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A Study on the Atmospheric Dispersion of Radionuclide Released from TRIGA MARK II Reactor using Gaussian Plume Model

(Suatu Kajian Penyebaran Atmosfera pada Radionuklid Terbebas daripada Reaktor TRIGA MARK II menggunakan Model Gaussian Plum)

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ABSTRACT

TRIGA MARK II reactor is a research facility and site for neutron activation analysis. Should there be fuel rod damage for the first time, amongst its possible causes are human and environmental factor. Consequently, the study objectives were to determine types and released rates of radionuclides dispersed to air and deposited on land through core inventory using ORIGEN2 Code; to determine the concentrations of radionuclides released to air and deposited on land using Gaussian Plume Model; and to determine the exposure doses of radionuclides released to air and deposited on land using exposure dose equation. Core inventory identified types of radionuclides which were Br, I, Kr and Xe. The chosen radioisotopes of Br-83, I-131, Kr-85 and Xe-135 were based on its negative impact on human body system. The maximum released rate of Br-83 was 0.522×10^5 Bq/s; I-131 was 2.818×10^5 Bq/s; Kr-85 was 6.447×10^5 Bq/s and Xe-135 was 4.850×10^5 Bq/s, respectively. The maximum concentration in the atmosphere for Br-83 was 1.981 Bq/m^3; I-131 was 0.062 Bq/m^3; Kr-85 was 25.034 Bq/m^3 and Xe-135 was 4.248 Bq/m^3. The annual exposure doses for four selected radionuclides were 1326 µSv/yr (300 m), 119 µSv/yr (1000 m) and 7.463 µSv/yr (4000 m) for Category B, whereas for Category were 194 µSv/yr (300 m), 17.440 µSv/yr (1000 m) and 1.090 µSv/yr (4000 m), respectively. Conclusively, this study shows that in case of fuel rod damage on TRIGA MARK II reactor, radionuclide atmospheric dispersion at a distance of 300 m (Category B) was exceeding the standard annual exposure dose limit (1000 µSv/yr).

Keywords: Atmospheric dispersion; exposure dose; Gaussian Plume Model; TRIGA MARK II

ABSTRAK

Reaktor TRIGA MARK II merupakan sebuah insitut penyelidikan dan tempat untuk menjalankan analisis pengaktifan neutron. Sekiranya berlaku kerosakan rod bahan api buat pertama kalinya, antara sebab yang berkemungkinan adalah faktor manusia berserta persekitaran. Akibatnya objektif kajian adalah untuk menentukan jenis dan kadar pelepasan radionuklid yang tersebar ke udara dan mendap dalam tanah melalui inventori teras menggunakan Kod ORIGEN2; untuk menentukan kepekatan radionuklid terbebas ke udara dan mendap dalam tanah menggunakan Model Kepulan Gaussian; dan untuk menentukan dos dedahan radionuklid yang terbebas ke udara dan mendap dalam tanah menggunakan rumus dos dedahan. Inventori teras mengenal pasti jenis radionuklid yang terbebas berserta isotopnya iaitu adalah Br, I, Kr dan Xe. Radionuklid terpilih iaitu Br-83, I-131, Kr-85 dan Xe-135 adalah berdasarkan impak negatif terhadap sistem tubuh badan manusia. Kadar pelepasan maksimum masing-masing bagi Br-83 adalah 0.522×10^5 Bq/s; I-131 adalah 2.818×10^5 Bq/s; Kr-85 adalah 6.447×10^5 Bq/s dan Xe-135 adalah 4.850×10^5 Bq/s. Kepekatan maksimum di atmosfera bagi Br-83 adalah 1.981 Bq/m^3; I-131 adalah 0.062 Bq/m^3; Kr-85 adalah 25.034 Bq/m^3 dan Xe-135 adalah 4.248 Bq/m^3. Dos dedahan tahunan untuk empat radionuklid terpilih masing-masing adalah 1326 µSv/thn (300 m), 119 µSv/thn (1000 m) dan 7.463 µSv/thn (4000 m) bagi Kategori B manakala bagi Kategori D adalah 194 µSv/thn (300 m), 17.440 µSv/thn (1000 m) dan 1.090 µSv/thn (4000 m). Kesimpulannya, keputusan kajian menunjukkan sekiranya berlaku kerosakan rod bahan api pada reaktor TRIGA MARK II, penyebaran atmosfera oleh radionuklid pada jarak 300 m (Kategori B) adalah melebihi had dos dedahan piawai (1000 µSv/thn) yang dibenarkan.

