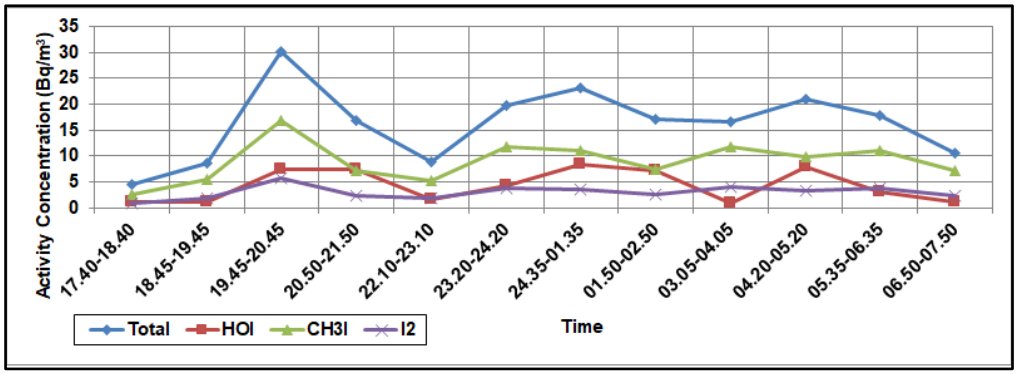

Figure 12. Concentration of I-131 activity at outdoor Puri Serpong on 11 to 12 December 2013

The measurement results of I-131 activity concentrations at outdoor BATAN Indah housings on December 18 to 19, 2013 are shown in Figure 13. The average concentrations of I-131 activity in the form of CH_3I, HOI and I_2 from large to small at outdoor housings of BATAN Indah were CH_3I, I_2 and HOI respectively. The order of I-131 activity concentrations (CH_3I, I_2 and HOI) at outdoor BATAN Indah housing was the same as the concentration of I-131 activity in the stack (CH_3I, I_2 and HOI). However, there are differences in spectrum patterns. The CH_3I, I_2 and HOI spectrum patterns are respectively the same in the stack, while the I_2 spectrum patterns are different from the CH_3I and HOI spectrum patterns in the BATAN Indah housing. This difference is likely due to elemental Iodine (I_2) in the stack during dispersion to the housing there is a chemical process (at 13.30-15.30) which is the process of hydrolysis with water in the air to form an inorganic Hypoiodic Acid (HOI) [19].

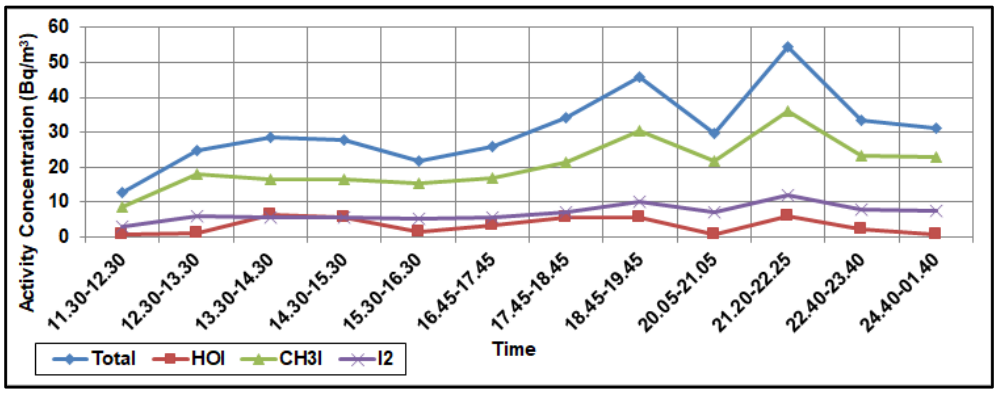

Fig. 13. Concentration of I-131 activity at outdoor BATAN Indah on 18 to 19 December 2013

The highest total concentration of I-131 activity at outside BATAN Indah measured was 54.34 Bq/m3 at time of 21.20 to 22.25. Measurement of I-131 concentration was only until time of 24.40 to 01.40, due to the limitations of charcoal filters. Most of the total concentration which 66.96% concentration came of Methyl Iodide (CH_3I), 22.31% concentration of I_2 and 10.70% concentration of HOI. The highest concentrations of CH_3I, and I_2 at times of 21.20 to 22.25 were 36.21 and 12.07 Bq/m^3 respectively. The highest concentration of I-131 activity from HOI is 6.51 Bq / m^3 at 13.30-14.30. Decreased concentration of activity I-131 occurred at 22:40 to

24:40. This decrease occurs, because the wind speed is quite high around 4.0 to 5.1 m/s at those times.

