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Original Research

TENORM radiation protection patterns for the sustainable health of workers

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Abstract

Background: Coal production in Indonesia continues to increase to meet national energy needs and export demand. Solid waste from the coal combustion process is estimated to increase significantly. One of the hazardous mining wastes is TENORM, but some TENORM is classified as production goods with economic value. The problem in this research is that the volume of waste containing TENORM is quite large, and the disposal, use, and recycling of TENORM has the potential to cause contamination for workers at the steam power plant and the surrounding environment.

Objective: The purpose of this research is to obtain a design model for the protection of the environment and workers against TENORM radioactive waste from coal ash through an analysis of the social and economic perceptions of steam power plant workers regarding TENORM radiation and the effectiveness of TENORM radiation protection education to workers.

Methods: A mixed method with a quantitative approach was applied. Data were gathered through field observation utilizing a questionnaire instrument that asked workers working at Steam Power Plant Units 1 – 7 a series of written questions.

Results: Prior to Counseling, most Suralaya Steam Power Plant workers had shallow social and economic perceptions of TENORM radiation, with 88 percent unaware of its effects. The majority also paid between 100,000 and 500,000 IDR monthly in medical expenses. All respondents agreed that TENORM radiation safety counseling for Suralaya Steam Power Plant workers was utterly compelling, with acceptance of TENORM and WTP estimates following Counseling being the most important aspect.

Conclusion: There was a significant relationship between the WTP variable after Counseling and the variables acceptance of TENORM protection (0.730), TENORM knowledge (0.627) before and after Counseling (after Counseling), and acceptance of TENORM protection (0.648), according to the pattern of protection for the SEM model.

Keywords: TENORM; steam power plant; protection; workers

Background

The plan to build several steam power plants with a total capacity of 35,000 MW or 35 GW has the potential to cause environmental problems, so environmental problems are an important problem, especially the problem of coal ash. This condition also causes consideration of fiscal and economic growth in the range of 6-7% (Widyarsana et al., 2021). Solid waste from the composition of coal in the combustion process produces metal materials and is expected to increase significantly if not utilized effectively (Nunes et al., 2016; Xing et al., 2019; Zhang et al., 2018; Zhou et al., 2017). Coal mining activities continue to experience significant development (Attaran, 2017; Aydalot & Keeble, 2018; Evans & Stoddart, 1990; Venables, 2016). The use of coal as a resource for the past four years has continued to increase, but coal supplies in nature have continued to decline due to the limited availability of coal sources. If the discovery of new brick reserves does not match this condition, it is estimated that coal reserves will be exhausted within 70 years (Cunningham et al., 2019; Daryanto & Samidi, 2018; Houser et al., 2017; Wu & Zhang, 2016).

TENORM (Technologically-Enhanced Naturally Occurring Radioactive Material) is a naturally occurring radioactive material (rock, soil, and minerals) that has increased its radioactive content due to industrial activities (Loan et al., 2021; Nabhani et al., 2016; Osmanlioglu, 2021; Wisnubroto, 2003). TENORM can provide external and internal radiation exposure effects on workers and the surrounding industrial site. Workers or the local area receives external radiation because TENORM has contaminated offices. In contrast, internal radiation exposure is obtained through inhalation, food, and drink contaminated by TENORM. Suppose someone breathes air containing radioactive particles, drinks water, and eats food that already contains radioactivity or makes direct contact. In that case, they will be at risk of developing cancer or other health problems. TENORM is generally found in mining areas, especially in Uranium mining.

