Monitoring and Analysis of Dose Rate and Gaseous Effluent Released from Radioactive Waste Installation in Indonesia

A. Wijayanto[1,*], I. P. Susila[2]
[1]*Center for Radioactive Waste Technology, National Nuclear Energy Agency (BATAN), Serpong, Tangerang Selatan, Banten, 15314, Indonesia*
[2] *Center for Nuclear Facilities Engineering, National Nuclear Energy Agency (BATAN), Serpong, Tangerang Selatan, Banten, 15314, Indonesia*
*Corresponding author's e-mail: adi_w@batan.go.id

ABSTRACT

Dose rate and gaseous effluent released monitoring system (Radmon) that real-time monitoring continuously measures gamma dose rate on 7 (seven) process room of Radioactive Waste Installation (RWI) in Indonesia. Gaseous effluent released monitor is used for RWI stack. Radmon is an important tool to present dose rate and gaseous effluent released information to the public or authorities for radiation protection during normal operation and radiological accidents. We have developed such a system that consist of 7 (seven) NaI(Tl) based device for monitoring the dose rate and gaseous effluent released monitoring system of RWI. It has operated since 2011. In this study, the analysis and the description of measured data of Radmon are presented. The analysis dose rate data for the last 5 (five) years shows that the average dose rate level were between 0.12-3.73µSv/h and The analysis gaseous effluent contamination released data for the last 1 (one) years shows gaseous effluent contamination released for alpha 0.002 Bq/m^3 and beta 0.097 Bq/m^3 which are similar with background radiation level and Radon (222Rn) 2.452 Bq/m^3, Thoron (Tn or 220 Rn) 0.022 Bq/m^3 which are lower than threshold. This result indicates that the system is good situation in normal condition and effective for a radiation early warning system for radiological emergency case.

Keywords: *Dose rate, Effluent release, RWI, Real-time Monitoring, Radiation Early Warning System, NaI(Tl)*

INTRODUCTION

The Center for Radioactive Waste Technology - National Nuclear Energy Agency (RWTC-BATAN) has a radiation facility namely the Radioactive Waste Installation (RWI). RWTC-BATAN has processed radioactive waste from all over Indonesia. The radioactive waste from internal BATAN as well as from external BATAN has a significant increase in volume every year. Therefore, the potential radiation hazards that allow radiological emergencies need to be minimized, namely by building an online radiation monitoring system that is equipped with an early warning radiation system, especially to find out radiation exposure in remote work areas and more than one monitoring area.

Today, the industrial revolution 4.0 demands an online radiation monitoring system that is equipped with an IoT (Internet of Things) based early warning system, so that the development of a radiation early warning system design as a radiological emergency decision support system in a RWI. This provides a solution to radiological emergencies that are very risky if (human) personnel take direct radiation measurements. This system also provides a solution to the weaknesses of radiation measurements manually or in situ in the past that cannot be an early warning system of radiation against abnormal events in a working area of nuclear facilities. This system is equipped with a buzzer alarm system and online notification through an SMS gateway, this system can deliver information on radiation abnormalities in real-time at nuclear facilities quickly and accurately, so that radiological emergency mitigation efforts can be done immediately to protect the radiation worker and the environment from the effects of radiation hazards [1]. In addition, this system is also expected to be able to make a radiological emergency decision support system that can provide fast and precise input to reduce the radiological impact on the community in the event of a radiological emergency. The radiologic emergency decision support system is one part of the radiological emergency preparedness and response program. This need to be disseminated to the workers to improve the psychological and community guarantees of the radiological impact of the operation of the radiation facility so that the community feels safe and secure, while living around the RWI. Dose rate and gaseous effluent released monitoring system (Radmon) that real-time continuously measures gamma dose rate on 7 (seven) process room of RWI in Indonesia. The gaseous effluent released monitor is used for RWI stack.

In this study, we would like to present dose rate and gasesous effluent contamination released from RWI analyzes that were measured since 2015 for doserate and 2018 for gasesous effluent. This analyzes used chi-square methods that have not been implemented in nuclear installation or radiation facilities in Indonesia. The objective are to figure out doserate and gasesous effluent contamination in RWI and to present the result to the public about investigate abnormal condition caused by radiation source in normal operation. Further more, research and development obtain to improve current system are discussed in this paper.

EXPERIMENTAL METHOD

Radiation monitoring (Radmon)

Several Gamma Area Monitor (Ludlum's 375 Series) have been installed in 7 (seven) room at RWI since 2011 [2]. Dose rate Radiation Monitoring Software at the Health Physic Room of RWI is shown in Fig.1.