Kata kunci: Dos dedahan; Model Kepulan Gaussian; penyebaran atmosfera; TRIGA MARK II

INTRODUCTION

Reactor TRIGA MARK II Tun Ismail Atomic Research Centre (PUSPATI) is an institution obligated to perform Probabilistic Safety Assessment (PSA) Level 3 that help to ensure the safety risk in case there is occurrence of a nuclear accident to predict the atmospheric release of radioactive materials to the environment. Referring back to the devastating Fukushima accident in the year 2011 of the INES-7 scale which released hazardous radionuclides to the atmosphere, this study was conducted to investigate the possible expected exposure doses in case of such accident would occur to TRIGA MARK II. The dispersion rate is analysed according to U-235 enrichment because every radioisotope produces different radioactivity dependent on its enrichment of 8%, 12% and 20%, respectively. Therefore, this study focused on determining types and released rates of radionuclides dispersed to air and deposited on land through core inventory using ORIGEN2 Code; to determine the concentrations of radionuclides released to air and deposited on land using Gaussian Plume Model; and to determine the exposure doses of radionuclides released to air and deposited on land using exposure dose equation. At the end of this study, the impact from a nuclear accident involving TRIGA MARK II have the possibilities of harming the workers, civilians as well as the environment when left unattended.

MATERIALS AND METHODS

CORE INVENTORY DATA PREPAREDNESS USING ORIGEN2 CODE

The ORIGEN2 Code was used to execute core inventory to identify and determine the source term in the core reactor (Usang et al. 2015) resulting from the fission of Uranium-235. Subsequently, core inventory had to be firstly executed in order to identify types of radionuclide being released from the reactor to the atmosphere. In this study, the execution of ORIGEN2 Code simulation at operational 24 h for 365 days with a maximum energy of 1 MW for TRIGA MARK II was programmed to identify the atmospheric dispersion based upon types of released radionuclide from the reactor (Preston 2013). This study focused upon the dispersion of radionuclide materials to the atmosphere by using the Gaussian Plume Model. The prediction of dispersion of radionuclide materials being released to the surrounding air and being deposited on the land based upon Pasquill Stability Category was made for two different weather conditions befitting the reactor site weather condition which are Category B for unstable yet neutral weather condition and Category D indicating extreme raining or hot season.

Moreover, the dispersion rate of radioisotopes being produced from Uranium-235 fission in the reactor core from the execution core inventory using ORIGEN2 is used as input data for Gaussian Plume Model (Muswema et al. 2014). Subsequently, data results from calculations of the concentration of the released radionuclides using the equation of Gaussian Plume Model used to determine the radionuclide materials atmospheric dispersion pattern being released to the air and deposited to the land (Benamrane et al. 2013). Exposure doses released into the air and deposited on land were determined by using exposure dose equation in which can be treated using chelation therapy in case of obtained exposure doses were to exceed the standard exposure doses (Šömen Joksić & Katz 2015).

PASQUILL STABILITY CATEGORY IN DETERMINING RADIONUCLIDE ATMOSPHERIC DISPERSION

The distribution of distances moved in the air by atmospheric dispersion of radionuclides was entirely dependent on the weather. Thus, Pasquill Stability Category was used to predict and determine wind level and distances travelled by the wind from one point to another (Chambers et al. 2015). Atmospheric dispersion moved in plume in the direction of the momentary wind and wind direction can be taken into consideration during dispersion (Imanaka et al. 2015) whether in time-averaged plume shape or instantaneous plume shape from its releasing point. Figure 1 shows atmospheric dispersion plume shape that majorly becomes a benchmark for calculation of plume concentration (Slade 1968).

