2017 International Nuclear Atlantic Conference - INAC 2017
Belo Horizonte, MG, Brazil, October 22-27, 2017
ASSOCIAÇÃO BRASILEIRA DE ENERGIA NUCLEAR – ABEN

Agência Brasileira do ISBN
ISBN 978-85-99141-07-6

A performance-based approach to design and evaluation of nuclear security systems for Brazilian nuclear facilities

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ABSTRACT

This study presents an application of a performance-based approach to definition of requirements, design and evaluation of physical protection systems for nuclear facilities. Such approach considers a probabilistic analysis of the threat, equipment, systems and response forces used to prevent, dissuade and detain malicious acts against the integrity of facilities and the nuclear materials inside them. Nowadays, in the context of Brazilian nuclear facilities licensing, a mostly prescriptive approach is adopted, which despite having advantages such as simplified inspections and homogeneous regulatory requisites amid different fuel cycle facility types, does not consider evolution, dynamism and capacities of external or internal threats to facilities and to Brazilian Nuclear Program itself, neither provides metrics to evaluate system performance facing such threats. In order to preserve actual plans and systems confidentiality, a facility hypothetical model is created, including a research reactor and a waste storage facility. It is expected that the methodology and results obtained in this study serve in the future as a basis to Brazilian nuclear operators, in elaboration process of their Physical Protection Plans, which must comply with future regulation CNEN NN 2.01, a revision of CNEN NE 2.01, once that regulation will include performance requisites.

1. INTRODUCTION

Nuclear Security is included as part of nuclear facilities licensing as a set of measures designed to prevent and mitigate theft and sabotage events in nuclear materials and facilities[1]. The present work, within the context of this area, presents a methodology based on performance for design and evaluation of physical protection systems for nuclear facilities in order to adequate it to Brazilian reality. This methodology had been developed by the United States Department of Energy (DoE) through the Sandia National Laboratories (SNL)[2] and is taught and recommended in several courses of the International Atomic Energy Agency (IAEA) as the "State of Art "in Nuclear Security.

Security differs conceptually from Safety, since the second aims at protecting individuals (occupationally exposed or from the public) from the harmful effects of radiation, the first has as its goal the protection of nuclear or radioactive material against unauthorized acts perpetrated by internal or external adversaries to the facility. Nuclear material is understood in this work as compounds containing uranium (U), thorium (Th) and plutonium (Pu), as advocated by the IAEA and CNEN.

The work starts with the creation of a fictitious facility model (to preserve the confidentiality of actual Brazilian facilities' physical protection plans) and a postulated and quantified threat assessment on a project base threat, as well as use of equipment and probability data in the materials of the International Training Course on the Physical Protection of Nuclear Material and Facilities (SNL, 2016), promoted by the IAEA in partnership with SNL and the National Nuclear Security Administration (NNSA) of the United States, and other international publications on the subject.

2. BRAZILIAN REGULATORY CONTEXT IN NUCLEAR SECURITY

Brazil, in its nuclear advent, decided to draw up and approve the regulation CNEN-NE-2.01 "Physical Protection of Nuclear Power Plants" through Resolution 06/77, published in the Federal Official Gazette in November 1977. This document, having been prepared during the early stages of construction of the first Brazilian nuclear power plant (Angra 1), applied to all physical protection activities involving the use, transport and storage of nuclear materials, mainly to the licensing of the Physical Protection Systems of that type of facilities.

Some years later, CNEN's Board of Directors revoked the previous rule and decided to approve, on an experimental basis, the regulation CNEN-NE-2.01 "Physical Protection of Operational Units of Nuclear Area", through Resolution 07/81, then published in the Federal Official Gazette in August 1981. This version of the regulation aimed to broaden the scope of action of the previous version, being applicable to the operational units whose activities are related to production, use, processing, reprocessing, handling, transport or storage of relevant materials for the Brazilian Nuclear Program, comprising:

(a) nuclear facilities under construction, maintenance or operation;
(b) transport of nuclear and radioactive material, and vital or specified equipment; and
(c) industrial facilities or educational and research institutions.