TENORM management requires special treatment to avoid the negative impact of TENORM exposure on the health of workers and the surrounding environment. This is because the radioactivity in TENORM generally is 238U, 232Th, 228Th, 226Ra, 228Ra, 40K, 210Pb, 210Po, 222Rn, and 220Rn. The TENORM contained in these components consists of natural radionuclides with very long half-lives (Toni, 2012). Developed countries such as America, China, and Japan have carried out many explorations to overcome the effects of TENORM radiation (British Petroleum, 2007; Doyi et al., 2013; Yu & Li, 2017), but in Indonesia, there are still not many data regarding the TENORM effect. By analyzing the social and economic perceptions of steam power plant workers toward TENORM radiation and the effectiveness of TENORM radiation protection education, this research developed a model of sustainable protection patterns that can be applied to reduce the effects of TENORM radiation exposure to workers from the coal burning process.

Methods

Study Design

This research applied a quantitative approach with mixed methods, relying on gathering and analyzing numerical data, using experimental designs, making measurements and observations, and conducting theory tests with statistical tests and field testing.

Setting

Data were collected for six months, from October 2021 to February 2022, in the Steam Power Plant Unit 1 - 7 area, administratively located in Suralaya Village, Pulomerak District, Cilegon City, Banten Province. The location was chosen based on the Coal Mining Business Permit Area.

Samples/Participants

People who work in the Steam Power Plant Units 1 through 7 comprise the population in this research. This sample is used to assess the socioeconomic circumstances of Steam Power Plant workers and to examine the variables that affect performance in the area of Steam Power Plant Units 1 through 7, including the effectiveness of TENORM radiation impact education. The Slovin formula calculates the representative sample, which might have been as many as 110 participants in this study.

Data Collection

The steps of analysis used in this research were primary data collection, processing, analysis, presentation, and interpretation. Individual factors and worker knowledge comprise the social circumstances that must be measured. Individual factors were questions on the respondent's background in the neighborhood, such as their gender, age, address, length of stay, number of families, ownership status of their home, and monthly income. Additionally, workers' knowledge included understanding the TENORM radiation they regularly expose themselves to. Income and the capacity to meet basic requirements were the economic factors to be measured. Income was the head of the household's monthly total income (in rupiah). Another factor was the capacity to cover additional costs for TENORM radiation prevention (consumption, hygiene, productivity, and facilities).

Data Analysis

The data were tallied and processed either through descriptions of frequencies or correlations between variables. All data were evaluated using statistical methods. SEM (Structural Equation Modeling) were utilized to produce this model, offering an overview of the protection model for workers from TENORM radiation based on the correlations employed in the research.

Ethical Considerations

This research met the requirements and passed the ethical review conducted by Universitas Indonesia. Before data collection, each respondent has signed informed consent.

Results

Social and Economic Perceptions of Steam Power Plant Workers

Social and economic perceptions were analyzed on steam power plant workers. Based on the educational level factor, it was found that as many as nine workers, or 6%, had a D1 - D3 level of education. As many as 141 people, or 94% of workers, had a bachelor's level of education. The graph of the education level of workers can be seen in **Figure 1**. An analysis of the status of steam power plant workers showed that 88% were permanent, and as many as 12% were temporary workers.

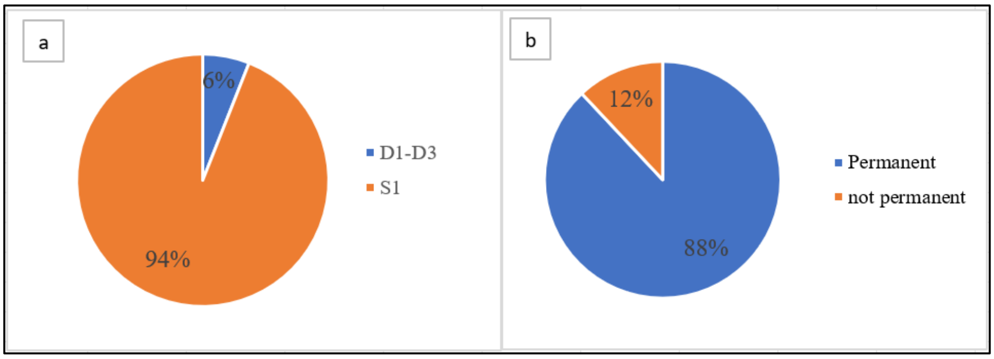

Figure 1 Graph of: a) Education Level; b) Status of Workers

Based on an analysis of the time they have worked at the plant, 5% of workers have worked for less than one year. Several 15% of workers have a working age of 1 - 3 years, 48% have an operational period of 3 - 5 years, and as many as 32% have worked at the STEAM POWER PLANT for five years and over.