The measurement results of I-131 activity concentration at outdoor Muncul housing on December 27-28, 2013 are shown in Figure 14. The average I-131 activity concentrations sequence in the form of CH_3I, HOI and I_2 from large to small at outdoor Muncul housing were CH_3I, HOI and I_2. The order of concentrations of I-131 activity in outdoor (CH_3I, HOI and I_2) were different with order of the concentration of I-131 activity in the stack (CH_3I, I_2 and HOI). However, there are differences in spectrum patterns. The CH_3I, I_2 and HOI spectrum patterns in each stack are the same, while the HOI spectrum patterns were different from the CH_3I and I_2 spectrum patterns in the Muncul housing.

The highest total concentration of I-131 activity in the outdoor was measured at 40.68 Bq / m^3 at 21.45-22.45. The method of measuring the concentration of I-131 is only until 05.40-06.40, due to the limitations of the charcoal filter. Most of the total concentration which 52.98% concentration came of Methyl Iodide (CH_3I), 29.36% concentration of HOI and 17.66% concentration of I_2. The highest concentration of I-131 activity from CH_3I, HOI and I_2 at time of 21.45 to 22.45 was 22.85; 10.21 and 7.62 Bq/m^3 respectively. The decrease in the concentration of activity I-131 occurred on time of 20.00 to 21.00 and 23.25 to 24.25. This decrease occurs, because the wind speed is quite high around 1.8 to 3.1 m/s at those times. Wind speed at time of 21.45 to 22.45 is quite low at around 0.6 m/s.

The results of measurements of outdoor I-131 activity concentrations at Sengkol housing on January 22-23, 2014 are shown in Figure 15. The average order of I-131 activity concentrations in the form of CH_3I, HOI and I_2 from large to small in outdoor, Sengkol housing, respectively namely CH_3I, HOI and I_2. The order of concentration of I-131 activity at outdoor (CH_3I, HOI and I_2) is different in order with the concentration of I-131 in the stack (CH_3I, I_2 and HOI). However, there are differences in spectrum patterns. The CH_3I, I_2 and HOI spectrum patterns in the stack are the same, while the HOI spectrum pattern is different from the CH_3I and I_2 spectrum patterns in the Sengkol housing. This difference is probably due to the elemental Iodine aerosol (I_2) in the stack during dispersion to the housing at times of 14.10 to 17.40 and 23.20 to 07.50 undergoing a chemical process that is the process of hydrolysis with water (H_2O) in the air to form an inorganic Hypoiodic Acid (HOI) [19].

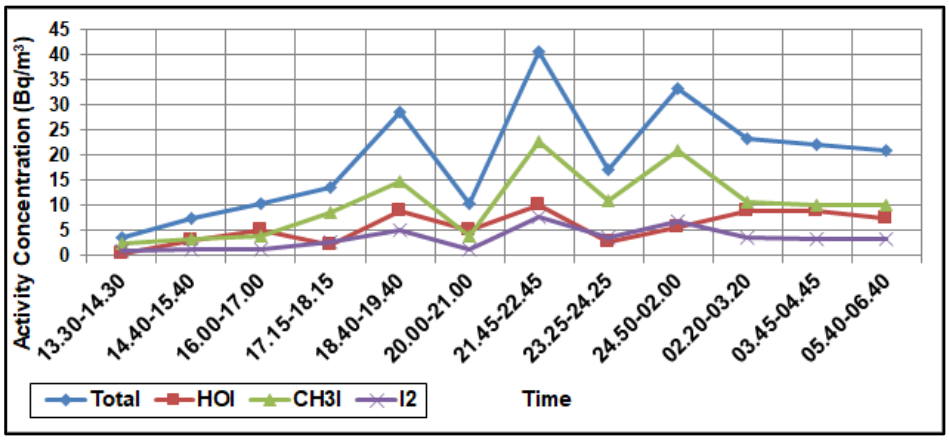

Fig. 14. Concentration of I-131 activity at outdoor Muncul on 27 to 28 December 2013

