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CASE STUDY ON PHYSICAL SECURITY ASSESSMENT OF A CATEGORY 1 GAMMA IRRADIA
TION FACILITY

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A Thesis Submitted in Partial Fulfillment of the Requirements
for the Degree of Master of Science Program in Nuclear Technology
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พรรณิภา น้อยธง : การศึกษาเรื่องการประเมินความมั่นคงปลอดภัยทางกายภาพของอาคารฉายรังสีด้วยต้นกำเนิดรังสีแกมมาประเภทที่ 1 (CASE STUDY ON PHYSICAL SECURITY ASSESSMENT OF A CATEGORY 1 GAMMA IRRADIATION FACILITY) อ.ที่ปรึกษาวิทยานิพนธ์หลัก: ดร. พงษ์แพทย์ เพ่งวาณิชย์, อ.ที่ปรึกษาวิทยานิพนธ์ร่วม: รศ. ดร. สุพิชชา จันทรโยธา, 110 หน้า.

การวิเคราะห์และการประเมินผลของการออกแบบระบบรักษาความมั่นคงปลอดภัยทางกายภาพ (PPS) เริ่มต้นด้วยการตรวจสอบและเข้าใจวัตถุประสงค์ของการออกแบบระบบ ระบบ PPS เป็นมาตรการที่ใช้ในการป้องกันหรือลดการสูญเสียของชีวิตทรัพย์สิน ประกอบด้วยสามส่วนที่สำคัญ คือ ระบบการตรวจจับการบุกรุก การหน่วงเวลาผู้บุกรุก และการตอบสนองต่อสถานการฉุกเฉิน ต้นกำเนิดรังสีประเภทที่ 1 เป็นวัสดุกัมมันตรังสีใด ๆ ที่มีกัมมันตภาพรังสีสูง จึงจำเป็นต้องมีระบบรักษาความมั่นคงปลอดภัยสูง ในประเทศไทยอาคารที่มีต้นกำเนิดรังสีประเภทที่ 1 ต้องมีระบบ PPS ที่มีประสิทธิภาพเพื่อปกป้องประชาชนและสิ่งแวดล้อมจากอันตรายจากรังสี ในงานวิจัยนี้จึงมุ่งศึกษาการประเมินความมีประสิทธิภาพของการตรวจจับผู้ บุกรุกของระบบ PPS ของอาคารฉายรังสีแกมมาที่เป็นต้นกำเนิดรังสีประเภทที่ 1 โดยใช้ EASI model การศึกษานี้ประกอบด้วย 4 ขั้นตอนคือ คือ การเก็บรวบรวมข้อมูลในการกำหนดวัตถุประสงค์ของระบบ PPS วิเคราะห์และประเมินข้อมูลของระบบความมั่นคงปลอดภัยทางการภาพของอาคาร พัฒนาระบบความมั่นคงปลอดภัยทางกายภาพของอาคาร และ การวิเคราะห์ผลการพัฒนาระบบและให้ข้อเสนอแนะ จากผลการศึกษาพบว่า สามารถจำลองสถานการณ์ได้ 6 สถานการณ์ บนพื้น ฐานของระบบความมั่นคงปลอดภัยทางกายภายที่มีอยู่และภัยคุกคามของประเทศไทย ซึ่งโหมดของการดำเนินการของฝ่ายตรงข้ามมีสามโหมด คือ โดยใช้การวิ่ง การขี่รถจักรยานยนต์ และการใช้รถบรรทุก ผลของการคำนวณค่า P_I พบว่าในหลายๆ สถานการณ์ P_I ยังอยู่ในช่วงที่ต่ำ คือ 0.50-0.75 แสดงว่าระบบควรได้รับการปรับปรุง หลังจากปรับปรุงระบบโดยการติดตังสิ่งกีดขวางคือ ประตูกรงเหล็กที่ประตูของห้องปฏิบัติการ ค่า P_I เพิ่มเป็น 0.90 ขึ้นไป ซึ่งทำให้ระบบความมั่นคงปลอดภัยมีค่าในช่วงที่สูงด้วย

ภาควิชา	วิศวกรรมนิวเคลียร์	ลายมือชื่อนิสิต	....
สาขาวิชา	เทคโนโลยีนิวเคลียร์	ลายมือชื่อ อ.ที่ปรึกษาหลัก	....
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KEYWORDS: PHYSICAL SECURITY / CATEGORY 1 SOURCES FACILITY / EASI MODEL / PROBABILITY OF INTERRUPTION

PANNIPA NOITHONG: CASE STUDY ON PHYSICAL SECURITY ASSESSMENT OF A CATEGORY 1 GAMMA IRRADIATION FACILITY. ADVISOR: PHONGPHAETH PENGVANICH, Ph.D., CO-ADVISOR: ASSOC. PROF. SUPITCHA CHANYOTHA, Ph.D., 110 pp.

Analysis and evaluation of a physical protection system (PPS) design begin with a review and thorough understanding of the protection objectives of the system. A physical protection system is deployed to prevent or mitigate loss of valuable assets (e.g., property or life). It consists of three important elements: detection, delay, and response. In our study, the asset is the Category I radioactive sources, which have high activity and need to have high security system to secure them. In Thailand, the Category 1 source facility is required to have effective PPS to protect people and environment from radiological hazards. This study focuses on the evaluation of a physical protection system of a Category 1 gamma source facility in Thailand against several potential cases of outsider intrusion, using the EASY model to calculate the probability of interruption (P_I). The study includes 4 parts: collect data to determine system objectives, evaluate the collected data for the current design, design additional PPS, and analyze result and recommendation. Based on the current PPS design and the design basis threat data, there are 6 potential attack scenarios to evaluate the PPS against. Each consists of three modes of transportation potentially used by the adversary: running, motorcycle, truck. The result shows that the P_I in several scenarios is in the range of 0.50-0.75, which is considered "too low" and something should be done to improve the PPS. After improving the PPS by installing a steel cage at the laboratory room door to increase delay, the P_I for all scenarios is increased to above 0.90, meaning that the security system effectiveness is high.

Department:	Nuclear Engineering	Student's Signature	....
Field of Study:	Nuclear Technology	Advisor's Signature	....
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CHAPTER 1
INTRODUCTION

1.1 Introduction

Physical Security Systems (PPS) are designed to protect unauthorized access to facilities, equipment and resources or to prevent or mitigate loss of valuable assets [12, 14]. In line with global best practices, an effectiveness of PPS would should address the following factors: 1) good entry control and minimum number of access points into the protected area and vital area; 2) predetermination of trustworthiness to require unescorted employees to have a security clearance or an authorization appropriate to their level of access; 3) checking of vehicles and taking measures to reduce the risk of forced vehicle penetration into a nuclear facility; 4) detecting of tampering or interference with equipment system or devices and taking special precautions during and following shutdown or maintenance; 5) security guards training to establish effective response force at all times and available immediately response; 6) development of emergency plans, drills and exercises to test the physical protection systems and manage the security response; 7) maintenance of the operation of alarm systems, alarm assessment systems, and necessary equipment in the security monitoring room; and 8) good and fast communication system to communicate inside and outside the facility [6].

PPS are designed by including detection, delay, and response elements. One way to evaluate the effectiveness of the PPS design is to calculate a probability of interruption (P_I). P_I is the probability that the security system can successfully interrupt the adversary attack along a pathway that the adversary may use to attack the target. The Estimate of Adversary Sequence Interruption (EASI) model is a simple calculation tool widely used to calculate P_I. The EASI model has been developed by the Sandia National Laboratories, USA [8].

A Category 1 radioactive source is any radioactive source that has high activity and need to have high security system to secure them. The Code of Conduct on the Safety and Security of Radioactive Sources issued by the International Atomic Energy

Agency (IAEA) defines the Category 1 radioactive source as any radioactive source that has A/D not less than 1000 where the A-value is the radioactivity of the source and the D-value reflects the danger of the source. The Category 1 source has to be secured under "Security Level A". The goal of the Security Level A is to prevent the unauthorized removal of the radioactive sources [3].

In Thailand, nuclear technology is used in many fields. Several Category 1 sources are used in the fields of agriculture, industry, medical, education, etc. These usages of nuclear facilities, nuclear materials, or radioactive sources require both safety and security systems. Nuclear security system in Thailand follows the regulatory requirement in the Royal Gazette, Volume 129, pages 6-7. Thailand is also one of the member states in the IAEA, thus the use of radioactive sources must also follow the code of conduct and other international requirements. The Category 1 source facilities in Thailand are required to have effective physical protection system to protect people and environment from radiological hazards which may happen due to the loss of control of radioactive sources through ineffective regulations and regulatory oversight, lack of management commitment or worker training, poor source design, and security incidents. Effective physical protection requires a designed mixture of security devices and procedures, including the organization of the guards and the performance of their duties and facility design including layout [10].

This study is divided into 3 parts. The first part is collecting information about facility characterization to determine the security objectives which includes defining the threat for the facility and identification of the target. The second part is evaluating the PPS effectiveness of the facility by assessing the existing detection, delay and response components using the EASI model to calculate P_I and to identify the weakness of the system. The third part is improving the system by adding additional security components or changing the security procedures. This study mainly focuses on finding the probability of interruption (P_I) of the security system in a Category 1 gamma sources facility in Thailand against various attack scenarios. For security reason, the name and detailed information of the facility are omitted in this Thesis. All models are redrawn to different configuration and scaling, but information vital to the calculation is still kept relatively the same. Such evaluation can be used to support security assessment and provide the basis for demonstration of security for licensing to ensure that the facility has been secured and can protect against malicious act or adversary action effectively.