In Figure 1, the red-lined is the calculation parameters in the Gaussian Plume Model. In relation to the figure, this study had chosen this instantaneous plume shape in accordance with Malaysia dominant plume rise shape

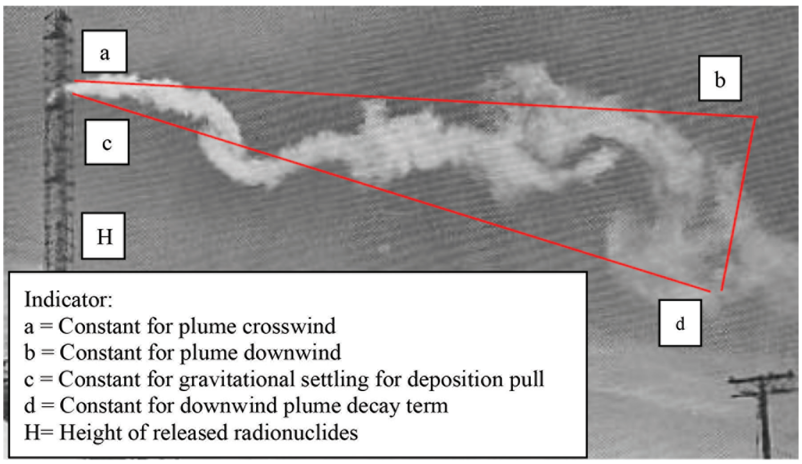

FIGURE 1. Plume shape consideration for atmospheric dispersion

Source: Slade 1968

in which the atmospheric dispersion will be from any directions upon its released point. Equation (1) shows the vertical atmospheric dispersion while (2) showed horizontal atmospheric dispersion that helped to make up the entire parameters of using Gaussian Plume Model (Bailey & Touma 1995):

$$\sigma_z = am^b \tag{1}$$

where σ_z is the constant for Pasquill downwind dispersion (m); m is the downwind dispersion distance (km); a is the constant for plume crosswind; and b is the constant for plume downwind.

$$\sigma_y = 465.11628 \text{ n } (\tan(0.017453293 \text{ (c} - \text{d ln x)))} \tag{2}$$

where σ_y is the constant for Pasquill advective crosswind dispersion (m); n is the advective crosswind dispersion distance (km); Θ is radians; c is the constant for gravitational settling for deposition pull; d is the constant for downwind plume decay term; and x is the chosen distances (m).

Pasquill Stability Category was divided into six different categories in which its constants were to its atmospheric dispersion distance of suspended materials in the air at that particular moment with chosen constants being dependent to chosen Pasquill Stability Category (Bailey & Touma 1995). Furthermore, (1) and (2) were complicated as both considered seasonal period of the reactor site in which chosen Category for our study were Category B and Category D. TRIGA MARK II PUSPATI (RTP) is located in Malaysia have two seasonal periods where Category A and B are chosen to be the benchmark for the appropriate take distances in Pasquill Stability Category as stated by ARL (2018). Category B is for a period of wet rose-wind where there is an occurrence of a thunderstorm that radionuclides fall faster and deposited on land meanwhile Category D is period of prolonged sunshine allowing radionuclides to disperse farther in the atmosphere. To relate to constant a and b which is to determine downwind dispersion, (1) is used in reference Table 1 while (2) for constant c and d in reference to Table 2 (Bailey & Touma 1995).

In conclusion, by understanding Pasquill stability category based upon elements of downwind dispersion as well as crosswind dispersion, types of a category that well-fitted to Malaysia's climate and weather can be determined and used correctly.

