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Cover Page Footnote

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Analysis of Nuclear Security and Safety Integration Using Survey Responses and Pairwise Comparison Methods

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Abstract
Integrating nuclear security and safety is important for implementing and sustaining nuclear technology because it promises improved and effective management. This integration is an ongoing effort to ensure that both work together with minimal conflicts. This research aimed to determine the preferred level at which nuclear security and nuclear safety integrate by using the pairwise comparison methods of decision-making. This methodology used survey responses from women nuclear professionals to identify the most-desired criteria at three levels: strategic, operational, and cultural. The strategic level includes actions that government officials and regulators can take. The operational level encompasses actions that deliver the integration. The cultural level involves actions that must be taken to change an organization's attitude toward integration. The survey results indicated that a majority (75%) of respondents agree nuclear security and safety integrate when the organizational structure and legal framework support integration at the strategic level. A majority (75%) of respondents agreed that nuclear security integrates with nuclear safety when the organizational structure and the legal framework support integration at the strategic level. A majority (70%) of respondents agreed that work comprising support for implementing an integrated interface and reporting mechanisms to report and address nuclear security and safety conflicts facilitates integration at the operational level. At the cultural level, more than half (55%) of respondents agreed that nuclear security and nuclear safety integration occurs when leadership is supportive and clearly accountable and staff fully

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understand their roles and responsibilities. Applying pairwise comparison methods to the survey data, nuclear security integrates with nuclear safety most at the operational level (with a priority of 0.44). The strategic level rated as the second highest priority (0.37), and the cultural level had the lowest priority (0.19). The results show that integrating nuclear security and safety is most recommended at the operational level. The sensitivity analysis (both sum rank and equal weights) showed that the best alternative for integrating nuclear safety and security is at the strategic level.

Keywords: nuclear security, nuclear safety, surveys, pairwise comparisons, integration

1. Introduction

Nuclear security and nuclear safety share the same objective: to protect people, society, and the environment from radiation hazards. They are similar because they are based on legally binding treaties but are voluntary regarding implementation [1]. The acceptable risk for both is reasonably the same, whether the initiating event is due to an event of malicious origin, human and equipment failures, or internal or external hazards [2, 3]. Both follow the defense-in-depth strategy of using layers of protection that ensure prevention, detection, and mitigation to avoid damage, although the types of barriers and protection may differ [2, 4]. Both nuclear security and safety apply to nuclear power plants and other nuclear facilities, transportation of nuclear materials, and use and storage of nuclear materials for medical, power, industry, and the military [2, 5].

Differences also exist in nuclear security and nuclear safety. Nuclear security has advanced largely in response to the terrorist attacks on the two World Trade Centers on September 11, 2001, in the United States [6], and nuclear safety matured quickly following the notable Three Mile Island and Chornobyl nuclear accidents [7]. Nuclear security is often implemented by law enforcement personnel, and nuclear safety is primarily the concern of engineers, scientists, and radiation health experts. Nuclear security events are intentional, whereas nuclear safety events are accidental [6, 8]. Security focuses on malicious parties of insider and outsider threats to the system, and safety focuses on unintentional events. These differences result in different foundations for prioritizing solutions [4].

Nuclear security and nuclear safety have traditionally been regulated and managed in isolation. However, as a matter of urgency, the two regimes should be integrated because the nuclear industry desires an effective global nuclear governance. Also, the increased use of nuclear and radioactive material for peaceful purposes has been heralded as the beginning of a nuclear energy renaissance [1, 8].

Integrating nuclear security and safety is an ongoing effort and implies crossing boundaries that must be facilitated to provide *whole* nuclear governance needs. Through coordination mechanisms and integrating the “integrable” aspects within the two regimes, synergy will be created, enabling the ideal implementation of an efficient and effective regulatory system [9, 10].

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One reason why addressing nuclear security and safety integration is of such paramount necessity—and is simultaneously a challenge—is the need to ensure that nuclear facilities do not endanger the public. This assurance can only be achieved by preventing a significant release of radioactivity to the environment, coordinating emergency preparedness and response to nuclear security and safety incidents, and preventing nuclear security and safety events [2, 11, 12]. There is also the need to know that nuclear security and safety cultures coexist and can reinforce each other to limit risk [8]. Developing an integrated nuclear security and safety framework identifies gaps, interactions, and conflicts that would be missed by the traditional approach of analyzing each regime in isolation [13].