1.2 Objective

To assess the physical security of a category 1 gamma irradiation facility with the given configuration based on an actual facility

1.3 Scope of study

- Assess the design of PPS for gamma irradiation facility based on an actual facility
- Evaluate the effectiveness of the PPS design according to the design from step one
- Based on the evaluation from step two, propose the improvement of the design

1.4 Expected Benefits

This research will provide a methodology for preparing the security assessment for a category 1 gamma Irradiation Facility. Physical protection system will be used to support security assessment, providing the basis for demonstration of security for licensing to ensure that the facilities have been secured and can protect against malicious act or adversary action effectively. Establish physical protection system or security system effectiveness for a category 1 gamma irradiation facility in Thailand.

1.5 General procedure

Table 1.1 General Procedure

Activity and planning	Sep-Oct	Nov-Dec	Jan-Feb	Mar-Apr	May-June	July-Nov	Dec
Collect information							
Study and analyze information							
*Part one							
*Part two							
*Part three and four							
Prepare paper and thesis book							
Thesis defense exam							

*Part one is to collect data to determine system objectives

*Part two is to evaluate the collected data for the current design

*Part three is to design additional PPS

*Part three is to analyze result and recommendation

CHAPTER 2
LITERATURE REVIEW

2.1 Background and rationale

The facility that use and contain radioactive sources if without well security protection might be likely to cause harm to asset, human, and environment. Thus the security system should be designed by the operator's security professionals to deter adversaries and malicious act or to minimize through detection, delay and response the likelihood successfully of adversary attack. The security system have four functions are deterrence, detection, delay, response, so a well-designed of security system should have five function are 1) deterrent cannot be measured, 2) detection before delay, 3). Detect requires assessment, 4) delay greater than assessment plus response time, 5) balanced protection and defense in depth. To have a well security system or system effectiveness in state, the state should have appropriate Law and Regulatory Requirements [3]. In 2004, IAEA (International Atomic Energy Agency) published the Code of Conduct on the Safety and Security of Radioactive Sources to help national authority requirements to ensure that radioactive sources are used within an appropriate framework of radiation safety and security. this code of conduct categorize radioactive sources in three category based on concept of dangerous, which category 1 sources are the most dangerous and category 3 sources the least dangerous [7] In 2009, IAEA published IAEA Nuclear Security Series No. 11 Implementing Guide of Security of Radioactive Sources intended for the member States use to develop security policy for radioactive sources and regulatory requirements that are consistent with the Code of Conduct. This publication state that in each category has different security level, category 1 sources should have security measures which meet the security objectives of Security Level A. Security Level B for Category 2 sources and Security Level C

Category 3 sources. Security level A is a highest security level [3]. From code of conduct and IAEA Nuclear Security Series No. 11 the category 1 source facility should be assessed or measured the security system effectiveness to meet the security objectives of Security Level A.

On January 2007, the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) established Radiation Protection Series No. 11, Codes of Practice the Security of Radioactive Sources, This Code said that “the stringency of the security of the source measures should be proportional to the likelihood of the consequences of malicious use” The objective of this code is to improving the security of radioactive sources, its effective implementation depend on the development and maintenance of an effective security culture. For radioactive sources category 1 security enhanced source is followed the threat level of malicious act [5].

On 2013, U.S.NRC Regulations part of Physical protection of category 1 and category 2 quantities of radioactive material for the category 1 Monitoring and detection must be performed, immediate detection of any unauthorized removal of the radioactive material from the security zone. Such immediate detection capability must be provided by: Electronic sensors linked to an alarm; or continuous monitored video surveillance; or direct visual surveillance [18].

In Thailand, we also have regulatory requirement on 2011, the Royal Gazette, Volume 129, pages 6-7 states that facility which has irradiator or radioactive source category 1 and 2 installed must contain security system and warning system to prevent intrusion or theft to the facility [20].

From above, facility which has irradiator or radioactive source should be conceder about security system, especially category 1 sources facility the system should have system effectiveness. Design and evaluate of physical protection systems (PPS) is used to assess the physical security system. The purpose of a PPS is to prevent an adversary from successful completion of a malevolent action against a facility. The primary PPS functions are detection, delay, and response [8]. The design of an effective PPS includes identification of the PPS objectives, establishing the facility design, providing an initial design of a PPS, evaluation of the design, and if the system does not meet required protection objectives, the system should be redesign or refinement [16]. For analyze and evaluate normally using computer model. The widely used of computer model use to evaluate the PPS is EASI (Estimate Adversary Sequence Interruption) model. EASI model is a fairly simple calculation tool, was developed by Sandia national laboratory in 1960. Input parameters of this model are the function of detection, delay, and response. Output of the model is probability of interruption (P_I) obtained from the security systems [8, 16] Which, P_I is the probability of detection from the start of the path up to the point determined by the time remaining for the guards to respond and interrupt the adversary. This value of P_I can use to measure the PPS effectiveness [8].

On 2009, W.F.Bakr and A.A.Hamed studied on Upgrading the Physical Protection System (PPS) To Improve the Response to Radiological Emergencies Involving Malevolent Action. They state that they used EASI Model to calculate the probability of interruption (PI). It is a simple calculation tool that quantitatively illustrates the effect of changing physical protection parameters along a specific path. It uses detection, delay, response, and communication values to compute the probability of interruption PI. In this model, input parameters representing the physical protection functions of detection, delay, and response are required. Communication likelihood of the alarm signal is also required for the model. Detection and communication inputs are in the form of probabilities that each of these total functions will be performed successfully. Delay and response inputs are in the form of mean times and standard deviations for each element. All inputs refer to a specific adversary path [15].

On 2011, Ludek Lukas and Martin Hromada studied on Utilization of the EASI model in the matters of critical infrastructure protection and its verification via the OTB SAF simulation tool and Simulation and Modeling in Critical Infrastructure

Protection. The study found that the crucial aspect in verifying theoretical basis not only in relation to generating input parameters into the chosen EASI model but also to individual outputs verification following from the EASI model was the application of OTB SAF simulation tool for the verification of the physical protection system functionality and structure as a critical infrastructure component [11, 13].

On 2012 Ludek Lukas and Martin Hromada studied on Critical Infrastructure Protection and the Evaluation Process. They state that EASI method (Estimation of Adversary Sequence Interruption) allows calculation of probability of interruption only on one predefined path. The path way of adversary describes facility and its security system as layers that separate external intruder from the target inside facility. Individual physical areas are separated by protective barriers that include everything that may delay or detect intruder [11].

On 2014, O. D. Oyeyinka and et. al. studied the determination of system effectiveness for physical protection systems of a Nuclear Energy Centre. the study found that The probability of interruption obtained for the security systems is 0.930 using EASI model, the security system is high due to the Probability of interruption is greater than the medium security system range of 0.50-0.75 [10].

Therefore, this research study and assess of the physical security of category 1 sources facility. Study the current design of PPS and the PPS function including detection, delay, and response. The design of category 1 facility will follow the regulatory requirement. The assessment of physical security of the facility using the computer model is EASI model to evaluate the system by creates the scenario based on facility characterization and threat in Thailand. Therefore, the aim of this study is to assess the physical security of a category 1 gamma irradiation facility with the given configuration based on an actual facility

2.2 Security of category 1 radioactive source

2.2.1 Categorization of radioactive sources

Any radiation sources were categorized in the Code of conduct by has 3 categories based on concept of dangerous (D), as follows

- Category 1 sources, if not secure and protects them; it would probably be fatal to be close to this amount of unshielded material for a period of a few minutes to an hour. Sources in this category such as radiothermal generators, irradiators and radiation teletherapy.
- Category 2 sources, if not secure and protects them, it could possibly be fatal to be close to this amount of unshielded radioactive material for a period of hours to days. Sources in this category such as industrial gamma radiography, high dose rate brachytherapy and medium dose rate brachytherapy.
- Category 3 sources, if not secure and protects them, it could possibly, although it is unlikely, be fatal to be close to this amount of unshielded radioactive material for a period of days to weeks. Sources in this category such as fixed industrial gauges involving high activity sources [7].

In some situations such as when use the unknown sources, to categorization of source use only the value of A/D may be more appropriate, when A is he activity of the radioactive material in TBq and D is dangerous sources. Category 1 source, if categorize sources base on A/D, the category 1 sources will have A/D>1000.

The A/D concept is the set of sources to be categorized on the basis of activity. If sources with various radionuclides are aggregated, then the sums of the ratios A/D use to determine the category, as following the formula:

$$\text{Aggregate A/D} = \sum_n \frac{\sum_i A_{i,n}}{D_n}$$

When: $A_{i,n}$ is activity of each individual source i of radionuclide n.

D_n is D value for radionuclide n.

In each category has different security level, category 1 sources should have security measures which meet the security objectives of Security Level A. Security Level B for Category 2 sources and Security Level C category 3 sources. The goals of each security level have been developed as following: Security level A is to prevent unauthorized removal of a source. Security level B is to minimize the likelihood of unauthorized removal of a source. Security level C is to reduce the likelihood of unauthorized removal of a source [3]. The categorize for commonly used sources shown in table 2.1

Table 2.1 categorize for commonly used sources [3]

Category	Source	A/D	Security level
1	Radioisotope thermoelectric generators (RTGs) Irradiators Teletherapy sources Fixed multibeam teletherapy (gamma knife) sources	$A/D \geq 1000$	A
2	Industrial gamma radiography sources High/medium dose rate brachytherapy sources	$1000 > A/D \geq 10$	B
3	Fixed industrial gauges that incorporate high activity sources Well logging gauges	$10 > A/D > 1$	C

2.2.2 The security level A

The security level A is highest security level. If unauthorized access or unauthorized removals occur, detection and assessment can be occurred early and have enough time to response and interrupt the adversary and prevent the source from being removed [3].

