Tri Dasa Mega Vol. 23 No. 2 (2021) 57–62

Jurnal Teknologi Reaktor Nuklir

Tri Dasa Mega

Journal homepage: jurnal.batan.go.id/index.php/tridam

Environmental Consequences of Routine Releases from Small Medium Reactor at Babel Site

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ARTICLE INFO

Article history:

Received: 11 February 2021
Received in revised form: 03 April 2021
Accepted: 05 April 2021

Keywords:

SMR
Consequences
Routine release
Environmental
ORIGEN2
PC-CREAM

A B S T R A C T

Radiation protection and safety documents for routine conditions are required to support the licensing requirements for nuclear power plant site. This research is focused in the assessment and analysis of the results of PWR safety study related to the routine release of radioactivity from the SMR subsystems and components of the 100 MWe-type PWR along with its consequences in the site. The core inventory calculation was done using ORIGEN2 software, applying release parameters from the existing analysis and calculation results. The radiological consequences were calculated by the PC-CREAM program package. Environmental and meteorological data were obtained using Arc-GIS and spatial analysis. The Bangka Belitung (Babel) site was used as the specific footprint. Analyzing PC-CREAM output data the radiological consequences of routine operation of 3 100 MWe PWR modules on Sebagin site (South Bangka) and Muntok site (West Bangka) in 16 sectors and within a radius of 20 km were concluded. The calculation results for the Sebagin site is that the maximum-dose within a radius of 500 m (exclusion zone) is 1.15E+02 µSv/year. For a radius beyond 500 m, the maximum dose is 4.71E+01 µSv/year. Whereas for Muntok site (West Bangka), the maximum dose in the exclusion area (<500m) is 9.47E+00 µSv/year, and outside exclusion area (>500m) is 3.10E+00 µSv/year. The individual dose for the Babel site in the exclusion area is below the dose constraint for non-radiation service workers as the general public of 0.3 mSv/year or 300 µSv/year, while the maximum dose for outside exclusion is also below the constraint as stipulated in BAPETEN Regulation No 4 Year 2013 on Radiation Protection and Safety.

1. INTRODUCTION

The construction plan of an SMR-type Nuclear Power Plant (NPP) in Indonesia requires a safety analysis to prove that the NPPs are safe for the community and the environment. Based on the selected SMR of 100 MWe-rated PWR, the radiation safety analysis under routine operating conditions is carried out. The study was conducted to ensure that the public received radiation doses below regulatory limits.

Source term is a starting point to calculate the radiological consequences at NPPs environmental site. Routine operation is the normal operation of a reactor in one or more cycles without any significant disturbances. Calculations about the environmental consequences of routine discharge for the PWR-1000 MWe, non-commercial power reactor (RDE) and research reactor have been carried out[1-3]. Calculation of the radiation consequences requires the source term or release of

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DOI: 10.17146/tdm.2021.23.2.6239

radionuclides to the environment in routine operation or postulated accident conditions[4-6].

This study aims to examine the environmental consequences of routine discharge for the 100 MWe PWR. In contrast to previous study[2] is the release assumption of three units 100 MWe PWR for two different sites in Babel, namely Sebagin and Muntok. The source term calculation for one unit PWR-330 MWt is based on the reference SMR from SMART using the results of calculations that have been done[2, 5].

Estimation of consequences starts from the source term released into the atmosphere, and influenced by the weather, it dispersed within the air and deposited on the ground surface. With various pathways such as cloud-shine, ground-shine, and foodstuff, human doses are received internally (inhalation, immersion and consumption) and externally[7-9]. The calculation uses PC-CREAM software[1, 10], which works based on segmented Gaussian[11-12]. Environmental and meteorological data were obtained using Arc-GIS and spatial analysis.

2. METHODOLOGY

The release of routine source term was calculated based on the 100 MWe PWR core[2, 5]. Estimated source term for routine operation of the 100 MWe PWR reactor, based on the assumption of 0.1% fission product release from small holes in the fuel cladding. These pinholes are formed due to fuel irradiation during several cycles of reactor operation. Apart from that, pinholes can appear from uranium impurities on the fuel surface, due to fabrication limitations[1,2,5].

Analysis of PC-CREAM output data for radiological consequences of routine operation of 3 100 MWe PWR modules in Sebagin site (South Bangka) and Muntok site (West Bangka) was directed to 16 sectors, which represents 16 wind directions. The chosen directions are adequate and commonly used for atmospheric dispersion directions[8-10,13-14]. The distance within a radius of 20 km with an increase of 100 m; 300 m; 500 m; 1 km; 2 km; 3 km; 4 km; 5 km; 6 km; 7 km; 8 km; 9 km; 10 km; 12 km; 15 km; 20 km.