This document reflects international agreements and recommendations on nuclear security area. For this review were used some base documents such as INFCIRC/225/Rev.1, issued in 1977, and the Convention on Physical Protection of Nuclear Material (INFCIRC/274/Rev.1), signed by Brazil in May 1981 and the only international legally binding document in nuclear security area.

After the end of world bipolarity in the early '90s, the emergence of non-state actors and the 9/11 attack, CNEN decided, in 2004, to create the Group of Physical Protection (current Office of Nuclear Security), which centralizes licensing and regulation on physical protection of all Brazilian nuclear facilities, based on the current regulation CNEN-NE-2.01.

2.1. The Regulation CNEN NE 2.01

The main objective of CNEN-NE-2.01 is to establish general principles and basic requirements for the physical protection of nuclear material and nuclear facilities. For this reason, this regulation is referenced by other Brazilian regulations: CNEN-NE-1.04 "Licensing of Nuclear Material and Nuclear Facilities", CNEN-NN-6.02 "Licensing of Radioactive Material and Associated Facilities", CNEN-NE-5.01 "Transport of Radioactive Materials", CNEN-NN-4.01 "Safety requirements and Radiological Protection for Mining-Industrial Facilities" and CNEN-NN-8.02 "Licensing of Radioactive Waste Deposits", about specific requirements for evaluation steps of the Physical Protection Systems of these facilities and operations.

2.1.1. Prescriptive approach versus performance-based approach

The performance approach represents an evolution from the purely prescriptive one (adopted in Brazil) in which the regulatory authority defines the measures to be taken by operators of nuclear facilities to prevent theft and sabotage events, as well as mitigate its consequences. The prescriptive approach, despite having the advantages of clarity in defining requirements, regulatory simplicity (compliance monitoring), and homogeneity in relation to multiple installations, does not allow for a clear and effective performance measurement, may prove to be inadequate or even excessive (in this case, demanding exaggerated expenditure of material and human resources), and the possibility of providing a false sense of security[2]. It is well known that, in practice, State-promoted Nuclear Security schemes are a mix of elements of the two approaches, prescriptive and performance-based.

Such a methodological evolution has occurred, at a global level, due to the increased level of threat to nuclear facilities and materials. The DEPO (Design and Evaluation Process Outline) [3][4] technique, developed in SNL, is used to properly sequence the tasks to be performed and the results to be obtained.

DEPO is based on three fundamental pillars:

- Definition of requirements: Facility characterization, definition of potential targets for theft and sabotage, evaluation of internal and external threats to the facility;
- Design of Physical Protection System: Analysis of detection, delay and response characteristics;
- Physical Protection System Evaluation: Multipath analysis, neutralization analysis, scenario analysis

3. DEFINITION OF REQUIREMENTS

3.1. Hypothetical Facility Model: PotirATOM

As previously mentioned on Section 1, a hypothetical facility model is used in this study, to simplify the design and evaluation process and make them didactically possible, as well as to preserve confidentiality of actual facilities' physical protection plans. By doing this way, it will be easier to analyze and understand limitations and needs during performance-based implementation, which is the main goal of the study. For the purpose of this study, in a hypothetical city named "Ibipotira" ("land of flowers" in ancient tupi-guarani indigenous language), there is a 4 km^2 research facility (PotirATOM Institute of Nuclear Research) containing a reactor (e.g. with low enriched uranium fuel in a quantity enough to be considered as Category II) and a waste disposal building (with spent fuel). There is also a Guard Barracks with a surveillance room where alarms are displayed to security personnel (see fig.1).

