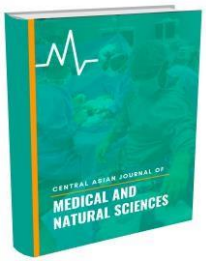

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Article

Nuclear Security Culture Assessment of Medical Facilities in Malaysia

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Abstract: National regulations are always consistent in providing the first layer of safety and security in nuclear-related medical facilities. Since its introduction, nuclear security has become the main focus of organizations to prevent any malicious activities due to internal and external threats made possible as harsh idealism growth is consistent with an increased number of populations. Briefly, the self-assessment allows an organization to develop and maintain a security culture among nuclear personnel by testing out knowledge and awareness involves radioactive sources. The objective of this study is to evaluate certain areas of an organization on nuclear security culture based on IAEA's nuclear security model. A survey was performed on 117 radiological personnel that uses ionizing radiation sourcing from radioactive materials as well as irradiating apparatuses direct and indirectly by handing out cross-sectional questionnaires. The questions (scaled using numerical values, 1-7) were collected and categorized into several populations which are level of education, age, years of working and etc. The scores were then analyzed using appropriate statistical method. A report on strengths and weaknesses in several areas was given back to the organization for further development and enhancement of security. The study shows that awareness is greater within personnel with higher level of education. The results also showed an in awareness with age due to the fact that workers who are older portrayed a deeper understanding of what they are doing. There is a significant difference of scores in terms of duration of service where workers with 6-10 years of experience were more aware of the importance of security culture compared to those with 21-30 years of experience. In conclusion, it is found that there are several factors including the subject's demographic that affect the level of awareness and knowledge among radiation personnel that works with radioactive materials.

Keywords: nuclear safety, security culture, International Atomic Energy Agency, questionnaires, helathcare worker

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1. Introduction

Nuclear security like any other security is implemented to protect lives, property, society and the environment against ionising radiation's negative effects [1]. According to the International Atomic Energy Agency, with nuclear security, theft sabotage, unauthorised entry, unlawful transfer, and other harmful acts involving nuclear and radioactive materials and associated facilities and activities can be detected and prevented [2]. There

are many professionals whose mandate includes nuclear security as just one of multiple areas of responsibility, in addition to the obvious contributors such as technical experts in nuclear sciences, plan writers, and analysts focused on nuclear security as the central mission of their profession. Policymakers and their supporting staff/organizations, at the highest level, are in charge of codifying a nuclear security policy apparatus as one of several policy areas under their purview [3] .

Even if a physical protective system uses cutting-edge technology, it could be rendered useless without a full understanding of nuclear security culture. The nuclear security culture is characterised as an amalgamation of human, organisational, and institutional qualities, attitudes, and behaviours that support and enhance nuclear security [4]. In order to evaluate nuclear security in an organization's culture, self–assessment must be made to identify key characteristics of nuclear security by analyzing the existing state of the culture to their ideal parameters [5]. It is vital to assess the status of nuclear security to persons who work at nuclear sites in order to raise cultural awareness [6].

Surveys are the best tool to assess the level of security culture awareness. Although nuclear security culture surveys are currently considerably less popular than general employee satisfaction surveys, this method can be effective in detecting gaps in a company's nuclear security culture and in helping to raise awareness [7]. One explanation for this is that businesses rarely highlight the importance of individuals in overall security plans. Another reason could be that security processes are usually classified, so senior management may believe that talking with employees about security issues could violate confidentially and put the facility at risk. A survey to study the level of awareness on nuclear security culture was conducted on 117 workers at medical associated facilities and agencies that involve with the usage, operation as well as regulation of radioactive materials.

2. Materials and Methods

Responses from the workers were collected via handing out questionnaires and collecting them back to calculate their total score on nuclear security awareness. Questionnaires were also used because it was the most appropriate way to conduct the survey[8] instead of doing interviews which was time consuming and less efficient as the number of respondents involved were quite high even if some research suggest misinterpretation can avoided in order to raise awareness [9]. The responses were collected and then recorded to be further analyzed with a suitable statistical test.

The questionnaires are prepared according to IAEA's model [10] of an effective nuclear security culture which is comprised of 4 characteristics which are beliefs, attitudes, behaviour and management system. There are other models that are built upon different sense of the public on nuclear safety and security and broken down into three aspects [11]. However, the questionnaires in this study were based on IAEA's model and were further divided into 4 categories which is shown in Table 1.

Table 1. Nuclear Security categories based on IAEA's model

Categories	Elements and criteria measured
Personnel behaviour	a. Professional conduct b. Teamwork and cooperation c. Personal accountability d. Vigilance
Management system and policy	a. Visible security policy b. Training c. Quality assurance d. Clear roles and responsibilities e. Work environment

Leadership among personnel and management	a. Management oversight b. Involvement of staff c. Improving performance d. Effective performance
Beliefs and attitudes	a. Nuclear security awareness

Before the study is conducted, the institutions and agencies that workers belonged to had to be engaged beforehand and initiated in order to get the administration and senior management's support and approval. This was to ensure the senior managers understand the purpose and scope of the study so the process of collecting responses from the workers could be done efficiently.