Our previous research has obtained a PWR safety analysis related to the release of radioactive substances from the one unit of 100 MWe PWR and the dose consequences at the Sebagin during routine operation[2]. Estimation of radiation dose includes the following pathways: external from gamma exposure (cloud-shine and ground-shine), internal from beta exposure (cloud-shine), and from ingestion of contaminated food. The atmospheric dispersion calculation is based on the segmented Gaussian equation, according to the PC Cream Software[13-14].

The calculation mechanism for the routine operating source term is shown in Figure 1, and the map of BABEL site on Figure 2.

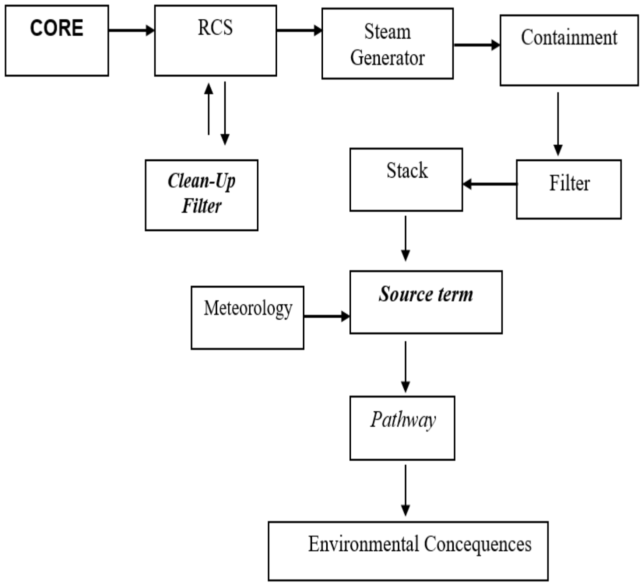

Fig. 1. Mechanism of environmental consequences of routine release for SMR

Fig. 2. Specific site of Bangka Belitung (BABEL)

3. RESULTS AND DISCUSSION

3.1. Source term for Routine release

The estimation results of the source term resulting from the routine discharge of the 3 units of 100 MWe PWR units are shown in Figure 3. This source term activity is obtained from calculations and assumptions from the source term mechanism as shown in Figure 1.

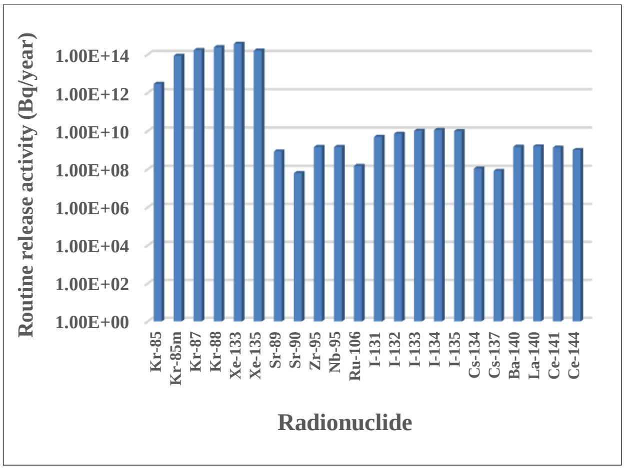

Fig. 3. Total routine release activity the 3 PWR-100 MWe

3.2. Environmental Consequences

The results of calculating dose consequences for radioactive releases to the atmosphere in routine operations for 3 modules of 100 MWe PWR (all nuclides and all pathways) for Sebagin site (South Bangka) within a radius of 20 km are shown in Table 1.

Table 1. Total adult individual dose of radioactive discharge into the atmosphere in routine operation 3 100 MWe PWR (all nuclides and all pathways); Sebagin site