Fig. 1. Radiation Dose Rate Monitoring Software in the Health Physic Room at the Radioactive Waste Installation.

On the other hand, 1 (one) Contamination Air Monitor (iCAM Canberra) have been installed in RWI Stack since 2018. Gaseous Effluent Released Radiation Monitoring Software at the Health Physic Room of is shown in Fig.2.

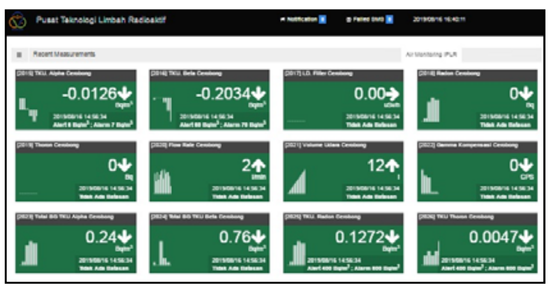

Fig. 2. Gaseous Effluent Released Radiation Monitoring Software at the Health Physic Room of RWI.

The devices are connected to computer server at Health Physic room thought a RS-232 to RS-485 and TCP/IP network. Each device of Gamma Area Monitor has 1 (one) detector model 44-2 with detector type NaI(Tl) scintillator, 2.5 cm (1 in) dia. x 2.5 cm (1 in) thick and can be used to measured gamma radiation of energies range recommended from 20 keV to 1.5 MeV with dose rate range 0.01 µSv/h to 99.99 µSv/h [2], but iCAM monitor has dual PIPS detector. The measurement range of the instrument extends to over 500 kBq (13.5 µCi) of combined alpha and beta activity deposited on the filter. A background activity check measurement and display function is provided, which can be accessed via the front panel controls. This check may also be used to identify the presence of contamination within the monitor or to assess ambient gamma background values [3]. At the beginning, two devices are installed in Interim Storage 1 (IS1) and Interim Storage 2 (IS2). Presently, 7 (seven) devices are installed in RWI as shown in Fig. 3.

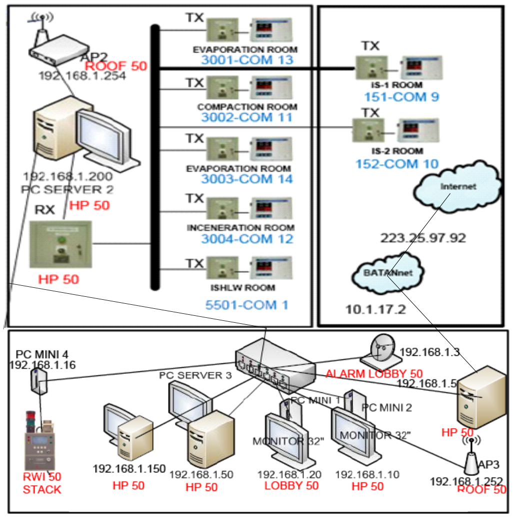

Fig. 3. Location and Networking of Dose Rate Monitoring Devices.

In this system, the dose rate along with calculation time stamp is collected every 2 (two) seconds for dose rate and 5 (five) second for gaseous effluent released monitor, both of them are stored in a database. As a result, in normal condition, at a certain time stamp, usually there are 10 data points with the same time stamp and dose rate value. The objectives of selecting this acquisition period are to minimize missing data in case of communication error, and to quickly detect any increase in dose rate caused by man-made radiation sources or radioactive materials that are probably released from the RWI. If the radiation dose is high enough, it will be indicate for alarm system warning because over than threshold. The threshold of dose rate at RWI is shown in Table 1.

Table 1. Threshold of dose rate and gaseous effluent released monitor at RWI.

ID's	Location	Zone of Radiation	Alert Dose Rate Threshold (μSv/h)	Alarm Dose Rate Threshold (μSv/h)
151	IS1 Room	4	23	25
152	IS2 Room	4	23	25
5501	ISHLW Room	4	23	25
3001	Evaporation Room	3	8	10
3002	Compaction Room	3	8	10
3003	Cementation Room	3	8	10
3004	Incineration Room	3	8	10

The gaseous effluent released monitor at RWI is shown in Table 2.

Table 2. Threshold of gaseous effluent released monitor at RWI.

ID's	Item	Alert Air Concentration Threshold (Bq/m^3)	Alarm Air Concentration Threshold (Bq/m^3)
2015	Alpha	6	7
2016	Beta	60	70
2025	^{222}Rn	400	600
2026	Tn or ^{220}Rn	400	600

Data analysis using chi-square

The chi-square methods used in the analysis of this data uses a range of acceptance in general, namely (χ^2 0.95 -χ^2 0.05) with the null hypothesis that the data is in harmony or in accordance with the normal distribution while the alternative hypothesis states that the data do not match the distribution normal or cannot be analyzed with a normal distribution [4].

