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Cover Page Footnote

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A Case Study Assessing the Integration of Nuclear Safety and Security in Facilities Using a Monte Carlo Simulation–Aided Analytical Hierarchy Process

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Abstract
Nuclear safety and security are essential in all operations using nuclear and radioactive materials. Even though both elements are important, the evolution of these programs has not developed at the same rate. As such, their integration has been met with challenges. This study analyzed the potential for synergy across different criteria and settings when integrating nuclear safety and security. The criteria included eight points where overlap could be identified between nuclear safety and security. Three work settings—industrial, medical, and research—were evaluated. Responses were collected from nine individuals who worked with nuclear materials in various capacities and different nuclear work settings. The individuals rated the eight criteria and three work settings based on the analytical hierarchy process. These results were then used in a Monte Carlo simulation that applied a beta-program evaluation review technique distribution to determine points with the greatest potential for synergy. The culture criterion was rated as having the greatest potential for synergy, thereby indicating that the integration of nuclear safety and nuclear security would provide the greatest benefit with this criterion. The analytical hierarchy process assisted with the Monte Carlo simulation and determined that the industrial setting ranked the highest in synergy potential—also indicating this setting would see the greatest benefit in integrating nuclear safety and security.

Keywords: analytical hierarchy process, nuclear security, nuclear safety, Monte Carlo simulation, integration

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1. Introduction

When working with nuclear materials and radiological devices, two programs of protection are employed: safety and security. Nuclear safety focuses on the protection of workers, the public, and the environment from hazards associated with accidents. Nuclear security also focuses on protecting workers, the public, and the environment; however, this area focuses on the hazards associated with malicious intent. These two foci are two sides of the same coin—both focus on protection, yet both analyze various potential hazards from different perspectives [1].

Despite being on the same coin, so to speak, these two nuclear disciplines—safety and security—have not developed at a comparable rate. Comparing rules, regulations, and actions within the practices of safety and security, nuclear safety is observably more robust than nuclear security. A primary reason for this disproportionate development over time can be viewed in the history associated with nuclear activities. Nuclear fission was first discovered in 1939, and its potential for destruction was quickly evaluated to assist in the war efforts of that time. After the war, in 1951, the Experimental Breeder Reactor-1 in Idaho (United States) demonstrated the tremendous benefits that could be provided through nuclear power. By 1954, the Obninsk reactor, which was in the former Union of Soviet Socialist Republics, provided enough power to light over 2000 homes. Nuclear power continued to grow, eventually providing an average of 1000 MW of energy, enough to power approximately 400,000 homes [2].

These benefits from nuclear energy have come with some costs. The most significant events demonstrating these costs include Three Mile Island, Chornobyl, and Fukushima. These tragic events originated from a lapse in safety: poor safety communication, lack of training, and unforeseen contingencies that were not addressed. Yet with every safety mishap, new methods have been developed to overcome and improve nuclear safety. This evolution is not limited to nuclear energy. Nuclear and radiological safety improvement can also be seen arising from research and medical events, such as understanding erythema threshold doses, developing new dosimetric devices, and improving training practices. Nuclear safety has steadily evolved and has been enhanced through various historical events, demonstrating how nuclear protection can be designed to protect against potential harm associated with nuclear operations.

The practice of nuclear security has not experienced as many historical events as safety. Naturally, a lack of nuclear security events is good; however, this lack of security events alone does not indicate that nuclear security is being sufficiently handled. Simply assuming that security is adequately handled allows a trap of complacency to be set and prevents the change needed to improve [3]. Nuclear security took its most progressive step forward after the September 11, 2001, attacks on the United States. After these attacks, every department related to security immediately responded through overhaul, reformation, and evolution. As this change occurred, nuclear security was reevaluated under the lens of nuclear terrorism, thereby revamping many of the past ideologies and plans and improving response efforts to new threats [4]. The evolution of nuclear security cannot be restricted to adverse events because a security

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event will potentially be much less forgiving than any other safety event previously experienced.

A method to help nuclear security change and improve at a comparable rate with nuclear safety is to identify the synergy between these two disciplines. *Synergy* combines two elements and observes an output greater than the sum of those elements working in isolation. Nuclear safety and security have the same goal: protection from radiation hazards. Having a similar goal implies there will be overlap in actions taken while the disciplines are in practice. These points of overlap are studied as the integration points of nuclear safety and security. The study of integration can help identify when the disciplines might interact in conflict or when they can agree—and that agreement is where synergy can be attained. This study analyzed the potential for synergy across different criteria and settings when integrating nuclear safety and security, specifically examining industrial, medical, and research settings, using a Monte Carlo (MC) simulation assisted by an analytical hierarchy process.