Distance	Individual dose for adult (µSv/yr)							
Sector	100 m	300 m	500 m	1 km	2 km	3 km	4 km	5 km
1	7.59E+00	3.18E+00	2.75E+00	1.39E+00	6.13E-01	3.98E-01	2.95E-01	2.35E-01
2	4.86E+00	2.00E+00	1.63E+00	8.76E-01	4.06E-01	2.69E-01	2.02E-01	1.62E-01
3	6.23E+00	2.58E+00	2.06E+00	1.08E+00	5.03E-01	3.37E-01	2.55E-01	2.06E-01
4	5.85E+00	2.50E+00	2.06E+00	9.69E-01	4.27E-01	2.83E-01	2.13E-01	1.72E-01
5	6.56E+00	2.72E+00	2.20E+00	1.17E+00	5.46E-01	3.59E-01	2.67E-01	2.13E-01
6	9.54E+00	4.07E+00	3.49E+00	1.81E+00	7.81E-01	4.81E-01	3.40E-01	2.61E-01
7	1.33E+01	5.52E+00	4.59E+00	2.71E+00	1.24E+00	7.67E-01	5.42E-01	4.14E-01
8	1.77E+01	7.30E+00	6.00E+00	3.55E+00	1.67E+00	1.06E+00	7.67E-01	5.96E-01
9	1.26E+00	4.89E-01	3.31E-01	1.92E-01	1.08E-01	8.18E-02	6.65E-02	5.63E-02
10	5.76E+00	2.24E+00	1.52E+00	9.18E-01	5.19E-01	3.87E-01	3.10E-01	2.59E-01
11	5.38E+00	2.09E+00	1.42E+00	8.13E-01	4.55E-01	3.48E-01	2.85E-01	2.42E-01
12	6.36E+00	2.47E+00	1.64E+00	9.53E-01	5.56E-01	4.29E-01	3.50E-01	2.97E-01
13	1.83E+01	7.26E+00	5.19E+00	3.03E+00	1.69E+00	1.22E+00	9.54E-01	7.83E-01
14	2.29E+01	9.50E+00	7.79E+00	4.23E+00	2.05E+00	1.35E+00	9.89E-01	7.77E-01
15	1.33E+01	5.53E+00	4.64E+00	1.41E+00	1.14E+00	7.46E-01	5.53E-01	2.38E-01
16	6.58E+00	2.73E+00	2.29E+00	1.21E+00	5.52E-01	3.64E-01	2.72E-01	2.18E-01
Mean	**9.47E+00**	**3.89E+00**	**3.10E+00**	**1.63E+00**	**8.29E-01**	**5.55E-01**	**4.16E-01**	**3.19E-01**
Distance	Individual dose for adult (µSv/yr)							
Sector	6 km	7 km	8 km	9 km	10 km	12 km	15 km	20 km
1	1.92E-01	1.63E-01	1.40E-01	1.23E-01	1.09E-01	8.69E-02	6.62E-02	4.53E-02
2	1.33E-01	1.13E-01	9.78E-02	8.55E-02	7.59E-02	6.08E-02	4.64E-02	3.18E-02
3	1.69E-01	1.45E-01	1.25E-01	1.10E-01	9.78E-02	7.84E-02	6.00E-02	4.11E-02
4	1.41E-01	1.21E-01	1.05E-01	9.19E-02	8.19E-02	6.58E-02	5.04E-02	3.45E-02
5	1.74E-01	1.47E-01	1.27E-01	1.11E-01	9.82E-02	7.84E-02	5.97E-02	4.07E-02
6	2.08E-01	1.72E-01	1.46E-01	1.26E-01	1.11E-01	8.74E-02	6.56E-02	4.43E-02
7	3.29E-01	2.72E-01	2.31E-01	1.98E-01	1.74E-01	1.37E-01	1.02E-01	6.86E-02
8	4.79E-01	3.99E-01	3.40E-01	2.94E-01	2.59E-01	2.05E-01	1.54E-01	1.04E-01
9	4.77E-02	4.16E-02	3.67E-02	3.25E-02	2.93E-02	2.37E-02	1.84E-02	1.27E-02
10	2.18E-01	1.89E-01	1.66E-01	1.47E-01	1.32E-01	1.06E-01	8.20E-02	5.63E-02
11	2.06E-01	1.80E-01	1.59E-01	1.41E-01	1.27E-01	1.03E-01	8.01E-02	5.52E-02
12	2.52E-01	2.20E-01	1.94E-01	1.72E-01	1.54E-01	1.25E-01	9.69E-02	6.67E-02
13	6.51E-01	5.59E-01	4.87E-01	4.28E-01	3.81E-01	3.06E-01	2.34E-01	1.60E-01
14	6.28E-01	5.27E-01	4.51E-01	3.90E-01	3.44E-01	2.72E-01	2.05E-01	1.39E-01
15	3.57E-01	3.02E-01	2.60E-01	1.15E-01	2.00E-01	1.60E-01	1.21E-01	4.25E-02
16	1.79E-01	1.52E-01	1.31E-01	1.15E-01	1.02E-01	8.15E-02	6.22E-02	7.44E+00
Mean	**2.73E-01**	**2.31E-01**	**2.00E-01**	**1.67E-01**	**1.55E-01**	**1.24E-01**	**9.40E-02**	**5.24E-01**

Radiation exposure pathways are differentiated through radioactive clouds; gamma and beta radiation for external and internal exposure. Meanwhile, through foodstuff, the exposure are from consumption of food from local agricultural products such as vegetables, livestock, tubers, and seeds.