In the table of statistical test, the results will be given the value of the dose rate and frequency for each value. In a normal distribution, the value of each frequency is ideally expected to be the same for each value, so getting a value of χ^2 0.05. In addition to the dose rate and frequency values, there are chi-square values (χ^2), df values or degrees of freedom and asymptotic significance values, namely the value of the conversion results between chi-square and degrees of freedom on the chi-square distribution table. This asymptotic significance value is expected to be in the range of χ^2 0.95 -χ^2 0.05.

RESULTS AND DISCUSSION

Long-term dose rate data result

The results of monitoring the dose rate at RWI over the past 5 years are summarized in Table 3. The monitoring period varies between 2015-08-18 to 2019-08-19. The average dose level for all 7 (seven) monitoring locations is between 0.12 to 3.73 µSv/h but 1 (one) location is evaporation room was used for ion exchange process. This value corresponds to 0.24 - 7.46 mSv per year (assumption 1 year = 2000 hours, less than 20 mSv/years).

Table 3. The average gamma dose rate for past 5 (five) year at RWI.

ID's	Location	First	Last	#Rec.	Avg. Dose rate (µSv/h)
151	IS1 Room	2015-08-18 08:14:46	2019-08-19 07:55:18	44584112	0.37
152	IS2 Room	2015-08-18 08:13:53	2019-08-19 07:55:18	43485425	3.73
5501	ISHLW Room	2015-09-10 06:28:17	2019-08-19 07:55:18	35690455	0.97
3001	Evaporation Room (Ion Exc.)	2015-08-18 08:13:53	2019-02-12 10:15:23	39284938	43.3
3002	Compaction Room	2015-08-18 08:14:45	2019-08-19 07:55:18	48712477	0.12
3003	Cementation Room	2015-08-18 08:14:43	2019-08-19 07:55:18	47403165	0.27
3004	Incineration Room	2015-09-03 05:55:33	2019-08-19 07:55:18	36825520	0.43

Long-term gaseous effluent concentration data result

The results of monitoring the gaseous effluent concentration at RWI on the past 1 year is summarized in Table 4. The monitoring period varies between 2018-10-24 to 2019-08-16. The gaseous effluent concentration level for RWI stack shows gaseous effluent released for alpha 0.002 Bq/m^3 and beta 0.097 Bq/m^3 which are similar with background radiation level and Radon (222Rn) 2.452 Bq/m^3, Thoron (Tn or 220Rn) 0.022 Bq/m^3 which are lower than threshold.

Table 4. The average concentration of gaseous effluent released for past 1 (one) year at RWI.

ID's	Item	First	Last	#Rec.	Avg. Conc. (Bq/m^3)
2015	Alpha	2018-10-24 08:46:17	2019-08-16 07:56:34	563695	0.002
2016	Beta	2018-10-24 08:46:17	2019-08-16 07:56:34	563715	0.097
2025	^{222}Rn	2018-10-24 08:46:17	2019-08-16 07:56:34	563721	2.452
2026	Tn or ^{220}Rn	2018-10-24 08:46:17	2019-08-16 07:56:34	563725	0.022

The results of dose rate data were analyzed using chi-square methods at RWI summarized in Table 5.

Table 5. The analysis of dose rate data used chi-square methods at RWI.

ID's	Location	Chi-square	Df	Asym. Sig.	(χ^2 0.95 -χ^2 0.05)
151	IS1 Room	4.28	5	0.510	1.15-11.07
152	IS2 Room	10.12	14	0.754	6.57-23.69
5501	ISHLW Room	8.60	12	0.737	5.23-21.03
3001	Evaporation Room	37.80	150	1.00	122.7-179.6
3002	Compaction Room	26.68	26	0.426	15.38-38.89
3003	Cementation Room	9.69	6	0.138	1.635-12.59
3004	Incineration Room	12.29	21	0.931	11.60-32.67

From this table, IDs (151, 152, 5501, 3002, 3003, and 3004) are accepted, but IDs (3001) is not accepted, because (3001) was used for continuous Ion Exchange monitor. The percentage of accepted data (6/7x100%) = 85.7%, the percentage of not accepted (1/7x100%) = 14.3%. It must use another method to analyze the data, like the linear regression method (due to trends the dose rate data tends to be linear). The chart of percentage of accepted and not accepted dose rate data of the RWI is shown in Fig. 3.