The highest total concentration of I-131 activity in the outdoor was measured at 30.39 Bq/m^3 on time of 18.25 to 19.25. Most of the total concentration of the method, 56.16% concentration came from Methyl Iodide (CH_3I), 25.16% concentration of HOI and 18.72% concentration of I_2. The highest concentration of I-131 activity of CH_3I and I_2 at 18:25-19.25 hours were 20.49 and 6.83 Bq / m^3, while the highest I-131 concentration of HOI was at time of 03.15 to 04.15 at 9.12 Bq/m^3. Decrease in concentration of activity I-131 occurred at 22.05-23.05 and 24.40-01.40. This decrease occurs, because the wind speed is quite high around 2.1 to 3.0 m/s at these hours. Wind speed at 23.20-24.20 is low, which is around 1.1 m/s.

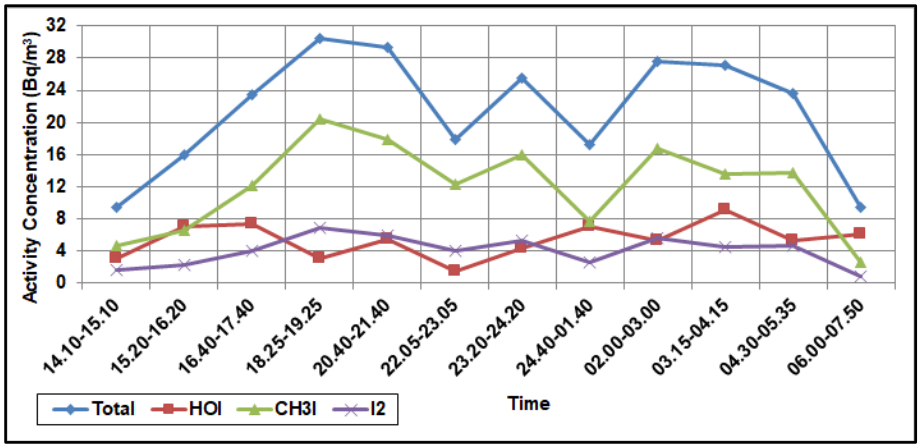

Fig. 15. Concentration of I-131 activity at outdoor Sengkol on 22 to 23 January 2014

The results of measurements of outdoor I-131 activity concentrations, Pabuaran housing, on 5 and 6 February 2014 are shown in Figure 16. At the time of the study at home of Pabuaran Village from 13.53 to 15.00 on 5 February 2014, a power outage occurred, so there is no study of I-131 activity concentration at outdoor at those times. The order of concentration of I-131 activity averages in the form of CH_3I, HOI and I_2 from large to small in outdoor of Pabuaran housings were CH_3I, I_2 and HOI respectively. The arrange of concentration of I-131 activity outdoor (CH_3I, I_2 and HOI) was the same as arrange of the concentration of I-131 within the stack (CH_3I, I_2 and HOI). However, there are differences in spectrum patterns. The CH_3I, I_2 and HOI spectrum patterns in the same stack, respectively, while the HOI and I_2 spectrum patterns differ from the CH_3I spectrum patterns in the Pabuaran housing. The concentration of HOI and I_2 activities at time of 20.45 to 21.45, 23.15 to 24.15 and 24.30 to 01.30 is almost the same. This is possible because elemental Iodine aerosols (I_2) in the stack during dispersion to the housing undergo a chemical process that is the process of hydrolysis with water (H_2O) in the air to form inorganic Iodine Hypoiodic Acid (HOI).

