PAKISTAN'S NUCLEAR SECURITY REGIME: POTENTIAL THREATS, RISK ASSESSMENT AND RISK MANAGEMENT FOR SAFE FUTURE

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Abstract

The nuclear industry is faced with several challenges and the first and foremost challenge is safety and security of nuclear installations (power plants), within which a deliberate terrorist attack or sabotage of a nuclear facility is the prime area of concern, yielding deadly consequences in form of release of radioactivity, contamination and causalities. Since 9/11, the growing threat of nuclear terrorism and usage of unconventional means of terrorism underscores the need to address the security vulnerabilities of civil nuclear installations and to enhance the effectiveness of security systems. To address this challenge, an effort has been made to analyze the security systems of Pakistani nuclear power reactors with the help of Probabilistic Risk Assessment. The results of probabilistic risk assessment indicate that there is a medium level of risk, with adequate effectiveness of the enacted security system, in order to prevent the possibility of a security event and to further initiate countermeasures if a potential event does occur. Based on the results of the assessment, a set of recommendations has also been suggested, aimed at reducing the calculated risk for Pakistani nuclear industry.

Keywords: Nuclear Industry, Nuclear Security Regime, Probabilistic Risk Assessment.

Introduction

Nuclear energy is both a great scientific invention to meet the ever-increasing energy demand by developing and developed nations, besides a gruesome threat to humanity due to its life threatening potential for causing devastation. Energy from nuclear sources is considered to be the one of the most environment-friendly energy sources, generated by using nuclear fuels and it contributes to the energy mix of leading nation-states across the nuclear-capable countries. The fact is evident in studies highlighting the benefits of nuclear energy for the energy mix besides posing a serious threat to the industrial accidents of extreme nature and loss due to the potential of intense damage in the backdrop of any nuclear accident, leading to a global crisis for the international community.[1] The world has witnessed three, worst of its kind, nuclear accidents in recent history (Three Mile Island[2], Chernobyl[3], and Fukushima[4]), where

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humans suffered horrifically besides the severe damage to nature and environment. These tragic incidents wreaked havoc upon the exposed population with deadly consequences and unveiled an ever-looming threat to nearby localities, given the plausibility of impending risks hovering over, due to the continuous operation of nuclear installations. These tragic accidents were significant enough for the policy makers to ponder upon the fragility and sensitivity of nuclear power. Nuclear energy posed a serious concern due to its risks of contamination, environmental degradation, threat to ecology, displacement, and serious health hazards that provided reasonable arguments to label nuclear energy as an energy source that cannot be regarded as absolutely safe.[5]

In the aftermath of 9/11, nuclear assets and facilities present more serious challenge concerning safety and security as any act of terrorism or sabotage at a nuclear facility can result in no less than an Armageddon for humanity. Recently, policy makers and analysts are deliberating on devising safety and security mechanisms to mitigate any potential threats to the nuclear-related industry and facilities, calling for strengthened and improved security regime for nuclear related decisions. It is evident that world cannot afford any breach in nuclear facilities (reactors) as any such nuclear security lapse or accident could plunge the world into a nuclear inferno. Stringent efforts have been made by not only the nuclear energy sector but also by the international security community to reduce the vulnerabilities of nuclear installations against terrorist attacks, sabotage, and theft of nuclear and spent fuel materials.[6] However, this impending threat spectrum associated with the nuclear-related matters cautions nuclear states and the policy analysts to make incessant efforts and revise safety and security measures, to ensure the effectiveness of nuclear security framework and its governance, to review the emplaced mechanisms frequently, and to take cautious steps for enhancing the level of quality of nuclear-related security procedures and guidelines for an even better and safe future of the world regarding nuclear energy.

