

Analysis of Radionuclide ^{137}Cs in Soil and Rice (*Oryza sativa*) Samples of Pandeglang Regency-Banten Using Gamma Spectrometer

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Abstract- ^{137}Cs is a radionuclide that can accumulate in soil and plants and is potentially hazardous to humans. When ^{137}Cs enters the human body, it will be distributed to soft tissues such as muscle and bone tissue. This study aims to determine the concentration of radionuclide ^{137}Cs in soil and rice (*Oryza sativa*) in the Pandeglang Regency. Soil samples were dried at 105 °C, ground, sieved, and put into a Marinelli beaker. The rice sample was mashed and put into a Marinelli beaker and then analyzed using a gamma spectrometer. The rice sample was washed at 400 °C and put into a vial and then analyzed again for comparison. The parameters tested were the concentration of ^{137}Cs in the sample, Minimum Detectable Concentration (MDC), and measurement uncertainty. The results of the measurement of the highest radionuclide concentration of ^{137}Cs in soil, rice, and rice ash samples were in Carita District, respectively 0.2178; 0.1588 and 0.3418 Bq/kg. This result is because Carita Subdistrict is close to the location of the explosion at PT. X which is located in Cilegon-Banten. The results of radionuclide analysis in soil samples, rice, and rice ash produced below the threshold set by PERKA BAPETEN No. 9 of 2009 the maximum concentration for radionuclide ^{137}Cs in the soil is 1000 Bq/kg and PERMENKES RI No. 1031 of 2011 the maximum concentration of radionuclides in soil. food ingredients are 500 Bq/kg.

Key words. ^{137}Cs , gamma spectrometer, radionuclide, rice, soil

I. INTRODUCTOIN

^{137}Cs is a gamma radiation emitter at energy (E) 661.66 keV with an abundance of gamma energy ($P\lambda$) of 0.85 and has a half-life of about 30 years [1]. The chemical and physical properties of a radionuclide greatly affect the absorption of metabolism in the body. One of the routes of entry of radionuclides into the body is through the digestive tract of food. ^{137}Cs in the body mostly (80%) is deposited in muscle while a small portion (8%) is deposited in bone and fat. Exposure to ^{137}Cs radiation can increase the risk of cancer, if the exposure is very high it can cause death) [2]. ^{137}Cs has the same properties as the element Potassium (K). Both of these elements are in Group IA on the periodic table of elements, so ^{137}Cs can replace the role of K in muscles and bones [3]. Each radionuclide has a certain energy and is specific [4].

Efforts to avoid the dangers posed by a radionuclide are important to do. One of them is by identifying radionuclide contamination in the environment. Radionuclide analysis in this study used soil samples. The sample selection in this study was based on the fact that this is one way to determine the radioactive contaminants present in the soil by using plants that are able to absorb radionuclides from the soil. This method is known as phytoremediation [5]. The plant used in this study is rice so that the analysis uses white rice (*Oryza sativa*). This is because white rice is a staple food for most Indonesian people. Poor rice quality can affect health and reduce the quality of human resources [6].

Research on radionuclide ^{137}Cs in food has been carried out by Nirwani et al. (2001) on the concentration of natural radionuclides and ^{137}Cs in rice in Jepara Regency. Rice was taken from several locations around the Muria Peninsula, namely Sidorejo, Bayuran, Tubanan, Duren, Bandungharjo, Dermayu, Kancilan and Sekuping villages. The highest concentration of ^{137}Cs in rice was in Bayuran Village at 2.64×10^{-5} Bq/kg with an average value of 1.19×10^{-5} Bq/kg.

Based on the dangers of a radionuclide, it is necessary to analyze radionuclides in foodstuffs in Pandeglang-Banten Regency. Pandeglang Regency is an area that has excellent and productive agricultural potential to become a leading sector. Pandeglang Regency is also a food barn in Banten Province that can determine regional food security [7]. Pandeglang Regency is the region that contributes the largest rice production, which is more than 30% or 721,872 tons of the total rice production in Banten Province which amounted to 2.3 million tons in 2016. This shows that Pandeglang Regency is the center of rice production in the Province of Indonesia. Banten [8]. Banten Province statistical data shows the total rice productivity per hectare in Pandeglang Regency in 2018 was ranked first with a total rice production of 449,695 tons with an area of 91,893 Ha [9].

Pandeglang Regency has a very wide area of 2,746.90 km² which consists of 35 Districts and 335 Villages/Kelurahan [10]. The sample in this study was taken in the western part of Pandeglang Regency, namely the Districts of Carita, Labuan, Jiput and Pulosari. Research on ¹³⁷Cs radionuclide contamination in the environment has been carried out by Nirwani et al. (2018) which is about "Gross Beta and ¹³⁷Cs Radioactivity Levels in Rainwater in the Serpong Nuclear Area". Rainwater sampling was carried out continuously every month from 2007 to 2016, and its activities included sample preparation by preconcentration, then analysis by gamma spectrometry. The measurement results showed that the gross beta radioactivity level ranged from 0.0135 to 0.4882 Bq/L, while the radioactivity of ¹³⁷Cs ranged from < 2.10 to 132.10 Bq/m³. This value is still below the environmental radioactivity level permitted by the Minister of Health of the Republic of Indonesia (1990) for clean water, namely gross beta 1000 Bq/L, while ¹³⁷Cs 260 (Bq/m³) according to Bapeten (2017), so it is categorized as relatively safe for drinking water. used.

The instrument used for the analysis of radionuclide ¹³⁷Cs is a gamma spectrometer with a high purity germanium semiconductor detector (HPGe). The gamma spectrometer is a tool for analyzing radioactive substances that emit gamma radiation [4]. Gamma spectrometer besides being able to be used to analyze ¹³⁷Cs radionuclide can also be used to analyze other radionuclides that can emit gamma radiation. So in this study there may be other radionuclides detected by the device.

Based on these background data, it is necessary to conduct research on the quality of soil and rice in Pandeglang-Banten Regency by measuring the amount of radionuclide content, in this case is cesium (¹³⁷Cs).

