ISSN 1411 - 3481
EISSN 2503 - 1287
https://doi.org/10.17146/jstni.2017.18.2.3575

ANALYSIS OF RADIATION SAFETY IN THE NUCLEAR POWER PLANT (NPP) SITE IN NORMAL OPERATION CONDITION, SEBAGIN SITE STUDY

Pande Made Udiyani[1] and Ihda Husnayani[2]

[1,2] Pusat Teknologi dan Keselamatan Reaktor Nuklir, BATAN
Kawasan Puspiptek Serpong Gd-80, Tangerang Selatan 15310

Diterima: 21-06-2017
Diterima dalam bentuk revisi: 19-08-2017
Disetujui: 19-09-2017

ABSTRAK

ANALISIS KESELAMATAN RADIASI DI TAPAK PUSAT LISTRIK TENAGA NUKLIR (PLTN) PADA KONDISI OPERASI NORMAL, STUDI TAPAK SEBAGIN. Pembangunan PLTN memerlukan analisis keselamatan radiasi untuk membuktikan bahwa PLTN dapat beroperasi secara aman dan selamat pada kondisi operasi normal dan abnormal. Analisis keselamatan radiasi PLTN diperlukan untuk melengkapi dokumen analisis tapak dan analisis keselamatan. Penelitian ini bertujuan untuk mendapatkan data dosis radiasi di lingkungan tapak PLTN pada kondisi operasi normal. Diasumsikan terdapat tiga PLTN jenis PWR daya 1000 MWe beroperasi di Tapak Sebagin, Provinsi Bangka Belitung. Data dosis dihitung dengan menggunakan perangkat lunak PC-CREAM. Metodologi yang diterapkan untuk analisis dari tiga PWR-1000 MWe tersebut yaitu mempersiapkan input PC-CREAM meliputi data *sourceterm* rutin, data meteorologi daerah setempat berupa frekuensi stabilitas cuaca untuk 16 sektor (arah angin) yang diambil dari data cuaca selama 1 tahun. Selain itu juga dibutuhkan data produksi pertanian dan peternakan serta data distribusi penduduk selama setahun untuk 16 sektor dan 20 arah radial. Hasil perhitungan menunjukkan bahwa dosis maksimum untuk semua jenis nuklida dan semua alur paparan yang diterima publik (dewasa) di sekitar tapak Sebagin dari lepasan tiga PWR-1000MWe untuk kondisi operasi normal adalah sekitar 0,053 mSv/tahun ke arah Utara dalam radius 1 km. Dosis ini di bawah Nilai Batas Dosis 1 mSv/tahun atau pembatas dosis 0,3 mSv/tahun (BAPETEN).

Kata kunci: keselamatan radiasi, operasi normal, PWR, PC-CREAM.

ABSTRACT

ANALYSIS OF RADIATION SAFETY IN THE NUCLEAR POWER PLANT (NPP) SITE IN NORMAL OPERATION CONDITION, SEBAGIN SITE STUDY. Construction of NPP requires an evaluation of radiation safety which proves that operation of the NPP under normal operating condition and postulated abnormal conditions is safe. Analysis of radiation safety at the NPP site under normal operating condition is required to complete the documents of site analysis and safety analysis. This study is aimed to obtain radiation dose in the environment of the NPPs at Sebagin site in Bangka Belitung province. The doses were calculated using PC-CREAM code. It is assumed that there are three 1000-MWe PWR operating in Sebagin site. Input data required for PC-CREAM simulation are routine sourceterm of three 1000MWe-PWRs, meteorological data, and agricultural and stock production, and population distribution. The meteorological data consist of stability frequency of weather for 16 sectors (wind direction) taken from local weather data for a year. The data of agricultural and livestock production and population distribution are also taken for 1 year in 16 sectors and 20 radial directions. The results show that the maximum dose from all types of radionuclides and all pathways accepted by adult public around Sebagin site is approximately 0.053 mSv/year to the north direction in the radius of 1 km. This dose is far below the dose limit value of 1 mSv/ year or dose constraint of 0.3 mSv/year as public acceptance criteria (BAPETEN).

Keywords: radiation safety, normal operation, PWR, PC-CREAM.

1. INTRODUCTION

Energy demand in Indonesia is predicted to increase rapidly in the future so that it requires more reliable and sustainable energy sources. In order to overcome this high energy demand and to achieve energy independency, Indonesia's government plans to introduce the use of nuclear energy by constructing large capacity nuclear power plant (NPP).