2. Methodology

Quantitative and qualitative methods of analysis each provide their own benefits and limitations. By combining these two methods, the strengths of one analysis method can be used to overcome the limits of the other method. Quantitative analysis methods provide strength in evaluating differences of opinion and generating clear, reliable data. Qualitative methods of analysis are robust in describing processes and providing great detail [5]. A qualitative approach was used to identify the potential for synergy between nuclear safety and security. The analytical hierarchy process (AHP), which is a quantitative analysis method, was used to devise a measurement scale in which the three work settings were analyzed for the potential to use synergy according to eight criteria for integration.

a. Criteria and Settings for Synergy

Nuclear safety and security disciplines can only attain synergy through integration. Eight points of disciplinary integration were identified as the primary evaluative criteria in the AHP. Those eight criteria are (1) access controls, (2) transportation of materials, (3) transparency in emergency response, (4) testing and maintenance, (5) proper disposition of disused materials, (6) training and education, (7) defense in depth, and (8) culture.

Access Controls

Access controls are the selective restriction of access to a place or resources. The potential for synergy with safety and security in access control is best emphasized in the International Atomic Energy Agency's (IAEA's) report, *The Interface Between Safety and Security at Nuclear Power Plants* (INSAG-24) [6]. This report notes that access controls are considered vital as a safety function because these prevent (or limit) individuals from being exposed to dangerous situations. The synergy is observed as a result of the access controls prohibiting unauthorized access to vital areas in the nuclear security program.

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Transport of Materials

The transport of materials focuses on the measures taken to protect radioactive materials in transit from accidents, deliberate incidents, or other violations. The synergy of safety and security in material transportation is found in the transportation vessel design, route, and strategy. The *as low as reasonably achievable* safety principles of time, distance, and shielding are used throughout this process. Time, when considered by security, looks for the quickest route, thereby maintaining the smallest window of attack—this minimized time translates to safety because there will also be less time for potential exposure to occur while interacting with the hazard. Distance is incorporated into the safety strategy via the inverse square law; this distance also aids security because anyone attempting to get too close may be more easily identified as an adversary. Shielding is observed as a security feature because the container requires a specific thickness and strength enough to withstand an attack; this requirement also implies that the container incorporates safety because the shielding will provide a significant degree of protection from radiation exposure [7].

Transparency in Emergency Response

Nuclear safety and security programs are designed to prevent negligent and malicious attacks on a facility. However, if a program's standards are thwarted, an emergency response plan must be in place. The IAEA established goals for emergency response (e.g., save lives, reduce risk, and protect); these goals emphasize the synergy of safety and security in emergency preparedness by preventing further harm or loss while also increasing awareness of adversarial threats throughout a response event [8].

Testing and Maintenance

Testing and maintenance include any form of routine, preventive, or corrective maintenance activities that are required to (1) assess the current condition and/or rate of degradation of equipment, (2) test the operation/functionality of equipment, or (3) prevent equipment failure that would eventually lead to safety or security concerns in the facility [9]. Although the safety aspect of this criterion has been observed in a plethora of historical events (e.g., Three Mile Island, Chornobyl, and Tokaimura), the synergy of security has been implicated in certain attacks that have thwarted safety features (e.g., Stuxnet).

Proper Disposition of Disused Materials

Responsible and proper disposal of radioactive materials includes spent fuel, nuclear waste, abandoned sources, orphan sources, and other radioactive waste resulting from civilian applications in industries such as oil and gas, construction, research, and medicine. Orphaned sources pose a terrible safety risk to the public (e.g., the Lia, Georgia, incident [10]); however, the implications of security issues that could result in such sources have been debated for decades—this debate is where nuclear safety and security integration can be located.

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Training and Education

Personnel training and educational awareness should be designed to address and improve nuclear security and safety efforts at a facility. New threats are emerging regularly, potentially compromising multiple security and safety elements. These threats include cybersecurity, physical security, regular checks and maintenance of functioning parts, and more [11]. Likewise, safety training must be conducted to promote personnel awareness and vigilance in preventing accidents. Without appropriate training, threats may not be unrecognized, accidents may not be prevented, and nuclear security and safety will be affected negatively.