II. MATERIALS AND METHODOLOGY

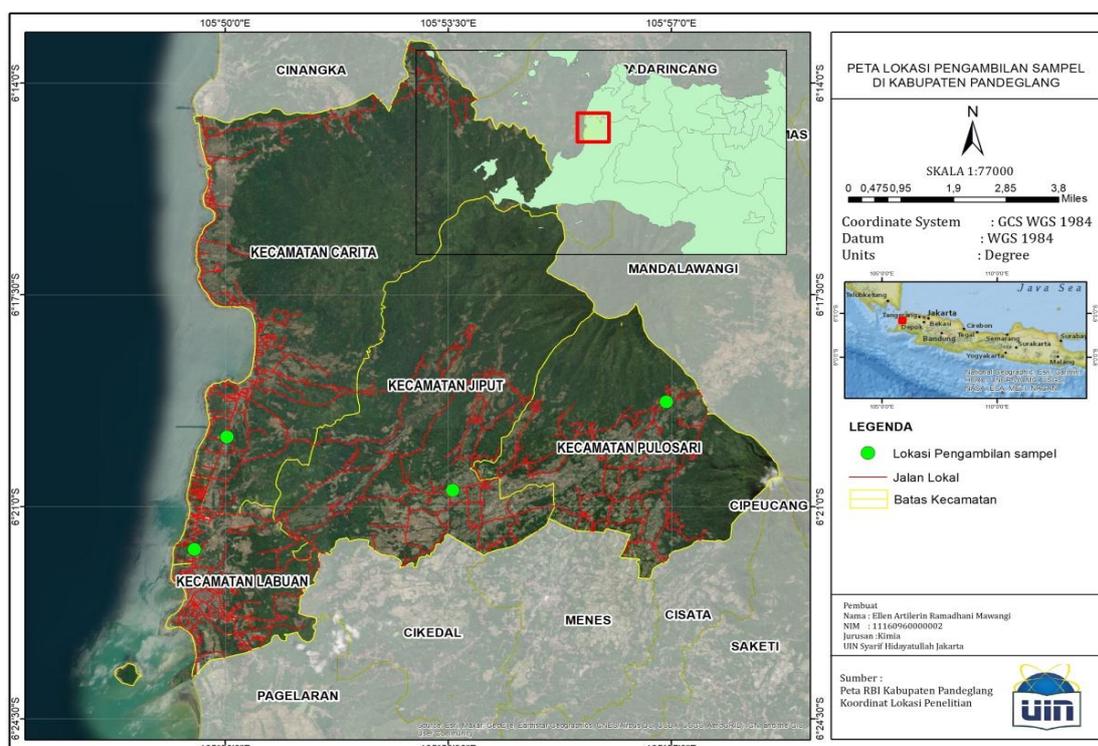
A. Tools and Material

The tools used in this research are muffle furnace, 1 liter marinelli beaker, vial, gamma spectrometer tool Gamma spectrometer (Ortec brand) with HPGe detector, masking tape, label paper, markers, glassware, tray, scissors, blender, plastic bag, 60 mesh sieve, and scale. The materials used in this study were 2 kg soil samples, 5 kg Ciherang rice and 20 L liquid nitrogen. Soil and rice samples were taken from Carita, Jiput, Labuan and Pulosari Districts.

C. Research Procedure

Determining the Location of Soil and Rice Sampling

In this study, sampling was carried out in Pandeglang-Banten Regency which included a sampling radius of 1 sample per sub-district on GPS coordinates at the midpoint or close to it (Figure 1 and Table 1).



| No. | Farmer | Sample Code | Sampling Location | Date | Time | Coordinate point |
|-----|--------|--------------------|-------------------|--------------------------------|---------|------------------------|
| 1. | A | TC1 / Soil | | | | |
| 2. | A | BC1 / Rice | Carita District | 9 th November 2020 | 1.03 PM | S06°19.828'E105°50.068 |
| 3. | A | ASH BC1 / Rice Ash | | | | |
| 4. | B | TJ2 / Soil | | | | |
| 5. | B | BJ2 / Rice | Jiput District | 10 th November 2020 | 1.20 PM | S06°20.732'E105°53.569 |
| 6. | B | ASH BJ2 / Rice Ash | | | | |
| 7. | C | TL3 / Soil | | | | |
| 8. | C | BL3 / Rice | Labuan District | 11 th November 2020 | 1.25 PM | S06°21.705'E105°49.501 |
| 9. | C | ASH BL3 / Rice Ash | | | | |
| 10. | D | TP4 / Soil | | | | |
| 11. | D | BP4 / Rice | Pulosari District | 12 th November 2020 | 1.05 PM | S06°19.256'E105°56.935 |
| 12. | D | ASH BP4 / Rice Ash | | | | |

Sampling and Analysis of Soil Samples

Soil samples were taken in rice fields planted with rice at a depth of 0-5 cm as much as 2 kg in each selected sub-district [11]. A 1 L Marinelli beaker was prepared and labeled with the sample code. The sample was cleaned of impurities, then the soil sample was dried at 105 °C in the oven. The sample was then ground with a mortar and sieved with a 50 - 60 mesh sieve. The sample was put into a 1 L Marinelli beaker until it was almost full then the sample weight was weighed and the container was closed. The weight of the sample was weighed and recorded. The Marinelli beaker is closed and sealed with tape. Soil samples were counted directly using a gamma spectrometer for 3600 seconds and then recorded [12].

Sampling and Analysis of Rice (*Oryza sativa*) Samples

Rice samples were taken in the fields and then milled to become 5 kg of rice at each selected location [2]. A 1 L Marinelli beaker was prepared and labeled with the sample code. The sample is cleaned from the skin and then mashed. The sample to be measured is put into a 1 L Marinelli beaker and the weight of the sample is measured and the weight is recorded. The Marinelli beaker is closed and sealed with tape. Samples were counted directly with a gamma spectrometer for 3600 seconds. The measurement results were recorded, and the samples were ashed in a muffle furnace at 400 °C. The weight of the ash was weighed after being homogenized by mixing one container with another sample container from the same location and then stirring, then put into a vial. The vial was closed and the concentration of ¹³⁷Cs in the sample was measured using a gamma spectrometer, the data obtained were recorded [13].

III. RESULTS AND DISCUSSION

The gamma spectrometer system needs to be calibrated with a standard source before being used for measurements. The calibrations carried out are energy calibration and efficiency calibration. Energy calibration is required to determine the relationship between channel number and gamma energy (keV). Each radionuclide has a different energy and is specific, this is what is used as the basis for both qualitative and quantitative analysis [14]. Measurement of gamma energy calibration is a qualitative analysis that aims to determine the background conditions of the enumeration room using standard sources [15]. Energy calibration aims to synergize the peaks of each energy spectrum with the actual energy so that for the next sample count, a spectrum with the appropriate energy peaks will be obtained [16]. This study used two types of sample containers, namely Marinelli and vials. The standard source types used are EW-679 for the Marinelli type of container and GM 011 V for the vial type of container. Both types of standard sources are calibrated. Energy calibration was carried out after calculating the radionuclide activity at the standard source.

Radiant activity represents the number of decays that occur per second. Activity is not related to the type of radiation and radiation energy, but only relates to the number of decays per unit time. If the initial activity of a radionuclide is A_0 then after t seconds its activity becomes A which follows equation 1 [17]. The results of the calculation of radionuclide activity at the standard source EW-679 are in Table 1.