- Detection

Security objective including five objectives are 1) to provide immediate detection of any unauthorized access to the secured area/source location mean that Electronic sensors linked to an alarm or continuous surveillance by operator personnel indicate unauthorized access to the controlled area or sources location and ensure that adversary cannot be passed. 2) Provide immediate detection of any attempted unauthorized removal of the source, it indicate and ensure that attempted unauthorized removal of a source cannot be bypassed. 3) Provide immediate assessment of detection; mean that the cause of the alarm should be an immediate assessment by operator personnel at controlled area or source location. 4) Provide immediate communication to response personnel, mean that if unauthorized removal has occurred, immediate inform should be occurred to response personnel by operator personnel in the facility with various communication devices. 5) Provide a means to detect loss through verification [3].

- Delay

Security objective is to provide delay after detection sufficient for response personnel to interrupt the unauthorized removal, mean that the facility that contain the category 1 source should separate the source from unauthorized personnel and provide sufficient delay at least two barriers following detection to ensure that the response personnel can interrupt adversary before the sources are removed [3].

- Response

Security objective is to provide immediate and adequate response to assessed alarm with sufficient resources to interrupt and prevent the unauthorized removal, meat that Immediate means that responders should arrive, once notified, in a time shorter than the time that adversary can bypass the barriers and tasks to remove the source. Adequate means that the response team has capability to interrupt the adversary [3].

- Security management

Security objective of security management including six objectives are 1) provide access controls to source location that effectively restrict access to authorized persons only. 2) Ensure trustworthiness of authorized individuals. 3) Identify and protect sensitive information. 4) Provide a security plan. 5) Ensure a capability to manage security events covered by security contingency plans. 6) Establish security event reporting system [3].

Recommended measures for security level A describes in Appendix A

2.2.3 Regulatory requirement

In Thailand, the Royal Gazette, Volume 129, pages 6-7 (OAP, 2011) states that facility which has irradiator or radioactive source category 1 and 2 installed must contain security system and warning system. To prevent intrusion or theft, as follows:

- Detection

(1) Contain equipment capable of immediate detection of intrusion, such as electronic sensor alarm or continuous surveillance by personnel, when there is unauthorized access to the security area

(2) Contain equipment to detect any attempted unauthorized radioactive material removal such as electronic sensor alarm or continuous surveillance by personnel

(3) Immediate Detection and alarm assessment, when (1) and (2) occur using equipment such as CCTV and immediate response by officer

(4) Quick communication system to response personnel such as cell phone or private mobile radio.

- Delay

Barrier to prevent unauthorized removal or movement of radioactive materials by installation of 2 barriers such as wall or key locks.

- Respond

Immediate response to prevent unauthorized radioactive material removal by officers, tools and procedures [20].

2.3. Physical Protection system (PPS)

The effectiveness of the PPS functions of detection, delay, and response. The system functions of detection can be accomplished by the use of electronic sensor and/or guards to detect adversary and for delay should have adequate barrier and delay material such as key lock, steel cage, high security pack lock etc. Response usually guards is a primary response and guards should have enough capability to interrupt the adversary and good guards communication. The main process of Design and evaluation of PPS has three parts as shown in figure 2.1. The first part is determining system objectives, including facility characterization, threat definition and target identification. The second part is designing physical protection systems, including detection, delay and response systems. The third part is analyzing and evaluating. If the system does not meet required protection objectives, the system will be redesigned [8].

- Protection Objectives Identification

Protection objectives are identified for each facility type from the applicable regulations. For the facility that contain the category 1 sources, protection objective include high assurance of protect the category 1 sources from unauthorized removal and sabotage of the facility [16].

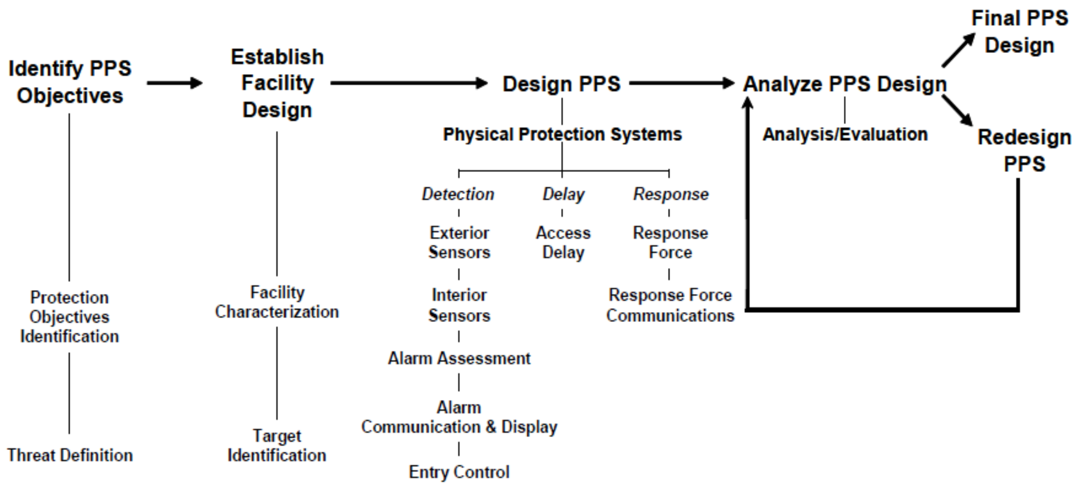

Figure 2.1 Activities associated with a physical protection system design and evaluation process [16].

2.3.1 Identify the PPS Objectives

- Threat Definition

In this study, the threat definition will be defined by the Design basis threat (DBT) as provided by the Thailand nuclear regulatory body, Thailand regulatory body is Office of Atom for Peace (OAP). Establishment of the DBT considers the three questions as following: 1) What class of adversary is to be considered? 2) What is the range of the adversary's tactics? And 3) What are the adversary's capabilities? [16] Adversary can be separated in three type is outsider, insider, and outsiders in collusion with insiders [8]. But in this study conceder the outsider because for insider worker and/or officer in facility don't have enough motivation to theft the radioactive sources or sabotage the facility

For each class of adversary, the full range of tactics is considered. Deceit is the attempted defeat of a security system by using false authorization and identification; force is the overt, forcible attempt to overcome a security system; and stealth is the attempt to defeat the detection system and enter the facility covertly.

Adversary capabilities include knowledge of the PPS, level of motivation, skills useful in carrying out the attack, the speed with which the attack is carried out, and the ability to carry and use tools and weapons [16]

- Facility Characterization

The first step in designing a new or upgrade PPS, is to characterize the facility to be protected. Before any decisions can be made concerning the level of protection needed, an understanding of what is being protected and the surrounding environment is essential. The data collection is necessary in this step are physical conditions, facility operations, facility policies and procedures, regulatory requirements, legal issues, safety considerations, and corporate goals and objectives [16].

- Target Identification

To be able to develop adequate protection one must know what to protect. Protecting everything is neither possible nor practical. Undesirable consequences are separated into two categories: those from theft of nuclear material and those from radiological sabotage. Both of Undesirable consequences might be considered during the design and evaluation of a PPS, radiological sabotage typically represents the more limiting case for the PPS at the category 1 facility [16].

2.3.2 Design the PPS

The step include the PPS function is detection, delay, and response

- Detection

Detection is the discovery of an adversary action. It includes sensing of covert or overt actions. In order to discover an adversary action, the following events need to occur:

1. A sensor reacts to a stimulus and initiates an alarm.

2. The information from the sensor and assessment subsystems is reported and displayed.

3. A person assesses information and judges the alarm to be valid or invalid.

Detection Functions in a PPS shown in figure 2.2

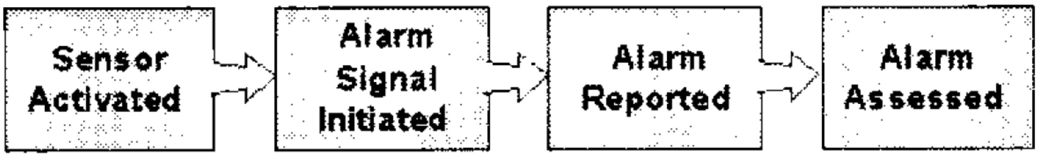

Figure 2.2 Detection Functions in PPS. Detection starts with sensor activation and ends with assessment of the alarm to determine the cause [16]

This function includes exterior sensors, interior sensors, alarm assessment, alarm communication and display, and entry control [8]

Exterior sensors are used in an outdoor environment and interior sensors are installed inside buildings., example of Exterior electronic sensor will be installed at outdoor environment are buried Line, seismic pressure, magnetic field, ported coaxial cable, fiber-optic cables, fence-associated, fence-disturbance and etc. Examples for interior electronic sensor are active glass break, Simple magnetic switch and etc. Sensors performance of bath sensors are described by the following three fundamental characteristics are probability of detection (PD), nuisance alarm rate, and vulnerability to defeat Classification of exterior sensors normally following: passive or active, covert or visible, line of sight or terrain following, volumetric or line detection, and application (buried-line, fence-associated, and freestanding) [8, 16].