GAUSSIAN PLUME METHOD EQUATION IN DETERMINING RADIONUCLIDE CONCENTRATION BASED UPON ITS DISPERSION DISTANCE

Gaussian Plume Model embedded as a running calculator for MESOS Code acted to determine the movement of radionuclides in term of concentrations (Imanaka et al. 2015). Equation (3) shows Gaussian Plume Model that was used to determine the concentration of radionuclides that had been dispersed into the atmosphere depended on its disperse distance (Green et al. 1980):

$$C_A(X, Y, Z) = \frac{Q_i}{2\pi\sigma_y\sigma_z\mu}\exp\left(-\frac{y^2}{2\sigma_y^2}\right)\left\{\exp\left[-\frac{(z-H)^2}{2\sigma_Z^2}\right]+\exp\left[-\frac{(z+H)^2}{2\sigma_Z^2}\right]\right\} \tag{3}$$

where C_A(x, y, z) is the Air concentration (Bq/m^3) on point (x, y, z) downwind released; H is the Height of released (4.2 m); x is the downwind distance (m); y is the crosswind distance (0 m); z is the height from land (m); μ is the average of wind speed (11 m/s); $Q_ɩ$ is the released rate for radionuclide, ɩ (Bq/s); σ_y is the constant for Pasquill advective crosswind dispersion (m); and σ_z is the constant for Pasquill downwind dispersion (m)

In reference to (3), determined radionuclide concentration was based upon its dispersion distance from one released point. The released height and average wind speed were obtained from Malaysia Nuclear Agency (2018), which was a height of 4.2 m and speed of 11 m/s.

EXPOSURE DOSE FROM RADIONUCLIDE ATMOSPHERIC DISPERSION

Exposure dose was related to its deposition rate on land and environment through the fall of rains (Srinivas et al. 2012). In this study, I-131, Br-83, Kr-85 and Xe-135 were taken into consideration for its exposure doses due to its significant impacts posed upon organisms once in the atmosphere (Marzo 2014). The concentration of radionuclides in the atmosphere potentially harmed human body for radionuclides deposited on the skin and absorbed into the body through food intake and breathing function (Potter 2008). The exposure dose by one radionuclide released to the air can be calculated based on (4) in reference to the dose coefficient efficient factor as recommendation stated by Salame-Alfie (2001).

$$P = Q.DCF_e.E_t \tag{4}$$

where P is the annual exposure dose (Sv/yr); Q is the radionuclide concentration from (3) (Bq/m^3) DCF_e is the dose coefficient efficient factor (Sv.m^3/Bq.s); and E_t is the 3.154×10^7 s/yr.

This study used the period of a human being exposed to radionuclides over a year. It is to easily compare the annual exposure doses to limit of standard annual exposure dose. Determining the exposure doses accepted by an individual enable preparedness plan to be implemented in case of overexposure of radionuclides dispersed in the atmosphere.

TABLE 1. Pasquill stability category for downwind dispersion

Category	Distance (km)	Constant for rural areas dependent on x	
		a	b
A (Highly unstable)	< .10	122.800	0.94470
	0.10 – 0.15	158.080	1.05420
	0.16 – 0.20	170.220	1.09320
	0.21 – 0.25	179.520	1.12620
	0.26 – 0.30	217.410	1.26440
	0.31 – 0.40	258.890	1.40940
	0.41 – 0.50	346.750	1.72830
	0.51 – 3.11	453.850	2.11660
	>3.11	**	**
B* (Unstable)	<.20	90.673	0.93198
	0.21 – 0.40	98.483	0.98332
	>0.40	109.300	1.09710
C (Lowly Unstable)	All	61.1410	0.91465
D* (Neutral)	<.30	34.459	0.86974
	0.31 – 1.00	32.093	0.81066
	1.01 – 3.00	32.093	0.64403
	3.01 – 10.00	33.504	0.60486
	10.01 – 30.00	36.650	0.56589
	>30.00	44.053	0.51179
E (Stable)	<.10	24.260	0.83660
	0.10 – 0.30	23.331	0.81956
	0.31 – 1.00	21.628	0.75660
	1.01 – 2.00	21.628	0.63077
	2.01 – 4.00	22.534	0.57154
	4.01- 10.00	24.703	0.50527
	10.01 – 20.00	26.970	0.46713
	20.01 – 40.00	35.420	0.37615
	>40.00	47.618	0.29592
F (Highly stable)	<.20	15.209	0.81558
	0.21 – 0.70	14.457	0.78407
	0.71 – 1.00	13.953	0.68465
	1.01 – 2.00	13.953	0.63227
	2.01 – 3.00	14.823	0.54503
	3.01 – 7.00	16.187	0.46490
	7.01 – 15.00	17.836	0.41507
	15.01 – 30.00	22.651	0.32681
	30.01 – 60.00	27.074	0.27436
	>60.00	34.219	0.21716
Symbol * indicates chosen Pasquill Stability Category for this study			