Table 1. EW-679 . standard source radionuclide activity data

| Radionuclide | Reference Time in Certificate | Half Time (day) | Activity Radionuclide on Certificate (Bq) | Count Date | Delay Time (day) | Activity on Count (Bq) |
|-------------------|-------------------------------|-----------------|---|------------|------------------|------------------------|
| ¹³⁷ Cs | 10/06/2020 | 10958 | 1806,6 | 06/01/2021 | 210 | 1782,766 |
| ⁶⁰ Co | 10/06/2020 | 1925 | 142,9 | 06/01/2021 | 210 | 132,495 |

The results of the calculation of the activity of the three radionuclides in this standard source are then compared with the values stated in the radionuclide standardization certificate as a reference value. The activities of these two radionuclides listed on the certificate are 1806.6 Bq and 142.9 Bq, respectively. Table 6 shows that the activity of the standard source radionuclides on the certificate was higher than that of the radionuclides when enumerated. This is due to the decay process (decay). Decay is the process of changing an unstable atomic nucleus (radionuclide) into a stable nucleus. Decay can also mean the process of emitting rays of radioactive substance by a radionuclide. In addition, the decay process is random. Atomic nuclei do not decay all at once but one by one in a certain time interval. Radioactive substances have a half-life that is required for a radioactive substance so that part or half of the radioactive nucleus decays [18]. The rate at which a radioactive nucleus decays is called activity. The greater the activity, the more atomic nuclei decay per second. The activity possessed by a radionuclide will be reduced if the radionuclide undergoes decay to achieve stability [19]. The standard source activity value after being obtained from the calculation results, then the standard source calibration is carried out. The data from the energy source calibration of the EW-679 standard is obtained as shown in Table 2.

Table 2. EW-679 . standard source energy calibration data

| Radionuclide | Energy (keV) | Yield | Activity Radionuclide on Certificate (Bq) | Channel Number | Net Area |
|-------------------|--------------|----------|---|----------------|----------|
| ¹³⁷ Cs | 661,657 | 0,85 | 1806,6 | 3061 | 32140 |
| ⁶⁰ Co | 1173,228 | 0,999 | 142,9 | 5426 | 1865 |
| ⁶⁰ Co | 1332,492 | 0,999824 | 142,9 | 6160 | 1718 |

This EW-679 standard source is used for samples placed on Marinelli such as soil samples (TC1, TJ2, TL3 and TP4) as well as rice samples (BC1, BJ2, BL3 and BP4). The data in Table 7 shows that the higher the energy possessed by a radionuclide, the higher the channel number. Faith et al. (2013) said that the interaction of γ -rays with the detector will produce a pulse signal. The pulse height will be proportional to the power of the γ -ray hitting the detector. The pulse height is recorded in a channel with a certain number, so that the channel number will be proportional to the energy of the γ -ray [20]. Indrayani (2018) explains that the pulse height generated by the detector in γ -spectrometry is equivalent to the energy of γ -rays hitting the detector, so the channel number of the dual-channel analyzer is also proportional to the energy of γ -rays. A plot of the γ -photon energy level versus channel number is then obtained as a straight line. This plot is called the energy calibration. The EW-679 standard source energy calibration curve is shown in Figure 5. The calibration curve equation (linearity) shows the relationship between line number and energy. Measurement of the calibration curve (linearity) was measured using a standard mixed source (mixed gamma) with a minimum of 3 energy peaks, namely using a standard source of ¹³⁷Cs with an energy of 661,657 keV, ⁶⁰Co with an energy of 1173.228 keV and ⁶⁰Co 1332.492 keV whose radionuclide activity is known from EW-679 certificate.

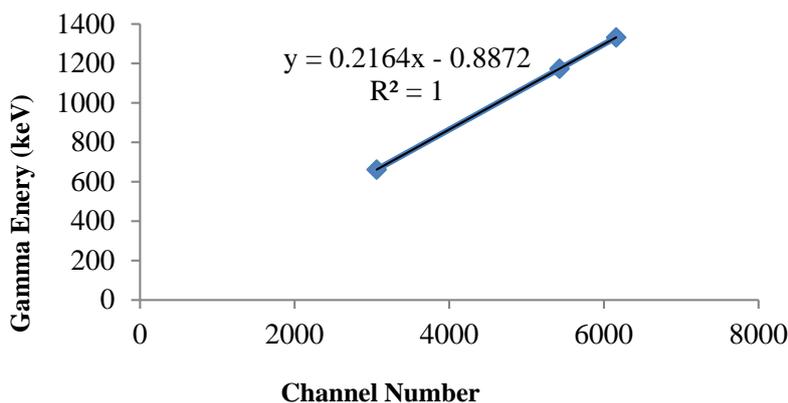


Figure 1. Energy Calibration Curve at Standard Source (Marinelli)

Figure 1 shows the equation $y = 0.2164 x - 0.8872$ and the correlation coefficient $R^2 = 1$. This value illustrates the existence of a directly proportional correlation between energy and channel number. These results also indicate that the results of the analysis meet the requirements with a correlation coefficient value of $R^2 = 1$. After energy calibration is carried out on the EW-679 standard source, then the standard source activity is determined and the standard source calibration is GM-011 V. Energy source calibration is GM-011 standard V was performed after the calculation of radionuclide activity. GM-011 V standard source activity data in Table 3.

Table 3. Standard source activity data GM-011 V

| Radionuclide | Reference Time in Certificate | Half Time (day) | Activity Radionuclide on Certificate (Bq) | Count Date | Delay Time (day) | Activity on Count (Bq) |
|-------------------|-------------------------------|-----------------|---|------------|------------------|------------------------|
| ⁶⁰ Co | 01/10/2004 | 1925 | 215,48 | 09/03/2021 | 6003 | 24,823 |
| ¹³⁷ Cs | 01/10/2004 | 10958 | 52,85 | 09/03/2021 | 6003 | 36,155 |
| ¹³³ Ba | 01/10/2004 | 3847 | 169,07 | 09/03/2021 | 6003 | 57,336 |
| ²⁴¹ Am | 01/10/2004 | 157899 | 225,03 | 09/03/2021 | 6003 | 219,179 |

Table 3 shows the radionuclide activity of ⁶⁰Co, ¹³⁷Cs, ¹³³Ba and ²⁴¹Am at the standard source count, which is 24,823 Bq; 36,155 Bq; 57,336 Bq and 219,179 Bq. The activity of each radionuclide in the standard source stated on the certificate is 215.48 Bq; 52.85 Bq; 169.07 Bq and 225.03 Bq. The time reference used to calculate the GM-011 V standard source activity is March 9, 2021. The time stated in the GM-011 V standard source certificate is October 1, 2004 so the delay is 6003 days. This long delay caused the radionuclide activity result at the time of enumeration to be much lower than the activity stated on the certificate. Activity is the change in the number of radioactive nuclei per unit time. Radioactive elements will decay at a certain time. When a radioactive element decays, the number of nuclei decreases, so the activity possessed by the radioactive element will decrease [21]. After the activity of the standard source is obtained, energy calibration is carried out (Figures 5 and 6).

Energy calibration data of standard source GM-011 V is in Table 9. This standard source is used for samples placed in vials such as rice ash samples (BC1 ash, BJ2 ash, BL3 ash and BP4 ash). Table 9 shows the results of energy calibration on radionuclides that have high energy, when the standard source count also obtains a high channel number. According to Sudiati (2005), the channel number is proportional to the energy of rays. The higher the detected -ray, the higher the line number of the resulting pulse. Measurement of a standard source whose energy is known and recorded the channel number corresponding to the energy, the result can be made a graph of the relationship between energy and channel number [22].