Alarms assessment of perimeter should be provided by CCTV. The CCTV displayed should cover all the assessment area and monitored by security operators or guards. Primary assessment of alarms can be done by CCTV displayed at the assessment area or by guards .The assessment system include the several cameras at remote sensor areas, a display monitor at the local end, and various transmission, switching, and recording systems. The main component of alarms assessment composed of security operators, the camera and lens, the lighting system, the data transmission system, a synchronization system, video switching equipment, a video recording system, video monitors, and a video controller interface between the alarm sensor system and the alarm assessment system [8, 15].

A good alarm communication system should be following: fast reporting time, supervision of all data transmission cables, easy and quick discovery of single-point failures, isolation and control of sensors, and expansion flexibility. Alarm display system must design by represent what information to display, how to present the information, how the operator will communicate with the system, and how to arrange the equipment at the operator work station [8, 15].

Entry control systems composed of the hardware and procedures used to check and detect the personnel entry authorization. The methods include credentials, personal identification number, and automated personal identity verification. A well entry control and an effective entry/exit control system consist, cannot be easily bypassed, allows observation by the protective force or guards, protects guards, accommodates peak loads, performs personnel and material control, blocks passage until personnel and material control are completed, is under surveillance by the central alarm station, provides secondary inspections for those who cannot pass the automated inspection, and is designed for both entry and exit [8, 15].

- Delay

This function is the slowing down of adversary action. It can delay the adversary and can be accomplished by barriers, locks, and activated delays, should have delay layer at least 2 layer. The protective force can be considered elements of delay if they are in fixed and well-protected positions. The measure of delay effectiveness is the time required by the adversary (after detection) to bypass each delay element. Although the adversary may be delayed prior to detection, this delay is of no value to the effectiveness of the PPS because it does not provide additional time to respond to the adversary [8, 15].

- Response

This function consists of the actions taken by the protective force to prevent and/or interrupt adversary success. Response consists of interruption and neutralization. Interruption is defined as a sufficient number of response force personnel arriving at the appropriate location to stop the adversary progress. It includes the communication to the protection force of accurate information about adversary actions and the deployment of the response force. The measure of response effectiveness is the time between receipt of a communication of adversary action and the neutralization of the adversary action. The response force time must shorter than adversary task time [8, 15].

2.3.3 Analysis and Evaluation of PPS

A PPS is a complex configuration of detection, delay, and response elements that can be analyzed to determine system effectiveness. The PPS design has been developed to meet the objectives of the protection system. For this study objective of protection system is to provide the high assurance of protection unauthorized removal and sabotage the category 1 sources facility. Using available tools and techniques, the PPS should be analyzed to determine the effectiveness of the design. Analyze of the design of a PPS involves three activities: pathway analysis this part identification of potential adversary paths and associated effectiveness measures, neutralization analysis, estimating the effectiveness of the protection and/or response force in preventing the adversary for accomplishing his goal, and risk assessment, estimating the overall effectiveness of the PPS as a component of risk.

In this study, analyze of the PPS by using pathway analyze and create scenarios based on the current design and DBT. each scenario was evaluate by using the computer model, the computer model is widely used and a simple calculation tool is EASI (Estimate of Adversary Sequence Interruption) model the detail of EASI model will describes in next topic [8, 15].

2.4. EASI (Estimate of Adversary Sequence Interruption) model

EASI is a simple calculation tool that quantitatively illustrates the effect of changing physical protection parameters along a specific path. It uses detection, delay, response, and communication values to compute the probability of interruption (P_I). But, since EASI is a path-level model, it can only analyze one adversary path or scenario at time. Path level means that the model analyzes the protection system performance along only one possible adversary path or one adversary scenario. Even so, it can be used to perform sensitivity analyses and analyze PPS interactions and time trade-offs along that path [5, 9, 19]. EASI model was developed in 1960 by Sandia national laboratory, USA. The simple formula to calculate the P_I is

$$P_I = P_C * P_D$$

When: P_I is the probability that the defined adversary will be interrupted by the response force in time to stop the adversary from accomplishing his or her objectives. The principle of timely detection is used in calculating this probability from 0 (the adversary will definitely be successful) to 1.0 (the adversary will definitely be interrupted in their path) [5].

P_C is probability of communication to the response force. Sandia National Laboratories recommends that most systems operate with a P_C of at least 0.95. This number can be used as a working value during the analysis of a facility [5].

P_D is The P_D is the product of the probability that the detector will sense abnormal or unauthorized activities by the adversary (P_S), the probability that an alarm indication will be transmitted to an evaluation or assessment point (P_T), and the probability of accurate assessment of the alarm (P_A). The relationship among these performance measures for PD can be summarized as: [5, 9].

$$P_D = P_S * P_T * P_A$$

Input parameters of EASI model representing the physical protection functions of detection, delay, and response are required. Communication likelihood of the alarm signal is also required for the model. Detection and communication inputs are in the form of probabilities that each of these total functions will be performed successfully. Delay and response inputs are in the form of mean times and standard deviations for each element. All inputs refer to a specific adversary path [5, 9]. The standard deviation (SD) for the response force time and the adversary T means are the values that the EASI program automatically assigns when you enter a layer T or response force time. The program assigns the SD to be approximately 30% of the mean entered [5].

Output of EASI model is P_I which it is the probability of detection from the start of the path up to the point determined by the time remaining for the guards to respond and interrupt the adversary. This value of P_I can use to measure the PPS effectiveness [5]. Formula used in OSI model for many path element descriptions in Appendix B

CHAPTER 3
RESEARCH METHODOLOGY

The research methodology consists of 4 parts: 1) collecting data to determine security objectives, 2) evaluating the collected data for the current design effectiveness, 3) designing additional PPS, and 4) Analyzing result of the change and providing recommendations

3.1 Collecting data to determine security objectives

3.1.1 Facility characterization

The layout of the institute is shown in Figure 3.1. The outer fence of the institute is a 2.5 m high steel fence. The main gate has CCTV and 4 guards. Inside along the fence is a canal (blue line color). The back entrance of the institute is permanently closed by steel chain and high security padlock. The pathway from the main gate to the gamma irradiation facility has 1 guard stationing at the building beside the facility.

The gamma irradiation facility is separated into two areas. The first area is the office area (in blue rectangle) -- this area does not have any radioactive source. The second area is the controlled area (in red rectangle) -- this area contains the gamma sources, thus needs to have security system to protect the radioactive source from any malicious act or adversary action.

The current of PPS design of the facility is shown in Figure 2. The diagram shows all sensor and delay equipment installed in the facility. The motion sensors are installed in front of every room. There are 2 motion sensors in the laboratory and the storage rooms, and 1 motion sensor in the electrical room.

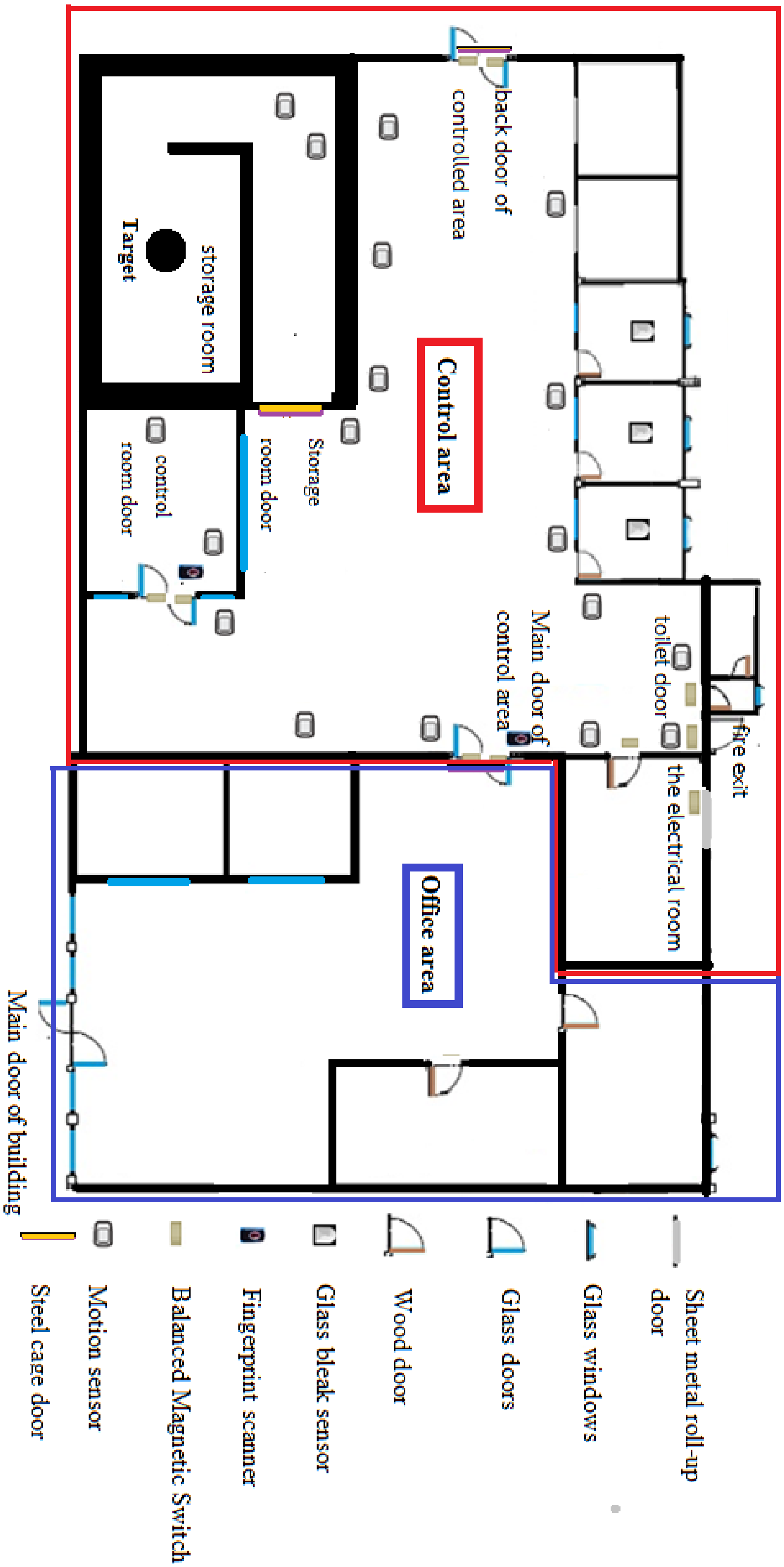

Figure 3.1 the layout of institute and Gamma irradiation facility.