Recent studies and publications championing the benefits of having an integrated approach to implementing nuclear security and safety have focused on the fact that they have the same role of protecting people and the environment [14–16]. The efforts promise effectiveness and efficiency benefits for the safe, secure, and peaceful operation of existing and future nuclear technologies [16]. Efforts also ensure that existing and emerging nuclear countries are supported by peaceful national programs that incorporate nuclear safety and security [10]. Finally, no studies or publications show that integrating nuclear security with nuclear safety is not beneficial. For these reasons, an integrated approach is considered justified [17].

Some research on integrating nuclear security and safety has focused on the roles and responsibilities played by the radiation protection expert or the operational security personnel regarding an attack by an adversary involving nuclear or radioactive substances [6]. Some have focused on developing professional courses in nuclear security for radiation protection experts and strategies for integrating radiation protection into nuclear security and vice versa [6, 18]. Others have focused on the research opportunities available for faculty, students, and research institutions in assessing nuclear security and its integration with nuclear safety in research, nuclear power, health care, and academia [18]. Finally, some have focused on designing methodologies to enhance the integration by encouraging a common language, training, and educating nuclear experts so they are aware and can connect the dots between the two regimes [19, 20].

Nuclear professionals know that effective management of the interface between nuclear security and safety is the best way to maximize performance. Interface management can optimize protection during routine operations and reduce the risk of harm to people, property, society, and the environment. Consequently, encouraging an integrated approach to nuclear security and safety is very important for successfully implementing, sustaining, and expanding nuclear technology [21]. Simply put, an integrated approach ensures that the solutions for nuclear security do not adversely impact the effectiveness of nuclear safety and vice versa.

To integrate nuclear security and safety, three levels must be considered: strategic, operational, and cultural, which are the three organizational levels of management used in most businesses. The strategic level pertains to actions that governments, regulatory

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bodies, boards, and senior executives of organizations can take to ensure the integration of nuclear security and safety. The operational level considers actions that must be taken to deliver and sustain integration. The cultural level deals with actions that must be taken to change an organization's thinking and approach toward integration [16, 20]. In this way, the current call for an integrated approach to nuclear security and nuclear safety can enhance the operations of both small and large nuclear facilities for their mutual benefits [10, 15, 16, 22].

With this background in mind, researchers need to assess the nuclear security and nuclear safety situation, identify possible areas of integration, and propose an integrated approach to enhance the implementation of nuclear security and nuclear safety to reduce the likelihood of unacceptable consequences in the nuclear industry as well as enjoy the benefits it offers [16]. This study aimed to identify the level at which nuclear security integrates with nuclear safety with no conflicts in support of the arguments for nuclear security and safety professionals to work together [6, 16, 23].

2. Methodology

a. Research Design and Survey Questionnaire

This study used a survey and applied pairwise comparison methods for decision-making. Quantitative data were collected from an online survey identifying the preferred aspects for ensuring nuclear security and safety integrated with no conflicts. The study used the survey responses of women nuclear professionals on where nuclear security integrates with nuclear safety to develop the criteria for integration. This approach helped establish the most suitable level (strategic, operational, or cultural) for integrating nuclear security and safety. The women nuclear professionals were selected as respondents because we wanted to know their perspectives, suggestions, and recommendations for integrating nuclear safety and nuclear security.

An online quantitative Likert scale questionnaire was used for the survey. The questionnaire consisted of 20 questions divided into two sections. Section A assessed the level of integration (strategic, operational, cultural); Section B covered the respondents' demographics. Respondents indicated their level of agreement with statements on a five-point scale ranging from "Strongly Disagree, Disagree, Agree, Strongly Agree" and "Don't Know." The questionnaire was prepared using the World Institute for Nuclear Security report, *Best Practice on an Integrated Approach to Nuclear Safety and Nuclear Security* [16]. Respondents were members of Women in Nuclear, Africa and come from Ghana, Nigeria, Kenya, Ethiopia, Cameroun, Democratic Republic of the Congo, and Zimbabwe, with majority coming from Ghana. They have expertise in physics, radiation protection, nuclear safety, nuclear security, nuclear safeguards, nuclear and environmental sciences, cybersecurity and computer sciences, public relations, medical physics, and nuclear medicine.

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b. The Pairwise Comparison Method

Although other methodologies like a quantitative agreement Likert scale survey and a qualitative document analysis were considered, the pairwise comparison was selected because it is normally used for social sciences research and not for applied sciences.