Table 4. Energy source calibration data standard GM-011 V

| Radionuclide | Energy (keV) | Yield | Activity Radionuclide on Certificate (Bq) | Channel Number | Net Area |
|-------------------|--------------|----------|---|----------------|----------|
| ⁶⁰ Co | 1173,228 | 0,999 | 215,48 | 5425 | 9821 |
| | 1332,492 | 0,999824 | | 6160 | 8525 |
| ¹³⁷ Cs | 661,657 | 0,85 | 52,85 | 3060 | 23168 |
| | 80,9979 | 0,3661 | | 375 | 34734 |
| | 276,3989 | 0,071 | | 1279 | 6340 |
| ¹³³ Ba | 302,8508 | 0,1833 | 169,07 | 1402 | 14751 |
| | 356,0129 | 0,623 | | 1647 | 43476 |
| | 383,8485 | 0,0892 | | 1776 | 6205 |

The graph obtained will generally be in the form of a straight line (linear) which is referred to as an energy calibration graph and is used as the basis for qualitative analysis. The graph of the energy calibration measurement results in Figure 2.

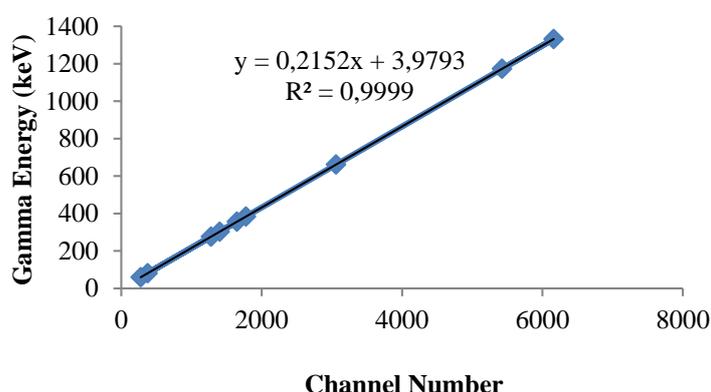


Figure 2. Energy Calibration Curve at Standard Source (Vial)

The energy calibration curve in Figure 2 is a calibration curve with a standard source vial container (GM-011 V) consisting of grass ash. The figure shows a linear relationship between channel number and energy and the equation $y = 0.2152x + 3.9793$ and the correlation coefficient $R^2 = 0.9999$. This value describes a very good linearity. As a general rule, a value of $0.90 < r < 0.95$ indicates a fairly good curve, a value of $0.95 < r < 0.99$ indicates a good curve and a value of $r > 0.99$ indicates a very good linearity. The maximum value of r is 1 which indicates the exact correlation coefficient between concentration and absorbance. Based on the data obtained, the correlation coefficient (r) is 0.9999, which means that it shows very good linearity [23]. The regression coefficient value obtained is greater than 0.98 or close to 1. These results indicate good linearity with respect to the accuracy of the measuring data that is close to the true value [24].

Efficiency Calibration

Efficiency calibration was carried out to determine the ability of the detector to capture every energy from the gamma emitting radionuclide contained in a sample [11]. The efficiency calibration curve is made by measuring radioactive standard sources with known productivity. The gamma spectrum can help researchers to find out the counts per second (cps) of each peak at a certain energy by finding the net area of the peak divided by the counting time in seconds [25]. Efficiency calibration curve, as abscissa is energy (keV) and ordinate is efficiency. The efficiency calibration curve shows that at energy < 100 keV, efficiency will increase in proportion to the increase in energy (gamma rays) and at energy > 100 keV the opposite is true, namely efficiency will decrease in proportion to the increase in energy [25]. The efficiency calibration of the HPGe detector gamma spectrometer system model GEM F5930-3 can be seen in Figures 7, 8 and 9.

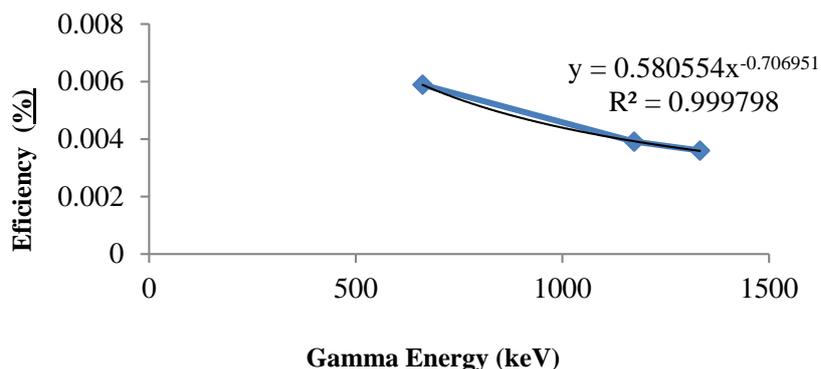


Figure 3. Efficiency Calibration Curve at EW-679 . Standard Source

Figure 3 shows the relationship between energy and efficiency with $y = 0.580554 x^{-0.706951}$ with R^2 of 0.989200. The value of the coefficient of determination obtained is 0.999798 (close to 1), this result shows the accuracy of the measured data that is close to the correct value. The efficiency calibration carried out is thus acceptable.

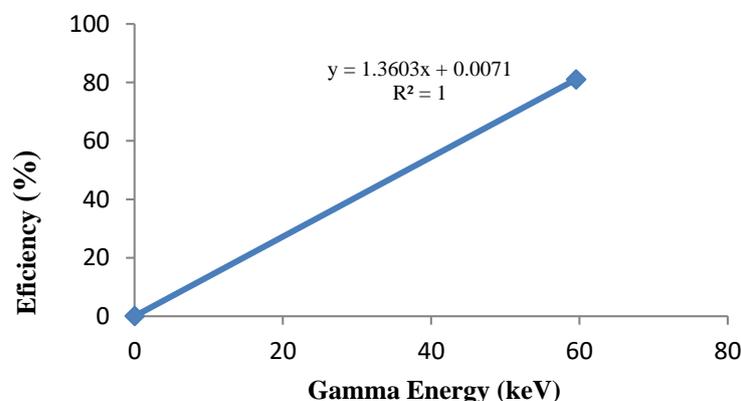


Figure 4. GM-011 V Low Energy Efficiency Calibration Curve

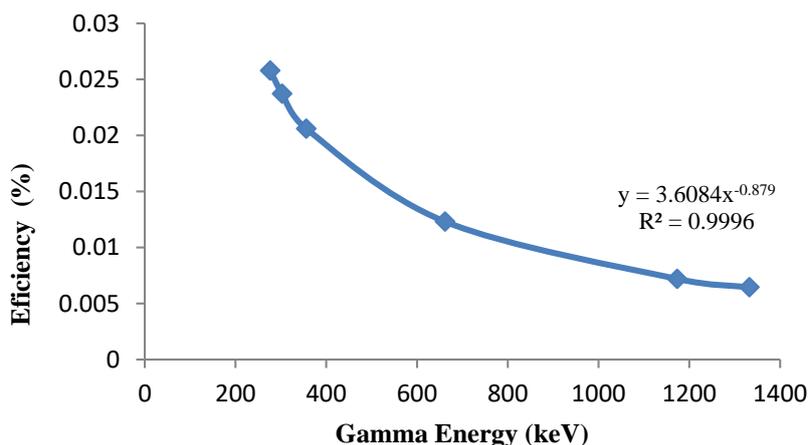


Figure 5. GM-011 V High Energy Efficiency Calibration Curve

Figures 4 and 5 can be seen that the efficiency of the gamma spectrometer system has specific characteristics. Efficiency values increase in the energy range below 100 keV. This is due to the absorption of low energy gamma photons by the cap or detector cover. Gamma photons with energies higher than 100 keV have sufficient energy to penetrate the detector cap; so that the absorption process for gamma photons with higher energy will decrease, and the efficiency of splitting gamma photons will increase. The decrease in efficiency occurs for gamma photon counts with energies above 100 keV. This is because when there is

an increase in energy from 100 keV to more than 1 MeV, most of the gamma photons still interact with the detector material. However, the interaction in the form of Compton scattering occurs more than the interaction of splitting gamma photons. Thus, the counting efficiency is reduced for gamma photon energies above 100 keV [26].