As part of NPP construction preparation, safety evaluation of the NPP has to be conducted regarding radiological impact to human and environment in the vicinity of the NPP. Among the lessons learned from Fukushima accident, the NPP safety should be highlighted again in order to rebuild and increase the public acceptance toward the use of nuclear energy. Some documents have to be prepared before constructing the NPP, two of them a site evaluation and a Safety Analysis Report (SAR) document. The evaluation of NPP safety in normal operation condition is needed to complete those documents. Therefore, this research was performed to obtain the radiological doses in the vicinity of the NPP operating in normal operation condition.

The radiological safety assessment in normal operation condition of NPP type of BWR and PWR have been performed in some previous works (1,2,3). In this research, the calculation of radiological dose for PWR was performed for different site with different assumption, calculation model, stack configuration, and sourceterm. In this research, the safety analysis of PWR in Sebagin site in province of Bangka Belitung was conducted using PC-CREAM computer code. It was assumed that there are three 1000-MWe PWRs operating in Sebagin site (PWR-1, PWR-2, and PWR-3). PWR-1 location is used as a reference, PWR-2 is 500 meters apart of PWR-1 and at the same angle with PWR-1, and PWR-3 is also 500 meters apart of PWR-1 but at the angle of 180^o. Sebagin is Nuclear Power Plant Siting candidate in Bangka Island. Sebagin is located in South Bangka Regency-Province of Bangka Belitung.

The method used in obtaining the radiological dose was preparing some data needed as the input for PC-CREAM code. Those data include routine sourceterm of three 1000-MWe PWRs, meteorological data of the site which is weather stability frequency in 16 sectors and 20 radial positions for one year (8760 data), agricultural and animal products data in 16 sectors and 20 radial position from the plants. The safety analysis was performed for each of these three 1000-MWe PWRs.

The sourceterm was calculated based on assumption that there is porosity in the fuel cladding due to longterm iradiation of around 3 years so that it causes pinholes and results in the releasing of fission products from the fuel gap into the primary coolant. The amount of fission products released through the pinholes was assumed around 0.1% - 1%, same as previous woks (2,3). Fission products release rate depends on the activity in the fuel gap, pinholes diameter, and fuel burnup. Beside fission products released from inside of the fuel, there are also fission products coming from natural and enriched uranium contamination in outer surface of the fuel cladding. Although there is no fission products release caused by the fuel damage, the uranium contamination can also cause the presence of fission products in the primary coolant. The amount of this contamination can reach up to 10 micron per weight of uranium in the outer surface (2).

Release factor from the core to the primary coolant for Iodine is about 0.3% - 0.5%, Cs and Rb are 0.25% - 0.30%, Ru and Te are 0.01, and other nuclides are about 0.25%. Filter efficiency in the clean-up filter and chemical and volume control system (CVCS) for Iodine is 0.5%, other fission products are 90%, and noble gases are 0%. Efficiency of the primary containment is 70% for Iodine and 90% for other nuclides (8). Efficiency of HEPA filter in reactor stack for noble gas is 0%, Iodine (organic) is 90%, and other nuclides (Br, Te, Cs, Rb) are 99% (2).

2. THEORY

Fission products inventory inside nuclear fuel depends on some parameters including type of the fuel, fuel enrichment, fissile material concentration, burnup, reactor power, core configuration, and irradiation time of the fuel in the reactor core. These parameters determine the activity of the fission products contained in the fuel. Fission products consist of many type of radionuclides such as noble gases (e.g Xe and Kr), halogen (e.g Iodine), Cs, Ru, Ce, La, Ba, and etc. Among those fission products, there are some that have as volatile, and the others are non-volatile. Due to the diffusion process, some fission products can release from the fuel to the fuel gap with release rate depending on the diffusion coefficient, fuel temperature and burnup.

In case of there are pinholes in the fuel cladding, fission products in the fuel gap can release into the primary coolant. Besides that, there are also some fission products in the primary coolant coming from the uranium contamination in the cladding. In normal operation condition, the fission products release through the reactor stack into the atmosphere in the form of gas, vapor, or aerosol and then they are carried by the wind and dispersed into the atmosphere (4-6). In modeling this dispersion, the plume is assumed to have Gaussian profile (7-10), with standard deviation depending on the meteorological condition and distance (9). Based on this dispersion model it can be calculated the concentration of radionuclide in the atmosphere and also its deposition in the ground (8-10). In other research regarding radionuclide dispersion, the plume can be modeled by using Lagrangian model (8).