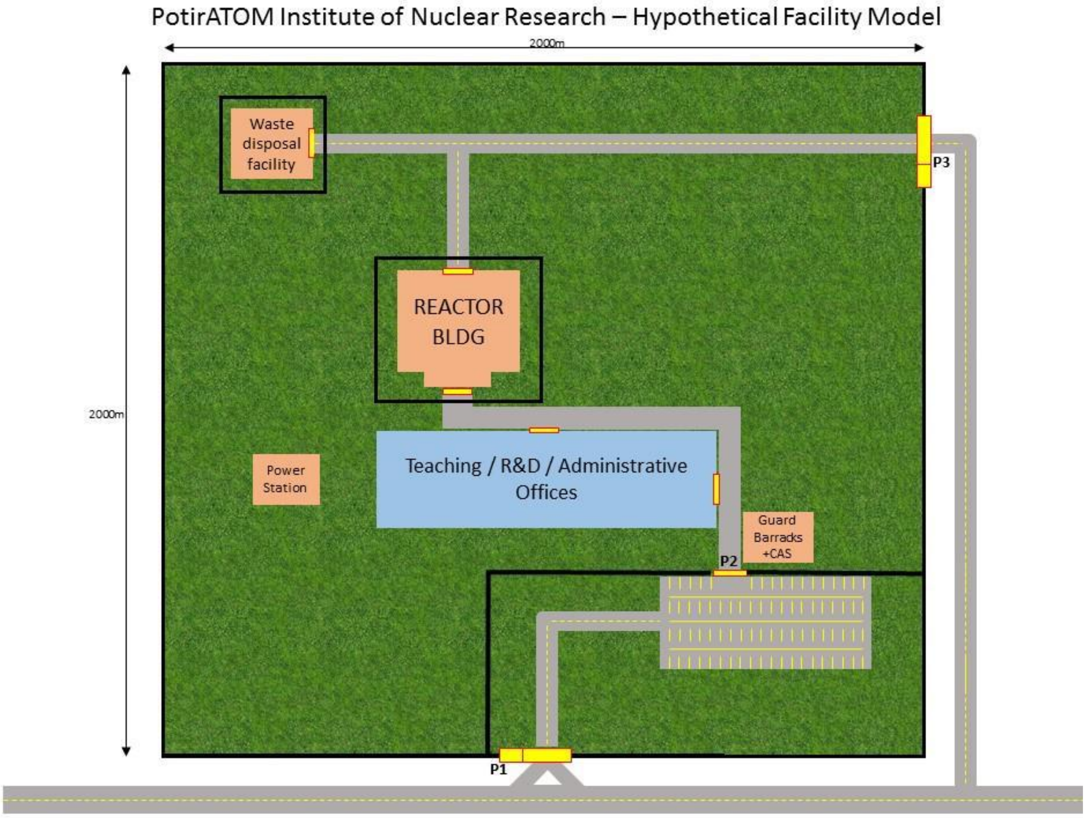

Figure 1: Hypothetical Facility Model - PotirATOM.

It is assumed that its location provides a 5-minute delay from a police station (10 policemen armed with assault rifles) and a 30-minute delay from a military barracks (around 30 well-equipped soldiers). In the facility, the security staff comprises two armed guards at P1 gate, one unarmed guard at P2. At P2 (pedestrian access control point) there is a metal detector and a visual badge check. All guards have a radio and a duress button. P3 (cargo gate) is left locked and unattended. In case of a transport operation from/to the facility, one of the guards at P1 leaves its position to open P3. At the guard barracks, located near P2, a supervisor is in charge of assessing alarms, camera visualization and communication with the guards. A car is available for non-periodic patrols and response.

3.2. Target Definition

In the reactor building, it´s possible to identify the following potential targets:

- Fresh Fuel (15.6 kg U enriched to 19.99%- Cat. II): theft or sabotage target;

- Fuel in Use (5.20 kg U): sabotage target;
- Equipment for reactor reactivity control: sabotage target.

In the waste facility, it´s possible to identify the following potential targets:

- 50 low-level waste containers: sabotage targets;
- 10 teletherapy devices with ^{137}Cs and ^{60}Co incorporated sources: sabotage targets;

3.2. Threat Evaluation

In Table 1 it´s possible to visualize a summary of postulated threat information for the model:

Table 1. Summarized Threat Assessment for PotirATOM Facility Model.