The total individual maximum average dose within a radius of 100 m which is included in the exclusion zone of 500 m with a dose of 1.15E+02 µSv/year, is below the dose limit for radiation service workers of 20 mSv/year or 2000 µSv/year as stipulated in BAPETEN Regulation No 4 Year 2013 on Radiation Protection and Safety. For radii beyond 500 m, the maximum mean dose is 4.71E+01 µSv/year, well below the constraint for the general population of 300 µSv/year. The maximum dose distribution is in the area to the North, on sector 16.

Table 2. Total adult individual dose of radioactive discharge into the atmosphere in routine operation 3 PWR-100 MWe (all nuclides and all pathways); Muntok site

Distance	Individual dose for adult (µSv/yr)							
Sector	100 m	300 m	500 m	1 km	2 km	3 km	4 km	5 km
1	7.59E+00	3.18E+00	2.75E+00	1.39E+00	6.13E-01	3.98E-01	2.95E-01	2.35E-01
2	4.86E+00	2.00E+00	1.63E+00	8.76E-01	4.06E-01	2.69E-01	2.02E-01	1.62E-01
3	6.23E+00	2.58E+00	2.06E+00	1.08E+00	5.03E-01	3.37E-01	2.55E-01	2.06E-01
4	5.85E+00	2.50E+00	2.06E+00	9.69E-01	4.27E-01	2.83E-01	2.13E-01	1.72E-01
5	6.56E+00	2.72E+00	2.20E+00	1.17E+00	5.46E-01	3.59E-01	2.67E-01	2.13E-01
6	9.54E+00	4.07E+00	3.49E+00	1.81E+00	7.81E-01	4.81E-01	3.40E-01	2.61E-01
7	1.33E+01	5.52E+00	4.59E+00	2.71E+00	1.24E+00	7.67E-01	5.42E-01	4.14E-01
8	1.77E+01	7.30E+00	6.00E+00	3.55E+00	1.67E+00	1.06E+00	7.67E-01	5.96E-01
9	1.26E+00	4.89E-01	3.31E-01	1.92E-01	1.08E-01	8.18E-02	6.65E-02	5.63E-02
10	5.76E+00	2.24E+00	1.52E+00	9.18E-01	5.19E-01	3.87E-01	3.10E-01	2.59E-01
11	5.38E+00	2.09E+00	1.42E+00	8.13E-01	4.55E-01	3.48E-01	2.85E-01	2.42E-01
12	6.36E+00	2.47E+00	1.64E+00	9.53E-01	5.56E-01	4.29E-01	3.50E-01	2.97E-01
13	1.83E+01	7.26E+00	5.19E+00	3.03E+00	1.69E+00	1.22E+00	9.54E-01	7.83E-01
14	2.29E+01	9.50E+00	7.79E+00	4.23E+00	2.05E+00	1.35E+00	9.89E-01	7.77E-01
15	1.33E+01	5.53E+00	4.64E+00	1.41E+00	1.14E+00	7.46E-01	5.53E-01	2.38E-01
16	6.58E+00	2.73E+00	2.29E+00	1.21E+00	5.52E-01	3.64E-01	2.72E-01	2.18E-01
Mean	**9.47E+00**	**3.89E+00**	**3.10E+00**	**1.63E+00**	**8.29E-01**	**5.55E-01**	**4.16E-01**	**3.19E-01**
Distance	Individual dose for adult (µSv/yr)							
Sector	6 km	7 km	8 km	9 km	10 km	12 km	15 km	20 km
1	1.92E-01	1.63E-01	1.40E-01	1.23E-01	1.09E-01	8.69E-02	6.62E-02	4.53E-02
2	1.33E-01	1.13E-01	9.78E-02	8.55E-02	7.59E-02	6.08E-02	4.64E-02	3.18E-02
3	1.69E-01	1.45E-01	1.25E-01	1.10E-01	9.78E-02	7.84E-02	6.00E-02	4.11E-02
4	1.41E-01	1.21E-01	1.05E-01	9.19E-02	8.19E-02	6.58E-02	5.04E-02	3.45E-02
5	1.74E-01	1.47E-01	1.27E-01	1.11E-01	9.82E-02	7.84E-02	5.97E-02	4.07E-02
6	2.08E-01	1.72E-01	1.46E-01	1.26E-01	1.11E-01	8.74E-02	6.56E-02	4.43E-02
7	3.29E-01	2.72E-01	2.31E-01	1.98E-01	1.74E-01	1.37E-01	1.02E-01	6.86E-02
8	4.79E-01	3.99E-01	3.40E-01	2.94E-01	2.59E-01	2.05E-01	1.54E-01	1.04E-01
9	4.77E-02	4.16E-02	3.67E-02	3.25E-02	2.93E-02	2.37E-02	1.84E-02	1.27E-02
10	2.18E-01	1.89E-01	1.66E-01	1.47E-01	1.32E-01	1.06E-01	8.20E-02	5.63E-02
11	2.06E-01	1.80E-01	1.59E-01	1.41E-01	1.27E-01	1.03E-01	8.01E-02	5.52E-02
12	2.52E-01	2.20E-01	1.94E-01	1.72E-01	1.54E-01	1.25E-01	9.69E-02	6.67E-02
13	6.51E-01	5.59E-01	4.87E-01	4.28E-01	3.81E-01	3.06E-01	2.34E-01	1.60E-01
14	6.28E-01	5.27E-01	4.51E-01	3.90E-01	3.44E-01	2.72E-01	2.05E-01	1.39E-01
15	3.57E-01	3.02E-01	2.60E-01	1.15E-01	2.00E-01	1.60E-01	1.21E-01	4.25E-02
16	1.79E-01	1.52E-01	1.31E-01	1.15E-01	1.02E-01	8.15E-02	6.22E-02	7.44E+00
Mean	**2.73E-01**	**2.31E-01**	**2.00E-01**	**1.67E-01**	**1.55E-01**	**1.24E-01**	**9.40E-02**	**5.24E-01**