The survey was conducted on medical facilities' workers who works are related to nuclear materials. Through handing out questionnaires and via online surveys, a total of 117 responses was collected from various hospitals throughout Malaysia. This study was also done on both operators (those who works and handles radioactive materials for medical procedures) as well as regulators (government body that enforces and supervises). The general information and characteristics are as in Table 2.

Table 2. Information of the respondents

Variables (N=117)	**Number (n)**	**Proportion (%)**
Gender		
Male	60	51.3
Female	57	48.7
Age		
18-25	6	5.1
26-30	27	23.1
31-40	75	64.1
41-50	3	7.7
Duration of service		
1-5 years	33	28.2
6–10 years	57	48.7
11-15 years	18	15.4
16-20 years	6	5.1
21-30 years	3	2.6
Position in workplace		
Science Officer	69	59.0
Radiation Technologist	48	41.0
Highest educational level		
A-Levels	27	23.1
Bachelor	54	46.2
Master	24	20.5
PhD	12	10.3
Radiation source		
Caesium-137	12	10.3
Cobalt-60	18	15.4
Iridium-192	9	7.7
Iodine-131	3	2.6
Americium-241	12	10.3
Others (X-ray irradiating apparatus)	63	53.8
Modality used		
PET-CT	3	7.7

CT-Scan	36	30.8
Blood Irradiator	3	2.6
Others	69	59.0
Use of radiation source		
Medical application	57	48.7
Non-Medical application	60	51.3

The questionnaires were comprised of 26 questions and the answers had to be filled in through a Likert Scale response that had 7 levels of agreement/disagreement. Likert scale bases questionnaires allows data to be collected quickly from large number of respondents as well as providing very reliable estimates of personal skills and views [12]. This is to measure the respondents agreement with various statements in the questionnaires that are related to nuclear security culture. The Likert scale uses numeric value 1-7 with 1 being strongly disagree and 7 ; strongly agree. Table 3. below shows the list of survey questions that was handed out during the data collection phase.

Table 3. Survey Questions handed out to respondents

Survey Questions
Personnel behaviour
Q1. I know how my security related functions fit into the broader picture at my organization.
Q2. I do not regard the procedures for activities significant to security as overburdening.
Q3. I am prepared to notify my co-workers that they are doing something that may downgrade security, even if it is not part of my job.
Q4. I consider myself personally responsible for security at the organization.
Q5. When I discover discrepancies in the implementation of security procedures, I promptly report them to management.
Management System and Policy
Q6. Action is taken by management when nuclear security performance does not fully reach its goals.
Q7. I find the text of security related guides and procedures user friendly and understandable
Q8. I have been instructed during basic security awareness training on requirements for reporting security violations.
Q9. I am aware that quality control measures are adequately enforced in the security area.
Q10. Staff members and contractors are held accountable for adherence to established policies and procedures.
Q11. Our organization has in place written policies, rules or procedures for recruitment and termination of employment as they pertain to security.
Q12. The security significance of various rules and procedures has been clearly and adequately explained to me.
Q13. Management holds my colleagues and me accountable for our behaviour.
Q14. It is easy for me to follow instructions on security because they are clear and user friendly.
Q15. There is a well-established practice to remind staff members and contractors through appropriate channels about the importance of following

Leadership among personnel and management
Q16. Management encourages me to seek, when necessary, clarification regarding my role and responsibility for nuclear security
Q17. Our leaders lead by example and — as is expected from all staff — by adhering to security policies and procedures in their personal conduct.
Q18. I have witnessed our leaders personally inspect performance in the field by conducting walkthroughs, listening to staff and observing work being carried out.
Q19. Managers demonstrate how their security commitments are translated into their daily job.
Q20. I am aware of vigorous corrective and improvement action programmes that are effectively managed by our leaders.
Q21. Leaders communicate their vision of the status of security in a variety of ways.
Q22. Managers frequently inspect my work to ensure that procedures are being followed as expected.
Beliefs and attitudes
Q23. I am aware of the nuclear security policy at my organization to the extent that I can specifically cite its provisions relevant to my job.
Q24. I have become familiar with the code of conduct through ongoing training and awareness sessions.
Q25. I recognize the importance of adhering to procedures and other protocols, such as information control.
Q26. Members of my team show trust in and acceptance of security procedures.

The responses are then recorded and calculated to get the total average score which reflect the respondents' awareness on nuclear security culture. The responses are further analyzed to investigate the relationship between the total scores and the different groups as well as to see which groups are strong and weak in the different categories.

The aim of the study is to determine if there are statistically significant differences between the groups of an ordinal independent variable on a continous dependent variable which in this case if the total average score which can also be represented as nuclear security awareness. The survey also categorised the respondents into 3 or more ordered groups for each variable. Therefore, Kruskal-Wallis H test is suitable to be carried out for data analysis.