A comparison chart of steam power plant workers' working hours can be seen in **Figure 2**. The security preferences of workers were also analyzed, and the results found that 33 workers felt relatively safe, 52% felt safe, and 26% felt very safe.

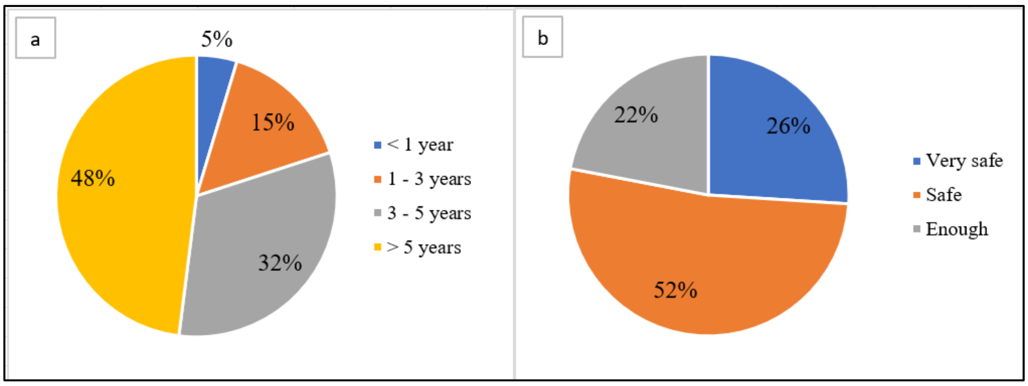

Figure 2 Graph of a) Workers' Working Time; b) Workers' Feeling Safe

An analysis of the workers' illness experience respondents found that as many as eight people had never experienced pain while working at the steam power plant, as many as 52% of workers experienced pain once a year due to work, as many as 40% of workers experienced pain 3 - 5 times a year as a result of job and as many as four people sick workers every month due to work. A comparison graph of the frequency of workers' illness experiences can be seen in **Figure 3**. An analysis of perceptions about health facilities showed that 20% of workers thought that the plant health facilities were quite good, and 67% of workers believed that the plant health facilities were good. Other workers gave an excellent rating of the plant health facilities.

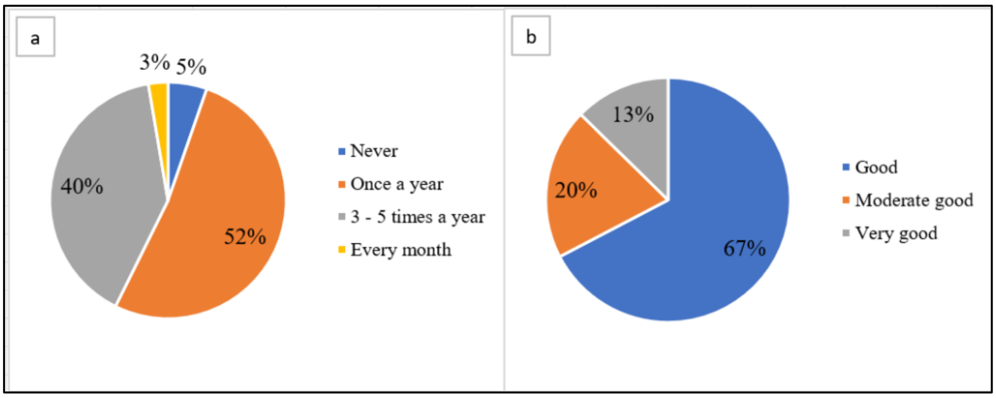

Figure 3 Graph of: a) Frequency of Workers Experiencing Work-related Illness; b) Assessment of Health Facilities