Source: Bailey & Touma 1995

TABLE 2. Pasquill stability category for crosswind dispersion

Category	Constant for urban dependent on Pasquill category	
	c	d
A	24.1670	2.5334
B	18.3330	1.8096
C	12.5000	1.0857
D	8.3330	0.72382
E	6.2500	0.54287
F	4.1667	0.36191

Source: Bailey & Touma 1995

RESULTS AND DISCUSSION

ANALYSED RESULTS ON TYPES AND RATE OF DISPERSED RADIONUCLIDES USING ORIGEN2 CODE

The execution of ORIGEN2 Code simulation for TRIGA MARK II operating for 24 h for a year with 1 MW maximum energy released upon its enrichment used by Malaysia Nuclear Agency were 8%, 12% and 20%. The number of fuel rods for TRIGA MARK II reactor in the research year of 2018 is 111 with 86 fuel rods for the enrichment of 8%, 15 fuel rods for the enrichment of 12% and 10 fuel rods for the enrichment of 20%, respectively.

The configuration inside the core reactor produced radioisotopes as it undergoes U-235 fission of enrichment 8%, 12% and 20% which then released its radioactivity to the atmosphere, respectively, as the reactor kept on operating at 1 MW non-stop for 24 h as long as 365 days. Figure 2 shows the TRIGA MARK II Core-15 Configuration inside the reactor being used to execute the simulation of core inventory using ORIGEN2 Code.

Table 3 shows the types and activities of radionuclides dispersed to the atmosphere upon enrichments in relation to the number of fuel rods using ORIGEN2 Code.

Based on Table 3, Br (Bromine), I (Iodine), Kr (Krypton) and Xe (Xenon) obtained from core inventory by ORIGEN2 Code. These radionuclides had variations of isotopes produced through Uranium-235 fission of the enrichment of 8%, 12% and 20%. Figure 3 shows the summary of dispersion rate depending on increasing distance on enrichment of 8% for 86 fuel rods, 16% for 15 fuel rods and 20% for 10 fuel rods.

The reason for decreased Kr-85 was because of its permeation cascade that increased as much as its enrichment until Kr-85 was mostly absorbed to core reactor wall preventing majority of it from escaping and being dispersed to the atmosphere (Demange et al. 2013). However, there was an increase in Br-83, I-131 and Xe-135 because as the reactor is operating, more of these radionuclides were being released and dispersed to the atmosphere.

DETERMINED CALCULATION OF RADIONUCLIDE ATMOSPHERIC DISPERSION CONCENTRATION USING GAUSSIAN PLUME MODEL

The concentration of dispersed radionuclides from core inventory into calculation using (3) is matched with the existence of Typhoon Lan from starting from October 2017 until March 2018 (Nadia Hamid 2018). The 20% enrichment was chosen because it had the highest concentration of radionuclides based enrichment. The