The likelihood of rejecting the null hypothesis in favour of the alternative hypothesis, if the alternative hypothesis is true, is defined as the power of a statistical hypothesis test. In other words, it's the likelihood that a statistical test will result in a right conclusion only if the alternative hypothesis is true [13]. When determining that there is no difference between three or more groups, the Kruskal-Wallis test assesses the likelihood of the probability is wrong [14]. The significance level, also denoted as alpha or α, is the probability of rejecting the null hypothesis when it is true. Significance level of this study is set to 0.05 which means that there is a 5% probability that the null hypothesis is true.

Since the variables are categorical (nominal and ordinal), the most appropriate test for this data is Kruskal-Wallis H test [15]. It is nonparametric approach to compare groups on a dependent variable, which in this case is the total average score of the respondents. Eq. 1 shows the H statistics for Kruskal-Wallis test used in this study;

$$H = \frac{12}{n(n+1)} \sum \frac{R_i^2}{n_i} - 3(n+1) \quad (1)$$

Where n is the total number of value, R is the sum of the ranks of each sample and ni is the number of in each sample. Next, the degrees of freedom (d.f.) is calculated by subtracting the number of groups by one [16]. Since the number of samples in each groups is not small and can be considered large, H is to be considered as Chi-Square. (Critical

value of Chi-Square is referred to the Chi-Square table of distribution in table 5). Asymptotic significance (Asymp. Sig. also denoted as p-value) refers to the value based on Chi-Squre approximation which in this study gives the conclusion of the data is not statistically significant when above 0.05.

Null Hypothesis H_0 : The independent variable has no effect on nuclear security awareness.

Alternative Hypothesis H_1: Nuclear security awareness is affected by the independent variable.

3. Results

Figure 1 illustrates the distribution of nuclear security awareness among different age groups. Figure 2 displays awareness levels based on participants' duration of service, while Figure 3 presents awareness levels across different educational levels.