The personal protective equipment provided by the company was rated as good by 67% of workers. As many as seven workers rated the company's protective equipment very well. In contrast, 29% of others gave an adequate rating for the quality of the personal protective equipment provided by the company. The comparison graph can be seen in **Figure 4**. The supervision carried out by the company regarding occupational risks in the workplace was considered sufficient by 4% of workers. As many as 40% of workers rated the supervision efforts adequate, and the rest rated them very satisfactory.

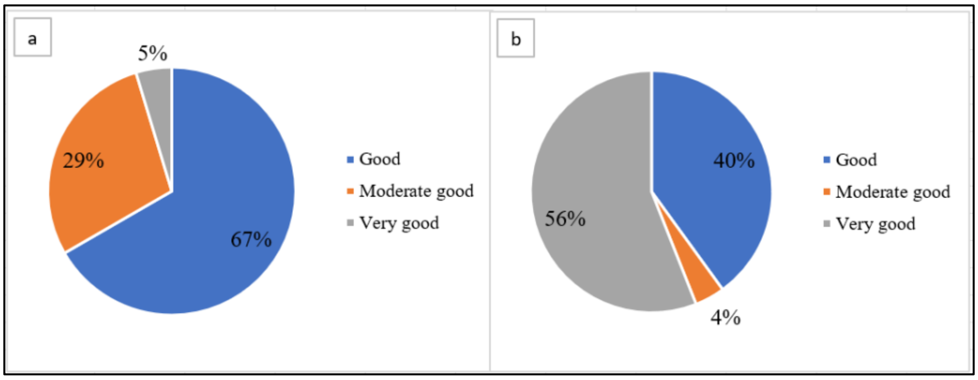

Figure 4 Graph of: a) Personal Protection Equipment at Work; b) Monitoring of Occupational Risks in the Workplace

The knowledge of workers on the risks of TENORM radiation was analyzed, and it showed that 88% of workers had very little knowledge about TENORM radiation. As many as 9% of workers did not know about TENORM radiation, as many as 2% knew enough, and the rest knew about this information. Completing the questionnaire also showed that most respondents had never heard of the potential for TENORM radiation exposure at the plant. The graph of respondents' knowledge of TENORM radiation is shown in **Figure 5**. An analysis is carried out on the company's willingness to conduct Counseling regarding the potential for TENORM radiation exposure at the steam power plant. The results show that 67% of respondents agreed, 27% of respondents strongly agreed, 5% of respondents were neutral, and the rest respondents disagreed.

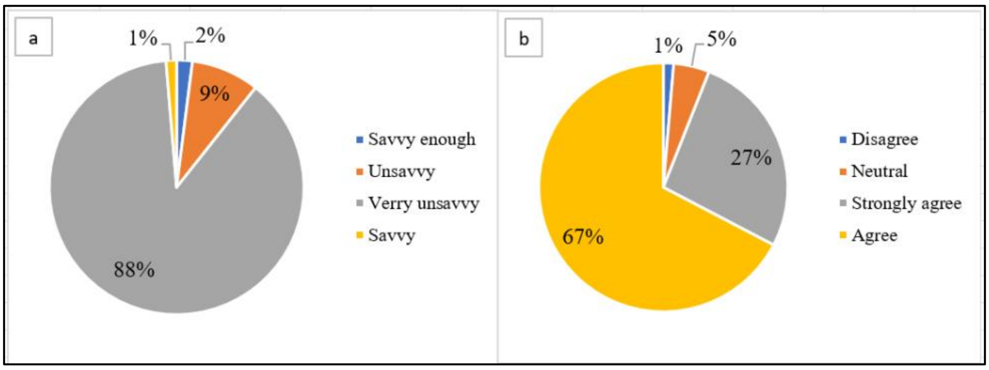

Figure 5 Graph of: a) Workers' Perception of TENORM Radiation; b) Company Agreement to Conduct Counseling