Pairwise comparison is a technique used for ranking a set of options based on the preferences of a group of respondents in multicriteria decision-making [24]. This technique was used to process the data collected from the survey responses to decide which nuclear security and safety aspects integrate without conflicts. The method started with the goal of selecting the most suitable level for integrating nuclear security and safety from three decision alternatives. The criteria considered were organizational culture, legal framework, integrated risk assessment, reporting mechanism, and leadership and accountability. The decision alternatives were the strategic, operational, and cultural levels. The selected criteria are defined in Table 1.

Table 1. Criteria for integrating nuclear security and safety.

	Strategic level	Operational level	Cultural level
Organizational culture	Ensures that the organizational structure supports the integration	Enables nuclear security and nuclear safety departments to take effective actions	Determines the attitude of staff toward nuclear security and nuclear safety
Legal framework	Ensures that nuclear laws and policies favor integrating nuclear security and nuclear safety	Ensures that the roles and responsibilities of the operator for an integrated nuclear security and nuclear safety interface are clearly stated in the regulations	Ensures that staff fully understand their nuclear security and nuclear safety roles and responsibilities
Integrated risk assessment	Enhances consistency in decision-making	An integrated nuclear security and nuclear safety risk assessment helps design more capable risk mitigation strategies	Gauges overall risks
Reporting mechanisms	Ensures that senior management puts measures in place for reporting operational experiences	Helps address possible nuclear security and nuclear safety conflicts	Creates opportunities for nuclear security and nuclear safety professionals to come together and resolve operational issues
Leadership and accountability	Ensures the availability of nuclear security and nuclear safety personnel and resources to carry out full-scale exercises	Ensures a coordinated approach to implementing nuclear security and nuclear safety activities	Ensures clear leadership for all nuclear security and nuclear safety activities within the organization

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Pairwise comparison was performed manually by recording the preferences for each pair combination using a ratio scale developed from the analytical hierarchy process (AHP) [25]. These data were then used to calculate the overall results table. The pairwise comparisons used the following steps.

Step 1: Setting the Prioritization

The prioritization method [25] and the ratings were based on a modified version of the fundamental AHP scale, shown in Table 2.

Table 2. The ratings scale for the pairwise comparisons.

Level of Importance	Definition	Explanation
1	Equally recommended	Two elements contribute equally to the objective
2	Slightly more recommended	Experience and judgement slightly favor one element over the other
3	Moderately more recommended	Experience and judgement moderately favor one element over the other
4	Strongly recommended	Experience and judgement strongly favor one element over the other

Two criteria were evaluated at a time in terms of their relative importance. Ratings modified from the fundamental AHP scale from one to four were used. If criterion A was exactly as important as criterion B, this pair received a rating of one. If A to B was rated with the relative importance of *n*, B to A has to be rated with 1/*n*. For example, if A is “strongly recommended” when compared with B, then the rating is four. This also means that B is much less important than A and has a rating of one-fourth. The values were entered row by row into a matrix, with diagonal pairs containing the reciprocals of the entered data. Matching criteria (e.g., A to A) received a rating of one.

Step 2: Calculating the Criteria Weights

In this step, the weights of the individual criteria were calculated. First, a normalized comparison matrix was created by dividing each value in the original matrix by the sum of its column. The criteria weights were derived by determining the mean of each row in this second matrix.

Step 3: Assessing the Consistency Matrix

Because inconsistency is expected with this method, a consistency ratio is calculated to ensure pairwise comparisons are not contradictory [26]. To calculate the consistency ratio (*CR*), the consistency index (*CI*) was divided by the Random Consistency Index (*RI*), as shown in Equation (2). The *RI* was calculated from a sample of 500 randomly generated reciprocal matrices using the nine-point scale. Each index was applied to a matrix of size *n*. The *CI* was calculated using Equation (1):

$$CI = \frac{\lambda_{\max} - n}{n - 1}, \tag{1}$$

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where λ_{max} is the ratio average of the weighted sum value to the criteria weights for all criteria in the matrix of size *n.*

$$CR = \frac{CI}{RI}. \quad (2)$$

A $CR \leq 0.10$ implies that the matrix contains data inconsistency less than or equal to 10%, which was considered an acceptable level of inconsistency [27]. Using Equation (2), the final criteria were calculated and are presented in Table 6. The calculated priorities for Steps 1–3 for all criteria are presented in the results.

c. Sensitivity Analysis

Sensitivity analysis (SA) is a technique that determines the effects of changes in input values on a model's results. Performing an SA on the results of a decision problem may provide valuable information to the decision-maker about the robustness of the solution.