In this backdrop, Pakistan has been taken as a prime case study to critically evaluate and analyze the effectiveness of enabled security systems and to improve the security regime of its rapidly flourishing nuclear industry. Pakistan belongs to the club of developing states and likewise needs energy resources to meet its energy demand against the supply. Lack of energy-related infrastructure and looming demand for energy in the country has been a serious challenge for the recent governments, confronted by the energy crisis due to the gap between the energy demand and supply. Pakistan's energy shortfall was up to 8,500 MWe in 2012 whereas this shortfall has been up to 3,000 MWe in 2019, resulting in the form of closure of various industrial units due to the acute energy crisis.[7] Pakistan's energy demand is increasing and governments have to opt for alternate energy sources besides relying heavily on the energy sources generated by fossil fuels, emitting carbon and other hazardous gases into the environment. In this backdrop, Pakistan is considering to utilize its nuclear capability for the generation of energy from nuclear fuel, adding a reasonable share of nuclear energy to its energy mix. Pakistan estimates to add 8,800 MWe of energy produced by civil nuclear sources to its energy mix till 2030 as the nuclear energy is considered to be environment friendly and sustainable for the growing demand of energy in the country.[8] For this purpose, Pakistan has two civil nuclear power facilities under its civil nuclear program namely (Karachi Nuclear Power Complex-KNPC) and (Chashma Nuclear Power Complex). Pakistan is generating nuclear energy from its five civil nuclear power generation units; Karachi Nuclear Power Plant Unit 1 designated as (K-1) and Chashma Nuclear Power Plant Unit 1,2,3,4 designated as (C-1, C-2, C-3, C-4) and total installed power capacity of these units is estimated 1,318 MWe.[9]

Pakistan plans to expand its civil nuclear program to meet its rapidly increasing energy demand as relying on other major sources of energy (hydro) is jeopardized due to the worsening situation of security on its water resources due to the Indian aggression and threats in the disputed territory of Azad and Jammu Kashmir. In the given geo-strategic situation of the region, Pakistan is left with no other option but to shift the burden of its energy demand on other sources and nuclear energy serves the purpose reasonably. Pakistan's energy policy seems to incorporate expansion plans for its civil nuclear energy units taking the civil nuclear program of the country to a new peak of achievements. This policy option demands Pakistan to review and ensure the safety and security of the nuclear energy program as a paramount aspect to be considered for these installations under a comprehensive security regime. Rigorous safety and security of nuclear plants is the need of the hour, not only for ensuring the safety of the Pakistani population but also for ensuring compliance with international standards. This demands to assess and evaluate the security regime critically, to warrant the safety of the general public and society at large, from consequences of any kind, such as nuclear terrorism act and industrial accidents, which has not been cited in literature earlier. Therefore, in this backdrop, an academic research inquiry is being carried out to assess the security regime of the Pakistani civil nuclear installations and two critical questions have been investigated: To what extent are Pakistan's civilian nuclear installations prone to security threats? And what kind of security measures should be devised and implemented to ward off these threats? This research paper will investigate the security risk to Pakistani nuclear reactors via the tool of Probabilistic Risk Assessment. In addition, this paper aims at identifying key measures for reducing the associated risks to Pakistan's nuclear power program.

This paper will proceed in three stages (i) the first outlines the main methodology for carrying out risk assessment; (ii) the second details the risk evaluation process through which risk assessment has been carried out and risk has been calculated by employing open-source data; (iii) the third summarizes key recommendations based on the outcome of Probabilistic Risk Assessment for reducing the residual risk. The conclusion elucidates the key findings of the research and suggests the future areas of research. This research work only builds upon reliable secondary source data in form of published reports, which has also been considered as the main limitation of the research in retrieving country specific information within the sensitive realm of nuclear safety and security.

Probabilistic Risk Assessment (PRA)

For the objective of assessing risk to Pakistani nuclear installations, probabilities risk assessment has been used as a practical methodology that could be defined in general as an evaluation process for calculating the probability of occurrence of harm and severity of harm.[10] The risk assessment process revolves around three crucial components including: risk drivers identification, the assessment of probability of concerned driver's occurrence and their consequences, and, definition of risk mitigation strategies.[11] Probabilistic Method[12] (within which postulated accidents and single criterion are used), and Deterministic Method[13] (entailing extensive usage of probabilities) are usually employed in the nuclear industry for carrying out risk assessment.[14] The probabilistic method holds better accountability given its effectiveness in dealing with various forms of uncertainties and production of accurate results, yielding perfect rationale for the employment of this method to assess the risks to Pakistani civil nuclear installations.[15] PRA is a key tool of probabilistic method most commonly referred to as a profound systematic-comprehensive methodological tool being used for evaluating risks normally linked to a complex technological unit, characterized by two quantities i.e. magnitude of potential consequences and the probability of occurrence of these consequences.[16] In the end, total risk is depicted as expected loss yielding a collective sum of consequences being multiplied with their probabilities.[17]