Figure 8 shows the efficiency at energy below 100 keV obtained by the efficiency equation = $1.3603 x + 0.0071$ with $R2 = 1$ with a fairly steep curve. Energy above 100 keV obtained the equation Efficiency = $3.6084 x - 0.879$ with $R2 = 0.9996$ with a fairly sloping curve. The equation for energy below 100 keV uses a linear equation, while the energy above 100 keV has the characteristics of an exponential equation. The value of the correlation coefficient (R2) shows that the efficiency curve has a correlation coefficient with a value of R2 1, this means that each point approaches the efficiency curve line. The analysis is carried out directly if the analyzed radionuclides are the same as the standard, while the efficiency curve is used to calculate different radionuclides but within the energy range contained in the efficiency curve [14].

Radionuclide Concentration in Sample

Measurement of the radionuclide concentration in the sample begins with measuring the background count for 3600 seconds. The measurement of the background count in this study was by inserting a sample container (Marinelli/vial) containing distilled water into the gamma spectrometer and then measuring it. After measuring the background radiation, each sample was measured for 3600 seconds and identified the radionuclides in the spectrum. The results of the sample enumeration, obtained data in the form of a γ -energy spectrum. Based on the γ -energy spectrum that emerged from the results of the sample enumeration, qualitative and quantitative analyzes were then carried out. Qualitative analysis was carried out by determining the peaks in the gamma energy spectrum. After determining the peak in the energy spectrum, it is adjusted to the Laboratoire National Henri Becquerel (LNHB), so the type of radionuclide contained in the sample can be known [27]. The width of the curve is strongly influenced by the type of detector and instrumentation used, and greatly affects the reliability of a spectroscopic system. The narrower the curve, the better the spectroscopic system because it can better distinguish two adjacent energy peaks [28]. High Purity Germanium (HPGe) detectors have two main characteristics that must be considered related to the quality of HPGe detector performance, namely efficiency and resolution. Resolution is the detector's ability to separate two adjacent peaks in the spectrum. The efficiency of the detector depends on the energy of the radiation, the distance between the sample and the detector, and the active volume of the detector crystal. The larger the volume of the detector the greater the efficiency. The narrower the curve, the better the spectroscopic system because it can better distinguish or separate two adjacent energy peaks. The value used as a measure of the width of this curve is called the resolution of the spectroscopic system [29]. The resolution value of commercial NaI(Tl) detectors is around 60 keV while commercial HpGe detectors are around 2 keV. So this means that the two energy peaks that are 50 keV apart are already difficult to separate when using a NaI(Tl) detector, but will be clearly separated using a High Purity Germanium (HPGe) detector. Semiconductor detectors have good resolution because the amount of charge produced per unit of energy is more than other detectors so that they have a smaller measurement uncertainty value [29].

Table 5. Data Analysis of ^{137}Cs and ^{60}Co and ^{131}I Radionuclides in Samples

| Sample | Radionuclide | | | | | | | | |
|----------|---------------------------------|----------------|---------------|--|----------------|---------------|--------------------------------|----------------|---------------|
| | ^{137}Cs (661,657 keV) | | | ^{60}Co (1173,228 keV dan 1332,492 keV) | | | ^{131}I (364,489 keV) | | |
| | Concentration (Bq/kg) | MDC (Bq/kg) | UC (Bq/kg) | Concentration (Bq/kg) | MDC (Bq/kg) | UC (Bq/kg) | Concentration (Bq/kg) | MDC (Bq/kg) | UC (Bq/kg) |
| TC 1 | 0,2178 | 0,3102 | 0,0405 | 0,3726 | 0,6557 | 0,0671 | <MDC | 0,3177 | <MDC |
| TJ 2 | 0,1201 | 0,3102 | 0,0271 | 0,3144 | 0,6557 | 0,0564 | <MDC | 0,3177 | <MDC |
| TL 3 | 0,1885 | 0,3102 | 0,0368 | 0,927 | 0,6557 | 0,1623 | <MDC | 0,3177 | <MDC |
| TP 4 | 0,1931 | 0,3102 | 0,0377 | 1,0251 | 0,6557 | 0,0899 | 0,0589 | 0,3177 | 0,0108 |
| BC 1 | 0,1588 | 0,3102 | 0,0309 | 0,3225 | 0,6557 | 0,1519 | <MDC | 0,3177 | <MDC |
| BJ 2 | 0,0848 | 0,3102 | 0,0218 | 0,3262 | 0,6557 | 0,0181 | <MDC | 0,3177 | <MDC |
| BL 3 | 0,0859 | 0,3102 | 0,0208 | 0,5786 | 0,6557 | 0,1218 | <MDC | 0,3177 | <MDC |
| BP 4 | <MDC | 0,3102 | <MDC | 0,7337 | 0,6557 | 0,0772 | <MDC | 0,3177 | <MDC |
| Ash BC 1 | 0,3418 | 0,4319 | 0,0593 | 0,1943 | 1,8002 | 0,0364 | <MDC | 0,8103 | <MDC |
| Ash BJ 2 | 0,2029 | 0,4319 | 0,0358 | 0,3594 | 1,8002 | 0,0632 | <MDC | 0,8103 | <MDC |
| Ash BL 3 | 0,2466 | 0,4319 | 0,0432 | 0,3638 | 1,8002 | 0,0644 | <MDC | 0,8103 | <MDC |
| Ash BP 4 | 0,0763 | 0,4319 | 0,0141 | 0,4716 | 1,8002 | 0,0819 | <MDC | 0,8103 | <MDC |

Description:

TC 1 : Soil in Carita
TJ 2 : Soil in Jiput

BC 1: Rice in Carita
BJ 2 : Rice in Jiput

Ash BC 1: Rice ash Carita
Ash BJ 2 : Rice ash Jiput

TL 3 : Soil in Labuan
 TP 4 : Soil in Pulosari

BL3 : Rice in Labuan
 BP4 : Rice in Pulosari

Ash BL3 : Rice ash Labuan
 Ash BP4 : Rice ash Pulosari

The results of the analysis of the Minimum Detectable Concentration (MDC) value of soil and rice samples compared to rice ash samples showed differences (Table 10). This difference is due to the soil and rice samples using Marinelli containers for measurement analysis so that the standard source used is also the Marinelli standard source, namely EW-679. The type of container used for the analysis of the rice ash sample is the type of vial container so that the standard source used is also the standard vial source, namely GM-011 V. The difference in this container is one of the factors that affect the mass of each different type of sample. The minimum detectable concentration (MDC) for a gamma spectrometer system is influenced by the counting efficiency, background count and sample weight [30]. Table 10 also shows that apart from the type of sample, the difference in MDC values is also seen in the different types of radionuclides analyzed. This value is because each radionuclide has a different efficiency value and is influenced by the abundance of gamma in each radionuclide. Data from the Henri Becquerel National Laboratoire (LNHB) show that the radionuclide ^{137}Cs has a gamma abundance of 85%; ^{60}Co 99.9% at energy 1173.228 keV; ^{60}Co 99.9824% at 1332.492 keV and ^{131}I energy of 81.2%. The calculation of the efficiency value for each container and each radionuclide uses equation 3. The equation shows that the greater the gamma abundance, the smaller the resulting efficiency value (inversely proportional).