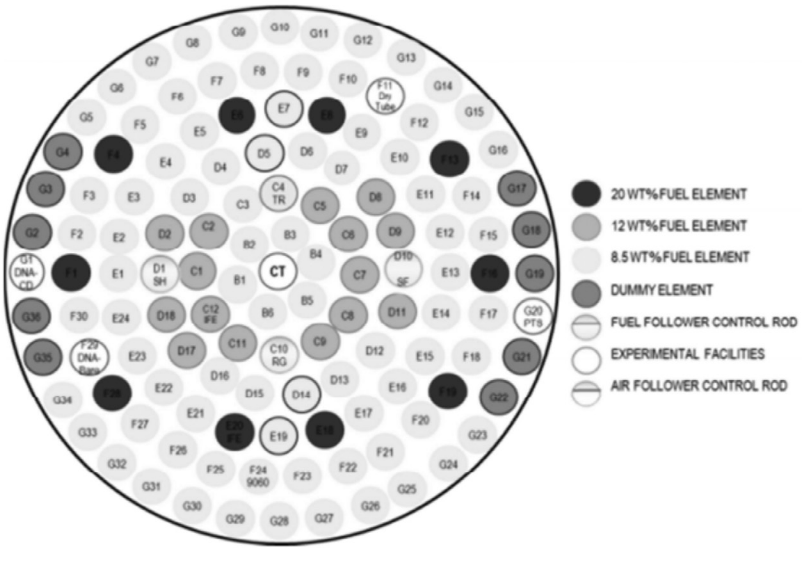

FIGURE 2. TRIGA MARK II Core-15 Configuration

Source: Malaysia Nuclear Agency 2018

TABLE 3. Types and activities of dispersed radionuclides based on annual enrichment

Type of radionuclide	Radioactivity based on enrichment ($\times 10^2$) (Ci/yr)			Critical system
	8%	12%	20%	
Br-83	0.435	0.440	0.445	Enzyme and protein
I-131	0.014	2.387	2.402	Thyroid
Xe-135	0.933	3.403	4.134	Nerve and blood
Kr-85	5.495	0.014	0.014	Breathing airways

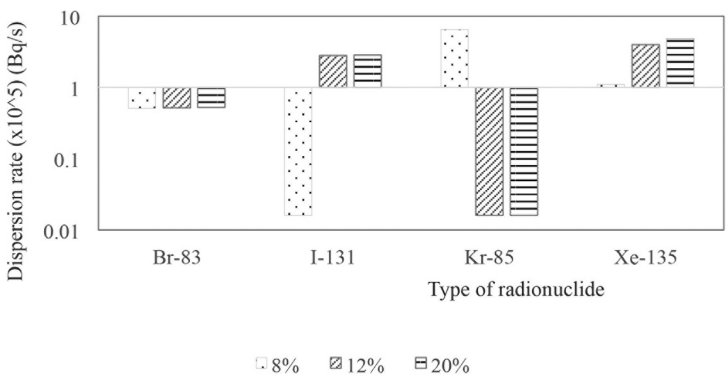

FIGURE 3. Chosen radionuclides dispersion rate on enrichment 8% for 86 fuel rods, 12% for 15 fuel rods and 20% for 10 fuel rods

concentration of radionuclide on distance for enrichment 20% for Category B of unstable condition was shown in the following Figure 4.

The radionuclide concentration decreased in Figure 3 due to the rainfall that radionuclide fall and deposited on land being washed down by rain as already simulated in the Gaussian Plume Model dispersion constant involving Category B (Doi et al. 2013). The concentration of radionuclide on distance for 20% enrichment for Category D of a stable condition indicating stable dry day as in Gaussian Plume Model constant involving Category D was shown in Figure 5 as radionuclide concentration decreased due to prolonged sunshine and its half-life being shortened (Long et al. 2012).

Consequently, referring back to the concentration of radionuclide for Category B and Category D, it can be concluded that dispersed radionuclides to the air can move farther from a released point and become even lesser in concentration once deposited on land.

RADIONUCLIDE EXPOSURE DOSE TO THE ENVIRONMENT

The standard for annual exposure dose for civilians prepared by ICRP (2006) is 1 mSv/yr. The selected distance

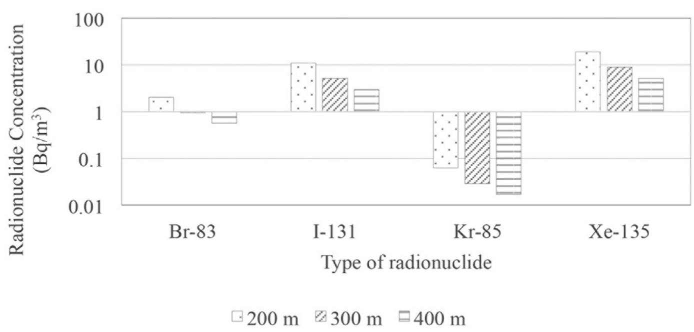

FIGURE 4. Radionuclide concentration based on distance on enrichment 20% for Category B (unstable yet neutral weather condition)