The meteorological data needed in modeling the atmospheric dispersion are wind speed and direction, rainfall rate, turbulence indicator which are collected per hour during one year. In term of turbulence indicator, it uses class stability of classic Pasquill – Gifford comprising Class A (unstable) trough Class F (very stable). In this research, it uses Pasquil Pasquill – Gifford equation (1,9,14-15):

$$\chi = \frac{Q}{2\pi\sigma_y\sigma_z\mu}[-1/2(y/\sigma_y)^2] \\ \{\exp[-1/2((z-H)/\sigma_z)^2] \qquad (1) \\ +\exp[-1/2((z+H)/\sigma_z)^2]\}$$

where: χ(chi) is the concentration in the air (Bq s/m^3), x axis is parallel with the wind direction, y axis is perpendicular with the wind direction, and z axis is the distance above the ground; Q is the average radionuclide activity release from the stack (Bq); μ is the average wind speed (m/s); σ_y is the horizontal dispersion coefficient (m); σ_z is the vertical dispersion coefficient (m); H is the height of the active stack (m).

The main pathways during and after the atmospheric dispersion are external exposure from the atmosphere, external exposure from the ground deposition, internal exposure from cloudshine, internal exposure from food which have been contaminated from dry and wet deposition. For each pathway, dose conversion factor released by national or international organization (e.g. ICRP, IAEA) can be used for each radionuclide, from dispersion concentration and deposition for radiological dose calculation (15-17). The main pathways that are considered in the PC CREAM are (17) external exposure from radionuclide deposited in the ground (groundshine), external exposure from radionuclide in the atmosphere (cloudshine), internal exposure from the inhalation of radionuclide in the atmosphere (inhalation), internal exposure from contaminated food (ingestion). The internal exposure from ingestion is related to the foodstuff and the food chain.

3. METHODOLOGY

The methology used in this research that has modified based on previous work (2,3), is shown in Figure 1. In general, the research process can be divided into fourth steps:

1. Input preparation for radionuclide inventory calculation (step 1). The radionuclide inventory for fission products was calculated using ORIGEN2.1 computer code. The parameters of the reactor type of AP-1000 were used as the base of this calculation. Those parameters are shown in Table 1 (2).
2. In the sourceterm calculation (step 2 to 8), it is assumed that one-fourth of the fuels in the core are replaced every 1.5 years. The pinholes in the cladding occur in the time of ≥ 3 years. It is also assumed that after 6 years of operation there are one-fourth of fuels that has been irradiated for three years. Due to the pinholes in the fuel cladding, around 0.1% to 1% of the fission products release from the fuel into the primary coolant (2,3).
3. The calculation of the radiological dose accepted in the environment around the reactors (step 9 to 12) was performed using PC CREAM computer code (1,12). The input data of the PC-CREAM consist of the meteorological data (wind direction, wind velocity, stability, and rainfall rate). This meteorological data are one full year data which are collected per hour (± 8760 data for each parameter) for 16 sectors of the wind direction. These data were measured in

the position of 60 m from the ground. Meteorological data taken from local Meteorology Climatology and Geophysics Agency - BMKG (2012).

4. The data of spatial distribution of public as well as the data of local agricultural and animal products are also collected for each radius (0.5, 1, 1.5, 2, 2.5, 3, 4, 5, 6, 7, 8, 9, 10, 20, 30, 40, 50, 60, 70, and 80 km) in 16 sectors of wind direction**.** The data for agricultural and animal products are grain products, root vegetables, potatoes, green vegetables, milk, meat, liver of cow, sheep, goat, and etc. Population distribution data and agricultural spatial data are taken from the data of the local Central Bureau of Statistics (2012). These input data were then prepared by using ArcGIS software.

Table 1. Reactor parameters for fission products inventory calculation (2)

Parameter	**Value**
Fuel assembly matrix	17 x 17
Number of fuel assembly	264 rods
Total mass of UO_2 in fuels	613,823.73 g
Fuel composition at enrichment of 2.35%	
- U_{235}	12,715.22 g
- U_{238}	528,357.86 g
- O_{16}	72,750.66 g
Fuel composition at enrichment of 3.40%	
- U_{235}	18,396.19 g
- U_{238}	522,668 g
- O_{16}	72,759.27 g
Fuel composition at enrichment of 4.45%	
- U_{235}	24,076.99 g
- U_{238}	516,978.87 g
- O_{16}	72,767.88 g
Electric power	1117 MWe
Thermal power	3400 MWe
Operation time	18 to 24 months
Average fuel burnup	50 GWd/tU