Defense in Depth

Defense in depth is an approach to security in which a series of defensive mechanisms are layered to protect vital assets. If one security mechanism fails, another mechanism is activated to thwart the attack. Defense in depth is a guiding principle first published by the IAEA in 1996 and has since provided a fundamental perspective in nuclear security [12]. This layered strategy can also be applied to safety regarding backup safety functions when the primary safety functions fail or are subverted. Through this multilayered concept, most threats to safety and security can be addressed and mitigated before causing harm.

Culture

Organizational culture consists of shared values, beliefs, expectations, and practices established by leaders and then communicated and reinforced through various methods, ultimately shaping employee perceptions, behaviors, and understanding. The IAEA states culture for an organization is akin to memory for an individual—it is a collective response of learned behaviors that have adapted to the work environment [1]. Improving a culture may start with the individual but must be practiced throughout the organization. If an organization does not work as a team, safety and security culture will never be integrated nor achieve synergy through integration.

Work Settings

The three work settings established for evaluation were research, medical, and industrial. The qualitative nature of the study allowed the definitions for each setting to be nonspecific, which provided an opportunity for the individuals participating in the study to provide their own interpretations of each setting. The research setting was generally considered a research reactor on a university campus. The medical setting was viewed primarily from a hospital perspective, such as a nuclear pharmacy, and included nuclear materials used for diagnostic and therapeutic purposes. The industrial setting was interpreted as nuclear applications outside the research or medical settings, such as well-logging and irradiator devices. The study did not consider individuals working with linear accelerators, particle colliders, or similar facilities.

With the criteria and work settings established through qualitative analysis, a quantitative method of analysis was required to establish where the potential for synergy was most significant among these factors. The methodology used in identifying the greatest potential for synergy between nuclear safety and security was the AHP.

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b. The Analytical Hierarchy Process

The AHP is a multitiered method using a pairwise comparison matrix (PCM) to rate criteria within and across each tier. Each criterion in the AHP is weighted according to its importance (compared with each other criterion). Those weights are analyzed and applied to the next tier (or hierarchy). The end result provides weights of importance for the criteria in all tiers and demonstrates the importance of the various criteria according to the compared weights. For purposes of the study, weights regarding each criterion quantized the potential for synergy, thereby identifying where the greatest benefit would be found among the criteria and settings.

The eight criteria previously analyzed as points of integration within the two nuclear disciplines provided the basis of the first tier. The second tier focused on the three work settings, with the weight of the initial tier applied to each setting. Figure 1 depicts the tiers and goals of this study. A two-part questionnaire was provided for nine individuals with experience in nuclear safety and security. The questionnaire's first part asked the individuals to compare each criterion's potential for synergy against the other criteria based on a nine-point scale designed for the AHP (see Table 1). The second part asked the individuals to compare each criterion's potential for synergy against the three different work settings. The aggregated results were then analyzed accordingly [13].