The ranking methods determination was used for the SA because of its effectiveness and simplicity [28]. The ranking method weight determination involves two steps: ranking the criteria according to their importance and weighting them from their ranks using one of the rank order weighting formulas. This method considers the information about the rank ordering of criteria weights, from which approximations for criteria weights are calculated.

Based on this information, the final priorities of the criteria (previously determined from the pairwise comparisons for the strategic, operational, and cultural levels) were used to generate the numerical weights in ascending (rank) and descending (inverted rank) orders (see Tables 3–5).

Table 3. Decision table for sensitivity analysis.

Objective	**Criteria**	**Rank**	**Inverted rank**	**Requirement weight**
Max	Organizational culture	4	2	0.10
Max	Legal framework	2	4	0.25
Med	Integrated risk assessment	1	5	0.42
Med	Reporting mechanism	3	3	0.16
Min	Leadership and accountability	5	1	0.07
	By using rank sum (total)	15	15	1.00

Table 4. Collected data for the sensitivity analysis.

Collected data criteria	**Strategic level**	**Operational level**	**Cultural level**
Organizational Culture	0.06	0.01	0.03
Legal Framework	0.12	0.08	0.05
Integrated Risk Assessment	0.11	0.25	0.07
Reporting Mechanism	0.05	0.09	0.02
Leadership & Accountability	0.03	0.01	0.02

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Table 5. Weighted sums.

Alternatives			
	Strategic level	**Operational level**	**Cultural level**
	3	4	3
	1	3	2
	2	1	1
	4	2	4
	5	4	4
Total score weight	**15**	**14**	**14**

Note: This table contains the ranking orders for the collected data from Table 4.

d. Rank Sum Method

With the rank sum method, a weight–rank functional relationship is assumed to exist between criteria ranks and average weight values [28]. Multiplying the weighted sums (in Table 5) by the requirement's weights for the rank sum method (in Table 6) generated the weighted sums (total scores), which gives the SA based on the rank sum method.

Table 6. Rank sum method.

Using the rank sum method criteria	Requirements weights
Organizational culture	0.10
Legal framework	0.25
Integrated risk assessment	0.42
Reporting mechanism	0.16
Leadership and accountability	0.07

e. Equal Weight Method

The equal or uniform weighting method (*EW*) requires minimal knowledge about the criteria priorities [28]. If no information exists about the true weights for the criteria priorities, then the true weights could be represented as a uniform distribution. This method is done by calculating the weights using Equation (3), where *n* is the total number of items or criteria. Using Equation (3), the requirements weights for the uniform weighting method are recorded in Table 7.

$$EW = \frac{1}{n}. \tag{3}$$

Multiplying the weighted sums (in Table 5) by the requirements weights for the equal weighting method (in Table 7) generated the weighted sums (total scores) in Table 11, which gave the SA based on the uniform weighting method.

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Table 7. Equal weighting.

Using equal weighting method criteria	Requirements weights
Organizational culture	0.20
Legal framework	0.20
Integrated risk assessment	0.20
Reporting mechanism	0.20
Leadership and accountability	0.20

3. Results and Discussion

a. Demographics of Respondents

From the survey results (Table 8), 20 female respondents had a highest level of education completed of tertiary (secondary high-school) education. The majority (40.0%) of respondents were within the age range of 30–39 years. The majority of respondents had expertise or specializations in physics and radiation protection, represented by six (30.0%). In total, 7 were scientific and technical staff (35.0%), 8 had worked between 1 and 10 years (40.0%), 12 worked as regulators (60.0%), and 8 were knowledgeable in nuclear safety and security matters and have nuclear safety and/or security responsibilities (40.0%).

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Table 8. Survey respondents' details.