Glass break sensors are installed in every room on the glass windows. Balanced magnetic switches are installed on the main and the back doors of the controlled area, the back and the front doors of the electric room, the fire exit, the toilet door, and the control room door. The main and the back doors of the controlled area are also protected by steel cage which requires key to open. The main door of controlled area and the control room door also have fingerprint scanner. The storage room that contains Category 1 gamma source is protected by a lead hydraulic door that can be controlled only from the control room. There is also another layer of steel cage door with high security padlock that can only be manually opened.

For barrier of the building a wall made of lightweight brick and smooth plaster. The wall thickness is 10 cm. The wall of the storage room is a normal concrete, 180 cm thick. The glass window and glass door material is a normal glass 6 mm thick. Several 5 cm thick wooden doors are installed in this facility. The diagrams shown in Figures 3.2 are drawn with different geometry and scale from the actual facility, but all important security components are kept the same for security reason. -- if all the security systems of the facility are known by adversaries, they will be able to plan an attack that is more likely to success because they already know what obstacles they will face, the size and arms of the guard force, the location of the important targets within the facility, and etc [1].

The entry controls into the institute and the facility are as follows:

- To enter the institute, the guard must first unlock and manually open the main gate. The guard will then manually check the vehicle and the driver. Once through, the guard will shut and lock the main gate.

- To enter the controlled area of the facility, the workers must be authorized via fingerprint scanner at the main door of controlled area and the control room. Each person from outside the facility cannot pass through the door without being accompanied by worker. For the storage room, worker will open the hydraulic door using a control program in the control room, and then manually open the steel cage by key. This process takes around 3 minutes. If there is an alarm or if the package is suspicious, the guard of institute will performs an inspection.

The response time for the institute guards equals to 2 minute, but in reality the guards cannot interrupt the adversary because from the DBT (below), the adversary has hand gun or auto rifle. The institute guards carry only baton, shackle, and radio communication. They are only responsible for: assessing alarms, performing administrative duties such as access control and key service, responding to all assessed intrusion alarms (non-confrontational), and informing the local police for serious case. Thus, response force time of this study is the response time of the local police force. A group of local police patrols consists of two police officers in a standard police car and two on a patrol police motorcycle. The four police patrols will be able to reach the facility within 5 minutes after notified by the guard. They are responsible for protecting the neighborhood around the institute, including the facility. There are four groups of patrols in the area 24 hours a day. They perform periodic checks with the local guard force (8 hours per round) and if serious situation arises, they will respond to the assessed intrusion to delay the intruder until the military tactical response team arrives. Thus, the response force time for the facility is 5 minute. These information are acquired from the interview with the local police.

The operation time of the facility is from 8.30 to 16.30. However, there may be overtime on some days until 20.30 O'clock. Normally, the facility has 13 workers.

3.1.2 Theft Identification

The latest Design Basis Threat (DBT) of Thailand was evaluated in 2007 by the Office of Atom for Peace (OAP) and relevant security organization. The DBT is shown in Table 3.1.

Table 3.1 External threat in Thailand on 2007 (DBT from OAP)

	Terrorist	Criminal	Extremist / Activist
Potential Action:			
Theft	L-M	H	L
Sabotage	H	L	M
Intruder	H	L	H
Motivation:			
Ideology	H	L	H
Economy	L	H	M
Personnel	L	M-H	L
Capabilities:			
Amount*	L	L	H
Weapon	Hand Gun, Auto Rifle	Hand Gun	Conventional
Tools	Explosive	Hand Tool	Conventional
Vehicle	Land	Truck Car, Motor Cycle, etc.	Medium Truck , Bus, Car, etc.
Tech Capabilities	H	M	H
Internal Collusion	M	H	L

Points		Amount*
L (Low)	= 1 point	L: 1-4 persons
M (Medium)	= 2 points	M: 5-10 persons
H (High)	= 3 points	H: >11person

The threat definition is derived from the DBT established by the State. The design and evaluation of a security system should follow the current national threat assessment [4]. The information in Table 1 shows that the potential adversary groups consist of terrorist and criminal. Terrorist has a low-to-medium probability to be theft, but high to perform sabotage. Possible weapons and tools for the terrorist include hand gun, auto rifle, and explosive. Criminal has a high probability to be theft, but low to perform sabotage. Possible weapons and tools for criminal include hand gun and hand tool. Adversaries groups may use truck, car, and motorcycle for transport. The number of adversaries attacking the facility is from 1 to 4 persons. This threat definition is used to create attacking scenarios.

3.1.3 Target Identification

The source in this facility is a Co-60 gamma source. Its original activity at 2009 is 58,800 Ci. Since its A/D value is greater than 1000, it is classified as a Category 1 radioactive source. The source is shielded by a 140 cm diameter lead thickness for container body and 8.5 cm diameter foe source exposure tubes by have 1.2 cm lead thickness surrounding. The diagram of sources shown in figure 3.3

There are two potential targets of attack. First is the building that contains the Category 1 source which is the target of sabotage. Second is the Category 1 source inside the facility which is the target of theft.

3.2. Evaluating the collected data for the current design effectiveness

This part evaluates the collected data for the current design effectiveness by using the Estimation of Adversary Sequence Interruption (EASI) model to estimate the probability of interruption (P_I) and to predict the likelihood that the threat will functions of detection, delay, and response and communication likelihood of the alarm signal. Probabilities of communication, which evaluation of many systems succeed.

In case adversary takes a vehicle from the main entrance of institute to the gamma irradiation facility which covers the distance of 250 meters, from Figure 4 for example, a motorcycle traveling at 77 km/hr would take 11.7 seconds, while the truck traveling at 60 km/hr would take 15 sec. These speeds are the average speeds of motorcycle and truck commonly assumed for the calculation.

EASI is a fairly simple calculation tool developed by the Sandia National Laboratories, USA. It quantitatively illustrates the effect of changing physical protection parameters along a specific path. It uses detection, delay, response, and communication values to compute P_I. Since EASI is a path-level model, it can only analyze one adversary path or scenario at a time. It can also perform sensitivity analyses and analyze physical protection system interactions and time trade-offs along that path. Input parameters for EASI model are the physical protection designed and implemented by Sandia National Laboratories. Output of EAST model is Probability of interruption (P_I); it can determine the security system range [8]. The Equation use in EASI model as shown in Appendix B. Input parameter for EASI model as following:

- Probability of detection (P_D) is the detection function for each sensor encountered by an adversary. In case of the pathway has several sensor PD at the path is $1-(1-P_{D1})*(1-P_{D2})*(1-P_{D3})*...*(1-P_{Di})$, P_{Di} is the probability of detection for the sensor i at the path. When $P_{Di} = P_{Di}$ if detection is at the beginning, $P_{Di}/2$ if detection is in the middle, and P_{Di} have no effect to the system, if detection is at the end [8]. The detection devices in the facility consist of motion sensors, balanced magnetic switches, and glass break sensors. The probability of detection (P_D) of each sensor used in this study [2] shown in Table 3.2.

- Probability of communication (P_C), Sandia National Laboratories indicates that most systems operate with a P_C of at least 0.95.
- Delay time mean including the access delay time for the delay equipment and the adversary travel time, adversary's equipment choice to break down the delay equipment, and penetration time (in seconds), are show in Table 3.3. Based on the DBT, the adversary will have various modes of transportation which are running, motorcycle, and truck. The adversary travel time from one point to the next using various modes of transportation can be calculated from the graphs in Figure 3.4 (for running) and 3.5 (for motorcycles and trucks).

In this study, one of the potential scenarios is to have an adversary running with a 16 kg in toolbox. Using the 4^{th} line in Figure 3.4, we can estimate the adversary travel time as follows:

- From the main entrance of the institute to the gamma irradiation facility, the distance is 250 meters. Thus the travel time is 62.5 seconds for the adversary running.
- From the main door of the facility to the controlled area, the distance is 12 meters. Thus, the travel time is 3 seconds.
- From the controlled area door (in the front) to the control door, the distance is 8 meters. Thus, the travel time is 2 seconds.
- From a glass window to the wooden door in the controlled area, the distance is 4 meters. Thus, the travel time is 1 second.