Economic analysis is carried out on the amount of workers' expenditure. The average monthly cost shows that as many as 3% of workers spend IDR 1.000.000 - IDR 3.000.000 monthly. 38% of workers have an average of IDR 3.000.000 - IDR 5.000.000, and the rest have an average of IDR 5.000.000 and above. The comparison graph of the average monthly expenditure can be seen in **Figure 6**. The average personal expenditure of each worker, specifically for health control, was also analyzed, and it was found that as many as 3% of workers had costs below IDR 100.000. 33% of workers have IDR 100.000 - IDR 500.000, 41% have IDR 500.000 - IDR 1.000.000, and the rest have IDR 1.000.000 and above.

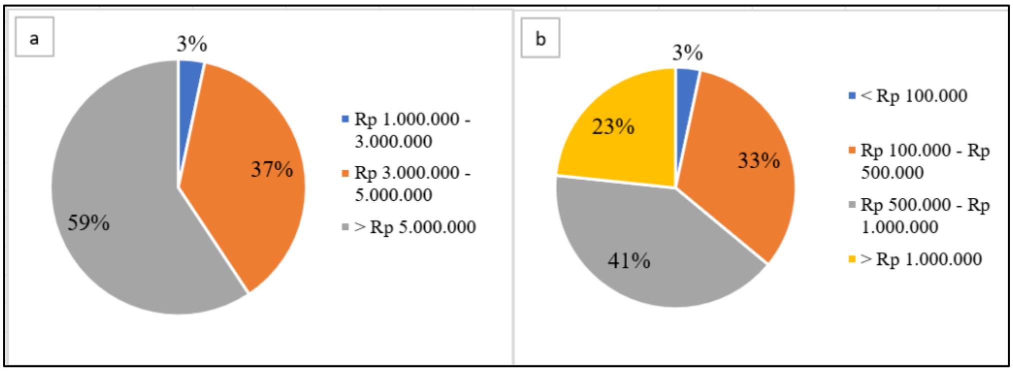

Figure 6 Graph of: a) Average Expenditures per Month; b) Average personal expenditure per month for health

Based on insurance ownership, the results show that all workers have health insurance. In addition, based on workers' perceptions, it is known that the company will provide compensation if workers experience illness due to work. The graph of insurance ownership is shown in **Figure 7**, section (a), and company compensation can be seen in section (b).

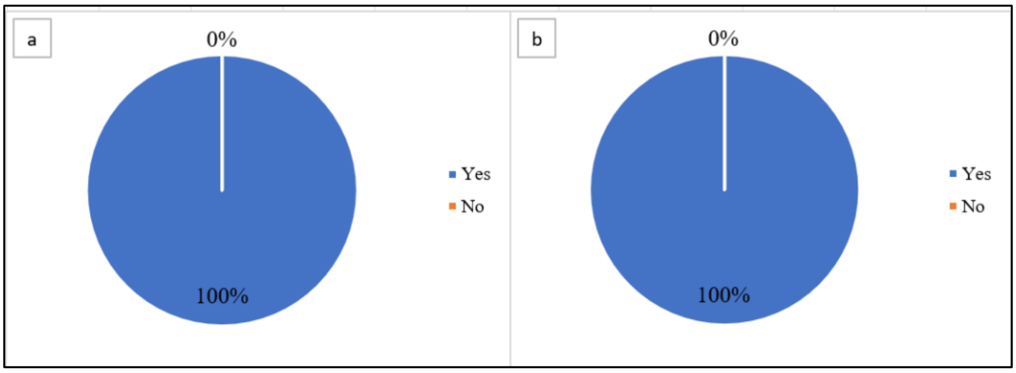

Figure 7 (a) Have health insurance, and (b) The company provides compensation if the workers experience illness due to work

Based on the economic perceptions of the respondents, it was found that 98% of the total workers had an emergency fund if they were sick, and three others did not. A graph of workers' emergency fund ownership is shown in **Figure 8**. Of all the respondents who filled out the questionnaire, 97% had received Counseling about TENORM radiation for the first time. A total of five other people had previously received Counseling about TENORM radiation.