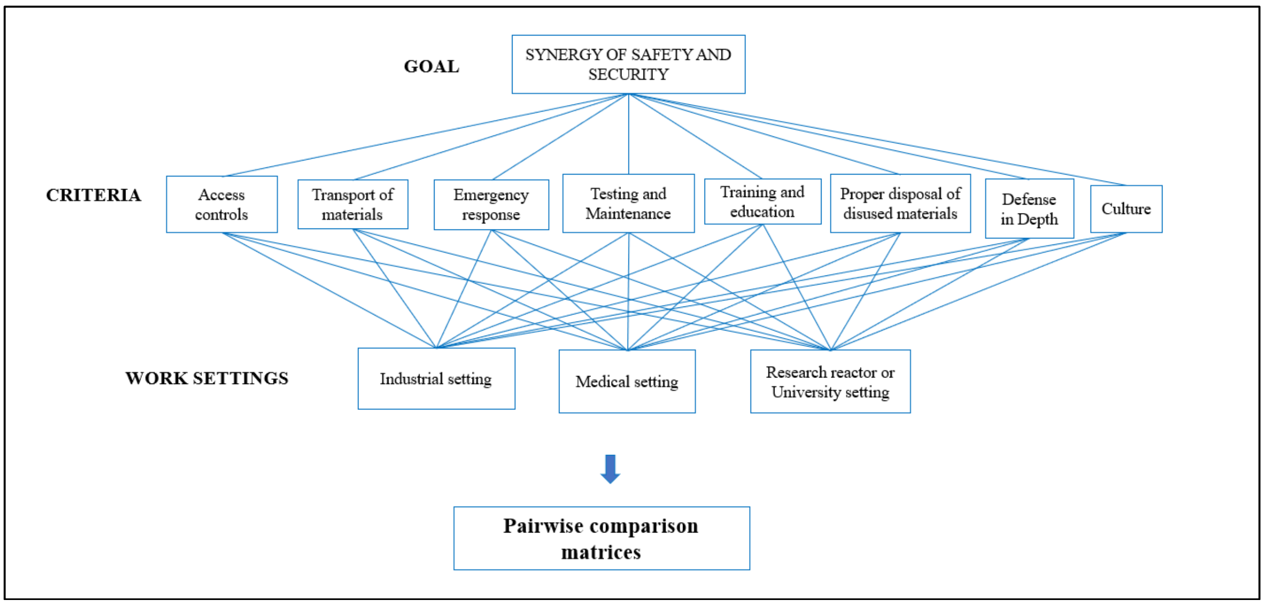

Figure 1. AHP hierarchy levels.

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Table 1. The fundamental scale for AHP (in evaluating the potential synergy between nuclear safety and nuclear security).

Importance for synergy	Definition	Explanation
1	Equal importance for synergy	Two comparisons have equal importance when considering the respective potentials for creating synergy.
3	Moderate importance for synergy	One activity is considered moderately more important for synergy when compared with the other activity.
5	Strong importance for synergy	One activity is strongly considered more important for synergy when compared with the other activity.
7	Very strong importance for synergy	One activity is very strongly considered more important for synergy when compared with the other activity.
9	Extreme importance for synergy	One activity is considered the highest importance for synergy when compared with the other activity.
2, 4, 6, 8	Intermediate values between relative adjacent potentials	Use when one activity has a consideration of importance that lies between one of the above values.
Reciprocals	When value *i* has been assigned to one of the numbers above, then value *j* is the reciprocal in the PCM.	One activity is of less importance compared with its reciprocal in the PCM.

The aggregated results were analyzed based on the matrices developed by the individual survey results. Table 2 demonstrates how the matrices were created from the survey results. Here, C_n represents each criterion survey respondents were asked to evaluate. The synergistic value for each criterion, compared with another criterion (a_{nm}), is provided in each corresponding row and column of the matrix. The associated diagonal value is the reciprocal of the value provided, thereby establishing a pairwise comparison. Any criteria rated against itself must receive a value of 1 to demonstrate equal value for synergy.

Table 2. AHP matrix for survey responses.

	C_1	C_2	C_3	…	C_n
C_1	1	a_{12}	a_{13}	…	a_{1n}
C_2	$1/a_{12}$	1	a_{23}	…	a_{2n}
C_3	$1/a_{13}$	$1/a_{23}$	1	…	a_{3n}
…	…	…	…	1	…
C_n	$1/a_{1n}$	$1/a_{2n}$	$1/a_{3n}$	…	1

The synergy weights of the criteria and settings were evaluated using PCMs and evaluated for consistency. Data consistency was analyzed by calculating each matrix's

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consistency index (*CI*)—*CI* was calculated using the number of matrix elements (*n*) and the maximum eigenvalue of the matrix (λ). The consistency ratio (*CR*) was then determined using the ratio of *CI* and the random consistency index (*RI*; see Equations 1 and 2). The *RI* is a predetermined value explicitly used for the AHP based on *n* (see Table 3).

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

$$CR = \frac{CI}{RI}. \tag{2}$$

Table 3. The random consistency index [*13*].

n	≤2	3	4	5	6	7	8	9	10
RI	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

After the consistency ratios were determined to be within an acceptable limit (<0.1), the data were provided as input for an MC simulation.

c. Monte Carlo Simulation

Although the AHP has been known to be an effective and validated method for converting qualitative into quantitative data, it has also been recognized for certain shortcomings. Some of the shortcomings associated with the AHP include the results' lack of statistical significance and judgment uncertainty associated with the finalized data. The lack of statistical significance is related to the lack of individuals who can provide answers. The AHP can be an extensive process and is not designed to be taken by a large population (thereby making it difficult to establish statistical significance). Judgment uncertainty is derived from criteria that end with very similar weights. When this uncertainty occurs, it is difficult to perceive where the greater importance lies among the criteria (or, in our case, where the greatest potential for synergy would lie).