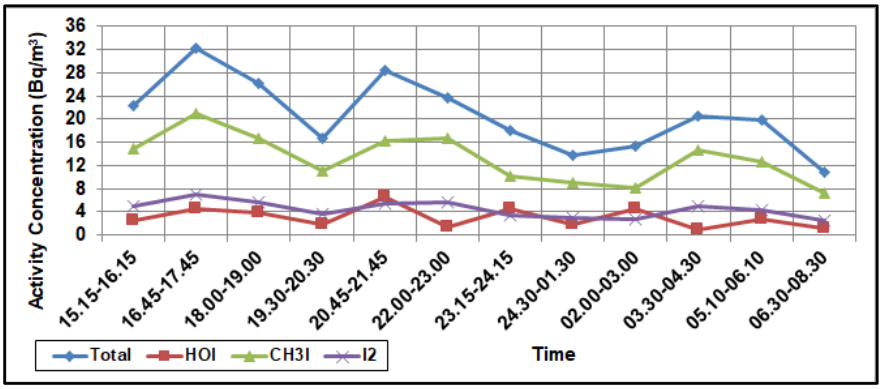

Fig. 16. Concentration of I-131 activity at outdoor Pabuaran on 5 to 6 February 2014

The highest total concentration of I-131 activity in the outdoor was measured at 32.33 Bq/m^3 at 16.45-17.45. The highest concentration of I-131 activity at these hours, because at time of 15:30 to 16:30 the method of changing the phase from the solution phase to the gas phase amid the disintegration process of Mo-99 into I-131 gas in the hot cell. There is an I-131 gas that get away through the sockets of the elastic connector to the stack amid this gas phase, so the concentration of I-131 activity rises.

The total concentration came from 64.01% concentration were in the shape of Methyl Iodide (CH_3I), 21.34% concentration in the shape of I_2 and 14.66% concentration in the shape of HOI. The highest concentration of I-131 activity from CH_3I and I_2 at 16:45 to 17:45 was 20.93 and 6.98 Bq / m^3, while the highest I-131 concentration of HOI was at 20.45-21.45 at 6.63 Bq / m^3. Decrease in concentration of activity I-131 occurred at 18.00-20.30 and 22.00-01.30. This decrease occurs, because the wind speed is quite high around 1.1 to 2.8 m/s at these hours. Wind speed at 16.12-17.12 and 20.12-21.12 is low at around 0.5 m/s.

The results of measurements of outdoor I-131 activity concentration at Suradita housing on February 19-20, 2014 are shown in Figure 17. The average concentration of I-131 activity in outdoor of Suradita housing in the shape of CH_3I, HOI and I_2 from large to small were namely CH_3I, I_2 and HOI respectively. The order of concentration of outdoor activity I-131 (CH_3I, I_2 and HOI) was in the same sequence with the concentration of I-131 in the stack (CH_3I, I_2 and HOI). The CH_3I, I_2 and HOI spectrum patterns in each stack are the same, while the CH_3I and I_2 spectrum patterns are different from the HOI spectrum patterns in Suradita housing. The highest I-131 activity concentrations of I_2 and HOI were 6.50 Bq / m^3 at 23.35-24.35 and 2.67 Bq / m^3 at 18.00-19.20, respectively. Thus, aerosol elemental Iodine (I_2) in the stack during dispersion to the housing at 18.00-19.20 undergoes a chemical process that is the process of hydrolysis with water (H_2O) in the air to form inorganic Iodine Hypoiodic Acid (HOI), so that the highest HOI activity concentration is at 18.00-19.20 19.20.

The highest concentration of I-131 activity from I_2 and CH_3I at 23.35-24.35. Decrease in concentration of activity I-131 occurred at time of 19.30 to 21.55 and 01.15 to 02.15. This decrease is due to high wind speeds, which is around 0.9 to 1.4 m/s at those times.

The most elevated total concentration of I-131 activity within the open air (27.95 Bq/m^3) was measured at time of 23.35 to 24.35. The total concentration of I-131 activity (19.82 Bq/m^3) was high at time of 18.00 to 19.20, due to the method of changing the phase from the solution phase to the gas phase amid the disintegration process of Mo-99 into I-131 gas in the hot cell. There is an I-131 gas that get away through the sockets of the elastic connector to the stack amid this gas phase, so the concentration of I-131 activity rises.