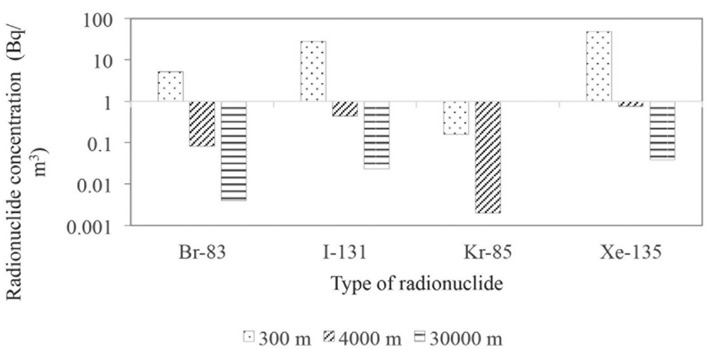

FIGURE 5. Radionuclide concentration based on distance on enrichment 20% for Category D (extreme raining or hot weather condition)

TABLE 4. Radionuclide annual exposure dose for 85 fuel rods of enrichment 8%, 16 fuel rods of enrichment 12% and 10 fuel rods of enrichment 20%

Type of radionuclide	Annual exposure dose (μSv/yr)					
	Category B			Category D		
	300 m	1000 m	4000 m	300 m	1000 m	4000 m
Br-83	3.910	0.352	0.022	0.000	0.000	0.000
I-131	613.156	55.184	3.449	89.778	8.080	0.505
Kr-85	4.089	0.368	0.023	0.711	0.064	0.004
Xe-135	705.601	63.504	3.969	103.289	9.296	0.581
Total	1326.756	119.408	7.463	193.778	17.440	1.090

to calculate the dispersion of radonuclides in the form of exposure dose was essential also to cover the entire TRIGA MARK II PUSPATI, which was its released point. The selected distances were chosen because the area exceeding the reactor was the area of civilians in which civilians should not be exposed to the unnecessary exposure of dose potentially exceeding 1 mSv/yr. In this study, the distance of 300 m, 1000 m and 4000 m were chosen as it covered the dispersion distance in civilians area up to the standard evacuation areas designated by Ohnishi (2012). However, should there be exposure dose exceeding annual exposure dose for civilians, the precaution steps were to be taken in stages such as prioritising evacuation of individuals from heavily affected area and then proceeding to ensure healthcare of affected individuals by medical chelation therapy. Calculated annual exposure dose for this study in Category B and Category D on 85 fuel rods of enrichment 8%, 16 fuel rods of enrichment 12% and 10 fuel rods of enrichment 20% was shown in the following Table 4.

Deductively from these obtained exposure doses for distances of 300 m to 4000 m were significant to be adequately monitored since at 300 m for Category B calculated doses exceeded 1000 μSv/yr, although the others did not. Hence, precaution steps need to consistently maintained in order to ensure the released of radionuclides into the atmosphere is at the tolerable amount by the workers, civilians and the environment.

CONCLUSION

The occurrence of fuel rod damage for TRIGA MARK II PUSPATI could lead to a significant impact upon the environment and human beings surrounding radius of 300 m from. Precaution steps should be implemented to ensure safety from over-exposure of radiation for workers of Malaysia Nuclear Agency and civilians if there is an incident that happened.

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REFERENCES

ARL. 2018. *Pasquill stability classes*. https://ready.arl.noaa.gov/READYpgclass.php. Accessed on May 2018.

Bailey, D.T. & Touma, J.S. 1995. *User's Guide for the Industrial Source Complex (ISC3) Dispersion Models*. Volume II- Description of Model Algorithms. North Carolina. Environmental Protection Agency (EPA).

Benamrane, Y., Wybo, J. & Armand, P. 2013. Chernobyl and Fukushima nuclear accidents: What has changed in the use of atmospheric dispersion modeling? *Journal of Environmental Radioactivity* 126(1): 239-252.

Chambers, S.D., Wang, F., Williams, A.G., Xiaodong, D., Zhang, H., Lonati, G. & Crawford, J. 2015. Quantifying the influences of atmospheric stability on air pollution in Lanzhou, China, using a radon-based stability monitor. *Atmospheric Environment* 107: 233-243.