The most effective method for overcoming these disadvantages in the AHP is by incorporating an MC simulation. Other studies have determined an MC simulation combined with the AHP data provides statistical significance to the results and can help overcome judgment uncertainty. The study by Jing et al. (2013) [14] determined that a more effective MC simulation method was applying a beta-project evaluation and review technique (PERT) distribution. The beta-PERT distribution is triangular in nature (focusing on the mean, minimum, and maximum values). It provides a more accurate assessment of the multiplicative nature associated with a PCM (as opposed to a normal or Poisson distribution). A similar format [14] was used when conducting the MC simulation. To run a beta-PERT distribution, the mean, standard deviation, alpha, and beta values needed to be calculated, where *p* is the number of participants (Equations 3, 4, 5, and 6).

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$$mean = \frac{min + 4modal + max}{p}, \tag{3}$$

$$SD = \frac{max - min}{p}, \tag{4}$$

$$\alpha = \left(\frac{mean - min}{max - min}\right)\left(\frac{(mean - min)(max - mean)}{SD^2} - 1\right), \text{and} \tag{5}$$

$$\beta = \left(\frac{max - mean}{mean - min}\right) \times \alpha. \tag{6}$$

Applying the beta-PERT formulas, the MC simulation performed 1000 iterations of the nondiagonal values for all PCMs. The total scores were aggregated based on the sum of the weighted criteria and compared for final analysis, where A_k is the final score (to the *k*th alternative), b_{kj} is the score according to the *k*th alternative and the *j*th criterion, W_j is the normalized weight of the *j*th criterion, and *q* is the number of criteria (Equation 7):

$$A_k = \sum_{j=1}^{q} \left(b_{kj} \times W_j\right). \tag{7}$$

Once all values and scores were calculated, the results were compared to determine where the greatest potential for synergy could be found among the criteria previously mentioned. The results were also evaluated to determine variations of the criteria among the three different work settings.

3. Results and Discussion

The nine individuals' survey responses were applied to nine individual PCMs. After using the AHP methodology with the responses, it was found that four individuals rated culture as having the most potential for synergy, three rated training and education as having the greatest potential, and two rated defense in depth as the highest criteria. The mean weights of individual responses can be found in Table 4a. The MC simulation was run using the individual results and the methodology from the study by Jing et al. [14]. The end result for the MC simulation found culture with the highest potential for synergy in nuclear safety and security, followed by training and education, then defense in depth (see Figure 2).

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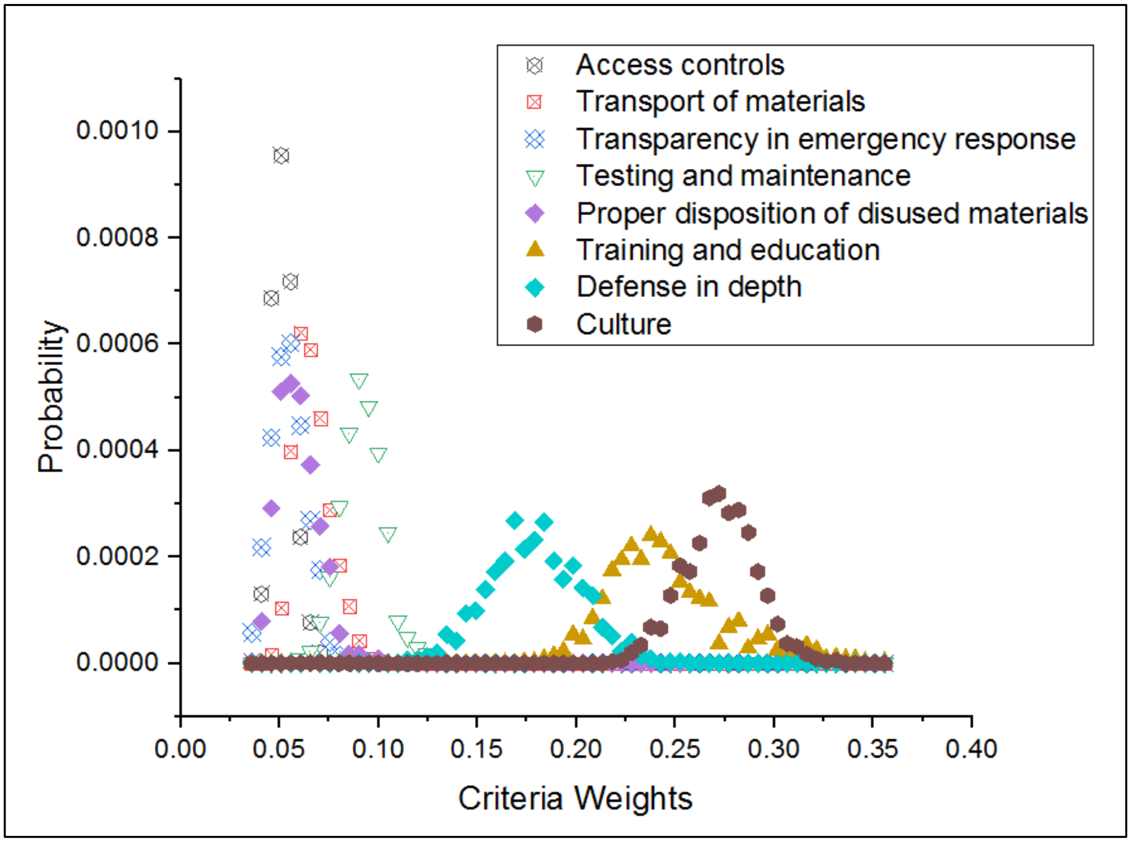