The uncertainty value obtained in this study is different for each sample. The resulting uncertainty value is because the concentration of the results of the enumeration in each sample is different, besides that the mass of each sample is also different. This result is in accordance with the statement of Wahyudi et al. (2007) that the uncertainty value of efficiency is obtained from several factors, namely; value from standard source certificate (U Cert), enumeration (U count), weighing (U_w), and from yield (U_p) [31]. Ratnawati & Imam (2015) stated that none of the measurement results had absolute truth, even though the tools used were very sophisticated and the environmental conditions around the measurements were very stable. This is due to the limitations of human capabilities. For this reason, if there is a measurement result, whether in the field of testing, analysis or calibration which states that the measurement result is the actual value of what is being measured, it can be said that the measurement is not correct, because there is always a source of error that contributes to the measurement process. The sources of these errors include: incomplete definitions of measuring quantities, realization of imperfect definitions of measuring quantities, measuring samples, the influence of environmental conditions, personnel influences, tool resolution, standard reference materials, constant values, and so on [28].

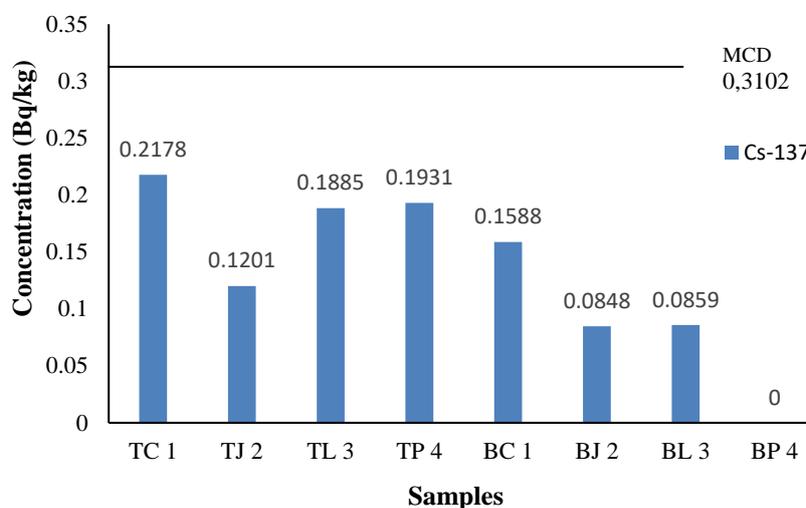


Figure 6. Concentration of ^{137}Cs radionuclide in soil and rice samples

Figure 6 shows the highest concentration of radionuclide ^{137}Cs in the soil sample in Pandeglang district, namely in sample TC 1 from Carita District, which is 0.2178 Bq/kg. The resulting ^{137}Cs radionuclide concentration is very low and its value is below the MDC. Soil conditions in Carita Sub-district did not contain ^{137}Cs contamination, although the sampling location was located behind dr. Immanuel (a few meters from the Hospital). According to Sulaeman (2003), radionuclides ^{137}Cs , ^{60}Co , and Ra are widely used in the medical field for radiotherapy. This radiotherapy aims to cure patients by using radiation components including photons and radioactive substances such as: ^{137}Cs , ^{60}Co , and Ra. This hospital does not use radiotherapy equipment so it cannot emit radiation to the environment. Radiotherapy can be used as curative, palliative or prophylactic (preventive) therapy. Curative therapy is usually in the form of single therapy to cure a cancer, for example used in cases of early-stage Hodgkin's lymphoma, nasopharyngeal cancer, some skin cancers, and early glottic cancer. Palliative therapy aims to improve the quality of life by

eliminating the symptoms of cancer by applying palliative radiation doses. Its application includes cases of maternal brain and bone and superior vena cava syndrome. Prophylactic (preventive) therapy is therapy that aims to prevent the possibility of metastasis or recurrence through the application of radiotherapy, for example whole-brain radiotherapy for acute lymphoblastic leukemia and small cell lung cancer [32].

Calculation of the concentration of a radionuclide using equation 4, from the equation it is proven that the value of counts per second (Ns/ts) can affect the value of the concentration of a radionuclide. The highest concentration of ^{137}Cs radionuclide in the rice sample was in Carita District at 0.1588 Bq/kg. These results are because the sampling location is closest to the location of the industrial accident in Cilegon-Banten City. Based on the BAPETEN report there has been an explosion at the PT. X in Cilegon-Banten City, on Monday 15 December 2014 at 13.10 WIB. The explosion in the converter area caused damage to part of the walls and roof of the building in the Steel Making Plant area. It is estimated that the cause of the explosion was the seepage of water that fell into the converter containing molten steel. Burns and traumatic victims were 7 (seven) people consisting of 5 (five) employees of PT. X and 2 (two) employees of the outsourcing company PT. X itself is an agency that utilizes 6 sources of ^{137}Cs ionizing radiation for gauging purposes and measuring plate thickness in the Plate Mill with each activity of 50 Ci (37×10^9 Bq). With this incident, the Director of Engineering and Nuclear Preparedness of BAPETEN, Tuesday, December 16, 2014, immediately dispatched a team of inspectors to take measures to measure radiation exposure around the location of the explosion. The team then joined a team from the local government involving the manpower office, the environment office, and the mining and energy office, to hold a meeting with PT. X. Further investigations were carried out regarding the impact of the explosion.

The results of the investigation show that the location of the incident is in the Steel Making Plant area which is 500 meters from the location of the installed radiation source (Plate Mill), which has radiation exposure which is the same value as background radiation exposure (measured 0.02 - 0.03 microsievert/hour). Measurement of radiation exposure using a radiation measuring instrument Radeye type PRD [33].

Radionuclide ^{137}Cs in sample BP4 (rice sample in Pulosari District) was not detected. This is because the concentration of ^{137}Cs in the Pulosari rice sample is smaller than the MDC value, so that the value is beyond the detector's ability to detect a radionuclide. The MDC value in the Marinelli container for the radionuclide ^{137}Cs obtained was 0.3102 Bq/kg. The concentration of ^{137}Cs radionuclide produced in soil samples and rice samples in Pandeglang Regency was below the MDC value in Table 10. According to Taftazani & Sumining (2000), the undetected element of ^{137}Cs was possible due to the distance between the nuclear test site and the sampling location [34].