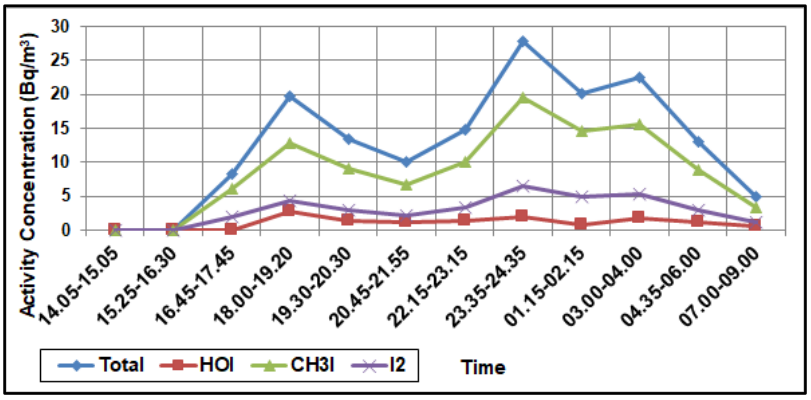

Fig. 17. Concentration of I-131 activity at outdoor Suradita on 19 to 20 February 2014

The total concentration came from 68.78% concentration of organic Iodine within the shape of Methyl Iodide (CH_3I), 22.95% I_2 and 8.27% HOI. The highest concentration of I-131 activity of CH_3I and I_2 at time of 23.35 to 24.35 were 19.50 and 6.50 Bq/m^3, while the highest I-131 concentration of HOI at time of 18.00 to 19.20 was 2.67 Bq/m^3. Decrease in concentration of activity I-131 occurred at time of 19.30 to 21.55 and 01.15 to 02.15. This decrease occurs, because the wind speed is quite high around 1.1 to 2.8 m/s at these hours. Wind speed at times of 18.06 to 19.06, 23.06 to 24.06 and 03.06 to 04.06 is low at around 0.5 m/s.

The results of measurements of outdoor I-131 activity concentrations, Jeletreng housing, on March 13-14, 2014 are shown in Figure 18. The average order of I-131 activity concentrations in the form of CH_3I, HOI and I_2 from large to small in outdoor, Jeletreng housings, respectively namely CH_3I, I_2 and HOI. The order of concentration of outdoor activity I-131 in the same sequence with the concentration of I-131 in the stack namely CH_3I, I_2 and HOI. The CH_3I, I_2 and HOI spectrum patterns in each stack are the same, while the CH_3I and I_2 spectrum patterns are different from the HOI spectrum patterns in the Jeletreng housing. Spectrum patterns I_2 and HOI almost coincide.

The highest I-131 activity concentrations of CH_3I, I_2 and HOI were 21.60; 7.20 and 5.31 Bq / m^3 at 02.00-03.20. I-131 activity concentrations of I_2 and HOI almost coincided at 20.40-24.30 and 03.45-07.15. Thus, aerosol elemental Iodine (I_2) in the stack during dispersion to the housing at these hours undergoes a chemical process (hydrolysis) with water (H_2O) in the air to form inorganic Iodine Hypoiodic Acid (HOI)

The highest concentration of I-131 activity from CH_3I, I_2 and HOI at the time of 02.00-03.20. This phenomenon is quite interesting, because around 23:00 to 02:00 there was a big rain, but the highest I-131 concentration. Diminish in concentration of I-131 activity happened, after coming to the most elevated concentration of I-131 beginning from 03.20. This decrease is a result of high wind speeds of around 1.4 m/s to 2.7 m/s during these hours.