Demographic	**Counts frequency (*n*)**	**Percent (%)**
Gender		
Female	20	100
Age range		
18–29	3	15.0
30–39	8	40.0
40–49	6	30.0
50–59	2	10.0
60 and above	1	5.0
Areas of specialization		
Radiation protection	2	10.0
Nuclear safety	2	10.0
Nuclear security	1	5.0
Nuclear safeguards	1	5.0
Radiation protection, nuclear safety, and nuclear security	1	5.0
Physics and radiation protection	6	30.0
Nuclear and environmental sciences	2	10.0
Cybersecurity and computer sciences	2	10.0
Public affairs	2	10.0
Medical physics and nuclear medicine	1	5.0
General employment group		
Senior management group	3	15.0
Engineering staff	2	10.0
Nuclear safety staff	2	10.0
Scientific and technical staff	7	35.0
Business and administrative staff	2	10.0
Communications and public relations staff	1	5.0
Information technology staff	3	15.0
Number of working years		
Less than a year	3	15.0
1–5 years	4	20.0
5–10 years	4	20.0
15–20 years	1	5.0
20 years and more	2	10.0
Level of integration		
National level	4	20.0
Regulatory level	12	60.0
Facility level	4	20.0
Sector of work		
Nuclear facilities	3	15.0
Government	2	10.0
Regulators	11	55.0
Research institutions	4	20.0
Criteria that best describes nuclear professional		
Knowledgeable in nuclear safety and nuclear security matters	5	25.0
Have attended a nuclear safety and security training	5	25.0
Knowledgeable in nuclear safety and security matters and have nuclear safety and/or security responsibilities	8	40.0
Knowledgeable in nuclear safety and security matters and have attended nuclear safety and security training	1	5.0
Knowledgeable in nuclear safety–security matters, have safety–security responsibilities, and attended training	1	5.0

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Respondents agree that when the legal framework represented by 15 (75%) and the organizational structure also represented by 15 (75%) within an organization supports the integration of nuclear security and nuclear safety, then there would be an integration at the strategic level (Figure 1).

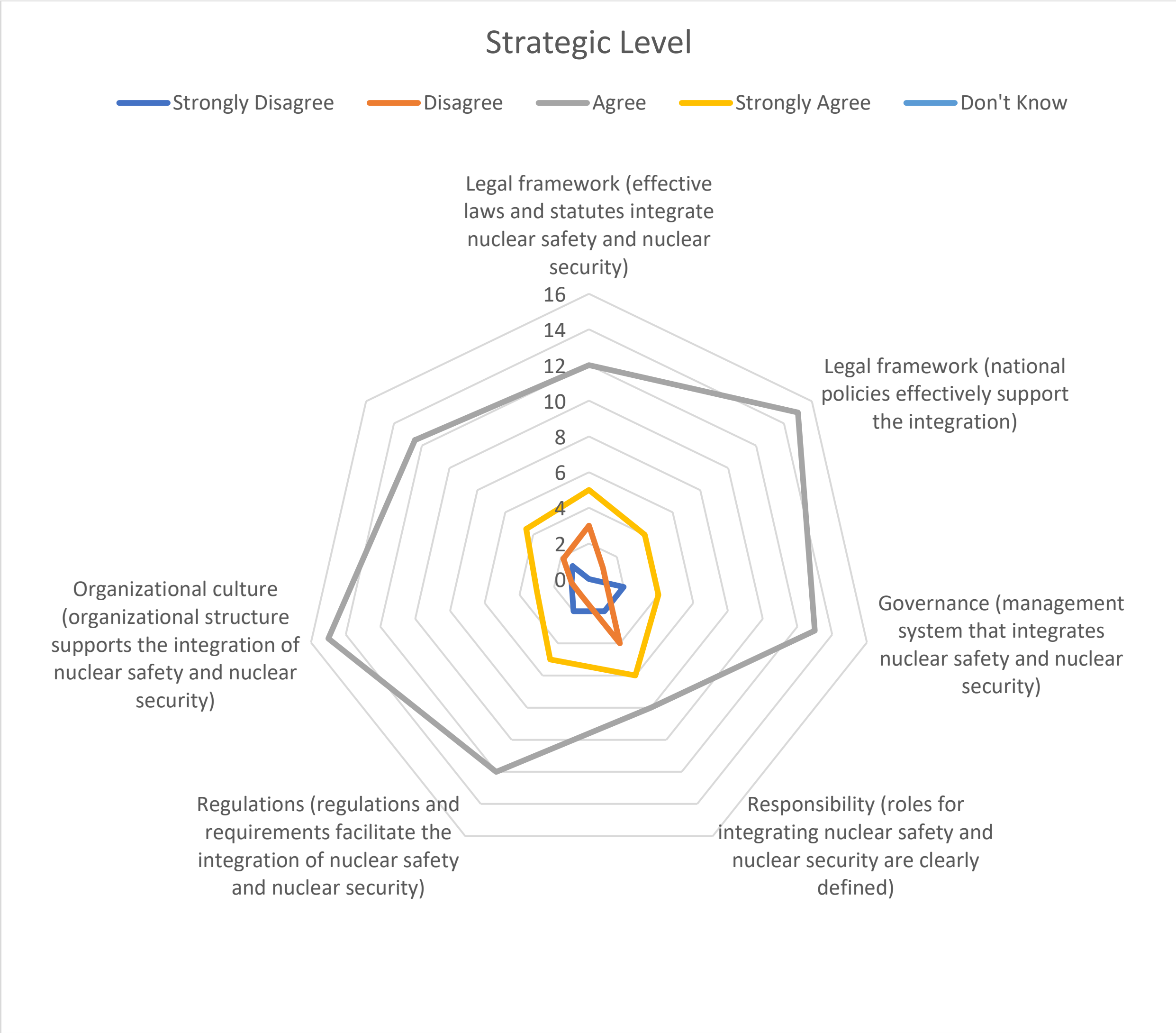

Figure 1. Integrating nuclear security and safety at the strategic level.