Risk Equation

A critical choice has been made in devising the methodology while keeping in view the critical nature of data and its limited availability that is focused on qualitative risk assessment rather than quantitative risk assessment, yielding the following equation for quantification of risk in the qualitative sphere.

$$\mathbf{R = P * C}$$

This risk equation for security assessment could be further narrated as follows termed (Equation 1), where the probability of an event could be considered as the probability of (sabotage or theft) yielding a security event.

Equation 1

$$\mathbf{R = (1 - P_E) * Consequences}$$

(Probability of an Accident) (Assumed to be 100 Percent) ↙ ↘ (Effectiveness of Security System)

In the aforementioned equation, P_E value is being subtracted from the factor of 1 whose product yields probability of system failure contributing towards risk, which is further multiplied with consequences (C) for predicting risk being faced by operational facilities within the security domain. The overall process of PRA could be understood from Equation 1, which will be utilized for evaluating the effectiveness of security systems, currently enabled by the Pakistan Nuclear Regulatory Authority (PNRA) at K-1, C-1, C-2, C-3, and, C-4 for tackling security threats and for calculating the residual risk, which still persists, in order to define necessary strategies or measures for requisite upgrades that will strengthen security system vulnerabilities. For further simplification, R in Equation 1 is denoted in a notional value as the risk of an attack to the nuclear facilities owing to security systems failure, and is expressed in ranges (very low, low, medium, high and very high),which is illustrated in depth in the Fact Sheets of Canadian Centre for OSH.[18] Whereas, the value of effectiveness of the security systems corresponds to three risk categories including; high, medium, and low as represented below:

Effectiveness of Installed Systems	➡	Risk Level
(Unacceptable)	➡	(High)
(Satisfactory)	➡	(Medium)
(Good)	➡	(Low)

For the first part of Equation 1, the probability of security systems failure is represented by $(1-P_E)$ which is also considered as an adversary attack such as (sabotage or theft) in a given timeframe. The value of $(1- P_E)$ can be calculated by critically evaluating security area parameters detailed in table 2. The value could not be calculated directly owing to the limited availability of data concerning Pakistani nuclear installation security measures, in open sources. Therefore, only nuclear materials security index reports of Nuclear Threat Initiative (NTI) have been utilized as a credible source of information and data.[19] While the value of (C), is represented via a scale that is aimed to provide the severity of consequences as consequence value.

Risk is considered as High, if product of $(1-P_E)$ is High and the risk is considered Low, if the same value of $(1-P_E)$ is Low, thus yielding high effectiveness of security systems and vice versa. The multiplication of calculated value with C generates overall risk value. The same pattern is employed yielding the overall scheme of steps being followed for this study as represented by a schematic diagram in figure 1; encompassing determination of security area hazards, calculation of the value of $(1\text{-}P_E)$, estimation of the value of C via consequence analysis process, calculation of risk and lastly risk mitigation. This methodology could be simply labeled as risk assessment but the usage of the term "PRA" has been considered for the rationale of probability factor inclusion in the risk equation.