The calculation results of the dose consequences for radioactive release into the atmosphere in routine operations for 3 modules of 100 MWe PWR (all nuclides and all pathways) for Muntok site (West Bangka) in a radius of 20 km are shown in Table 2. The maximum dose distribution is in the areas to the sector 14.

Total average maximum individual dose in radius of 100 m, within the exclusion zone of 500 m, is 9.47E+00 µSv/year, below the dose limit for radiation workers. For a radius beyond 500 m, the maximum dose is 3.10E+00 µSv/year, well below the constraint for general public.

The maximum total effective individual dose for the various pathways for all radionuclides is received within a radius of 100 m from the reactor. Maximum effective individual dose of West Bangka (Muntok) occurs in the wind direction of sector 14, and for South Bangka (Sebagin) in sector 16. The largest dose contribution is from the gamma component of plume pathway, followed by the ingestion pathway. The data is presented in Figure 4.

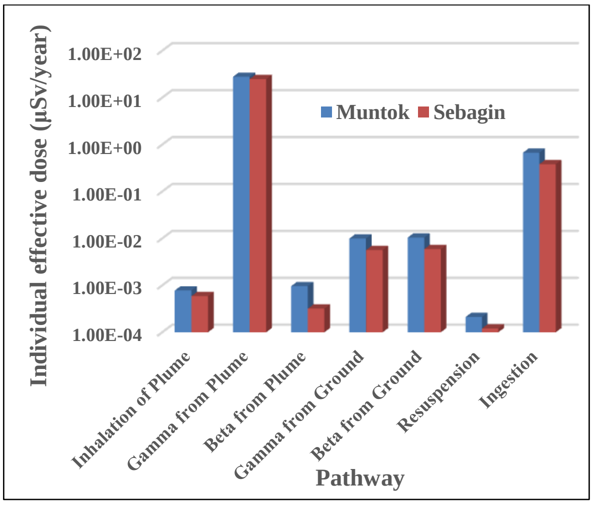

Fig. 4. Total individual effective dose maximum for all nuclides by pathway

Figure 5 illustrates the maximum effective individual dose for both sites, for all pathways by radionuclide types. The largest dose contribution was given by the noble gas group (Xe, Kr, Ar), followed by the iodine (I-131) and cesium (Cs-134, Cs-137) group. Figure 6 illustrates the received dose from all nuclides and all pathways. Radionuclides from the noble gas group, since they are inert, will contribute to gamma dose from the radioactive cloud. Meanwhile, ingestion is contributed by iodine and cesium radionuclides.