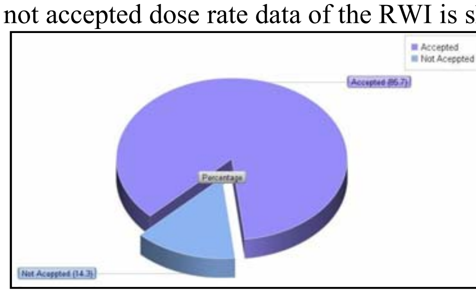

Fig. 4. The chart of percentage of accepted and not accepted dose rate data of the RWI

The results of gaseous effluent concentration data were analyzed using chi-square methods at RWI summarized in Table 6.

Table 6. The analysis gaseous effluent concentration data using chi-square methods at RWI.

ID's	Location	Chi-square	Df	Asym. Sig.	(χ^2 0.95 -χ^2 0.05)
2015	Alpha	0.58	1	0.446	0.004-3.841
2016	Beta	1.77	1	0.184	0.004-3.841
2025	222Rn	3.98	2	0.137	0.103-5.991
2026	Tn or 220Rn	3.17	2	0.126	0.103-5.991

The chart of accepted and not accepted percentage gaseous effluent data of the RWI is shown in Fig. 5.

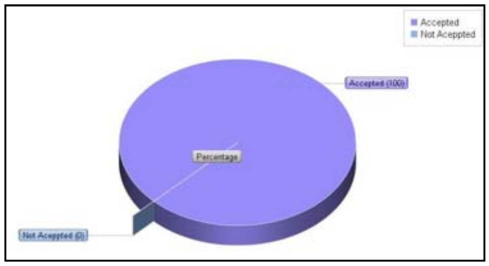

Fig. 5. The chart of accepted and not accepted percentage of gaseous effluent contamination data of the RWI

From this table, all of IDs (2015, 2016, 2025, and 2026) are accepted. The percentage of accepted data (4/4x100%) = 100%, the percentage of not accepted = 0%. During normal operation system, sometimes alarm occurred. When an alarm occurs, the typical environmental dose rate profile observed.

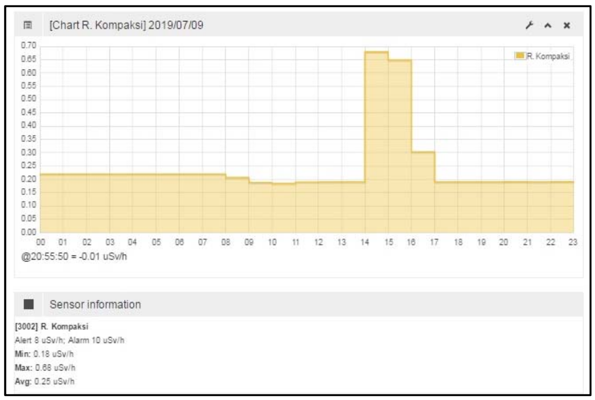

Fig. 6. Dose rate profile during the inspection and testing of the monitoring system using check source.

A check source was used to verify whether the system would provide alerts in case there were radioactive materials releasing gamma ray in the room. As seen in the figure, peaks with values greater than background level were observed. At the same time, an alert was given by the monitoring software package at the control center and was verified by radiation protection officer. Typically, operation of the monitoring system, sometimes alerts occurred. An example of typical gamma dose rate profile observed when an alert or alarm occurs is shown in Fig. 7. As shown in the figure, increases of dose rate level were observed at monitoring location IS-2 room. Peaks with almost the same time stamp that were observed at several monitoring locations indicate high probability of the presence of radioactive materials moved. Dose rate of Ir-192 is higher than background and threshold during operation moving of Disused Sealed Radioactive Source (DSRS) transfer to container.

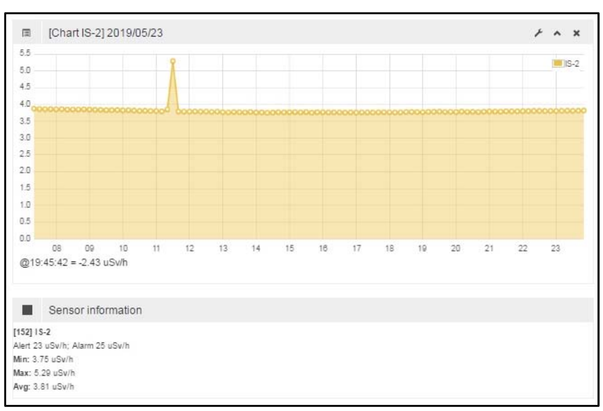

Fig. 7. Dose rate profile during operation of DSRS (Ir-192) transfer to container.