Potential Adversary	Motivation	Intention	Capabilities
Environmentalist protesters	Ideological	Provoke disruption via breakout of security barriers, stop operations, embarrassment	Cyber capability (website hacking), insider assistance, stealthy actions
Common criminals	Financial	Theft	Possible heavily armed groups, insider assistance
Terrorist groups	Ideological/Political	Theft/Sabotage	Possible heavily armed groups, explosives, insider assistance
Political protesters	Political/Financial	Provoke disruption via breakout of security barriers, political instability	Cyber capability (website hacking), insider assistance, stealthy actions

Consolidating Table 1 data into a simplified DBT (numerical design basis threat) model, it can be stated that a credible baseline threat would be a group of 5 criminals, armed with assault rifles, motivated by financial and ideological issues, would perform either theft on nuclear material and weapons of the security force or sabotage on the reactor building, with insider assistance and medium capabilities and tactics to perform such acts.

It is important to highlight that in Brazil there is no national DBT available so far. As preconized by IAEA, in accordance with graded approach principle, a DBT document is required for Category I and other high radiological consequences nuclear material, which is not current Brazilian situation nowadays, once there is not any Cat I material in Brazil. Anyway, the lack of a DBT can be a strong limitation during a possible implementing process of a mixed prescriptive and performance-based approach.

4. DESIGN OF PHYSICAL PROTECTION SYSTEM

In this phase, three basic functions have to be addressed in order to perform the design: detection, delay and response. Those three functions must act together in order to:

- Make the PPS be perceived as too difficult to overcome by possible adversaries (deterrence), even considering the impossibility to measure this feature;
- Defeat adversaries in adequate time, not permitting them to complete their objectives.

Detection will combine different elements like intrusion sensing, entry control, contraband detection, alarm assessment, communication and display in order to provide timely response to adversary actions. Some performance parameters to be measured include probabilities of sensor alarms, alarm assessment and communication times, probability of correct assessment and nuisance alarm rate.

Delay characteristics provide obstacles to increase adversary task time. It can achieved through active barriers (dispensables, triggered devices) and passive barriers (doors, gates, walls). Performance measurements for delay include time to penetrate barriers, and time to go across areas (walking, running, driving vehicles, crawling, etc.)

Response functions mean security forces actions to interrupt/neutralize adversaries before they could complete their missions. Some performance measures include probability of communication with response force, communication times, probability of deployment to actual adversary location, deployment times and effectiveness of response forces.

5. PHYSICAL PROTECTION SYSTEM EVALUATION

In this phase, the PPS is evaluated so that its performance satisfies requirements defined in the first phase of the DEPO process, making possible identifying of possible deficiencies on the design, analyzing to verify effects of upgrades on the system, as well as estimating accurately changes in the system during its lifecycle.

In this phase, a set of algorithms and tools can be used to get the two main performance parameters, the probability of interruption PI and the probability of neutralization PN. The first (PI) refers to the cumulative probability of interruption along one possible intrusion path (normally the weakest), calculated until the last timely detection point possible, named CDP (Critical Detection Point) , while PN represents probability of the security force gain control over (neutralize) the adversaries, once they have been correctly detected, assessed and interrupted. The overall effectiveness of the PPS (PE) can then be calculated by the product of PI and PN.

In order to calculate PI, among other mathematical and simulation models and tools, adversary sequence diagrams (ASD) or scenario analyses can be used. ASDs represent multiple adversary paths, and PPS elements along every path. This tool is useful in determining the weakest path of the facility, which will be upgraded to achieve the required global PPS performance, in a process called “Multipath Analysis”.

Another method is postulating credible scenarios and then calculating cumulative probabilities of detection (PD) and delay times (TD) and then compare to the response timeline. Evaluation of scenarios might allow more detailed analysis of the attack, defense and results than path interruption analysis.