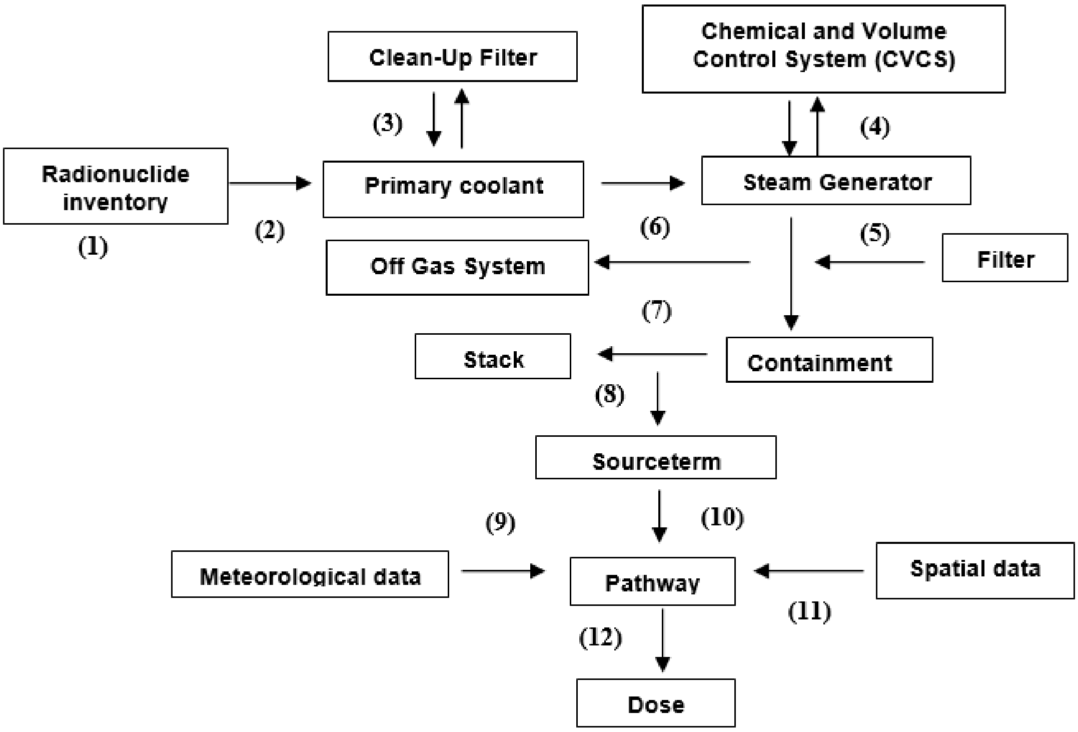

Figure 1. Calculation model for radiological safety evaluation of PWR at Sebagin Site

4. RESULTS AND DISCUSSION

The results for effective individual doses for each of the reactor (PWR-1, PWR-2, PWR-3) as well as the total dose from the three reactors are shown in the Figure 2. These results are the maximum individual doses from all of the released radionuclides, all exposure pathways, and all sectors. This dose are resulted from three PWRs which are separated by 500 m from each others. from the radius of 0.8 km instead of the radius of 0.5 km. The different results are observed from the PWR-3. The maximum dose comes from the radius of 0.5 km and then decreases with the increase of the radius. If the dose results from these three reactors are compared, the highest dose is resulted from the release of the PWR-3. The results for the total doses from these three reactors have the same trend with the results of PWR-1 and PWR-2 with maximum dose in the radius less than 1 km is about 0.332 mSv/year. This dose level is still much below the dose limit for the society which is 1mSv/year but near with the level of dose constraint which is 0.3 mSv/year (BAPETEN). This dose level is still acceptable since the radius of 800 m for 1000 MWe PWR is the exclusion area for radiation workers. From Figure 2 it can be stated that the atmospheric dispersion of the released radionuclide from three 1000MWe-PWRs in Sebagin site are affected by the meteorological condition which dominantly comes from the south direction.

From Figure 2, it can be observed that the doses are decreasing along with the increasing of the radius from the reactors. The reactor position (the distance and the angle position of each reactors) and meteorological condition affect the activity of the radionuclide and the dose level.