At the operational level, respondents (represented by 15 [75%]) agreed that when a reporting mechanism is in place to report and address nuclear safety and nuclear security conflicts; and an integrated risk assessment approach is used for nuclear safety and security, then integration would occur (Figure 2).

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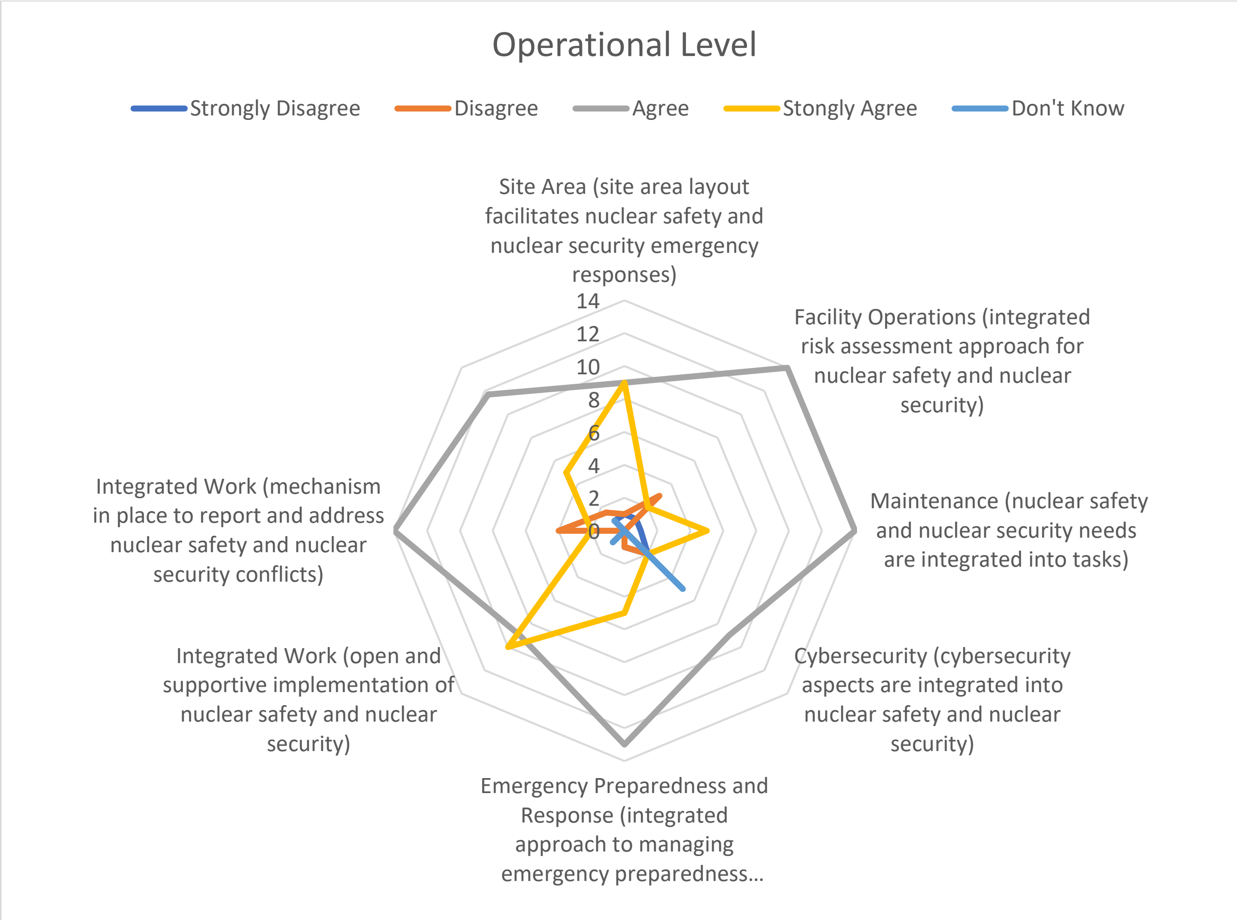

Figure 2. Integrating nuclear security and nuclear safety at the operational level.