In both methods, it´s necessary to input the models with the values (experimental or aleatory) of PD´s and TD´s in order to calculate cumulative probabilities and determining the critical detection point. In Figure 2 an ASD for the facility model can be visualized.

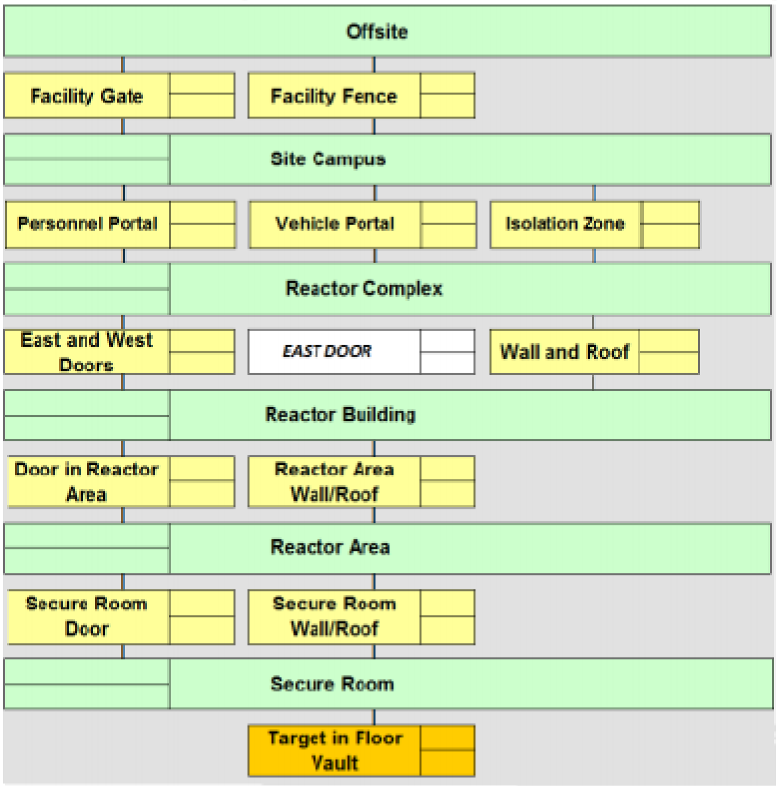

Figure 2: ASD for reactor building – fresh fuel vault target.

The next step in evaluation process is Neutralization Analysis, which corresponds to the determination of PN. It can be estimated by using several methodologies, such as mathematical models, simulations, expert judgements or even actual engagements, but any of them require data about threat and response numbers, capabilities, equipment, forces locations, terrain, and possibly other parameters.

6. NEXT STEPS

Efforts are being made by Brazilian Nuclear Energy Commission to strengthen its regulatory framework, by including some performance-based parameters in the upcoming security regulations, in order to better reflect best practices adopted internationally. This paper presented a preliminary study that aimed to point basic needs, challenges and improvements that will be need to be fulfilled in order to achieve a balanced prescriptive/performance-based approach in an adequate manner to the country´s threat scenario, limitations and constraints. Some of the needs and challenges derived or highlighted from this study include:

- Establishment of a national DBT, to serve as a basis for PPS design;

- Establishment of a methodology for Targets Identification/Vital Areas definitions (based on high or unacceptable radiological consequences, for instance);
- Adoption of up-to-date international practices and equipment on detection systems, delay functions, response equipment and security personnel (e.g. measures against insiders, cyber security measures);
- Development/use of methodologies for vulnerability assessments (e.g. response times, alarm assessment times, simulation metrics and tools, tabletop exercises, force-on-force exercises, scenario analyses, neutralization data);
- Training of operators to develop/use of the methodologies related to performance-based approach;
- Establishment of a basic laboratory infrastructure for testing and gathering relevant data from equipment/sensors to serve as parameters for more accurate analyses;
- Training and formation of stakeholders in order to maintain a well-established security culture.

It is believed that this study will provide basis to future actions under the regulatory scope to perform changes in the current regulatory scenario regarding Nuclear Security in Brazil.

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