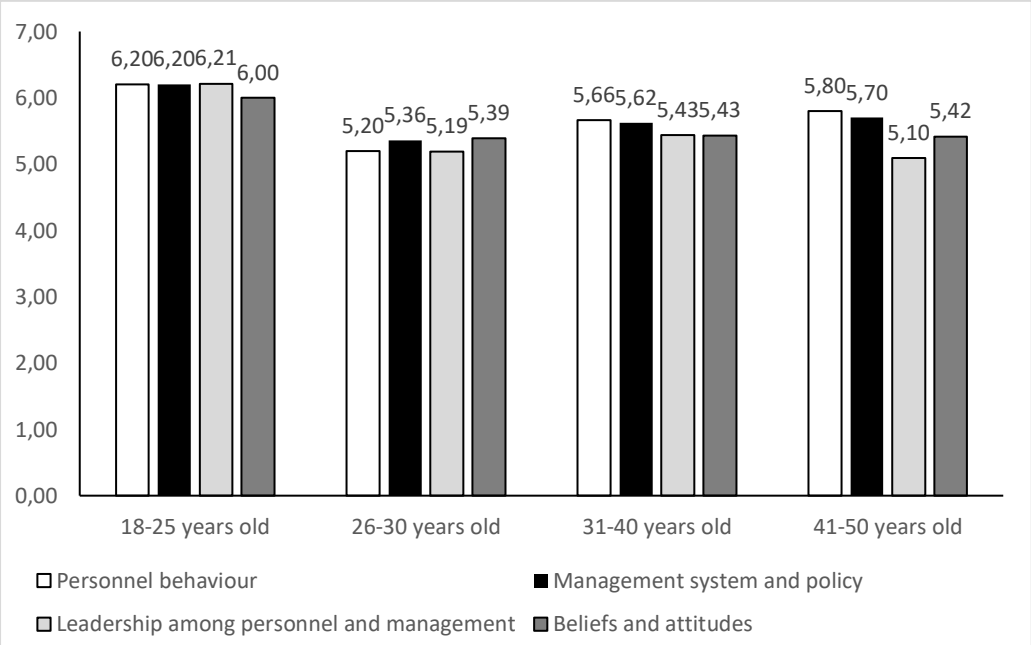

Figure 1. Scoring of nuclear security awareness based age

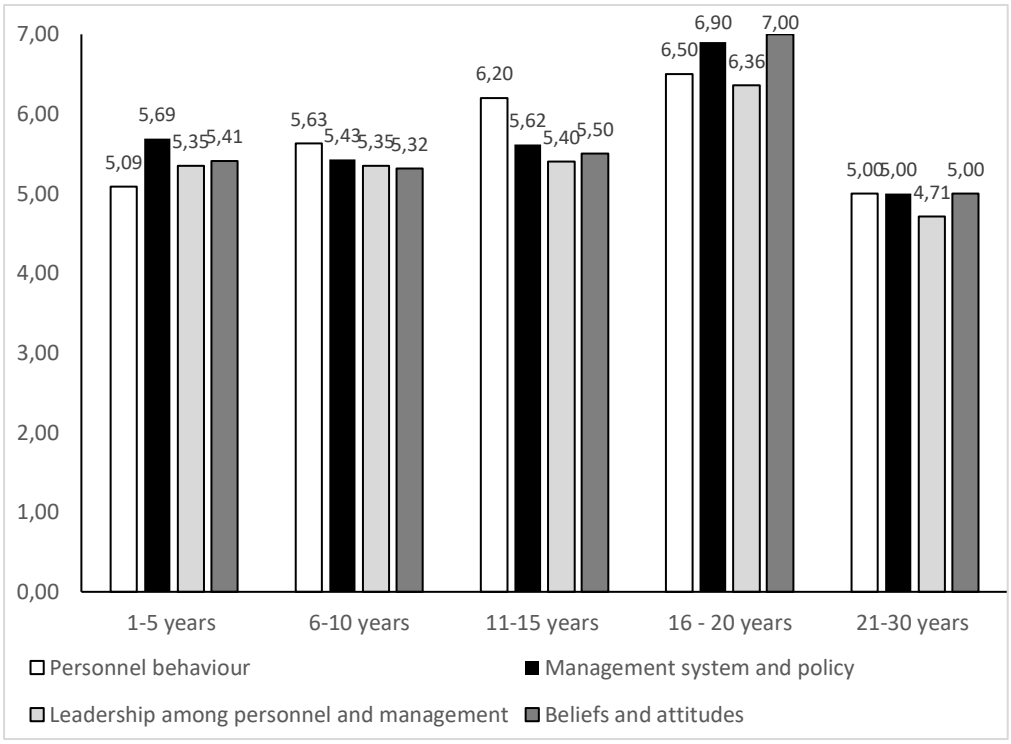

Figure 2. Scoring of nuclear security awareness based duration of services

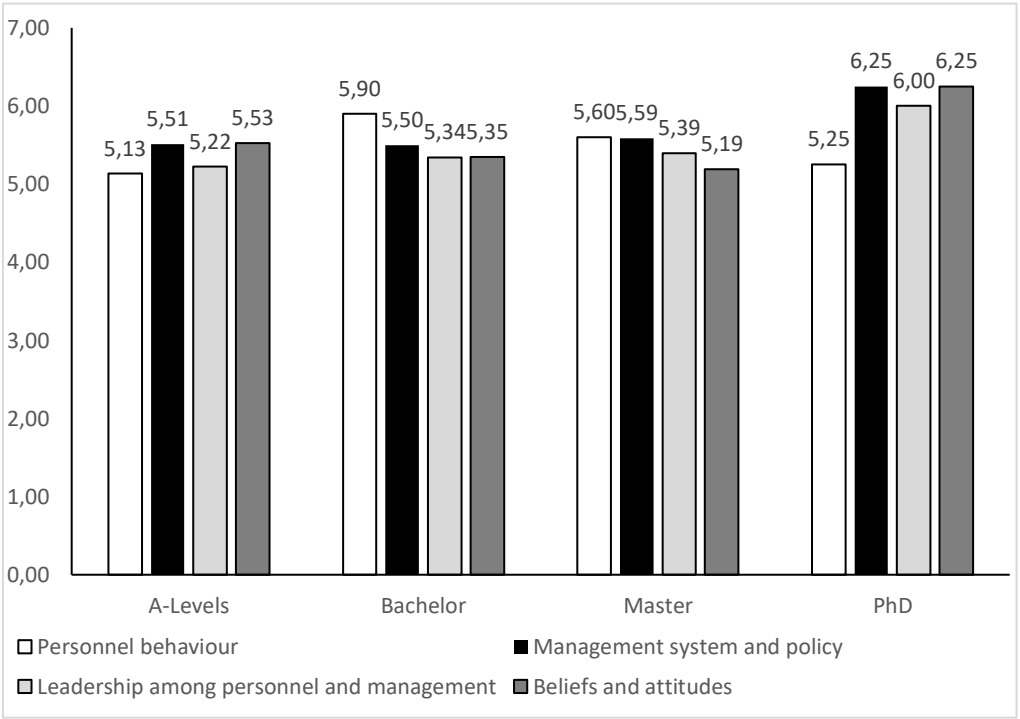

Figure 3. Scoring of nuclear security awareness based on the education levels

Comparative analysis of awareness levels among demographic categories is depicted in Figure 4 through 6. These visualizations highlight differences in awareness levels among age groups, educational backgrounds, and durations of service within the organization.