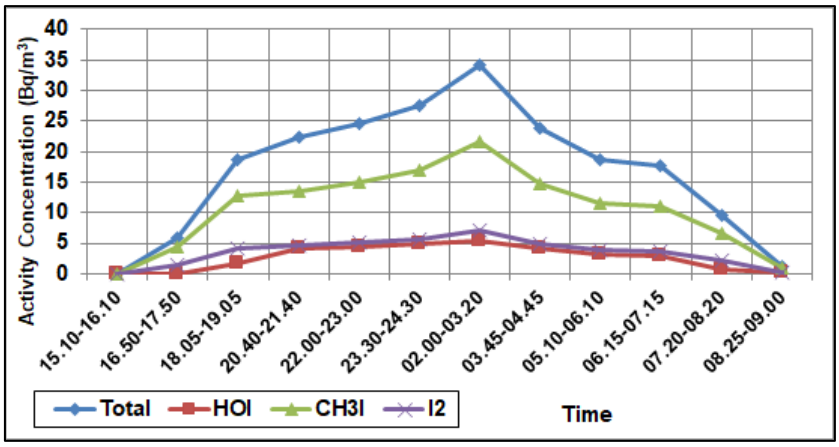

Fig. 18. Concentration of I-131 activity at outdoor Jeletreng on13 to 14 March 2014

The highest total concentration of I-131 activity in the outdoor was measured at 34.11 Bq / m^3 at 02.00-03.20. Concentration of I-131 activity is tall at these hours, due to the method of changing the phase from the solution phase to the gas phase amid the disintegration process of Mo-99 into I-131 gas in the hot cell. There is an I-131 gas that get away through the sockets of the elastic connector to the stack amid this gas phase, so the concentration of I-131 activity rises.

The results of measurements of the overall I-131 concentration in outdoor housings are each shown in Table 3 and Table 4. The most elevated average I-131 concentration of the seven investigate areas were exterior the BATAN Indah Housing, which were 30.84 Bq/m^3. The maximum I-131 concentration in BATAN Indah differs in time and magnitude, because the measurement is only until time of 01.40. The most elevated total concentration of I-131 activity (54.34 Bq/m^3) was at time of 21.20 to 22.25. The concentration of I-131 is the biggest in BATAN Indah from 7 research locations, because most (37%) of wind direction goes between North-North-West and North-North-East on 18 and 19 December 2013 and most of the wind direction goes between to North-West and to the North with a velocity between 2.1 to 5.7 m/s in September 2012 to August 2013. Thus, the dispersion of I-131 average from the stack to the houses in the North direction of the stack, the concentration of I-131 shaped a parabolic curve beginning to ascend from the Sengkol housing (distance of 0.8 km), the most elevated in BATAN Indah (distance of 2.6 km) and diminishing in Jaletreng (distance of 4.2 km). Overall the concentration of I-131 activity in seven investigate destinations is still underneath the standard quality of I-131 radioactivity level in the air which is 530 Bq / m3 based on PERKA BAPETEN rule No. 7/2013 [11]. The RQ (Risk Quotient) value of the I-131 concentration in seven locations measured outdoor is below 1 (RQ < 1), the I-131 concentration measured in outdoor and indoor housings does not present a significant risk to public health [20].

Table 3. Summary of the measurements result of CH_3I and I_2 activity concentration at Outdoor

No.	Location	Date	Concentration (Bq/m^3) and Time at Outdoor					
	Direction-distance of stack	I-131 production time	CH_3I			I_2		
			Minimum	Maximum	Average	Minimum	Maximum	Average
1	Puri Serpong	11-12 Des 2013	2.59	16.99	8.98	0.86	5.66	2.99
	E, 2,2 km	17.00-05.00	17.40-18.40	19.45-20.45	17.40-07.50	17.40-18.40	19.45-20.45	17.40-07.50
2	BATAN Indah	18-19 Des 2013	8.79	36.21	20.65	2.93	12.07	6.88
	N, 2,6 km	11.30-21.40	11.30-12.30	21.20-22.25	11.30-01.40	11.30-12.30	21.20-22.25	11.30-01.40
3	Muncul	27-28 Des 2013	2.60	18.87	7.70	1.30	9.43	3.85
	NE, 1,3 km	13.30-05.00	13.30-14.30	21.45-22.45	13.30-06.40	13.30-14.30	21.45-22.45	13.30-06.40
4	Sengkol	22-23 Jan 2014	2.56	20.49	12.02	0.85	6.83	4.01
	N, 0,8 km	14.00-01.30	06.00-07.50	18.25-19.25	14.10-07.50	06.00-07.50	18.25-19.25	14.10-07.50
5	Pabuaran	5-6 Feb 2014	7.22	20.93	13.23	2.41	6.98	4.41
	S, 1,9 km	12.30-21.30	06.30-08.30	16.45-17.45	15.15-08.30	06.30-08.30	16.45-17.45	15.15-08.30
6	Suradita	19-20 Feb 2014	0	19.50	8.90	0	6.50	2.97
	W, 3,2 km	11.00-21.00	14.05-16.30	23.35-24.35	14.05-09.00	14.05-16.30	23.35-24.35	14.05-09.00
7	Jaletreng	13-14 Mar 2014	0	21.60	10.77	0	7.20	3.59
	N, 4,2 km	11.00-21.00	15.10-16.10	02.00-03.20	15.10-09.00	15.10-16.10	02.00-03.20	15.10-09.00