This objective of Radmon is used for radiation early warning system design. The design as a radiological emergency decision support system in the RWI also provides solutions to radiation monitoring in the event of an emergency, which is very risky if done directly by personnel (humans). That way, the measurement results of this system are able to provide an assessment of the success of the radiological/ nuclear emergency response efforts [5,6]. In addition to radiation data information that is delivered, online real-time per 2 seconds, this system also provides notification of abnormal events related to radiation in the work area in the form of buzzer alarms, online notifications, and SMS gateway application. The objective with this notification mitigation can be carried out immediately and minimize the impact on radiation abnormalities quickly [7,8]. The indicator of Radiation Early Warning System of RWI is shown in Fig. 8.

Fig. 8. Indicator of Radiation Early Warning System of RWI.

Radon is a gaseous radioactive element, which is a product of Uranium decay chain in nature. Inhalation of radon in indoor spaces contributes to about half of the annual dose of ionizing radiation [9,10]. Long-term exposure to radon and radioactive progenies can increase the risk of lung cancer [10,11]. The concentration of radon indoor is in fact, a complex function of different parameters and it can change considerably even during a single daytime interval. Therefore, the average value of long-term tests (1 year) is normally used in radon assessment studies [10,11]. However, the results of short-term tests can be used for initial screening or to perform follow-up test (i.e. Radmon) when the results of long-term test exceed the limit values.

Radon profile measured in 2019/02/01 is shown in Fig. 9. From this chart, we can know the radon is radon tends to go down on 7:30 when the VAC of gas is turned on and tends to go up when VAC of gas is switched off. Based on this chart, It is necessary to minimize radon by VAC off gas operation.

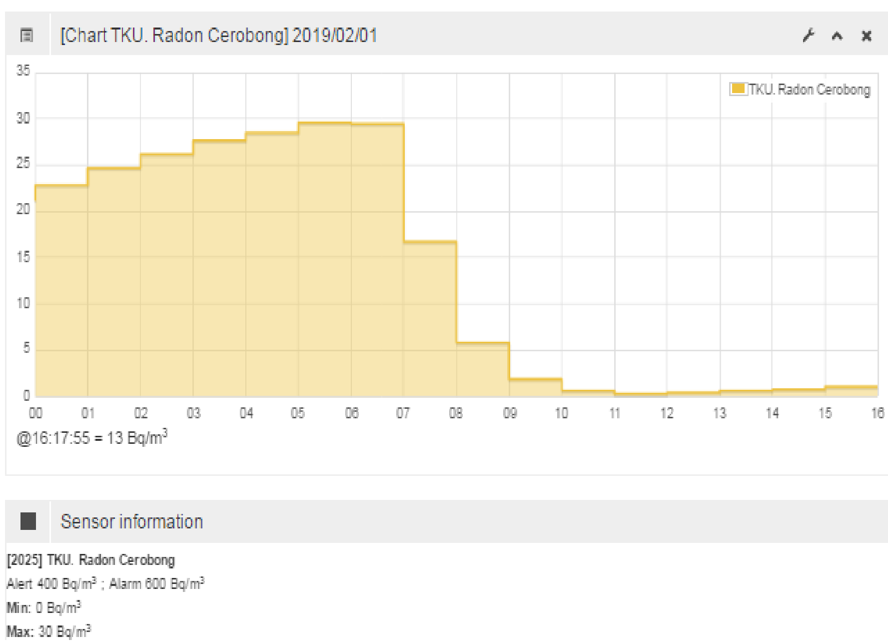

Fig. 10. Thoron profile measured in 2019/02/01.

Thoron profile measured in 2019/02/01 is shown in Fig. 10. It is necessary to minimize radon and thoron concentration in the room radon is one of the contributors to the dose of natural radiation that is large enough to reduce the risk of lung cancer. The most possible effort is to regulate the ventilation system.

CONCLUSION

Doserate and gaseous effluent released monitoring system (Radmon) that realtime continuously measures gamma dose rate on 7 (seven) process room of RWI in Indonesia. Gaseous effluent released monitor is used for RWI stack. The analysis dose rate data for the last 5 (five) years shows that the average dose rate level were between 0.12-3.73µSv/h except ion exchange station and the analysis gaseous effluent released data for the last 1 (one) years shows gaseous effluent released for alpha 0.002 Bq/m^3 and beta 0.097 Bq/m^3 which are similar with background radiation level and Radon (222Rn) 2.452 Bq/m^3, Thoron (Tn or 220Rn) 0.022 Bq/m^3 which are lower than threshold. This result indicates that the system is good situation in normal condition and effective for a radiation early warning system for radiological emergency case.

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