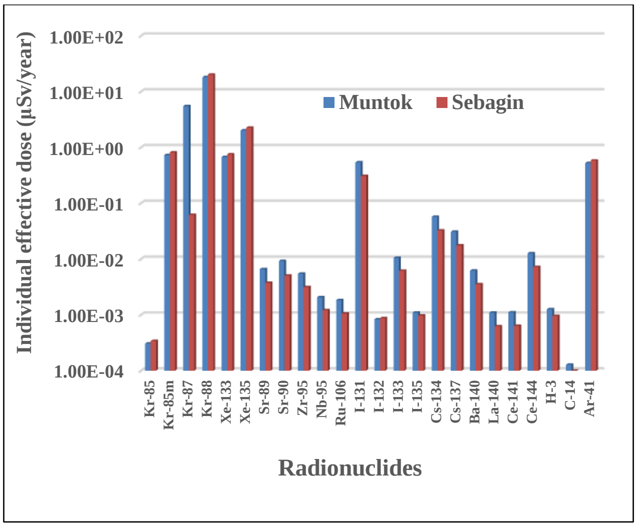

Fig. 5. Total Individual effective dose maximum for all pathway by radionuclide

Figure 6 illustrates the mean effective individual doses for both sites, for all pathways and radionuclide releases. The received dose decreases with increasing radius from the reactor. In general, the dose for each pathway in both sites, Bangka Barat (Muntok site) was slightly higher than Bangka Selatan (Sebagin site).

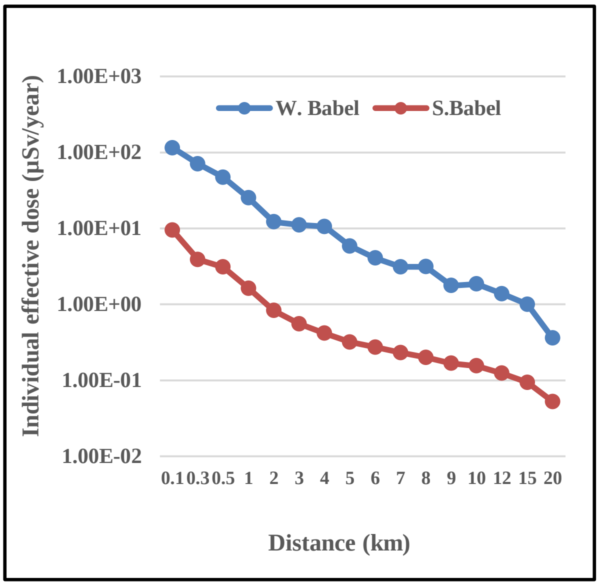

Fig. 6. Effective individual dose of radioactive discharge into the atmosphere in routine operation for 3 PWR-100MWe (all nuclides and all pathways)

4. CONCLUSION

A safety analysis of the PWR-100 MWe for radioactive releases and its environmental consequences at Babel site (Sebagin and Muntok) during routine operation is presented. Radiological consequence calculation was done using PC-CREAM software. The calculations covered 16 wind directions (sectors) within a radius of 20 km.

The calculation results for the Sebagin site are as follow: the maximum average individual total dose within a radius of 100 m (exclusion zone) is 1.15E+02 µSv/year. For a radius beyond 500 m, the maximum average dose is 4.71E+01 µSv/year. Whereas for Muntok site (West Bangka), the maximum average total dose in the exclusion area (<500 m) is 9.47E+00 µSv/year, and the external dose exclusion (> 500 m) is of 3.10E+00 µSv/year at maximum. The received dose for the Babel site for the exclusion area is below the dose constraint for non-radiation workers (public) of 0.3 mSv/year or 300 µSv/year, and the maximum dose for outside exclusion is also below the constraint for the general public as stipulated in BAPETEN Regulation No 4 Year 2013 on Radiation Protection and Safety.

ACKNOWLEDGMENT

The works are conducted under the government research and funding managed by Center for Nuclear Reactor Technology and Safety (PTKRN), BATAN, for the year of 2020. It is also partially supported by 2020-2021 RISTEK/BRIN-LPDP project (SK. 11/E1/III/PRN/2020)

AUTHOR CONTRIBUTION

All authors contribute together as the main contributors to this paper. All authors read and agree to the final version of the paper. All authors read and approved the final version of the paper.

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