Although the sourceterms of the three reactors are the same, but the different position of the reactors produces different results for both the trend and the dose levels. The doses from the PWR-1 and PWR-2 have the same trend. The maximum dose obtained from the radius of 0.8 km instead of the radius of 0.5 km. The different results are observed from the PWR-3. The maximum dose comes from the radius of 0.5 km and then decreases with the increase of the radius. If the dose results from these three reactors are compared, the highest dose is resulted from the release of the PWR-3. The results for the total doses from these three reactors have the same trend with the results of PWR-1 and PWR-2 with maximum dose in the radius less than 1 km is about 0.332 mSv/year. This dose level is still much below the dose limit for the society which is 1mSv/year but near with the level of dose constraint which is 0.3 mSv/year (BAPETEN). This dose level is still acceptable since the radius of 800 m for 1000-MWe PWR is the exclusion area for radiation workers. From Figure 2 it can be stated that the atmospheric dispersion of the released radionuclide from three 1000MWe-PWRs in Sebagin site are affected by the meteorological condition which dominantly comes from the south direction.

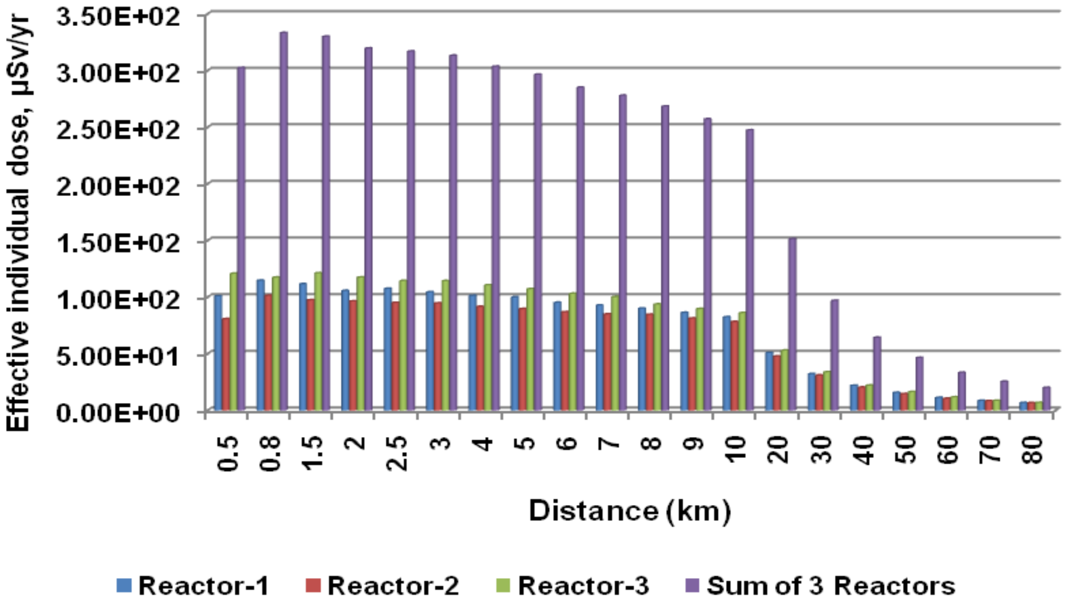

Figure 2. The individual effective doses from each of the PWRs as a function of the radius from the reactor

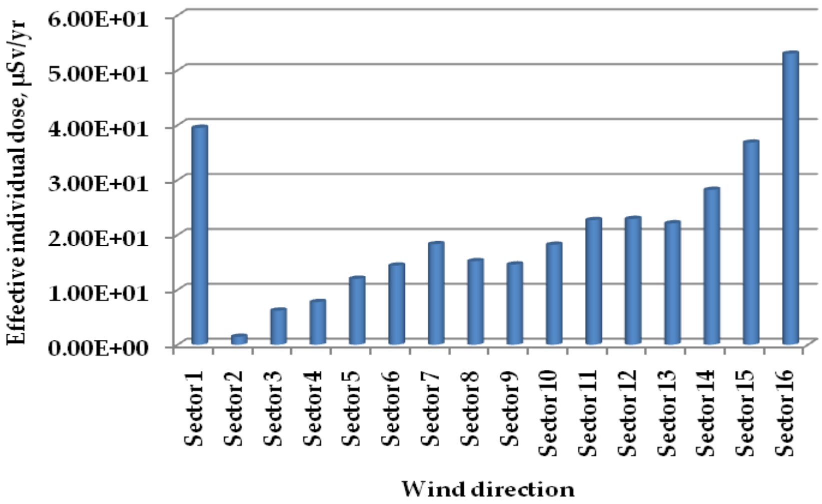

Figure 3. The individual effective doses from the three reactors in the radius of 1 km as a function of the wind direction.