Table 4. Summary of the measurements result of HOI and Total activity concentration at Outdoor

No.	Location	Date	Concentration (Bq/m^3) and Time at Outdoor					
	Direction-distance of stack	I-131 production time	HOI			Total		
			Minimum	Maximum	Average	Minimum	Maximum	Average
1	Puri Serpong	11-12 Des 2013	0.84	8.52	4.31	4.60	30.14	16.29
	E, 2,2 km	17.00-05.00	03.05-04.05	24.35-01.35	17.40-07.50	17.40-18.40	19.45-20.45	17.40-07.50
2	BATAN Indah	18-19 Des 2013	0.64	6.51	3.30	12.59	54.34	30.84
	N, 2,6 km	11.30-21.40	20.05-21.05	13.30-14.30	11.30-01.40	11.30-12.30	21.20-22.25	11.30-01.40
3	Muncul	27-28 Des 2013	0.18	7.10	3.26	4.08	35.24	14.80
	NE, 1,3 km	13.30-05.00	13.30-14.30	21.45-22.45	13.30-06.40	13.30-14.30	21.45-22.45	13.30-06.40
4	Sengkol	22-23 Jan 2014	1.53	9.12	5.39	9.37	30.39	21.42
	N, 0,8 km	14.00-01.30	22.05-23.05	03.15-04.15	14.10-07.50	14.10-15.10	18.25-19.25	14.10-07.50
5	Pabuaran	5-6 Feb 2014	0.90	6.63	3.03	10.81	32.33	20.67
	S, 1,9 km	12.30-21.30	03.30-04.30	20.45-21.45	15.15-08.30	06.30-08.30	16.45-17.45	15.15-08.30
6	Suradita	19-20 Feb 2014	0	2.67	1.07	0	27.95	12.94
	W, 3,2 km	11.00-21.00	14.05-16.30	18.00-19.20	14.05-09.00	14.05-16.30	23.35-24.35	14.05-09.00
7	Jaletreng	13-14 Mar 2014	0	5.31	2.64	0	34.11	17.01
	N, 4,2 km	11.00-21.00	15.10-16.10	02.00-03.20	15.10-09.00	15.10-16.10	02.00-03.20	15.10-09.00

4 Conclusion

The discharge of I-131 activity concentrations on average from the stack and the concentration of I-131 activity in seven outdoor places around the isotope production installation are still underneath the standard level of I-131 radioactivity concentration within the air (530 Bq/m^3) based on controls of Nuclear Energy Supervisory Agency (BAPETEN) Head, No. 7/2013. Potential risk of removable dispersion radioactive iodine-131 from the stack of radioisotope production facility for the health of residential communities around radioisotope

production facility does not pose a significant risk to public health (Risk Quotient <1). I-131 Dispersion from the stack to the housing average with the north of the stack, the concentration of I-131 shapes a parabolic curve beginning to ascend from the Sengkol housing (distance of 0.8 km), the most elevated in BATAN Indah (distance of 2.6 km) and diminishing in Jaletreng (distance of 4.2 km). The activity concentration of I-131 during rain and high humidity tends to rise, while the presence of sunlight decreases the activity concentration of I-131. The activity concentrations of I-131 in stack from large to small were CH_3I (63.03%), I_2 (30,27%) and HOI (7.70%) respectively. While the activities concentration of I-131 on average in the outdoors were CH_3I (61.12%), I_2 (20.37%) and HOI (18.39%).

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