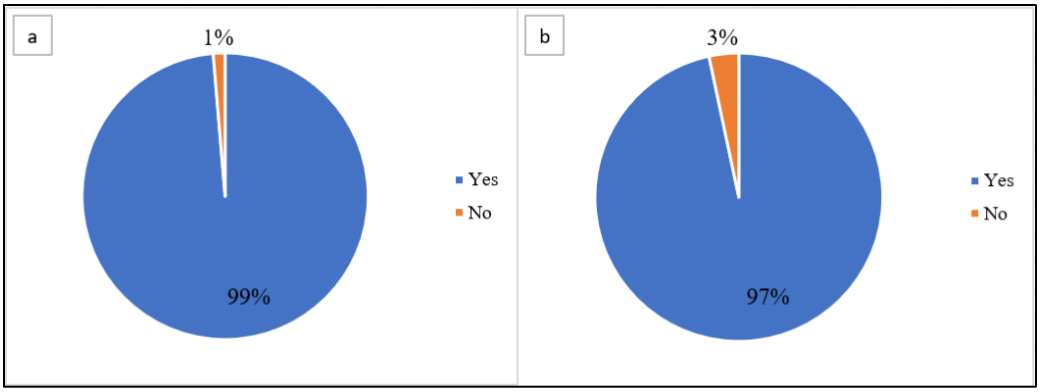

Figure 8 Graph of: a) Have an emergency fund if the workers are sick; b) The first counseling about TENORM radiation at PLTU

TENORM Radiation Protection Pattern Model

The pattern of protection patterns for workers from TENORM radiation is described through the SEM (Structural Equation Modeling) model. The SEM model provides an overview of the relationship between the variables used in the research. The SEM model overviews the correlation between the research's variables. PAPs before Counseling, corporate perceptions, TENORM knowledge before Counseling, TENORM knowledge after Counseling, acceptance of TENORM Protection, and PAPs after Counseling were the variables in this research.

The following indicators are related to the company's perception variable:

- PP1 Feeling safe at work
- PP2 Health facilities in the workplace are adequate
- PP3 Adequate personal protective equipment in the workplace
- PP4 Adequate education from companies about the risks of working
- PP5 Adequate supervision of occupational risks in the workplace

The TENORM knowledge variable before extension has the following indicators:

- PTS1 Knowledge of TENORM radiation risks
- PTS2 Approval for the company to conduct Counseling on the potential for TENORM radiation exposure at STEAM POWER PLANT

The PAP variable before extension has the following indicators:

- WTP1 Average Spending per Month
- WTP2 Average Personal Spending

The TENORM Knowledge Variable after Extension has the following indicators:

- PTSP1 Interest in studying the risks of TENORM radiation more deeply
- PTSP2 Level of knowledge about TENORM radiation at STEAM POWER PLANT

The variable Acceptance of TENORM Protection has the following indicators:

- PPT1 Willingness to optimize the use of PPE while working
- PPT2 Willingness to increase vigilance while working
- PPT3 Willingness to take personal risk prevention measures for TENORM radiation at a steam power plant while working

The WTP variable after the extension has the following indicators:

- WTPSP1 Willingness to spend additional personal funds related to prevention risk of TENORM radiation in steam power plant
- WTPSP2 Average additional private funds willing to be spent related to TENORM

radiation risk prevention at the steam power plant

After receiving Counseling regarding the negative effects of TENORM exposure, the Suralaya Steam Power Plant workers' knowledge of and acceptance of the TENORM protection they used differed significantly, as shown by the SEM model in **Figure 9**. This follows Government Regulation of the Republic of Indonesia No. 33 of 2007 concerning Ionizing Radiation Safety and Radioactive Source Safety. The second management requirement, namely the necessity for worker education and training, is controlled in the section on radiation safety, which is an activity conducted to protect workers, the general public, and the environment from radiation threats. The permit holder, in this case, the Suralaya Steam Power Plant, ensures the security of both the environment and workers.