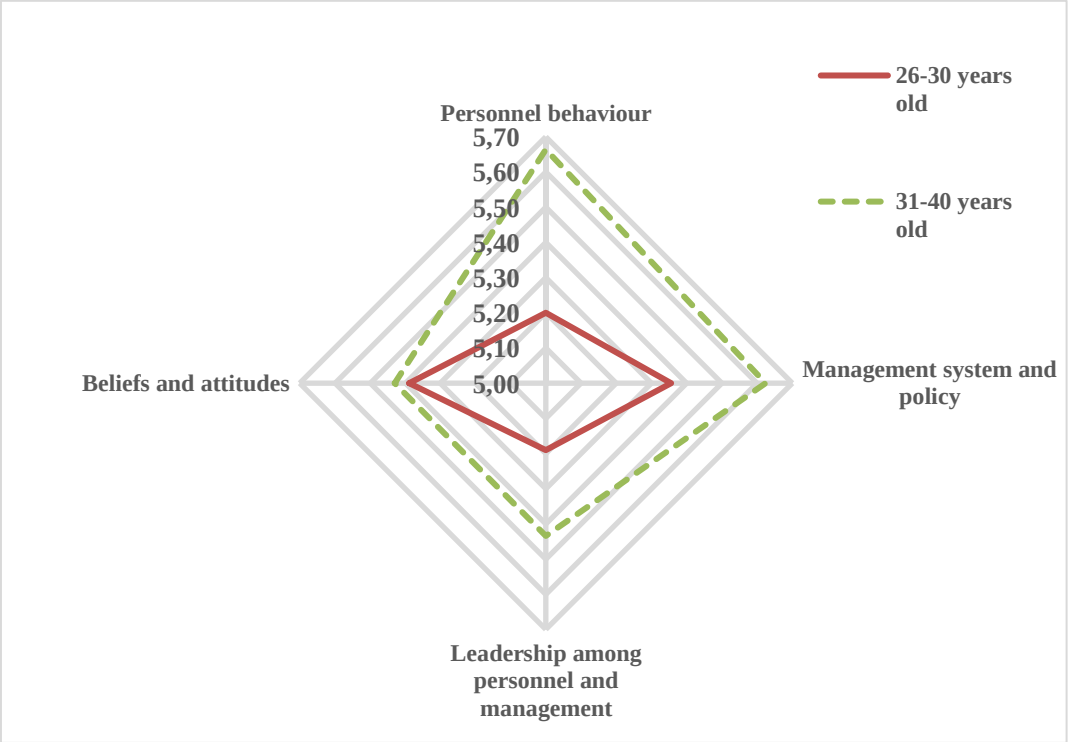

Figure 4. Security Awareness of different age groups

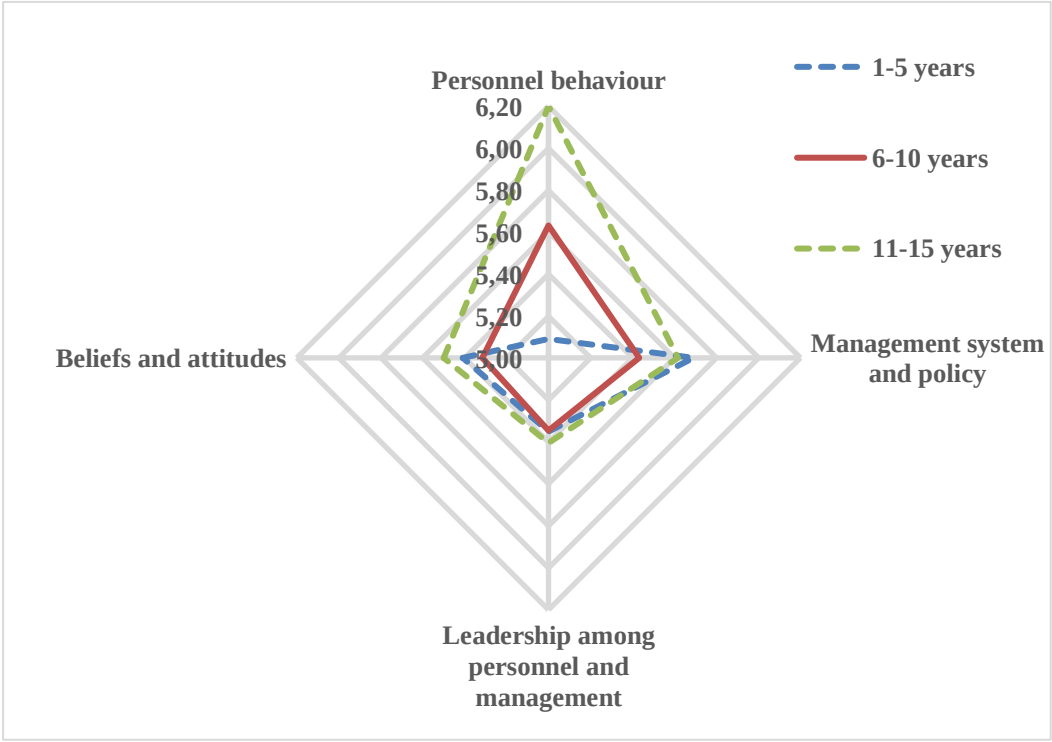

Figure 5. Nuclear Security Awareness of different duration of service groups

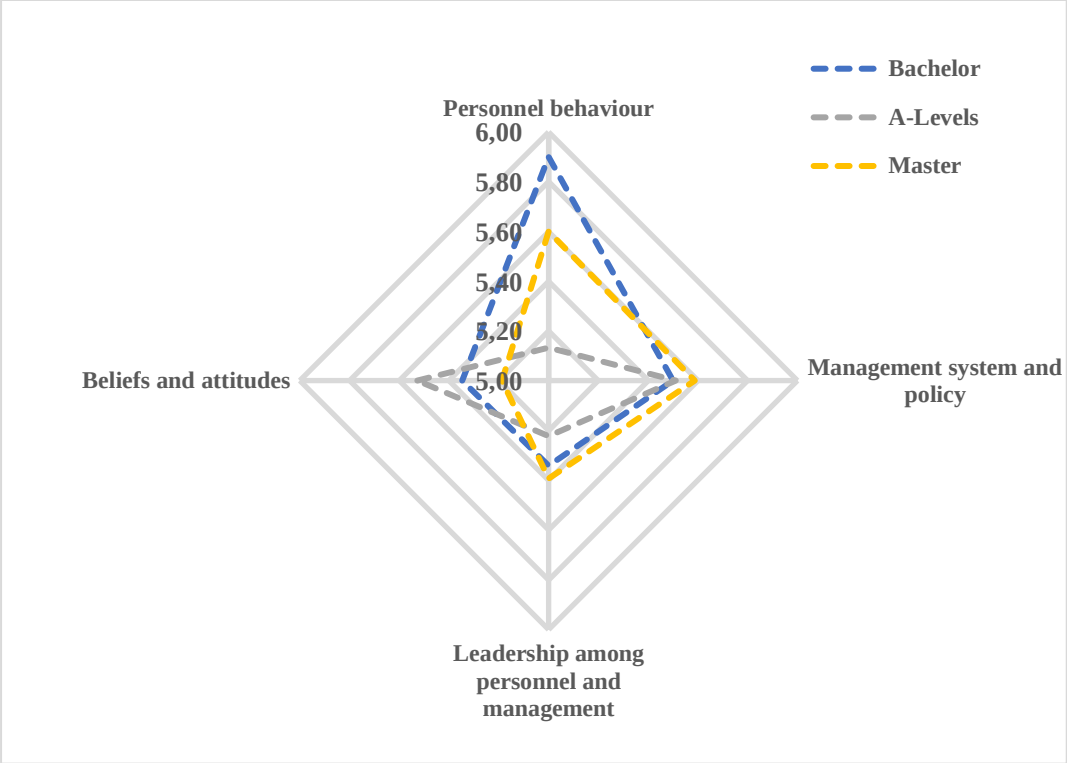

Figure 6. Nuclear Security Awareness of different highest educational level groups