Demange, D., Borisevich, O., Gramlich, N., Wagner, R. & Welte, S. 2013. Zeolite membranes and palladium membrane reactor for tritium extraction from the breeder blankets of ITER and DEMO. *Fusion Engineering and Design* 88(9-10): 2396-2399.

Doi, T., Masumoto, K., Toyoda, A. & Tanaka, A. 2013. Anthropogenic radionuclides in the atmosphere observed at Tsukuba: Characteristics of the radionuclides derived from Fukushima. *Journal of Environmental Radioactivity* 122: 55-62.

Green, A.E.S., Singhal, R.P. & Venkateswar, R. 1980. Analytic extensions of the gaussian plume model. *Journal of the Air Pollution Control Association* 30(7): 773-776.

ICRP. 2006. Radiation Overview on External Eposure and Doses Calculation. *International Commission on Radiological Protection, Publication 26/30,* Argonne National Laboratory, USA.

Imanaka, T., Hayashi, G. & Endo, S. 2015. Comparison of the accident process, radioactivity release and ground contamination between Chernobyl and Fukushima-1. *Journal of Radiation Research* 56: 56-61.

Long, N.Q., Truong, Y., Hien, P.D., Binh, N.T., Sieu, L.N., Giap, T.V. & Phan, N.T. 2012. Atmospheric radionuclides from the Fukushima Dai-ichi nuclear reactor accident observed in Vietnam. *Journal of Environmental Radioactivity* 111: 53-58.

Malaysia Nuclear Agency. 2018. Education and training. http://www.nuclearmalaysia.gov.my/malay/. Accessed on 11 May 2018.

Marzo, G.A. 2014. Atmospheric transport and deposition of radionuclides released after the Fukushima Dai-chi accident and resulting effective dose. *Atmospheric Environment* 94: 709-722.

Muswema, J.L., Darko, E.O., Gbadago, J.K. & Boafo, E.K. 2014. Annals of nuclear energy atmospheric dispersion modeling and radiological safety analysis for a hypothetical accident of Ghana Research Reactor-1 (GHARR-1). *Annals of Nuclear Energy* 68: 239-246.

Nadia Hamid. 2018. *Tempias Taufan Lan pada Malaysia*. https://www.bharian.com.my/berita/nasional/2017/10/340180/panas-terik-kesan-tempias-taufan-lan. Accessed on 12 May 2018.

Ohnishi, T. 2012. The disaster at Japan's Fukushima-Daiichi nuclear power plant after the March 11, 2011 earthquake and tsunami, and the resulting spread of radioisotope contamination. *Radiation Research* 177: 1-14.

Potter, C.A. 2008. Human alimentary tract model for radiological protection. *Health Physics* 94(4): 373-375.

Preston, J.F. 2013. *Overview of Level 3 PSA-Assessment of Off-site Consequences*. International Atomic Energy Agency. 22-26 July 2013. PNRI Manila, Philippines.

Salame-Alfie, A. 2001. Assessing dose of the representative person for the purpose of radiation protection of the public and the optimization of the radiological protection: Broadening the process. In. *Health Safety*. ICRP Publication. p. 106.

Slade, H.D. 1968. Meteorology and atomic energy. National Technical Information Service, U.S Department of Commerce, Springfield, Virginia, U.S.

Šömen Joksić, A. & Katz, S.A. 2015. Chelation therapy for treatment of systemic intoxication with uranium: A review. *Journal of Environmental Science and Health, Part A* 50(14): 1479-1488.

Srinivas, C.V., Venkatesan, R., Baskaran, R., Rajagopal, V. & Venkatraman, B. 2012. Regional scale atmospheric dispersion simulation of accidental releases of radionuclides from Fukushima Dai-ichi reactor. *Atmospheric Environment* 61: 66-84.

Usang, M.D., Hamzah, N.S., Abi, M.J.B., Rawi, M.M.Z. & Abu, M.P. 2015. TRIGA MARK-II Source Term: AIP Conference Proceedings. *Advancing Nuclear Research and Energy Development* 1584: 45-49.

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