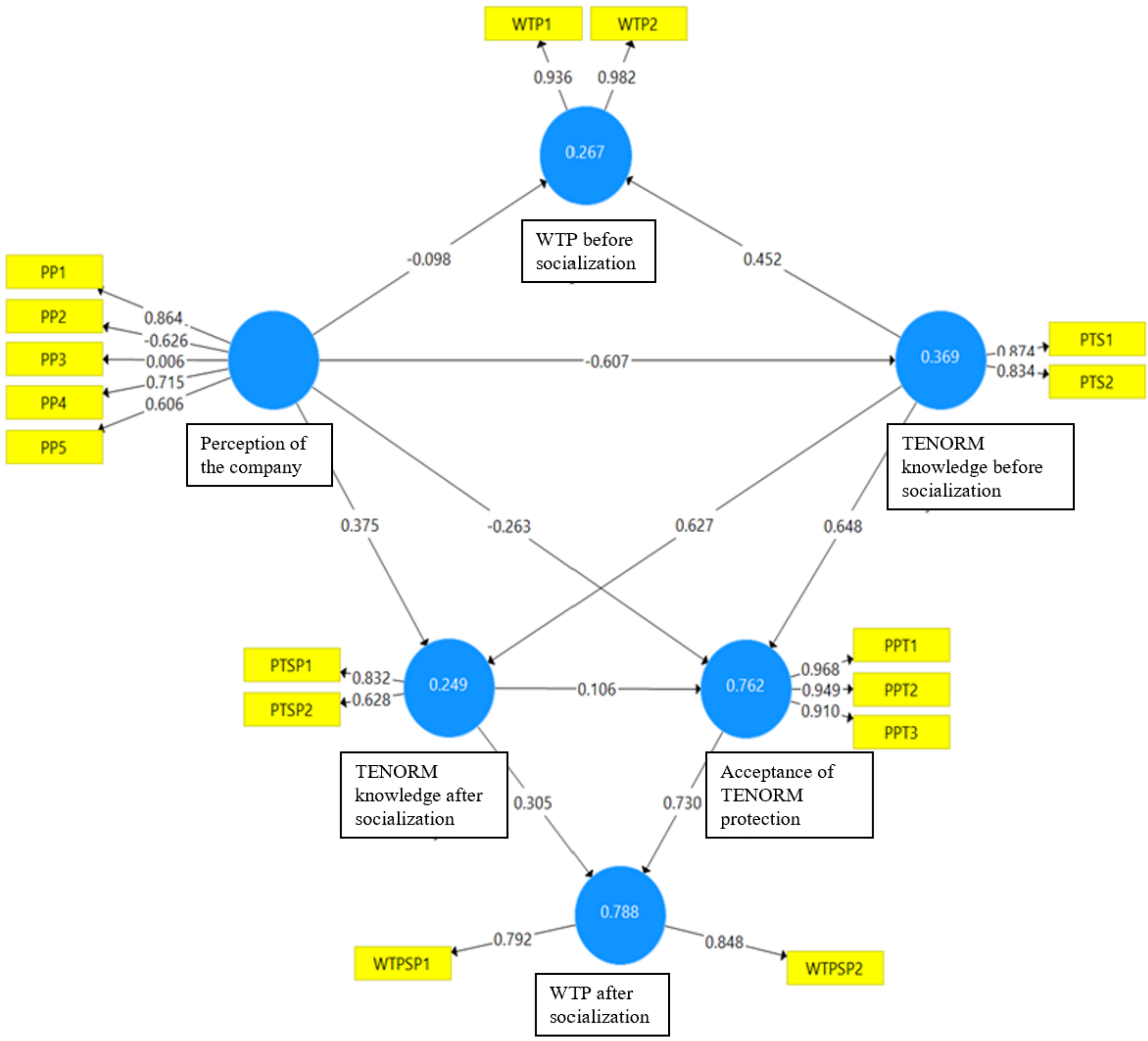

Figure 9 SEM Model of TENORM Radiation Protection Pattern

Discussion

According to the research findings, up to 78 workers go through work-related pain once a year. Up to 60 workers go through discomfort 3-5 times a year. Up to four people report having pain each month. Workers' exposure to TENORM radiation at work can induce illnesses, primarily if the disclosure occurs in high doses. The ratio of workers who worked for 3-5 years and above was found to be more significant than the number of workers who worked for under three years based on the findings of the respondents' completion of the questionnaire.

TENORM radiation exposure may negatively impact workers' health (Ali et al., 2020; Gupta et al., 2014). A radiation worker near a radiation field will get a radiation dose proportionate to how long they are there. Workers' radiation exposure dose increases the longer they spend in the radiation area (Malaka, 2019).

The effects of TENORM radiation exposure can be reduced by following safety protocols at work and wearing personal protective equipment. The necessary protective gear is a lab coat, gloves, boots, shoe covers, etc. Additionally, respiratory protective equipment such as filter-type respirators and masks must be used by workers (Malaka, 2019). The majority of respondents thought the PPE offered by the company was appropriate. The company has also supplied suitable medical facilities. The research on the economy of the workforce reveals that every worker has health insurance.

Additionally, the company offers compensation to workers who become ill at work. A way to safeguard, maintain, and enhance the welfare of employees is through health insurance and reimbursement for medical expenses. Health insurance lowers the cost of health care for employees (Sari et al., 2012). According to this research, on average, most workers spend less than IDR 1,000,000 per month on health care. When they are sick, most workers also have emergency money. In this instance, Suralaya Steam Power Plant has delivered excellent worker health insurance services. The results of this study have a positive impact locally and globally, locally, namely being able to increase the knowledge of the