

ABSTRACT
DETERMINATION OF TECHNOLOGICALLY ENHANCED NATURALLY
OCCURRING RADIOACTIVE MATERIAL (TENORM) IN ASHES FROM
COAL-FIRED THERMAL POWER PLANTS IN THE PHILIPPINES

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The activity concentration (AC) of TENORM - ^{238}U , ^{226}Ra (^{238}U series), ^{232}Th , ^{228}Ra , ^{228}Th (^{232}Th series) and ^{40}K in feed coal, bottom ash and fly ash samples from four coal-fired thermal power plants C, M, P and S were determined using two techniques: inductively coupled plasma mass spectrometry (ICP-MS) and high purity germanium (HPGe) gamma spectrometry. For ^{232}Th and ^{238}U [determined at National Institute for Radiological Sciences (NIRS) by the ICP-MS], Plant S feed coal (FC) sample that originated from China had the highest AC (15.77 ± 0.32 Bq/kg and 13.67 ± 0.82 Bq/kg, respectively), followed by Plant M FC sample also from China (8.31 ± 0.33 Bq/kg and 5.84 ± 0.12 Bq/kg, respectively), while Plants C and P FC samples that originated from the Philippines and Indonesia had the lowest ACs of ^{232}Th and ^{238}U . Plant S also had the highest bottom ash (BA) AC of 80.86 ± 3.23 Bq/kg and 100.20 ± 4.01 Bq/kg, respectively while Plant P had the highest fly ash (FA) AC of 155.96 ± 6.24 Bq/kg and 268.03 ± 10.72 Bq/kg, respectively. For AC's of ^{226}Ra , ^{228}Ra , ^{228}Th and ^{40}K determined by NIRS HPGe, Plant C had the highest in the FC sample (11.70 ± 1.39 Bq/kg, 13.65 ± 4.99 Bq/kg, 11.35 ± 3.96 Bq/kg and 80.23 ± 10.91 Bq/kg, respectively). For AC's in the BA samples, Plant M had the highest ^{226}Ra (106.73 ± 6.74 Bq/kg) and Plant S had the highest ^{228}Ra and ^{40}K (66.64 ± 8.16 Bq/kg and 400.93 ± 43.06 Bq/kg, respectively). For AC's in the FA samples, Plant S had the highest ^{226}Ra and ^{228}Ra AC's (131.13 ± 8.09 Bq/kg and 87.70 ± 10.45 Bq/kg, respectively) while Plant C had the highest ^{40}K AC (369.08 ± 40.87 Bq/kg). The highest AC enhancement of ^{238}U , ^{226}Ra (^{238}U series), ^{232}Th , ^{228}Ra , ^{228}Th (^{232}Th series) and ^{40}K relative to feed coal occurred in Plant P FA sample, with ^{238}U showing the highest enhancement of 93.72 among the radionuclides. When normalized with ^{40}K , ^{238}U in Plant P FA sample also had the highest enrichment factor (EF). Except for Plant C samples, ^{228}Ra , ^{228}Th and ^{40}K were about equally partitioned between BA and FA samples; ^{238}U had consistently higher partitioning in all FA samples than BA samples; ^{226}Ra and ^{232}Th had varied partitioning behavior among the Plants' BA and FA samples. The behavior of the radionuclides during combustion was explained to be influenced by their physical and chemical characteristics and their association with the alumino-silicate minerals in the coal. For most samples, positive correlations between NIRS ICP-MS and NIRS HPGe were very high for ^{226}Ra with ^{238}U ($R^2=0.98$), and ^{228}Ra with ^{232}Th ($R^2=0.94$). Correspondence between ICP-MS and HPGe results were generally high with slopes of 0.90 and zero intercept for both ^{226}Ra vs ^{238}U and ^{228}Ra vs ^{232}Th . Correlations between NIRS HPGe and PNRI HPGe were also very high for ^{226}Ra ($R^2=0.93$) and ^{228}Ra ($R^2=0.91$), and high for ^{40}K ($R^2=0.86$). However, the slopes of the correlation lines gave only 0.65 to 0.68 correspondence of NIRS HPGe relative to PNRI HPGe. This could be attributed to the slight difference in sample and standard geometry used in PNRI HPGe experiment and different multi-channel analyzer emulation software used by NIRS and PNRI HPGe's. The results of more detailed study in Plant C showed that the ACs of ^{226}Ra , ^{228}Ra , and ^{40}K were similar between two sampling periods in 2005 and 2006; the ACs in the ash pond were generally slightly lower than that in the BA and FA samples; and the ACs showed a slight decreasing trend with ash pond depth. The ACs in both BA and FA samples from Plants C, M, P and S were all below the International Atomic Energy Agency (IAEA) and

European Commission (EC) recommended AC levels for regulatory control. The absorbed gamma dose rates in air inside Plant C ranged from 29-36 nGy/h; in its vicinity (adjacent agricultural, public and residential areas) 27-41 nGy/h; and in the ash pond, 44-56 Gy/h. These were within the reported dose rates in Marinduque, Batan Island, and worldwide average in UNSCEAR. Based on the AC values in FA samples from Plant C, the estimated discharges of radionuclides from the stacks were lower compared to that of the European Commission screening levels, thus detailed site-specific dose assessment may not be necessary. Using the highest AC results of ^{232}Th , ^{226}Ra , and ^{40}K in FA samples from Plants C, M, P and S in calculating radium equivalent (Ra eq) classification (used for the purpose of controlling radiation dose from building materials), the fly ash from all Plants could be recommended for use in building residential houses.