Finally, at the cultural level, respondents (represented by 11 [55%]) agreed that integration occurs when management (including clear leadership for all nuclear security and nuclear safety responsibilities) supports integrating nuclear security and nuclear safety and staff are fully aware of their nuclear security and nuclear safety responsibilities (Figure 3).

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Figure 3. Integrating nuclear security and nuclear safety at the cultural level.

b. Pairwise Comparisons

The pairwise comparison method was applied to the survey results that identified key recommendations for integrating nuclear security and safety. Looking at the *organizational culture*, the strategic level is by far the most preferred level of integration of the three. This preference is because it dominates the operational level by a factor of four and the cultural level by a factor of two. The priority scores were 0.56, 0.28, and 0.14 for the strategic, cultural, and operational levels, respectively. The *legal framework* is more recommended at the strategic level than at the operational and cultural levels. Also, a similar relationship was shown at the cultural level, whereas the *legal framework* was recommended for the integration at the cultural and operational levels, and the integration was half that of the strategic level. The priority scores were 0.49, 0.31, and 0.20 for the strategic, operational, and cultural levels, respectively.

Integrated risk assessment was moderately more recommended at the operational and cultural levels than at the strategic level. This result means that an integrated risk assessment is preferred at the operational level compared with the strategic or cultural levels. Having a *reporting mechanism* in place to report and address possible nuclear security and safety conflicts is strongly recommended at the operational level compared with at the strategic and cultural levels. This result occurred because it is easier for the nuclear professionals to share operational experiences at that level than at the other levels. The priority scores were 0.66, 0.21, and 0.13 for the operational, strategic, and cultural levels, respectively. Finally, for *leadership and accountability*, the strategic level

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was the strongest of the three. Generally speaking, leadership and accountability dominated the operational level by a factor of almost three and the cultural level by a factor of almost two. The priority scores were 0.48, 0.32, and 0.17 for the strategic, cultural, and operational levels, respectively.

After evaluating the decision alternatives' strengths in meeting the criteria, the criteria were evaluated for their importance in reaching the goal of integrating nuclear safety and nuclear security. This integration was done with a series of pairwise comparisons using the ratings in Table 2 and a resulting pairwise comparison matrix. *Integrated risk assessment* (0.42) ranked as the overall most critical criterion for integration. The least critical criterion was *leadership and accountability* (0.07). *Legal framework* (0.12) was the most critical criterion for integrating nuclear security and nuclear safety at the strategic level; *integrated risk assessment* (0.25 and 0.07) was the most critical at the operational and cultural levels.

The priorities of ratings used for integrating each criterion are given in Table 9. The operational level, with a priority of 0.44, was by far chosen as the best option to integrate nuclear security and safety. The strategic level, with a priority of 0.37, was second, and the cultural level came third with a priority of 0.19. Thus, integration is highly recommended at the operational level.

Table 9. Priorities of ratings of level of integration under each criterion.

	Strategic level	Operational level	Cultural level	Total
Organisational culture	0.06	0.01	0.03	0.10
Legal framework	0.12	0.08	0.05	0.25
Integrated risk assessment	0.11	0.25	0.07	0.42
Reporting mechanism	0.05	0.09	0.02	0.16
Leadership and accountability	0.03	0.01	0.02	0.07
Total	**0.37**	**0.44**	**0.19**	**1.00**

Using Equation 2 for all the processed pairwise comparisons, the consistency ratios were calculated to be less than 0.10, meaning that all the matrices are consistent. Only the *leadership and accountability* pairwise comparison matrix, which had a consistency ratio of 0.12, was slightly outside the required range.

c. Sensitivity Analysis

Rank Sum Method

When the ranks of the criteria weights were reversed with the results, as shown in Table 10, *integrated risk assessment* (0.84) became the critical criterion for integration at the strategic level, *legal framework* (0.75) became the critical criterion at the operational level, and *reporting mechanism* became the critical criterion at the cultural level.

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Table 10. Weighted sum (total scores) for the rank sum sensitivity analysis.