Figure 2. MC simulation weights of criteria.

The difference in the mean and standard deviation of the individual criteria weights and the MC simulation were found to be comparable and did not differ significantly (with a slight exception to the criteria with higher weights of synergy). However, when comparing the two groups' variance and confidence intervals (CIs), the variance decreased considerably with the MC simulation, and the 95% CI became much narrower (see Table 4). The differences in these results follow expectations because the MC simulation provides a dramatically increased amount of statistical data that help better visualize the study's end results.

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Table 4(a). Individual weighted scores.

	Mean ($\times 10^{-2}$)	Standard dev. ($\times 10^{-2}$)	Variance ($\times 10^{-3}$)	CI (lower 95%) ($\times 10^{-2}$)	CI (upper 95%) ($\times 10^{-2}$)
Access controls	6.071	1.676	0.281	4.782	7.359
Transport of materials	7.660	1.981	0.392	6.137	9.182
Transparency in emergency response	5.199	1.703	0.290	3.890	6.508
Testing and maintenance	10.345	2.622	0.688	8.330	12.361
Proper disposal of materials	6.038	4.200	1.760	2.810	9.267
Training and education	20.938	4.616	2.130	17.389	24.486
Defense in depth	18.177	6.376	4.070	13.276	23.078
Culture	25.571	6.099	3.720	20.884	30.259

Table 4(b). MC simulation weighted scores.

	Mean ($\times 10^{-2}$)	Standard dev. ($\times 10^{-2}$)	Variance ($\times 10^{-3}$)	CI (Lower 95%) ($\times 10^{-2}$)	CI (Upper 95%) ($\times 10^{-2}$)
Access controls	4.928	0.550	0.0302	4.894	4.962
Transport of materials	6.390	0.908	0.0825	6.334	6.446
Transparency in emergency response	5.225	0.883	0.0780	5.170	5.280
Testing and maintenance	8.921	1.061	0.113	8.855	8.987
Proper disposal of materials	5.666	1.000	0.100	5.604	5.728
Training and education	24.288	2.970	0.882	24.103	24.472
Defense in depth	17.603	2.258	0.510	17.462	17.743
Culture	26.980	1.809	0.327	26.868	27.092

The work setting (research, medical, and industrial) matrices were compared pairwise with respect to the criteria in tier 2. The results of the MC simulation found that the medical and industrial settings offered the most potential for synergy with respect to the criteria, and research most often had the least potential (see Table 5).

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Table 5. Work settings with the most and least potential for synergy as a function of criteria (MC simulation).