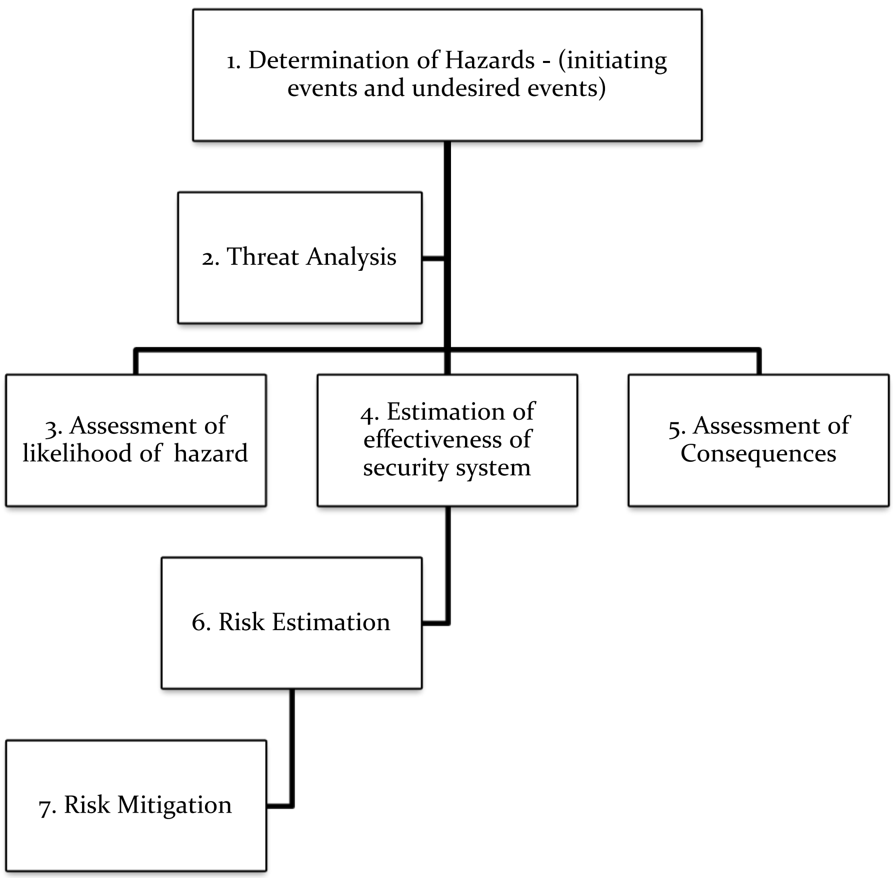

Figure 1: Process of Risk Evaluation

Parameters for Security Assessment

For identifying the parameters in the domain of plant security, the key objective that was followed was that there should not be a breakdown of physical protection system (PPS) that could result in weakening of protection against design basis threats, causing a security event. [20]Following are the identified parameters along with a set of indicators (Figure 2).[21]

Parameters	**Indicators**
Physical Protection System	Mandatory physical protection On-site reviews of security Design basis threat Security responsibilities and accountabilities Performance based program
Access Authorization	Personnel screening Behavior observations Fitness for duty programs
Access Control	Search and identification
Response to Contingency Events	Emergency response capabilities Armed response capabilities Protective strategies Law enforcement response training Nuclear infrastructure protection plan
Material Control (MC) and Accounting	Legal and regulatory basis for MC and accounting Measurement methods Inventory record Material balance area(s) Control measures

Figure 2: Key Parameters and Indicators

Risk Evaluation Process

As a first step, the specific type of hazards in the security domain, have been considered which could occur within nuclear plants. Design Basis Threat (DBT) is given critical priority in this study; thereby likelihood of initiating events is assessed in particular for the threats relevant to (DBT). These threats fall into three categories; natural threats, accident threats, and malevolent threats where malevolent threats constitute (Insider and Outsider threat) of radiological theft, sabotage or radiological material loss. Following initiating events could be considered for the aforementioned threats.

Fire	➡	Natural Threat
Occurrence of an Onsite Incident	➡	Accident Threat
Adversary or Terrorist Attack	➡	Malevolent Threat

As in the realm of safety, the probability of initiating events is evaluated in terms of likelihood of occurrence, however in the security realm, the case for probability of initiating events varies, and it is evaluated in form of threat-environment, which is usually judged as (High or Low). The initiating event is weighed based on the rating of threat-environment i.e. the initiating event will be considered as credible if the threat-environment is assessed as high. For the objective of this study and risk assessment, threat-environment is assessed as high, and initiating events are considered as credible and in the light of these assumptions, the effectiveness of security protection systems against initiating events has been evaluated.

Security Risk Assessment Equation

In order to begin the assessment process first, the values of each factor within Equation 1 for security assessment are needed to be determined, yielding the overall value of the equation. Firstly, in order to determine the (P_E) value being denoted as the effectiveness of security systems, assessment of pre-defined security parameters listed in (table 2) has been carried out.