community around the Suralaya PLTU regarding the dangers of TENORM and become more concerned about health due to TENORM radiation. Globally, the results of this study provide advice in the form of the need for training for workers regarding standard operational procedures for TENORM because TENORM radiation is different from radiation of other radioactive materials.

Conclusion

The research's findings indicate that, before Counseling, most workers at the Suralaya Steam Power Plant had shallow social and economic perceptions of TENORM radiation, with 88 percent unaware of its effects. The majority also paid between 100,000 and 500,000 IDR monthly in medical expenses. All respondents agreed that TENORM radiation safety counseling for Suralaya Steam Power Plant workers was utterly compelling, with acceptance of TENORM and WTP estimates following Counseling being the essential aspect. According to the pattern of protection for the SEM model, there is a significant relationship between the WTP variable after Counseling and the variables acceptance of TENORM protection (0.730), TENORM knowledge (0.627) before and after Counseling (after Counseling), and acceptance of TENORM protection (0.648). The Government Regulation of the Republic of Indonesia No.33 of 2007 concerning the Safety of Ionizing Radiation and Safety of Radioactive Sources and the SEM model for TENORM radiation protection for Suralaya Steam Power Plant workers conform.

Declaration Conflicting Interest

None.

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This study's processes are at personal expense, from the data collection stage to publication.

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Author Contribution

AP collected and analyzed research data. HK provided direction and input for data analysis related to TENORM radiation's impact on workers' health. RP provided direction and suggestions for analysis regarding the impact of TENORM radiation on environmental pollution MG provided direction and suggestions for data analysis and discussion regarding hazards and actions for handling TENORM radiation in the industrial sector. All authors approved the final version of the article to be published.

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