Figure 3 shows the results for individual effective doses from the 3 reactors for all radionuclides and all exposure pathways as a function of wind direction. These results are the dose level in the radius of 1 km based on sector or wind direction. The highest dose is observed in the sector 16 with dose level of about 0.053 mSv/year. Compared to the results of the previous works reference of dose assessment from two PWRs in Semenanjung Muria site, the maximum individual dose from all pathways is merely around 62 µSv/year (3). The difference between the results in these two sites is caused by the different number of the reactors, calculation model, reactor position, and site. However, the important point from these results is that the dose level does not exceed the dose limit (1 mSv/year) as well the dose constraint (0.3 mSv / year) appointed by the regulation body (BAPETEN).

Figure 4 shows the individual effective dose from the three reactors as a function of some type of radionuclide in the radius of 0.8 km at sector 16. The highest contribution to the dose level comes from Rb-88 with dose level of 38.0 µSv/year. The half-life of Rb-88 is 12.31 days and it decays by emitting beta particle. The Rb-88 possibly comes from the decay of Kr-88. The other dominant radionuclides are Kr-88 and other noble gas, I-131 and other halogen nuclides, H-3 and C-14.

Figure 5 shows the contribution of radinuclides to the individual effective dose from all the three reactors. The largest contribution comes from the Rb-88 which is approximately 96%. The other nuclides contribute only in small portion such as Kr-88 for 2%, I-131 for 1%, and the rest of radionuclides are for 1%. The type of the radionuclide affects the dose level from all of the pathways.

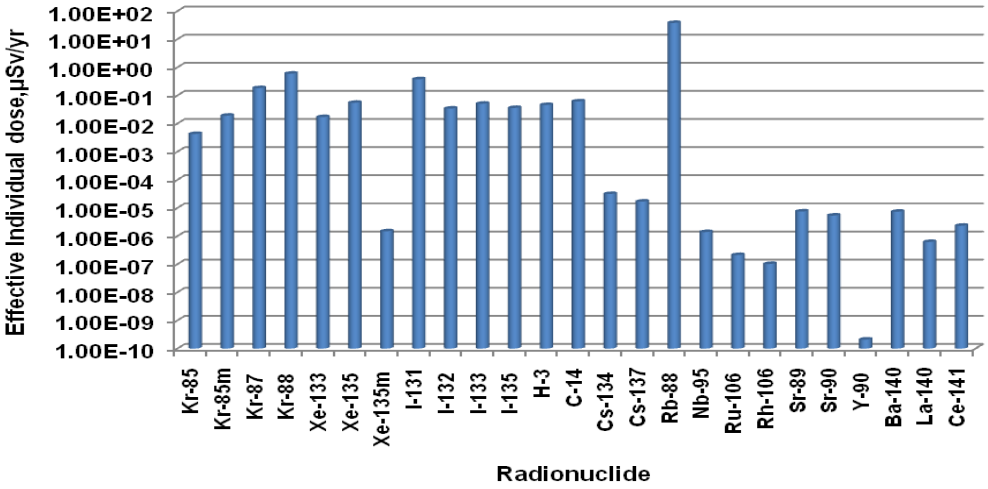

Figure 4. The individual effective doses from the three reactor in the radius 0.8 km of reactor 16 as a function of the type of the radionuclides.

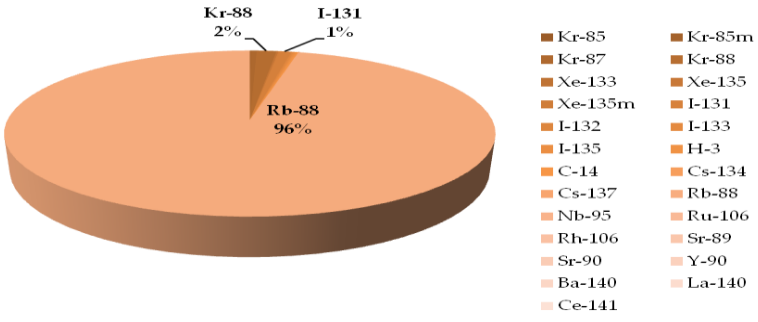

Figure 5. The contribution of the radionuclides to the individual effective doses from the 3 reactors in the radius of 1 km of sector 16