Concerning the security parameters, it was observed that information relating to Pakistani physical security procedures and measures has not been publically made available by the Pakistan Nuclear Regulatory Authority (PNRA) within open information and data sources. This practice is followed for ensuring and protecting access to sensitive and potentially valuable data to malicious actors or potential adversaries. Therefore, Nuclear Materials Security Index[22] Reports (2018, 2016 and, 2014) from NTI have been used to gain primary insights relating to security conditions of nuclear materials, for carrying out an assessment of key security parameters.[23]

According to NTI reports, Pakistan stands at 20th position having an inclusive score of 40/100 among the list of the nations containing weapons-useable nuclear materials.[24] The selected reports from the year (2018, 2016 and, 2014) validate that Pakistan has achieved major milestones while having the status of most improved state among the list of nuclear weapon states, via the adoption of numerous steps for implementation of best practices and modification of nuclear security rules and regulations.[25] Moving ahead on a positive pace, Pakistan has gained 4 additional points in its total score, from the year 2016 to 2018, which stands as an evidence of its substantial progress and has further strengthened its ranking.[26] Astonishingly from the year (2012 to 2018), Pakistan has accumulated a score of 37 with an addition of 18 points within the security and control measures category specifically, by implementing stringent legal and regulatory requirements and measures.[27]

There is a significant improvement within the indicator of physical protection system (PPS) and authorization/insider threat prevention specifically, as Pakistan has been successful to improve its score in these indicators by defining new regulations and security responsibilities, and further enhancing insider-threat prevention. The highlighted improvements in security and control measures area are evidence effectively demonstrating the efficiency and effectiveness of installed nuclear security systems of Pakistani nuclear reactors.[28] Referring to the 2018 report, emergency response has been ranked the highest, followed by the parameter of the physical protection system, access authorization/insider-threat prevention, material control and accounting, and cyber security.[29] The material control (MC) and accounting / cyber security are the weakest indicators that can generate numerous weak links for the malign adversary action and could significantly contribute towards the weakness of security systems. Recently, Pakistan has been extensively working on the protection against cyber threats including the formulation and adoption of new laws and regulations for enhancing cyber security at nuclear facilities.[30] However, further efforts are needed for improving the personal vetting system, material control (MC) and accounting, and cyber security.[31] Hence from the NTI reports data, it is assessed that only material control (MC) and accounting is the single potential parameter capable of posing risk to the reactor security area requiring risk mitigation efforts, whereas all the four key parameters stand at a satisfactory level.

For further assessment of the effectiveness of security systems, six critical benchmarks are deliberated and highlighted for building up analysis that has been retrieved from the data set available in open sources constituting the second crucial information source as shown in Table 1.[32]

Table 1: List of Benchmarks

I.	Pakistan is an active signatory party to the convention on Physical protection of Nuclear Material (CPPNM) and is objectively fulfilling the requirements and obligations of the CPPNM. PNRA as a regulatory body ensures that all the requirements for the physical protection of nuclear facilities are consistent with the document of IAEA Nuclear Security Fundamentals and the licensees take all the appropriate measures that are mandatory for the physical protection of the nuclear facilities /installations.
II.	All the Pakistani civil nuclear installations are subject to IAEA item specific safeguards. According to (INFCIRC/225/Revision 5) document, the section twenty-two of the item specific safeguards in particular, requires the implementation of physical protection system of nuclear installations and Pakistan has adamantly fulfilled this requirement.
III.	The entire genesis of Pakistani physical protection system is founded upon the

	foundational document titled "Nuclear Security Recommendation on Physical Protection of Nuclear Material and Nuclear Facilities (INFCIRC/225/Revision 5) that can be considered as the third benchmark for Pakistani security system effectiveness. The enacted system ensures the effective implementation of the IAEA safeguards and comprehensively meets all the requirements being presented in the document. In the light of the proposed recommendations of the document, PPS is being developed, implemented and maintained.
IV.	Pakistan is a signatory of UN Security Council Resolution under the international obligations and has been fully committed and driven to achieve the objectives of the UN resolution. Pakistan has displayed full cooperation with the 1540 committee for fulfilling its commitments and has also offered assistance to the committee. To this date, Pakistan has collectively submitted 6 comprehensive reports to the 1540 committee, in relation to the enacted measures undertaken by for the full fledge implementation of the 1540 resolution.
V.	The Pakistani nuclear security regime is primarily based on the multi-layered defense principle for catering the entire threat spectrum, including insider, outsider and cyber threat. PNRA has developed and trained a Special response force for the objective of ensuring accurate and effective response, in case of a potential nuclear security event.
VI.	A rigorous and sustainable nuclear security regulatory system has been developed by PNRA along with established response capabilities. All matters of nuclear security are regulated under nuclear security regulatory regime involving physical protection of nuclear facilities/installations, material control and accounting, border controls, transport security and capabilities in order to deal with radiological emergencies.