The distribution of total average scores across categories of nuclear security awareness is shown in Figure 7. Table 4 provides detailed information on the mean and standard deviation of scores within each group.

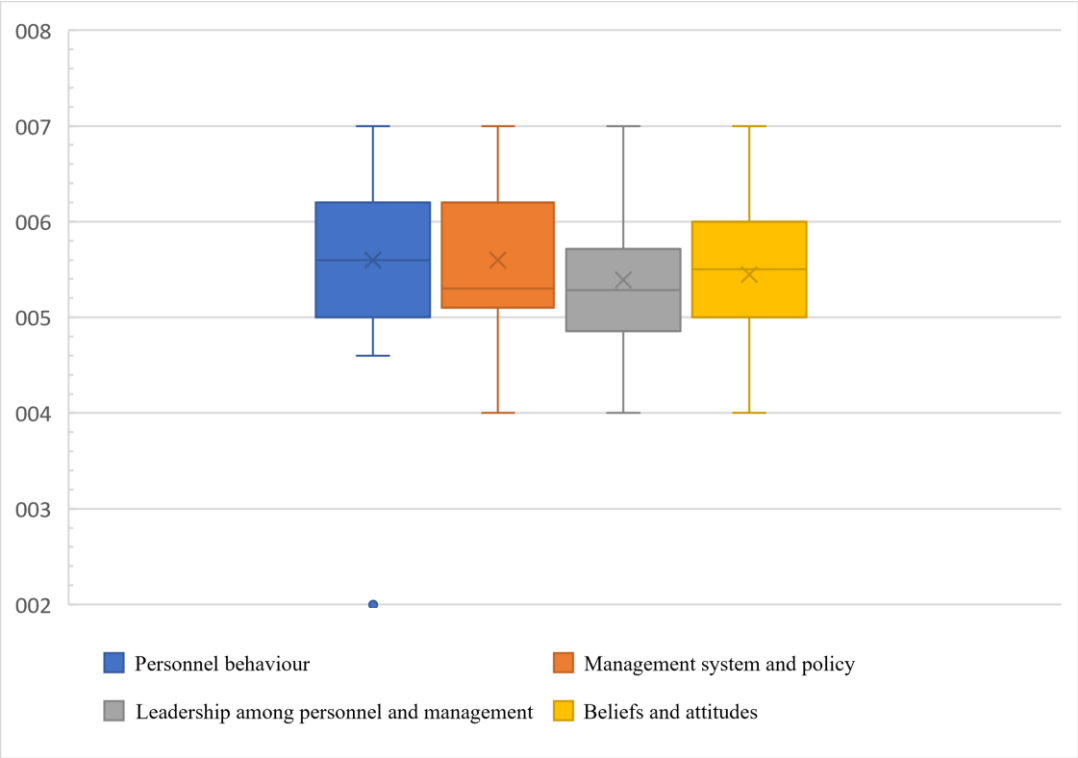

Figure 7. Box plot chart for total average scores by categories

Table 4. Statistical analysis on the scores among groups.