Criteria	*Most potential for synergy*	*Least potential for synergy*
Access controls	Industrial	Medical
Transport of materials	Medical	Research
Transparency in emergency response	Industrial	Research
Testing and maintenance	Industrial	Medical
Proper disposal of materials	Medical	Research
Training and education	Medical	Research
Defense in depth	Industrial	Research
Culture	Medical	Research

Finally, the criteria weights were applied to the different work settings to determine which work setting would have the greatest overall potential for applying a synergistic approach to nuclear safety and security. Analyzing the individual results, six responses rated industrial as having the highest overall potential, two rated medical as the greatest, and one rated research as the highest potential. Based on the MC simulation, the industrial setting was ranked the highest for overall potential in applying a synergistic approach to safety and security, followed by medical and research (see Figure 3).

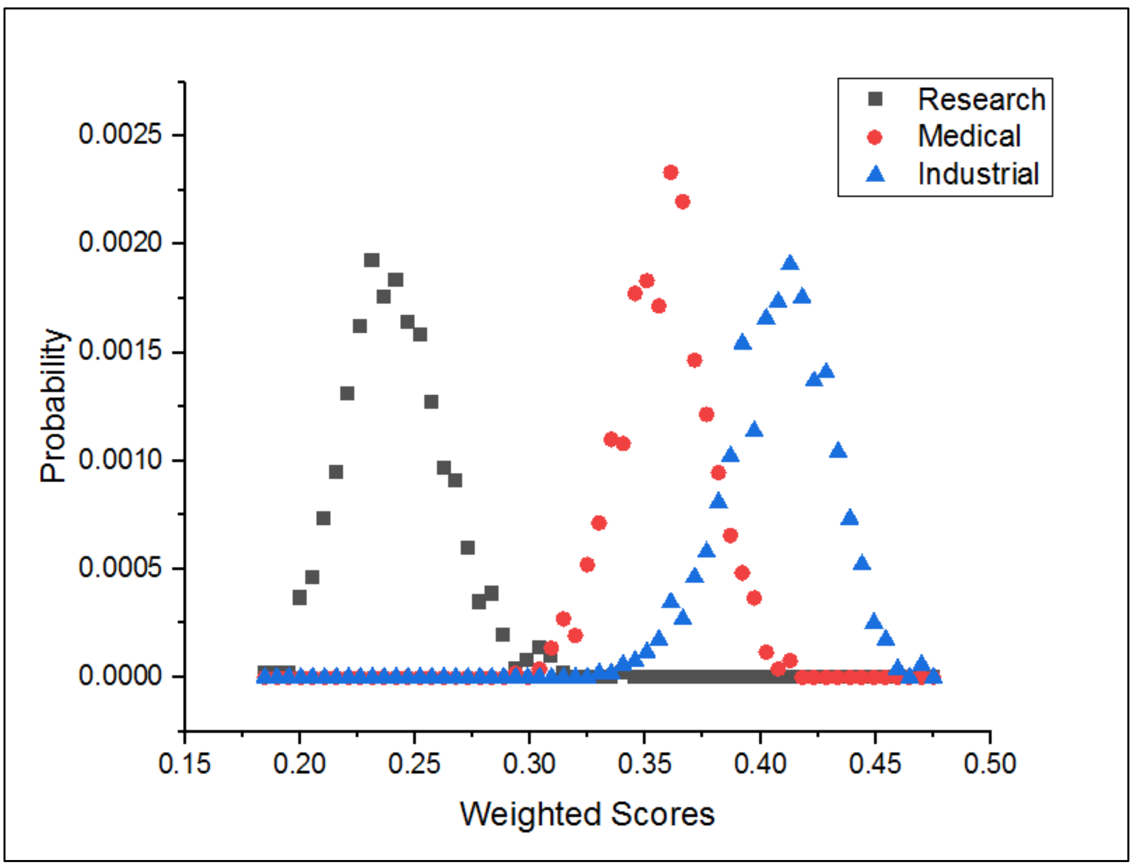

Figure 3. Final setting scores with aggregated criteria weights.

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It should be noted that several iterations from the MC simulation did not meet the recommended consistency ratio [13]. All individual responses met the recommended consistency ratio. The primary cause for the lack of consistency originated from the aggregated MC simulation from the “Transportation of materials” criterion. All other aggregated criteria scores in the MC simulation data fell within the recommended levels of consistency. Another item of note is regarding the AHP and its designed weight scale. The weighting scale is factor-based, but the beta-PERT distribution is not calculated for factored responses, creating the potential to cause a degree of inaccuracy with the MC simulation results. For example, a subcriterion had a range of individual responses, with 1/3 as the maximum and 1/7 as the minimum. The beta-PERT distribution calculated this as a range of 4/21. However, this range should have been viewed as a four-factor difference.