The consideration of the results of NTI reports and above mentioned benchmarks indicate the security preparedness of nuclear power industry of Pakistan and therefore it can be safely determined that stringent security measures related to the physical protection of nuclear reactors are adopted and implemented by Pakistan Nuclear Regulatory Authority (PNRA) that align with the international security community requirements. These measures stand as promising evidence and delegate control to the power plant regulators that prepares them for initiating effective and operational countermeasures in case of an event of theft of radiological materials or sabotage of a nuclear facility. Based on the foregoing analysis, it is concluded that the effectiveness of security systems designated as (P_E) corresponds to be at a satisfactory level.

Now moving on to the second crucial factor of (Equation 1), which is C has to be considered in detail. Here it is assumed that consequences of security event caused by a system-failure are similar to the consequences generated by a safety-accident. An example of the Goiania accident[33] and its consequences as a reference table has been quoted subsequently for understanding and developing clarity for the reader as Goiania accident stands as a safety event, holding considerable lessons for potential security events. Table 2 exemplifies that how a scenario involving an adversarial malicious act i.e. sabotage of a nuclear facility or radiological materials theft can generate similar consequences as of a safety event.

Table 2: Reference Table for Consequences of Goiania Accident

UNDESIRED EVENT		CONSEQUENCES						
		Negligible	Insignificant	Minor (Low)	Moderate (Medium)	Goiania (Major)	Extreme	Catastrophic
PARAMETERS/CRITERIA	Collective Dose (>50mSv)	0 Sv	0.1 Sv	1 Sv	10 Sv	>500m~ 64Gy	1000 Sv	10000 Sv
	Deaths	0	0.005	0.05	0.5	5 (4)	50	500
	Population Collective Dose 1-50mSv	0.01Sv	0.1 Sv	1 Sv	10 Sv	100 Sv	1000 Sv	10000 Sv
	Loss of Function	Few hours	Few days	Few weeks	1 to 6 months	6 months to 1 year	1 to 2 years	>2 years
	Economic Impact	$10000	$100000	$1M	$10M ($20-$35M)	$100M	$1B	$10B
	Area Contaminated	1 m^2	10 m^2	0.1 km^2	1 km^2	10 km^2	100 km^2	1000 km^2
	Population Monitored	1	10	100	1000	10k	100k	1,000k

By taking table 2 as a reference table, the Value of C is assumed to be equivalent to level 7 of internationally followed INES scale of International Atomic Energy Agency or to be catastrophic based on the reference table and is kept (constant) for all type of hazards. Now after the calculation of values of all the factors of (Equation 1), risk value can finally be calculated. As for the first factor of (Equation 1) value of (P_E) is satisfactory that is then subtracted from (1) and is multiplied by the value of C yields a medium level of risk for the risk equation.

Equation 1

$$R = (1-P_E) * (Consequences)$$
$$R = (1 - Satisfactory) * (Catastrophic)$$
$$R = Medium$$

As the result of the equation yields a medium risk value on risk scale (see figure 1), which dictates the efficiency of enacted security systems and indicates that these systems have the adequate capability for preventing the likelihood of a security event and for initiating countermeasures in case of likely occurrence of a potential event. Nonetheless, the result of risk assessment asks for further steps in order to further reduce the calculated risk value, which could be achieved by undertaking necessary security system upgrades, yielding a reduction of vulnerabilities and strengthened security system while ultimately contributing to reducing residual risk value that has been dealt with in the subsequent section.