- From the wooden door in the controlled area to the control room door, the distance is 12 meters. Thus, the travel time is 3 second.
- From the electrical room steel roll-up door to the wooden door of the electrical room, the distance is 4 meters. Thus, the travel time is 1 second.
- From the wooden door of the electrical room to the control room door, the distance is 4 meters. Thus, the travel time is 1 second.
- From the back door of the controlled area to the control room door, the distance is 24 meters. Thus, the travel time is 6 second.
- From the fire exit door to the control room door, the distance is 8 meters. Thus, the travel time is 2 second.
- From a glass window in front of the toilet in the controlled area to the wooden door, the distance is 4 meters. Thus, the travel time is 1 second.
- From the wooden door to the control room door, the distance is 4 meters. Thus, the travel time is 1 second.
- From the control room door to the storage room door, the distance is 5.5 meters. Thus, the travel time is 1.38 second.
- From the storage room door to the target (source), the distance is 16 meters. Thus, the travel time is 4 second.

In case adversary takes a vehicle from the main entrance of institute to the gamma irradiation facility which covers the distance of 250 meters, from Figure 4 for example, a motorcycle traveling at 77 km/hr would take 11.7 seconds, while the truck traveling at 60 km/hr would take 15 sec. These speeds are the average speeds of motorcycle and truck commonly assumed for the calculation.

The standard deviation of delay time mean can be approximated by using the mean 30%. As an alternative, tests at Sandia have shown that the standard deviation of a time event can be conservatively estimated at 30% of the mean and, therefore, if there have not been enough tests to establish a statistically significant standard deviation; one can simply use 30% of the estimated mean. These assumptions are equally applicable to delay times; that is there is a standard deviation associated with each mean time.

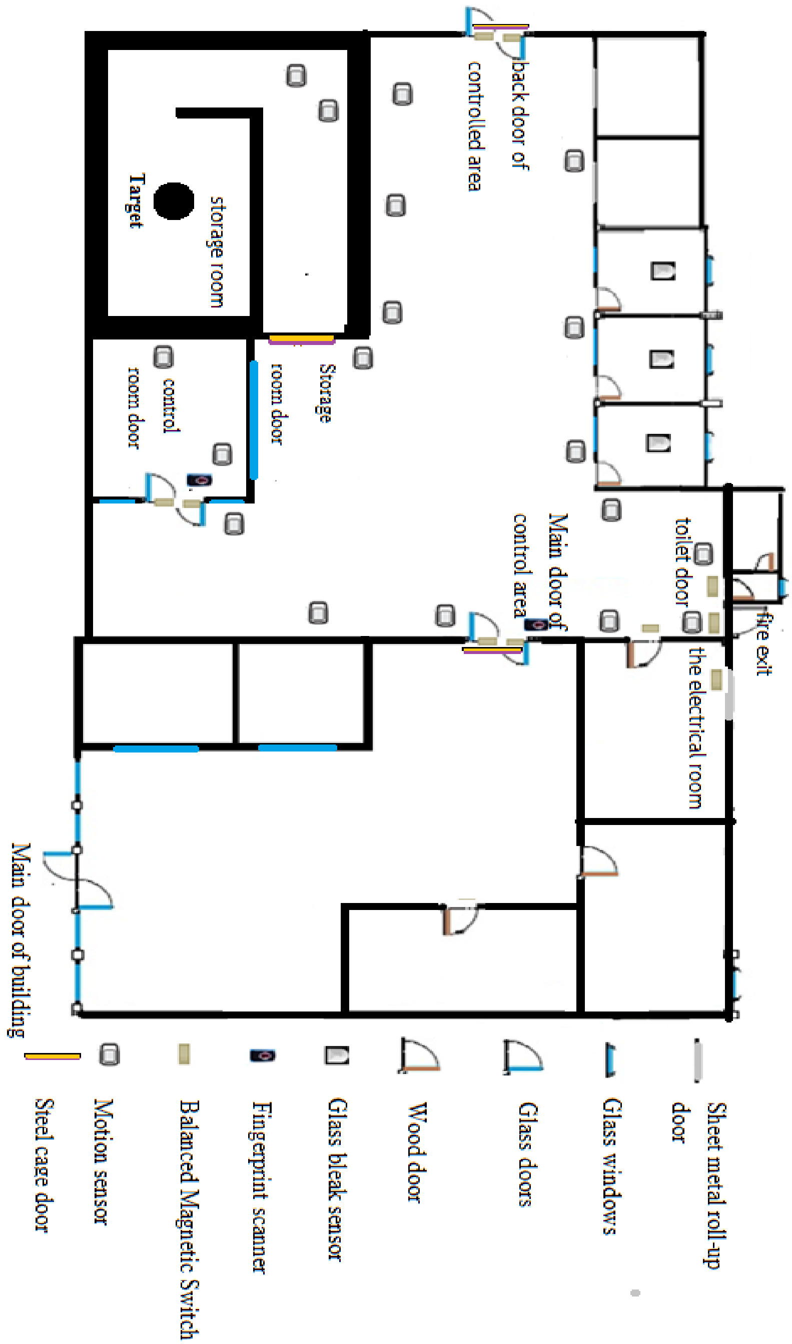

Figure 3.2 the current of PPS design of gamma irradiation facility.

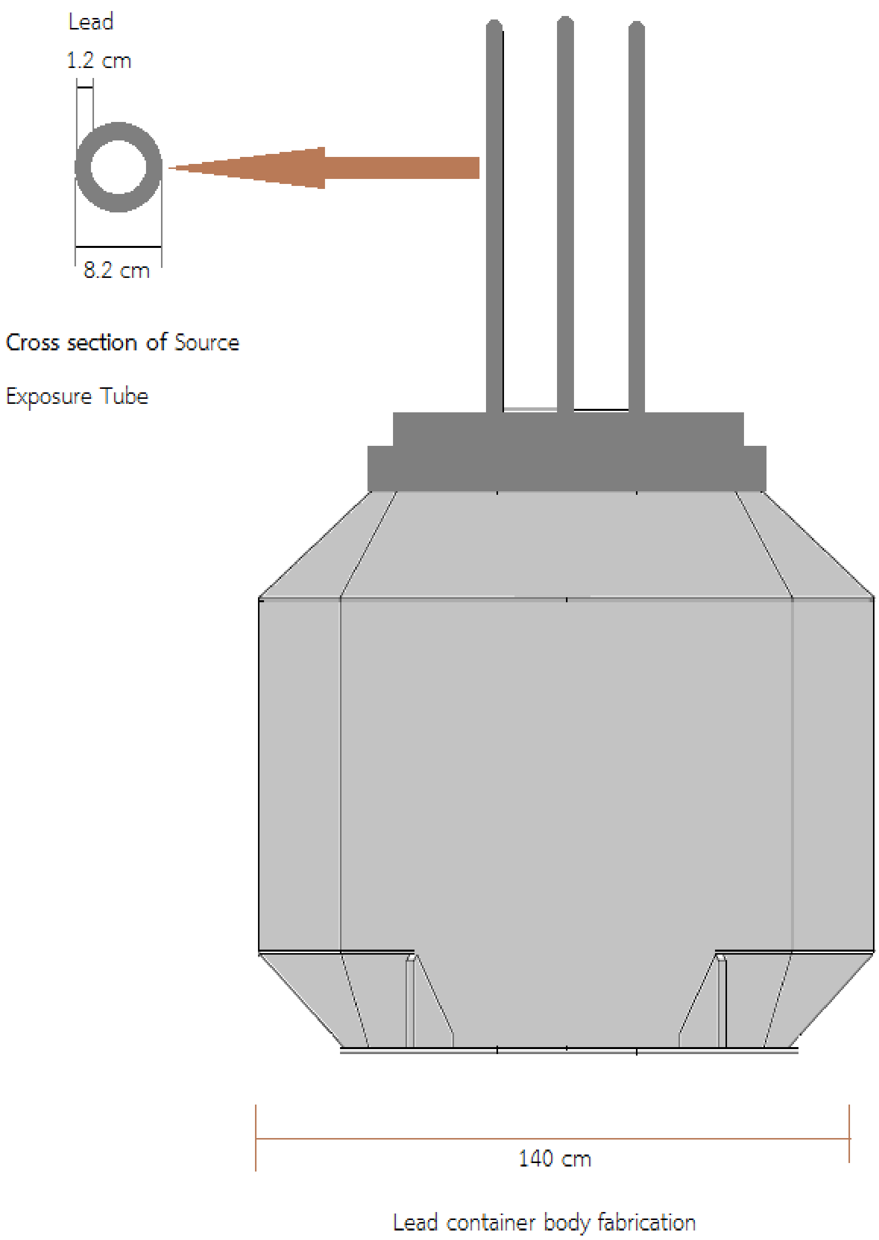

Figure 3.3 diagram of source container.

3.3. Designing additional PPS

The results from part 3.2 are used to design the new PPS of the facility. The new PPS design will add some sensor device or delay equipment based on the current design and low additional cost, but will have higher security system effectiveness.

3.4. Analyzing result of the change and providing recommendations

Result from Parts 3.2 and 3.3 are reanalyzed and compared. This part also provides some recommendations in the part of detection, delay, and response.