Weighted sum (total scores)			
Alternatives with weighted			
Criteria	**Strategic level**	**Operational level**	**Cultural level**
Organizational culture	0.30	0.40	0.30
Legal framework	0.25	0.75	0.50
Integrated risk assessment	0.84	0.42	0.42
Reporting mechanism	0.64	0.32	0.64
Leadership and accountability	0.35	0.28	0.28
Total scores:	**2.38**	**2.17**	**2.14**

Equal Weights Method

When the ranks were equalized as shown in Table 11, *leadership and accountability* (1.00) became the critical criteria for integrating nuclear security and nuclear safety at the strategic level. *Organizational culture* (0.80) and *leadership and accountability* (0.80) became the critical criteria for integrating nuclear security and nuclear safety at the operational level. Finally, *reporting mechanism* (0.80) and *leadership and accountability* (0.80) were critical criteria for integrating nuclear security and nuclear safety at the cultural level. Thus, the best alternative for integrating nuclear security and nuclear safety is at the strategic level.

Table 11. Weighted sum (total scores) for the equal weighting sensitivity analysis.

Weighted sum (total scores)			
Alternatives with weighted			
Criteria	**Strategic level**	**Operational level**	**Cultural level**
Organizational culture	0.60	0.80	0.60
Legal framework	0.20	0.60	0.40
Integrated risk assessment	0.40	0.20	0.20
Reporting mechanism	0.80	0.40	0.80
Leadership and accountability	1.00	0.80	0.80
Total scores	**3.00**	**2.80**	**2.80**

Overall Determination of the Levels at which Nuclear Security and Nuclear Safety Integrate

As summarized in Table 12, integration is highly recommended at the operational level for the pairwise comparison method and at the strategic level based on the rank sum and equal weighting sensitivity analysis methods.

Table 12. Overall determination of levels at which nuclear security and nuclear safety integrate.

	Strategic level	**Operational level**	**Cultural level**	**Overall**
Pairwise comparison	Legal framework	Integrated risk assessment	Integrated risk assessment	Operational level
Rank sum	Integrated risk assessment	Legal framework	Reporting mechanism	Strategic level
Equal weight	Leadership and accountability	Organizational culture	Reporting mechanism	Strategic level
		Leadership and accountability	Leadership and accountability	

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4. Summary and Conclusion

In summary, this research provided aspects and levels at which nuclear security and safety integrate with no conflicts. Based on the survey, nuclear security and safety will integrate when the *legal framework* and the *organizational structure* support integration at the strategic level. At the operational level, when a *reporting mechanism* is in place to report and address nuclear security and nuclear safety conflicts and an integrated approach is used to manage emergency preparedness and response, nuclear security will integrate with nuclear safety without conflicts. At the cultural level, nuclear security will integrate with nuclear safety when management (including clear leadership for all nuclear security and safety responsibilities) supports integrating nuclear security and safety and staff are fully aware of their nuclear security and safety responsibilities.

Based on the pairwise comparison, it can be inferred that integrating nuclear security and safety is highly recommended at the operational level. The sensitivity analysis (both sum rank and equal weights methods) showed that the best alternative for integrating nuclear security and safety is at the strategic level.

This research has shown that women nuclear professionals, based on their responses, would like to see more integrated work through the provision of a *legal framework* for integrating nuclear security and nuclear safety. An *organizational culture* that supports integration and a *reporting mechanism* in place to report and address nuclear security and nuclear safety conflicts should also be in place. An integrated approach to managing emergency preparedness and response should also be included. Lastly, they would also like to have management (including clear leadership for all nuclear security and safety responsibilities) supporting integration; their nuclear security and safety responsibilities should be clearly defined and reviewed.

The main limitation of this study was the difficulty in getting respondents for the survey due to a lack of comprehensive data on nuclear professionals in the country. Most of the nuclear professionals are tasked to do radiation protection, nuclear safety, or nuclear safeguards tasks, which introduces some overlaps. Thus, a database needs to be compiled of these professionals and their roles in terms of nuclear safety or security.

For those in the nuclear industry (state, nuclear regulators, and operators), this research has shown that integrating nuclear security and safety should start at the operational level with a reporting mechanism to address nuclear safety and security conflicts; an integrated approach to managing emergency preparedness and response should also be considered. This approach will provide practical operational experiences that would inform the development of the legal framework for integration, which would clearly encourage management's support for integration and its implementation without conflicts.

For academia, this research focused on determining where nuclear security and safety can integrate without conflicts by using survey responses, pairwise comparisons, and sensitivity analysis. Notable areas that emerged as highly recommended for integration were integrated risk assessments and the relevant legal framework. These results are

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the same as those identified in previous research [5, 8, 13, 15]. Consequently, this work recommends that further studies be done to identify the actual areas of conflict for integrating nuclear security and safety.

5. Acknowledgments

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