Independent variables	Categories	Mean ± SD
Age		
18-25	Personnel behaviour	6.20 ± 0.88
	Management system and policy	6.20 ± 0.88
	Leadership among personnel and management	6.21 ± 0.86
	Beliefs and attitudes	6.00 ± 1.10
26-30	Personnel behaviour	5.20 ± 0.44
	Management system and policy	5.36 ± 0.55
	Leadership among personnel and management	5.19 ± 0.50
	Beliefs and attitudes	5.39 ± 0.50
31-40	Personnel behaviour	5.66 ± 1.04
	Management system and policy	5.62 ± 0.75
	Leadership among personnel and management	5.43 ± 0.77
	Beliefs and attitudes	5.43 ± 0.88
41-50	Personnel behaviour	5.80 ± 0.62
	Management system and policy	5.70 ± 0.84
	Leadership among personnel and management	5.10 ± 0.47
	Beliefs and attitudes	5.42 ± 1.23
Duration of service		
1-5 years	Personnel behaviour	5.09 ± 0.03
	Management system and policy	5.69 ± 0.03
	Leadership among personnel and management	5.35 ± 0.03
	Beliefs and attitudes	5.41 ± 0.03
6-10 years	Personnel behaviour	5.63 ± 0.72
	Management system and policy	5.43 ± 0.46
	Leadership among personnel and management	5.35 ± 0.52
	Beliefs and attitudes	5.32 ± 0.57
11-15 years	Personnel behaviour	6.20 ± 0.44
	Management system and policy	5.62 ± 0.65
	Leadership among personnel and management	5.40 ± 0.77
	Beliefs and attitudes	5.50 ± 0.85
16-20 years	Personnel behaviour	6.50 ± 0.55
	Management system and policy	6.90 ± 0.11
	Leadership among personnel and management	6.36 ± 0.70
	Beliefs and attitudes	7.00 ± 0.00
21-30 years	Personnel behaviour	5.00 ± 0.00
	Management system and policy	5.00 ± 0.00
	Leadership among personnel and management	4.71 ± 0.00
	Beliefs and attitudes	5.00 ± 0.00
Highest educational level		

A-Levels	Personnel behaviour	5.13 ± 0.41
	Management system and policy	5.51 ± 0.63
	Leadership among personnel and management	5.22 ± 0.51
	Beliefs and attitudes	5.53 ± 0.67
Bachelor	Personnel behaviour	5.90 ± 0.81
	Management system and policy	5.50 ± 0.76
	Leadership among personnel and management	5.34 ± 0.82
	Beliefs and attitudes	5.35 ± 0.87
Master	Personnel behaviour	5.60 ± 0.43
	Management system and policy	5.59 ± 0.67
	Leadership among personnel and management	5.39 ± 0.32
	Beliefs and attitudes	5.19 ± 0.62
PhD	Personnel behaviour	5.25 ± 2.01
	Management system and policy	6.25 ± 0.78
	Leadership among personnel and management	6.00 ± 1.04
	Beliefs and attitudes	6.25 ± 0.78

4. Discussion

Assessment of nuclear security culture across the age groups can be seen as shown in Figure 1. The total average score of the survey was highest among the youngest age group, 18-25 years old and a lower but steady score was recorded on all other age groups. However, there is a small difference of total average score between age groups 26-30 and 31-40 as well as 41-50 where personnel between the age of 26 to 30 years old have lower scores compared to those older than them. Respondents between 26 years of age until 50 years of age showed an increasing trend in awareness all across the four categories but those in 41-50 years age group have lower scores in Category 3 and Category 4 (Leadership among personnel and management, beliefs and attitudes). It is found that respondents in 18-25 years old age group are found to be better in all four categories of nuclear security culture.

Based on Figure 2, it can be concluded that nuclear security awareness does increase with the duration of service up to a certain point, in this case until 20 years of service. This justifies that as people work more, their awareness on nuclear security does inrease over time. This can be proven with those who have worked longer show better scores compared to those who have worked shorter years. The lowest score that was recorded is seen in workers who have been working the longest which is 21-30 years while those have worked between 16-20 years have the highest scores in all 4 categories. For Category 1 (Personnel behaviour), there is a increasing trend of change in scores between 1-5 years group until 16-20 years group with 21-30 years group with the lowest score in the category. However, for group 1-5, 6-10 and 11-15 years, the scores for Category 2 (Management System and Policy), 3 and 4 are all more or less the same. This could be an indication that without undergoing certain courses as well as training related to nuclear security, working experience do not have a big impact on nuclear security culture within an organization.