Table 3.2 Probability of detection of sensor devices used in this study

device	P_D No Equipment	P_D Hand Tools	P_D Power Tools	P_D High Explosives	P_D Land Vehicle
-motion sensor (dual technique)	0.9	0.9	0.9	0.9	N/A
-Balanced Magnetic Switch	0.8	0.8	0.8	0.8	N/A
-Glass Breakage	0.9	0.6	0.6	0.9	N/A

Table 3.3 Access delay time for equipment [2]

Description	Adversary Equipment	Equipment Weight (Kg.)	Penetration Time (Seconds)			
			Min.	Mean	Max.	Standard Deviation
Steel mesh fence, 2.5 m height	ladder	5	6	12	18	2.4
Steel gate, 2.5 m height	ladder	5	6	12	18	2.4
	Truck	1500	3	6	9	1.2

Table 3.3 Access delay time for equipment [2] (cont.)

Description	Adversary Equipment	Equipment Weight (Kg.)	Penetration Time (Seconds)			
			Min.	Mean	Max.	Standard Deviation
High security padlock	Hand tools	3	60	90	120	18
	Power saw	4	30	60	90	12
Glass window	No equipment or hand tools	0	3	5	10	1.5
5-cm wood pedestrian door	Fire Ax	4.5	9	12	15	2.4
	Circular saw	10	9	12	15	2.4
Steel cage door with 4-mm thickness, 5 x 10 cm rectangle	pliers	1	60	120	180	24.6
Sheet metal roll-up vehicle door	Fire Ax	4.5	66	132	198	27
0.75-cm steel plate door	Pry bar, sledgehammer	17	240	300	360	54
	Cutting torch	20	15	30	45	12
Target	Explosives	3	20	30	45	12
guard at post	Delay time = 30 sec.					

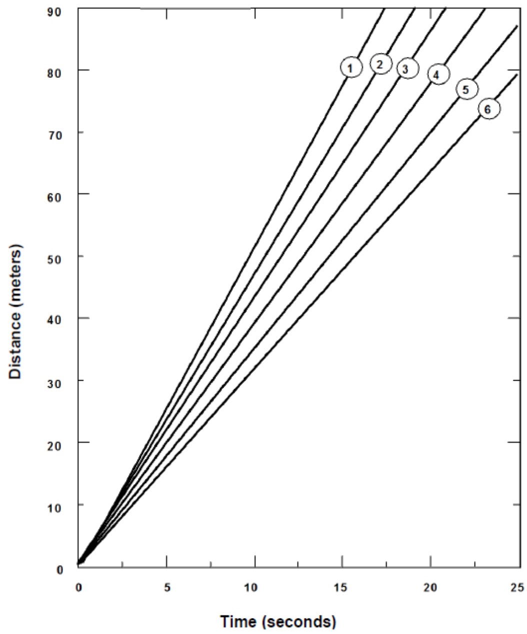

Figure 3.4 Adversary running rates [2]

Note: Fatigue is ignored and estimate that an adversary on foot can run at approximately 4 meters/second.

1-On paved/unpaved ground | 2-With tools

3-On sand | 4-With weight (16 kg in toolbox)

5-With 2.4-m stepladder | 6-With 10-m extension ladder (2 men)

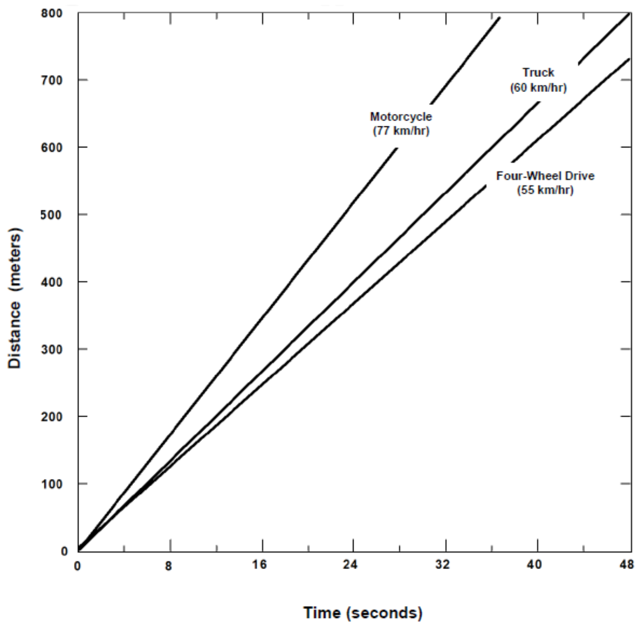

Figure 3.5 Vehicle rates for experienced drivers [2]

CHAPTER 4
RESULTS AND DISCUSSION

4.1. Evaluate the collected data for the current design

The current PPS design for detection, delay and response are shown in Table 4.1. Based on the collecting data and the current PPS design in chapter 3, an adversary sequence diagram (ADS) can be created as shown in Figure 4.1. From the off-site to the target, six attacking scenarios/pathways for each mode of transportation (run, motorcycle, and truck) shown in Figures 4.2. From the DBT, the adversary can go from the off-site to the facility by various modes of transportation, including running and using vehicles such as motorcycles and trucks.

Table 4.1 the current of PPS design in gamma irradiation facility, P_D (Probability of detection) from PTR data source [2]

Detection	device	P_D No Equipment	P_D Hand Tools	P_D Power Tools	P_D High Explosives	P_D Land Vehicle
	-motion sensor	0.9	0.9	0.9	0.9	N/A
	-Balanced Magnetic Switch	0.8	0.8	0.8	0.8	N/A
	-Glass Breakage	0.9	0.6	0.6	0.9	N/A
	-guard at post	P_D = 0.5 for adversary run			Delay time = 30 sec.	
		P_D = 0.5 for adversary take motorcycle and truck				
	Entry Control	Key for Steel cage, Fingerprints scanner, and Balanced Magnetic Switch,				

Table 4.1 the current of PPS design in gamma irradiation facility, P_D (Probability of detection) from PTR data source [2] (Cont.)

Delay	- Doors with key - Back door of controlled area: Steel cage door and with key - control room door: fingerprint scanner - Main door of control area: steel cage door with key and fingerprint scanner - storage room door: steel cage door and High Security Padlock and lead hydraulic door can control only worker in control room and concrete barrier 1.8 matter thickness
Response	- Four Guards at post distance from facility 250 meter, one guard at another building nearby the facility, when have any alarm will inform to local police medially - Four local police patrols will come to facility within 5 minutes after guard inform. Each patrol consists of two police officers in a patrol car and 2 in a patrol motorcycle. They are responsible for protecting the neighborhood around the institute including the facility. There are four patrols in the area 24 hours a day. They are responsible for: performing periodic checks with local guard force (8 hours per round) and if have serious case, they will responding to assessed intrusion to delay intruders until the military tactical response team arrives

Off site	
1	1. Main entrance of institute, Steel gate, 2.5 m height, has 4 guards, and CCTV
Limited Area	
1	1. Open location, distance of around 250 meter, and have 1 guard at another building
Protected Area	
1	1. Main door of building is glass door, 6mm thickness, have CCTV
	2. Glass windows have Glass bleak sensor, 6 mm thickness, after break the window need to pass wooden door 5 cm thickness, in front of the room have motion sensor and can see by CCTV
2 3 4 5 6	3. Break back of electrical room door is steel role door has Balanced Magnetic Switch and then run to the wooded door 5 cm thickness of to electrical room to go inside the control area this door has Balanced Magnetic Switch and motion sensor and CCTV in front of the room
No. 2-6 Adversary can go directly to control area no need to pass control room door	4. Back door, 6 mm thickness, steel cage and key lock, this door has Balanced Magnetic Switch, motion sensor and can see by CCTV
	5. Fire exit door, thickness 1 ¾ inches (or 4.445 cm). have Balanced Magnetic Switch alarm, motion sensor and can see by CCTV
	6. Glass window in front of toilet room, 6 mm thickness, and then need to pass wooden door 5 cm thickness has Balanced Magnetic Switch and motion sensor in front of the room and can see by CCTV
Building	
1	1. Main door of controlled area has steel cage and High Security Padlock and fingerprint scanner, this door has Balanced Magnetic Switch, sensor alarm, motion sensor and can see by CCTV
Controlled Area	
1	1. Control room door has fingerprint scanner, sensor alarm, motion sensor and can see by CCTV. Laboratory room door is glass 6 mm thickness. The storage room door is controlled by control system laboratory room, take time to open around 3 minutes. The steel cage of irradiation room have high security padlock and can open by manual
Storage room	
1	1. Walkway go to storage room area can see by CCTV and has motion sensor
Target	

Figure 4.1 Adversary sequence diagram from the off-site to the target for any asset in the Category 1 gamma Irradiation Facility.

Figure 4.2 Six scenarios for sabotage and theft for each mode of transportation based on the adversary sequence diagram.

In the first scenario, the adversary comes from outside and passes through the main door of the building, which is a glass door (6 mm thickness). He then penetrates the main door of the controlled area. The pathway is shown in the pink color in Figure 4.2 and this scenario have been drawn as shown in Figure 4.3 and detail for each pathway shown in table 4.2

Table 4.2 the detail of adversary travel time, penetrates time, and P_D for each pathway of adversary from offside to the target for the first scenario. (When R is Run, M is motorcycle, and T is truck)

Description	Adversary travel time (s)			Penetrates time for delay equipment (s)			P_D		
	R	M	T	R	M	T	R	M	T
1) Adversary penetrates the main gate of institute that had four guards at post and the gate is steel gate, 2.5 m high, with High Security Padlock, for adversary run they can used ladder to pass through this gate, for adversary take motorcycle they need to break High Security Padlock by Power saw to open the gate, and for adversary take truck, by cash the gate	-	-	-	42	90	36	0.5	1	1
2) Adversary runs to the building by using different mode of transportation. This area is open area and had one guard at there, distance is 250 meter	62.5	11.7	15	30	30	30	0.5	1	1

Table 4.2 the detail of adversary travel time, penetrates time, and P_D for each pathway of adversary from offside to the target for the first scenario. (When R is Run, M is motorcycle, and T is truck) (cont.)