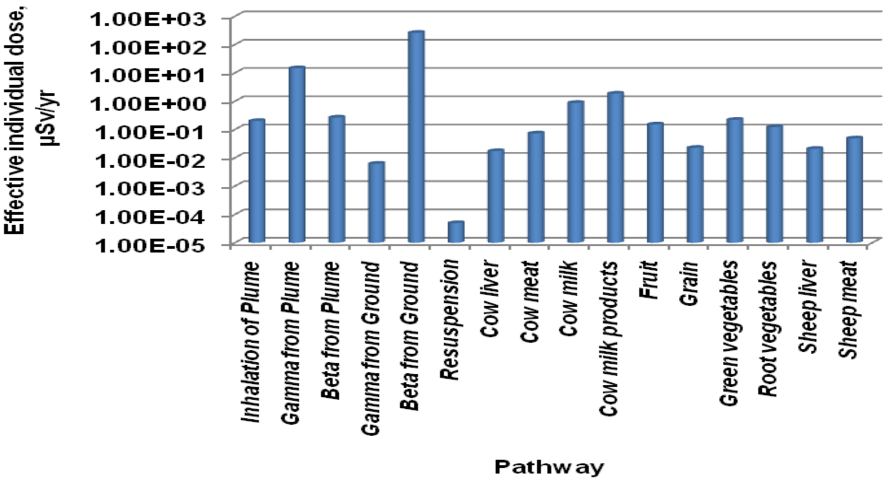

Figure 6. Individual effective doses from the 3 reactors in the radius of 0.8 km of sector 16 as a function of the pathways.

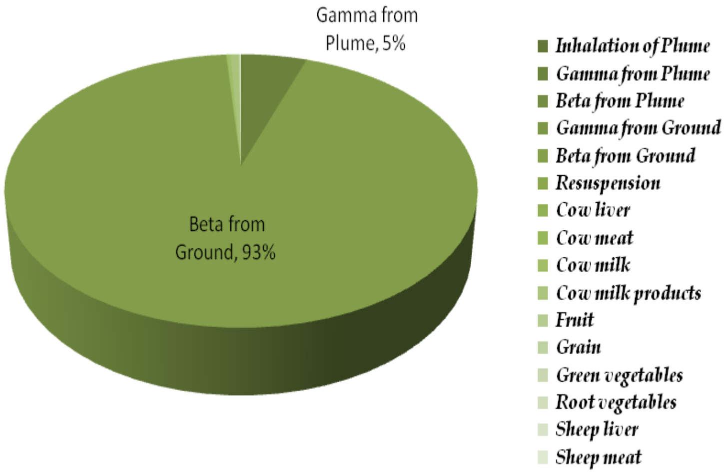

Figure 7. The contribution of the pathways to the individual effective dose from the 3 reactors in the radius of 0.8 km of sector 16

Figure 6 shows the results for individual effective dose as a function of pathways in the radius of 0.8 km at sector 16. The pathways that are considered by PC CREAM consist of internal exposure (inhalation, immersion, and ingestion) and external exposure. The inhalation and immersion pathway include the inhalation of plume and beta from plume. The ingestion pathway includes the beta from the ground, resuspension, consumption of local products such as cow liver, meat and milk, cow milk product, fruit, green vegetables, root vegetables, sheep liver, and sheep meat. The external exposure includes gamma and beta from plume, and resuspension. From Figure 6, it can be observed that the highest dose level comes from the pathways of Beta from Ground which is approximately 0.262 mSv/year.

Figure 7 shows the pathways contribution to the individual effective dose in the radius of 0.8 km at sector 16. It can be seen that around 93% of doses level is contributed by the Beta from Ground exposure, 5% from Gamma from Plume exposure, and 2% from other pathways. Figure 7 is consistent with the Figure 5 where the Rb-88 as the largest contibutor for dose with Beta from Ground pathway followed by Kr-88 and other noble gas from Gamma from Plume pathway. The individual effective dose from internal exposures are approximately 0.266 mSv/year from the inhalation, 0.0467 mSv/year from the immersion, and 0.265 mSv/year from the ingestion. The effective dose from external exposure is approximately 0.0467 mSv/year.

5. CONCLUSION

The results of this research show that the maximum dose from all type of the radionuclide and all of the pathways accepted by the public in the vicinity of the three PWRs at Sebagin site in normal operation condition is approximately 0.053 mSv/year toward the north direction in the radius of 1 km. This dose level is much lower than dose limit of 1 mSv/year or dose constrain of 0.3 mSv/year appointed by BAPETEN.

6. ACKNOWLEDGEMENT

The study is supported by PTKRN-BATAN through the facilities of Government Budgets in fiscal years 2014 as part of the research activity on safety analysis of PWR. Authors thank to colleagues from Safety Technology Division and fellow colleagues in the Reactor Safety Technology Division who have helped and encouraged author to complete this study.