An example of observed inaccuracy is found when considering the difference between the geometric and arithmetic means. The AHP’s rating scale ranges from 1/9 (minimum) to 9 (maximum), only considering the integers from 1 to 9 and their associated reciprocals. The central rating of 1 indicates that the compared entities are of equal importance or value. When calculating an arithmetic mean of this range, the result is 3, which is not the central point on the rating scale. However, calculating with the geometric mean will give 1, which is the central point of the rating scheme. The beta-PERT mean is calculated differently and cannot provide a value because no mode can be established using this rating scale alone. However, the beta-PERT mean is calculated in a manner that is more similar to the arithmetic mean. This method creates inconsistent results in the MC simulation.

Despite the potential for inaccuracy, applying the beta-PERT distribution to the MC-AHP has been one of the most effective methods for this application [14–16]. The AHP provided valid weights to criteria essential to nuclear safety and security. When the MC simulation was applied to the individual AHP results, judgment uncertainty was addressed with a higher statistical significance to the results. This uncertainty is best seen in Table 3. Consider the criterion of defense in depth: with the individual results, the mean for this criterion was relatively close to training and education, and the CI had a wide enough distribution to potentially mask the top two criteria; however, after running the MC simulation, we can clearly see that defense in depth was the third highest-rated criterion, and the CI is narrow enough to not create any overlap with other criteria. Judgment uncertainty was eliminated, and statistical significance was validated through the MC simulation applied to the AHP.

4. Conclusion

The MC-AHP has proven to be a useful and versatile tool for determining the weighted importance of different criteria and providing reliable guidance for future actions. Based on the results of this study, culture was determined to have the highest potential for synergy when integrating nuclear safety and security. This result means that if institutions were to apply a combined approach to safety and security regarding the organization’s culture, then they should expect to see a safety and security culture that is more robust and beneficial than if there were two separate cultures in the institution

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(i.e., one for security and the other for safety). This study also indicates the nuclear industrial environment would benefit the most from a synergistic approach to safety and security.

This study also found that some criteria will be more challenging to apply a synergistic approach (e.g., access control). Although using an integrated approach with these criteria may be more difficult, this study does not imply that such an approach should not be taken. Radiological and nuclear safety workers should always seek methods and practices to improve the institution and foster work practices that encourage safety and security. Access control (and the other lower-rated criteria) still has the potential for integration. Likewise, even though the medical and research environments did not rate at the top, it does not mean a synergistic approach should not be applied to nuclear security and safety in these environments. By finding and using integration points in nuclear safety and security programs, synergy can be applied for an effect more significant than if these two disciplines operate separately.

Future research opportunities should look to apply these findings further to nuclear safety and security programs, thereby increasing the capabilities of these programs and strengthening the workers' ability to apply the principles inherent in these disciplines.

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7. Author Biographies and Contact Information

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Captain Theodore Thomas is a doctoral student at Purdue University School of Health Sciences. He earned a bachelor’s degree in physician assistant studies through the University of Nebraska, a bachelor’s degree in radiation sciences through Midwestern State University, and a master’s degree in health physics and radiation protection through Oregon State University. Captain Thomas is a commissioned officer in the United States Army and serves as a health physicist for the military. He has worked as a radiation safety officer for multiple hospitals and a nuclear safety advisor for force commanders. He has earned various awards and accolades in the military for his work in healthcare, radiation safety, and military service; some of these include the Meritorious Service Medal, seven Army Commendation Medals, the Military Outstanding Volunteer Service Medal, and the Expert Field Medical Badge. He is a member of the Health Physics Society and looks forward to continuing his service in the military after completing his education at Purdue University. His email address is thom1051@purdue.edu.

Shraddha Rane

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Jason Harris
Dr. Jason Harris is an associate professor and director of the Health Physics Program and Center for Radiological and Nuclear Security at Purdue University. His research interests include several areas related to radiation detection and measurement, nonproliferation, and nuclear security. He teaches radiation detection and instrumentation courses, health physics, radiation physics, laboratory experimentation, nonproliferation, and nuclear security. He is a member of the Health Physics Society, the American Nuclear Society, and the Institute for Nuclear Materials Management. Contact: jtharris@purdue.edu.

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