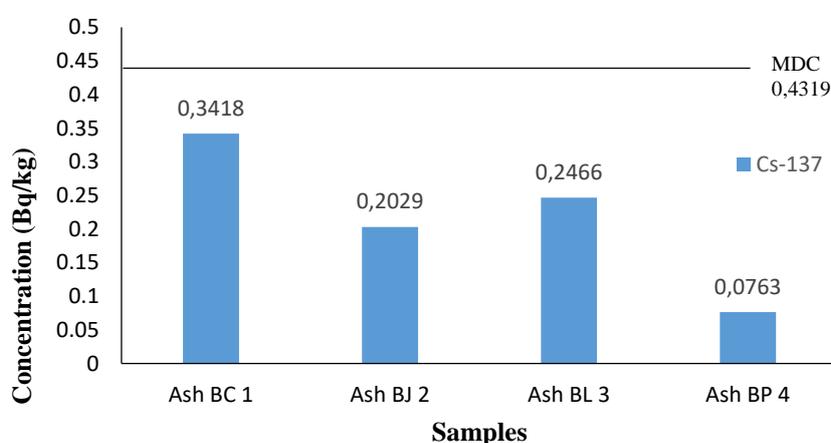


Figure 7. Concentration of ^{137}Cs radionuclide in rice ash samples

Concentration of ^{137}Cs radionuclide in rice ash sample

Figure 12 shows the results of the analysis of the radionuclide concentration of ^{137}Cs in the highest sample of rice ash in Carita District, which is 0.3418 Bq/kg. This result is quite greater than the radionuclide concentration in soil and rice samples. Ash is an inorganic substance left over from the combustion of an organic material. The principle of dry ashing is to oxidize all organic compounds at a high temperature of about 400-600 °C and then weigh the substances left behind after the combustion process [17]. The high concentration of ^{137}Cs radionuclide in the rice ash sample was due to the oxidation process of organic compounds contained in the sample, so that when analyzed the radioactive substances were higher.

Figure 13 shows the analysis data for the ^{137}Cs radionuclide in the soil sample is higher than the rice sample, this is because the ^{137}Cs radionuclide present in the soil cannot be fully absorbed by the rice plant. The ^{137}Cs radionuclide in the rice ash sample was higher than the rice sample because the radionuclides contained in the ash sample after being heated with a high temperature radionuclide looked more visible and measurable.

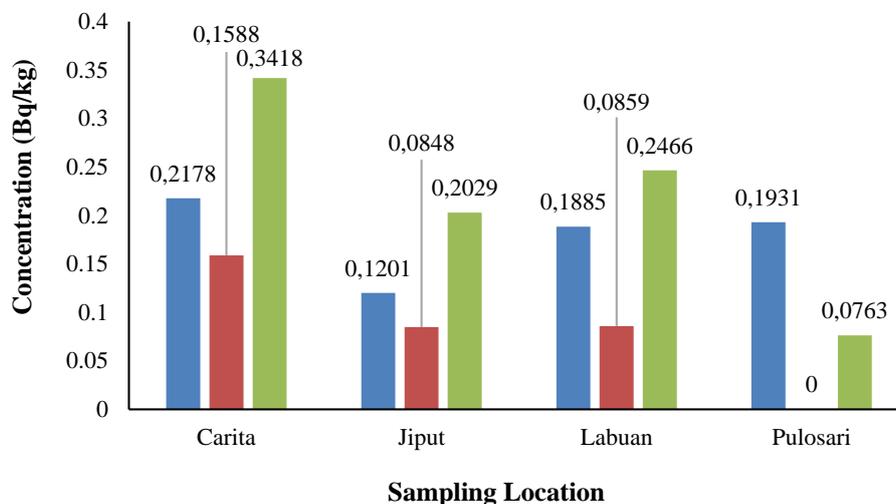


Figure 8. Concentration of ^{137}Cs radionuclide in each sample

The results of the analysis of the concentration of ^{137}Cs in food ingredients in Pandeglang Regency which were detected were very small and safe for consumption because they did not exceed the concentration limit of ^{137}Cs set by PERMENKES No. 1031 of 2011. The concentration of ^{137}Cs radionuclides in foodstuffs stipulated by PERMENKES RI No. 1031 of 2011 was 500 Bq/kg. The concentration of ^{137}Cs radionuclide in soil samples in Pandeglang Regency is currently still below the threshold based on PERKA BAPETEN No. 9 of 2009, which is 1000 Bq/kg. The results of this analysis can be concluded that it is still safe and has not caused a hazard to the health of the people living in the area. According to Muthmainnah et al. (2020) radionuclide ^{137}Cs is an artificial radionuclide derived from nuclear testing and radioactive dust falling at the time of a nuclear accident. ^{137}Cs in foodstuffs that are not detected are caused by small or no ^{137}Cs drops at the place of origin of these foodstuffs [4].

Radionuclide Distribution Pattern

The highest concentration of ^{137}Cs radionuclide was in the sample located in Carita District. The concentrations of radionuclide ^{137}Cs obtained in soil, rice and rice ash samples in the sub-district were 0.2178 Bq/kg, 0.1588 Bq/kg and 0.3418 Bq/kg, respectively. Sources of environmental radioactivity pollution, among others, can come from mining, processing and chemical processes of nuclear materials, nuclear fuel enrichment and fabrication processes, nuclear reactor operations, fuel reprocessing, radioactive waste management, radionuclide manufacturing processes, use of radioisotopes in research, industry and medicine, decontamination and decommissioning of a nuclear facility, accelerators, use of fossil fuels, experiments and atomic bomb explosions [35].

Rina (2002) stated that the activated radionuclides may be released into the environment due to activities in the nuclear field at the Serpong Nuclear Energy Research Center (PPTN). The transport of radionuclides in the soil is strongly influenced by the porosity of the soil or rock and the permeability of the soil, with the presence of pores, the soil will serve as a storage area so that radionuclides will be retained in the pores. If the water flow in the area is small, it is expected that the radionuclides will decay before flowing into the groundwater. If the presence of the pore is adjacent to the impermeable layer, then this layer can hold the radionuclides in place [36].