In respect with educational level, those with PhD scored the highest in the survey compared to those with A-Levels, Bachelor's and Master's Degree. Figure 3 also shows that nuclear security culture somehow do not follow the trend of highest educational level. Bachelor's Degree and Master's Degree holders have higher scores than A-Levels holders with those with PhD scored the highest considering that they have higher educational

certification and qualification which can be observed in Figure 6 where a web chart is plotted among the three groups.

Since there is no observable relationship workers' age and their awareness on nuclear security, a closer look is taken into the categories of their responses. Figure 4 shows the categories of the surveys among 26-30 years old and 31-40 years which account for 23.1 percent and 64.1 percent respectively of the total number of respondents. It can be seen that workers between the age of 31-40 years old has better overall score in all categories compared to those who are between 26-30 years old. However, for beliefs and attitudes, workers in both age groups are somehow similar. This indicates that for 26-30 years old, training in categories other than beliefs and attitudes is required.

A comparison of scores in different categories by workers that have different years of working can is shown in Figure 5. Those that have been working for 6-10 years have much better score compared to those who are within 21-30 years of working. This is mainly because training on nuclear security is mostly given to workers who are young and still new in the organisation while those who are considered seniors in the field with longer experience are neglected from undergoing training.

Fig. 6 shows the comparison of the different categories in the survey between Bachelor's Degree holders which make up of 46.2 percent of the entire respondent and PhD that is only 10.3 percent. Bachelor's Degree holders' scores lean more towards personnel behaviour and beliefs and attitudes while PhD holders' scores are higher in management system and policy and leadership among personnel and management. What this tells about the workers in the two educational level is that both have strength and weaknesses in different aspect on nuclear security culture and awareness.

Table 5. Chi -Square table of distribution

Critical value of Chi-Square, C			
d.f.	0.05	0.01	0.001
1	3.841	6.635	10.828
2	5.991	9.210	13.816
3	7.815	11.345	16.266
4	9.488	13.277	18.467

Table 6. Kruskall Wallis Test Summary

	Age	**Duration of service**	**Highest educational level**
Kruskal-Wallis H	6.514	21.286	8.475
d.f.	3	4	3
Asymp. Sig. (p-value)	0.089	0.000	0.037

Based on the Kruskall Wallis Test summarised in Table 6., different groups has different results that affect the nuclear security awareness of the medical facilities' workers. Kruskal-Wallis test proved there was no stastically significant difference in total average score between age groups (*H(3) = 6.514, **p = 0.089). However, it can be concluded that for duration of service and highest educational level, the null hypotheses is rejected. This showed that there were statistically significant differences in total average score between between duration of service (*H(4) = 21.286, **p = 0.000) and highest educational level (*H(3) = 8.475, **p = 0.037).

As safety culture promotes lack of secrecy, security culture necessitates secrecy to prevent any unwanted information being exposed to non-vital personnel. Employees in a well-developed safety culture must freely communicate information, but employees in a well-developed security culture must only share information with necessary authorised

persons. Safety and security cultures should not be blended, but neither should they be pitted against one another. From the start of the NPP's design, the synergy between nuclear safety and nuclear security must be maximised. In terms of operational principles, routine testing and maintenance programmes, operating experience input, legal and regulatory framework, training and education, there is a lot of overlap between safety and security [17].

A study conducted has revealed that human mistake or other culture-related issues are the fundamental causes of security breaches [18]. Additionally, it is an undeniable reality that when an irregular or stressful scenario arises, the likelihood of personnel making mistakes rises significantly.

To prevent malevolent actors from gaining access to nuclear facilities and radioactive materials, Southeast Asia especially Malaysia must establish effective nuclear security capabilities. Despite strong regional collaboration on nuclear security and safety with neighboring ASEAN countries, one obvious failing of Southeast Asia's nuclear energy governance is a lack of nuclear security and safety culture, emphasising the significance of human aspects such as attitudes, awareness, and behaviour[19]. Southeast Asia can adopt multiple existing policy frameworks from Northeast Asia to foster strong safety-security cultures.

Security culture necessitates a quick response to verified or suspected threats, as well as issues involving safety and cybersecurity. Only authorised people should be able to communicate in the case of security. As a result, the most important common goal of security and safety culture is to reduce the risk connected with radioactive material and infrastructure. This goal is mostly founded on collective concepts, such as strict and discrete methods, a critical mindset, effective communication, and open two-way communication[20]. Several groups are concerned about nuclear security. Individuals and institutions concerned in the protection and transportation of radioactive material, as well as their accompanying facilities, fall under this category. Some of these groups may have just a rudimentary understanding of nuclear or other radioactive materials.

5. Conclusion

The degree of awareness on nuclear security of 117 workers was looked into based on multiple factors to see which one affected the total average scores. This study was conducted by using questionnaires that consists of questions that evaluate different categories of nuclear security awareness. Of all the demographics information recorded from the respondents, 3 were selected to see whether which has an effect on the total average score. Between the 3 independent variables, Kruskal-Wallis Test with 95 % confidence level showed that age has no significant effect on nuclear security while duration of service as well as highest educational level affects the level of nuclear security awareness of the workers.

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