Recommendations

As risk mitigation stands as a final step of the risk evaluation process, it is critical to undertake effective steps and measures for mitigating the calculated value of the risk that is the ultimate objective of carrying out this study. For the Pakistani state, the final outcome of (PRA) presents factual evidence regarding the security status of its nuclear power industry, with a satisfactory level of security systems effectiveness corresponding to risk being at medium level. For dealing with calculated risk and identified weaknesses, an attempt has been made to propose plausible measures as recommendations to be considered, as a concluding step. These will contribute to enhancing security systems robustness and reducing the probability of occurrence of a highly undesired potential security event or accident. These measures are listed below:

- Sabotage of a nuclear facility by a potential adversary having malicious intentions via deliberate aircraft attack or crash presents a probable vulnerability area of nuclear power plants resulting in reactor containment breach and core damage that is needed to be considered critically along with the development of relevant procedures and measures. (PNRA as a National regulatory may have devised specific security controls and measures for dealing with this critical concern but owing to limited security data availability, relevant information could not be found, resulting in this particular recommendation).
- For dealing with the insider threat, more stringent standards are required for security personnel of nuclear installations yielding affective and strict security controls against insider radiological sabotage or theft scenarios.

- The physical protection system as a key security parameter could be substantially upgraded by following a periodical approach of testing security measures regularly, increased surveillance of the protected areas, and developing a productive security excellence culture, significantly mitigating the concerning threats.
- For strengthening the parameter of material control (MC) and accounting, regulatory procedures and controls are needed to be implemented rigorously ensuring a resilient foundation of national nuclear security regime against (insider or outsider threat).
- The cyber security regulations should be implemented more stringently and cyber security measures should be further strengthened in order to cater to complex cyber threats.
- Nuclear plant emergency planning and cyber-incident emergency planning, in addition to outlining effective response strategies, needs to be stressed and carefully carried out for effectively dealing with cyber-attacks, further increasing the protection of nuclear installations against malicious cyber-attacks.
- It is strongly felt that open source literature lacks in providing satisfactory information on security arrangements of the Pakistani nuclear power industry. As other states have substantiated that it can be done by publishing information in the form of regulations and annual reports affectively, without yielding specified security measure's details and also catering for protection of sensitive information simultaneously. Thereby in a similar manner, PNRA could cater for releasing public documents, outlining security regulations while providing information on broader security arrangements that would serve the purpose of building confidence regarding the emplaced national security regulatory framework.

Conclusion

This research work has been carried out as an attempt to provide credible, risk-informed data and analysis of Pakistan's nuclear security regime, with an aim of ensuring the safe and secure working of the Pakistani nuclear industry in the upcoming decades. In order to conclude, the employed methodology in the form of PRA has indicated that Pakistani nuclear power reactors are operating in a safe and secure manner and there is a minimum risk with regards to the likelihood of a potential security event, corresponding to a high level of preparedness in the reactor security realm. The security systems currently enacted at five operational nuclear installations are effectively capable of dealing with any unanticipated security event while initiating countermeasures to prevent and mitigate the consequences, having satisfactory status and ranking. For reduction of calculated risk and strengthening of weak links within the security framework, proposed recommendations would enable to enhance the robustness of security systems and to create a vigilant security picture. Pakistani nuclear security apparatus is highly efficient to deter and avoid any undesired security event, which can be strengthened further by addressing critical areas of cyber security, material control and accounting, and a physical protection system that will guarantee a safe future of rapidly flourishing nuclear power industry of Pakistan. For future areas of research, it is suggested that quantitative risk assessment has to be conducted, focused on the subject of the provision of numerical risk measures quantification, assessment of security management, yielding a conclusive contribution to the field of risk management and mitigation while promoting a risk-informed approach towards building a Pakistani nuclear security regulatory regime.

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[33] In 1987, a radioactive accident occurred in Goiania Brazil, due to theft of an old radiotherapy source from an abandoned hospital site which was handled by many individuals and thereby resulted into four deaths. This accident illustrated the hazardous consequences (ranked as major) resulting from unintentional acts involving a source. In this particular case the unintentional act was loss of control of the source that resulted into a radioactive accident. See *The Radiological Accident in Goiania* (Vienna: International Atomic Energy, 1988), 2, http://www-pub.iaea.org/mtcd/publications/pdf/pub815_web.pdf; and also see R. Mellouki, "Loss of Control and Malicious use of sources," (Presentation, Training Course on Protection against Nuclear Terrorism: Security of Radioactive Sources, Riyadh, Saudi Arabia, April 2008).