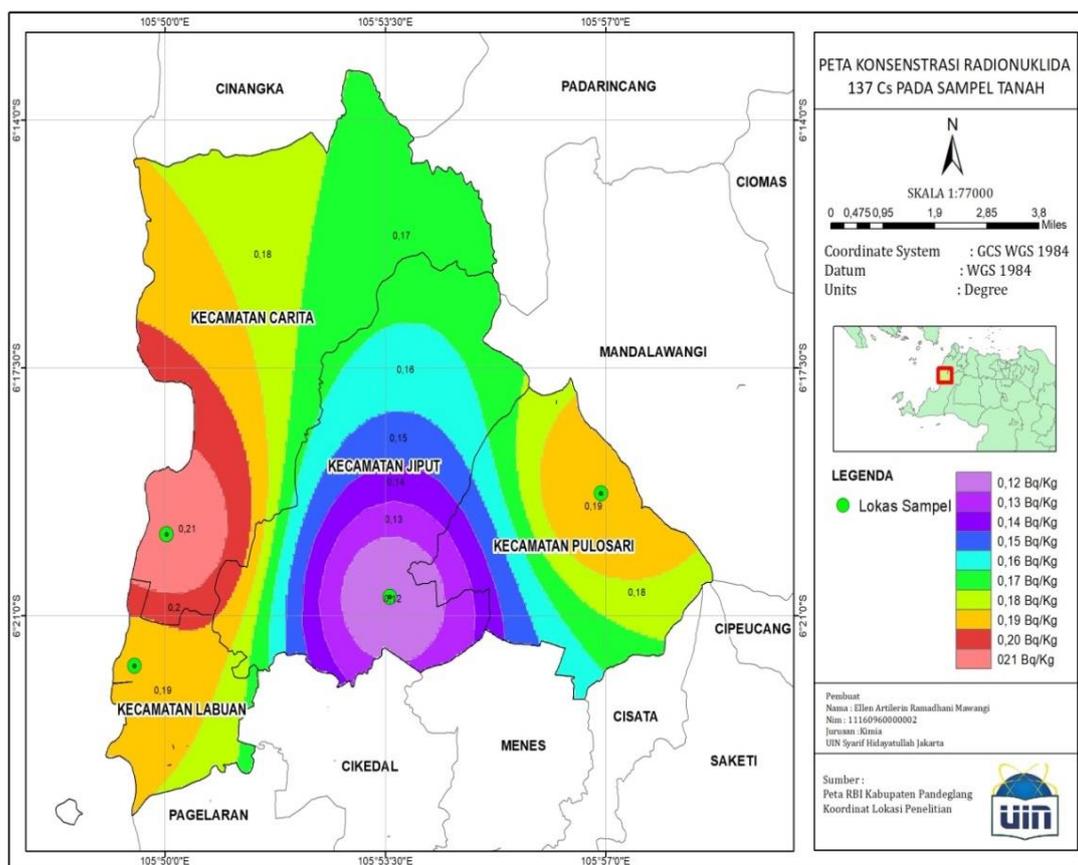


Figure 9. Distribution pattern of ^{137}Cs radionuclide in soil

Figure 9 shows the distribution pattern of ^{137}Cs radionuclides in the soil. Radionuclides in the soil also experience sideways and downward movements. The sideways movement is caused by erosion of the soil surface by heavy rain or wind, especially in arid areas, so that the nuclides are scattered around them. Downward movement can be caused by the mechanism of particle movement itself, or due to the stirring process due to soil fauna or human activities. Wind and rain can also cause a mixing mechanism even a few millimeters from the ground surface [36].

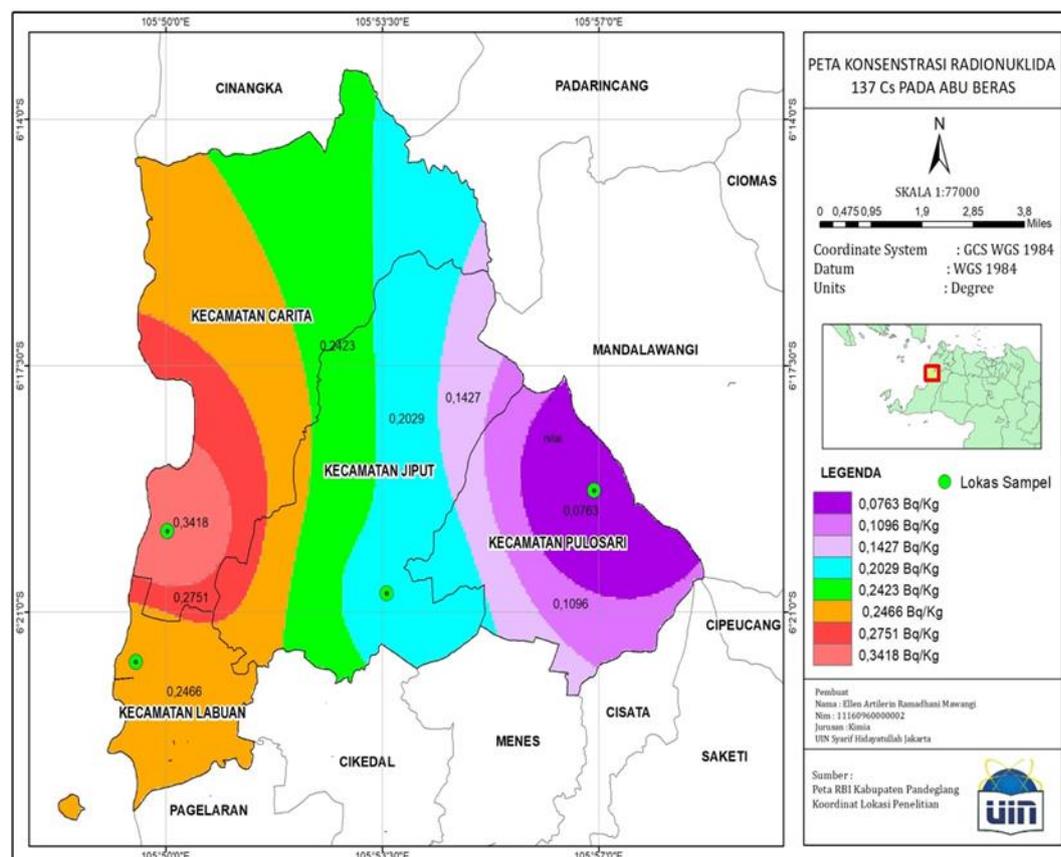


Figure 10. Distribution pattern of ¹³⁷Cs in rice ash

Figure 10 shows the difference in the distribution pattern of the ¹³⁷Cs radionuclide in the rice ash sample with the ¹³⁷Cs radionuclide distribution pattern in the soil sample [37]. This is because the ability to absorb ¹³⁷Cs radionuclide between rice plants from each location is different, besides that the results of measuring the concentration of ¹³⁷Cs radionuclide are also different.

Conclusion

Based on the research conducted, it can be concluded as follows:

1. Based on the results of the measurement of the concentration of ¹³⁷Cs radionuclide in the soil sample, the highest yield obtained was in Carita District, each with 0.2178 Bq/kg. These results are still below the threshold set by PERKA BAPETEN No. 9 of 2009 the maximum concentration of ¹³⁷Cs radionuclide in the environment is 1000 Bq/kg.
2. Based on the results of the measurement of the concentration of ¹³⁷Cs radionuclide in rice and rice ash, the highest yields obtained were in Carita District, respectively 0.1588 Bq/kg and 0.3418 Bq/kg. These results are still below the threshold set by the Minister of Health Regulation No. 1031 of 2011 the maximum concentration of ¹³⁷Cs radionuclide in food is 500 Bq/kg.

Suggestions

Suggestions for further research, it is better if the sampling location is based on a radius per sub-district of 1 sample on GPS coordinates at the center point or close to it, so that the results obtained are more optimal. It is advisable to vary the counting time so that it can determine the effect of the counting time on the resulting radionuclide concentration.

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