7. REFERENCES

1. BIRIKORANG, S.A., ABREFAH, R.G., SOGBADJI, R.B.M. et al,. Ground deposition assessment of radionuclides following a hypothetical release from Ghana Research Reactor-1 (GHARR-1) using atmospheric dispersion model. Progress in Nuclear Energy. 2015. (79) 96-103.
2. UDIYANI, P.M,. Evaluasi Lepasan Radionuklida dari Reaktor AP-1000 ke lingkungan pada Operasi Rutin, Prosiding Seminar Nasional Pengembangan Energi Nuklir V. 2012 (in Bahasa Indonesia).
3. UDIYANI, P. M, and Sugianto, "Analisis Dispersi Radiasi Atmosferik Pengoperasian Reaktor Daya Air Ringan LWR", Prosiding Seminar Nasional ke-14 Teknologi dan Keselamatan PLTN serta Fasilitas Nuklir. No. ISSN 0854-2910. Bandung 2008 (in Bahasa Indonesia).
4. Vandenhove, H., Sweeck, L., Batlle, J. V., et al, Predicting the environmental risks of radioactive discharges from Belgian nuclear power plants, Journal of Environmental Radioactivity 2013 (126) 61-76
5. Schöppner, M., Plastino, W., Povinec, P.P., et al, Estimation of the time-dependent radioactive source-term from the Fukushima nuclear power plant accident using atmospheric transport modelling, Journal of Environmental Radioactivity 2012 (114) 10-14
6. Katata, G., Ota, M., Terada, H., et al, Atmospheric discharge and dispersion

of radionuclides during the Fukushima Dai-ichi Nuclear Power Plant accident. Part I: Source term estimation and local-scale atmospheric dispersion in early phase of the accident, Journal of Environmental Radioactivity 2012 (109) 103-113

7. GIUSEPPE, A., and MARZO. Atmospheric transport and deposition of radionuclides released after the Fukushima Dai-chi accident and resulting effective dose. Atmospheric Environment. 2014 (94) 709-722.
8. CHAI, T., DRAXLER, R., STEIN, A., Source term estimation using air concentration measurements and a Lagrangian dispersion model Experiments with pseudo and real cesium-137 from the Fukushima nuclear accident. Atmospheric Environment. 2015 (106) 241-251.
9. UDIYANI, P.M, and WIDODO, S., Penentuan koefisien dispersi atmosferik untuk analisis kecelakaan reaktor PWR di Indonesia. Jurnal Teknologi Reaktor Nuklir. Tri Dasa Mega 2012. 14 (2) 122-127 (in Bahasa Indonesia).
10. JEONG, H., PARK, M., JEONG, HAESUN et al, “Radiological dose assessment according to dilution characteristics of radioactive materials in nuclear sites”, Annals of Nuclear Energy. 2014. (63) 261–267.
11. YAO, R., “Atmospheric dispersion of radioactive material in radiological risk assessment and emergency response”. Progress in Nuclear Science and Technology. 2011. (1) 7-13.
12. LOZANO, R.L. HERNÁNDEZ-CEBALLOS, M.A., ADAME, J.A. et al, “Radioactive impact of Fukushima accident on the Iberian Peninsula: Evolution and plume previous pathway”, Environment International. 2011. (37) 1259–1264.
13. WOO, T. H., “Atmospheric modeling of radioactive material dispersion and health risk in Fukushima Daiichi nuclear power plants accident”, Annals of Nuclear Energy. 2013 (53) 197–201.
14. M. Sohrabi, Z. Parsouzi, R. Amrollahi, “Public exposure from environmental release of radioactive material under normal operation of unit-1 Bushehr nuclear power plant”,Annals of Nuclear Energy. 2013. (55) 351–354.
15. PETR, P., and PECHOVA, E., “An unconventional adaptation of a classical Gaussian plume dispersion scheme for the fast assessment of external irradiation from a radioactive cloud, Atmospheric Environment. 2014. (89) 298-308.
16. LEELOSSY, Á., MÉSZÁROS, R., LAGZI, I., “Short and long term dispersion patterns of radionuclides in the atmosphere around the Fukushima Nuclear Power Plant”, Journal of Environmental Radioactivity 2011 (102) 1117-1121.
17. CRAWFORD, J., and DOMEL R.U., “Rad-Con: a Radiological Consequences Model”, User Guide, ANSTO M-128, ISBN 0-642-59983, Sydney. 2005. 2-10.