Description	Adversary travel time (s)	Penetrates time for delay equipment (s)	P_D
3) Adversary penetrates the main door of building, this door is glass door, 6 mm thickness and no sensor device, adversary can use on equipment to break this door,	R	R	R
	-	5.00	0.00
4) Adversary runs to the controlled area door, distance is 12 meter	3.00	-	0.00
5) Adversary break the controlled room door, which this door is glass 6 mm thickness with steel cage door with key and have BMS, adversary use no equipment to break the glass door and use pliers to break the steel cage door	0.00	125.00	0.80
6) Adversary runs to the control room door, pathway have 3 motion sensors (1^{st} sensor detect at the beginning, 2^{nd} sensor detect at the medium, and 3^{rd} detect at the end), distance is 8 meter	2.00	-	1-(1-0.9)*(1-0.45) = 0.95
7) Adversary break glass door 6 mm thickness of the control room, use no equipment, and MBS installed at the door	-	5.00	0.80

Table 4.2 the detail of adversary travel time, penetrates time, and P_D for each pathway of adversary from offside to the target for the first scenario. (When R is Run, M is motorcycle, and T is truck) (cont.)

Description	Adversary travel time (s)	Penetrates time for delay equipment (s)	P_D
8) Open the storage room from the control room, in this room have 2 motion sensor (1st sensor detect at the beginning, and 2nd sensor detect at the medium), they need to take time around 3 minute to control the system and open the storage room door	-	180.00	1-(1-0.9)*(1-0.45) = 0.95
9) Adversary runs from control room to storage room door, this pathway have 3 motion sensor(1st sensor detect at the beginning, 2nd sensor detect at the medium, and 3rd detect at the end), distance is 5.5 meter	1.38	-	1-(1-0.9)*(1-0.45) = 0.95
10) Adversary open the steel cage door with High Security Padlock of storage room by using power saw, in front of the door have 1 motion sensor	-	60.00	0.90
11) Adversary runs to the target, pathway have 2 motion sensors (detect at the medium) and distance is 16 meter	4.00	-	1-(1-0.45)*(1-0.45) = 0.70
12) Adversary sabotage or theft the sources	-	-	-

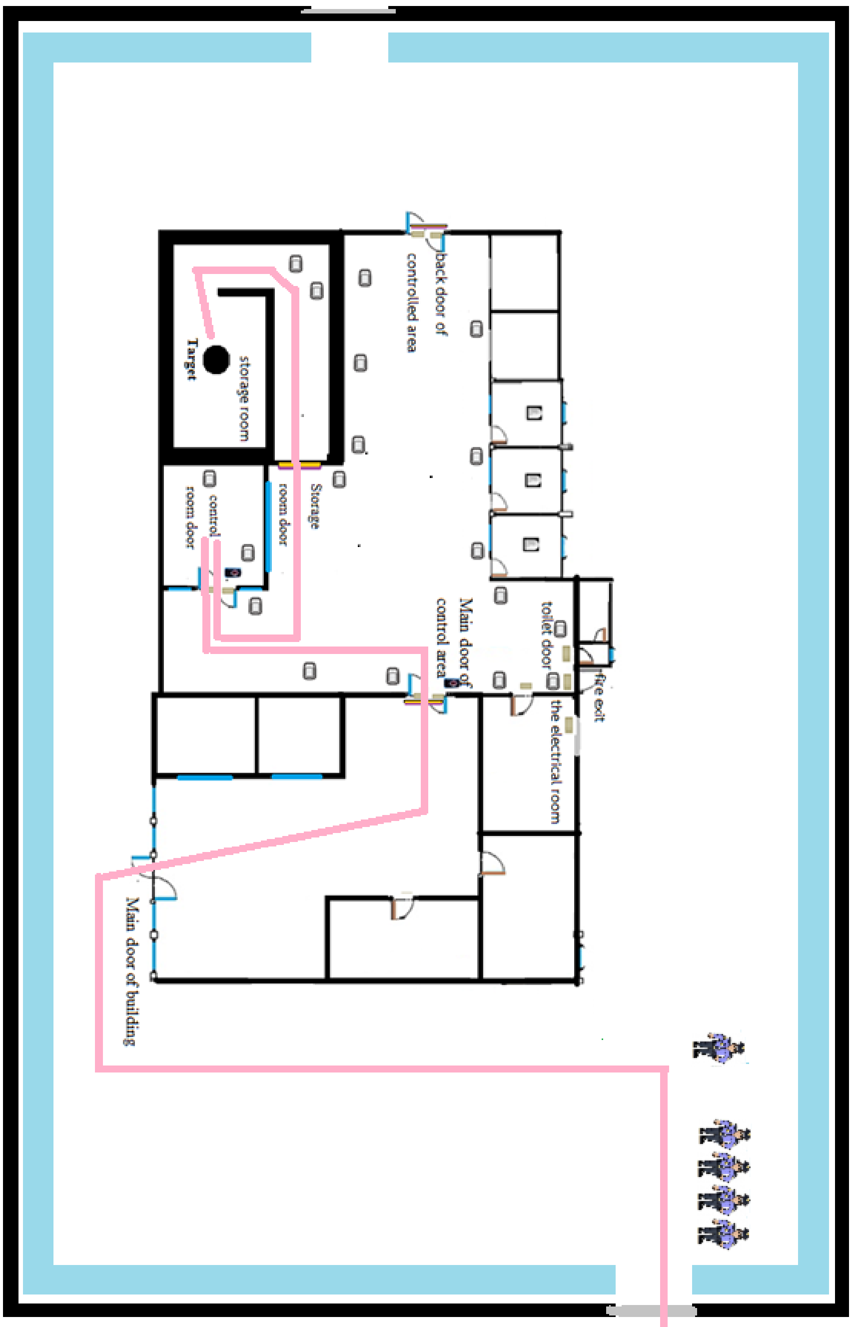

Figure 4.3 Diagram of adversary path ways in the category 1 gamma Irradiation Facility for the first scenario related to figure 4.2

In the second scenario, the pathway is shown in the blue color in Figure 4.2. This scenario have been drawn as shown in Figure 4.4 and detail for each pathway shown in table 4.3

Table 4.3 the detail of adversary travel time, penetrates time, and P_D for each pathway of adversary from offside to the target for the second scenario. (When R is Run, M is motorcycle, and T is truck)

Description	Adversary travel time (s)			Penetrates time for delay equipment (s)			P_D		
	R	M	T	R	M	T	R	M	T
1) Adversary penetrates the main gate of institute that had four guards at post and the gate is steel gate, 2.5 m high, with High Security Padlock, for adversary run they can used ladder to pass through this gate, for adversary take motorcycle they need to break High Security Padlock by Power saw to open the gate, and for adversary take truck, they can take the truck pass through the gate.	-	-	-	42	90	36	0.5	1	1
2) Adversary runs to the building by using different mode of transportation. This area is open area and had one guard at there, distance is 250 meter.	62.5	11.7	15	30	30	30	0.5	1	1
3) The adversary passes through one of the 6 mm thick glass windows of a room in the controlled area, the window have glass break sensor.	R			R			R		
	-			5			0.9		

Table 4.3 the detail of adversary travel time, penetrates time, and P_D for each pathway of adversary from offside to the target for the second scenario. (When R is Run, M is motorcycle, and T is truck) (cont.)

Description	Adversary travel time (s)	Penetrates time for delay equipment (s)	P_D
4) Adversary runs to the wooden door, pathway have on sensor, distance is 4 meter.	1.00	-	0.00
5) Adversary break the 5 cm thick wooden door to go inside the inner area by using Fire Ax	-	12.00	0.00
6) Adversary runs to the control room door, pathway have 4 motion sensors (1st sensor detect at the beginning, 2nd and 3rd sensor detect at the medium, and 4th detect at the end), distance is 8 meter	2.00	-	1-(1-0.9)* (1-0.45)* (1-0.45) = 0.97
7) Adversary break glass door 6 mm thickness of the control room, use no equipment, and MBS was install at this door	-	5.00	0.80
8) Open the storage room from the control room, in this room have 2 motion sensor (1st sensor detect at the beginning, and 2nd sensor detect at the medium), they need to take time around 3 minute to control the system and open the storage room	-	180.00	1-(1-0.9)* (1-0.45) = 0.95

Table 4.3 the detail of adversary travel time, penetrates time, and P_D for each pathway of adversary from offside to the target for the second scenario. (When R is Run, M is motorcycle, and T is truck) (cont.)

Description	Adversary travel time (s)	Penetrates time for delay equipment (s)	P_D
9) Adversary runs from control room to storage room door, this pathway have 3 motion sensor (1st sensor detect at the beginning, 2nd sensor detect at the medium, and 3rd detect at the end), distance is 5.5 meter	1.38	-	1-(1-0.9)* (1-0.45) = 0.95
10) Adversary open the steel cage door with High Security Padlock of storage room by using power saw, in front of the door have 1 motion sensor	-	60.00	0.90
11) Adversary runs to the target, pathway have 2 motion sensors (detect at the medium) and distance is 16 meter	4.00	-	1-(1-0.45)* (1-0.45) = 0.70
12) Adversary sabotage or theft the sources	-	-	-

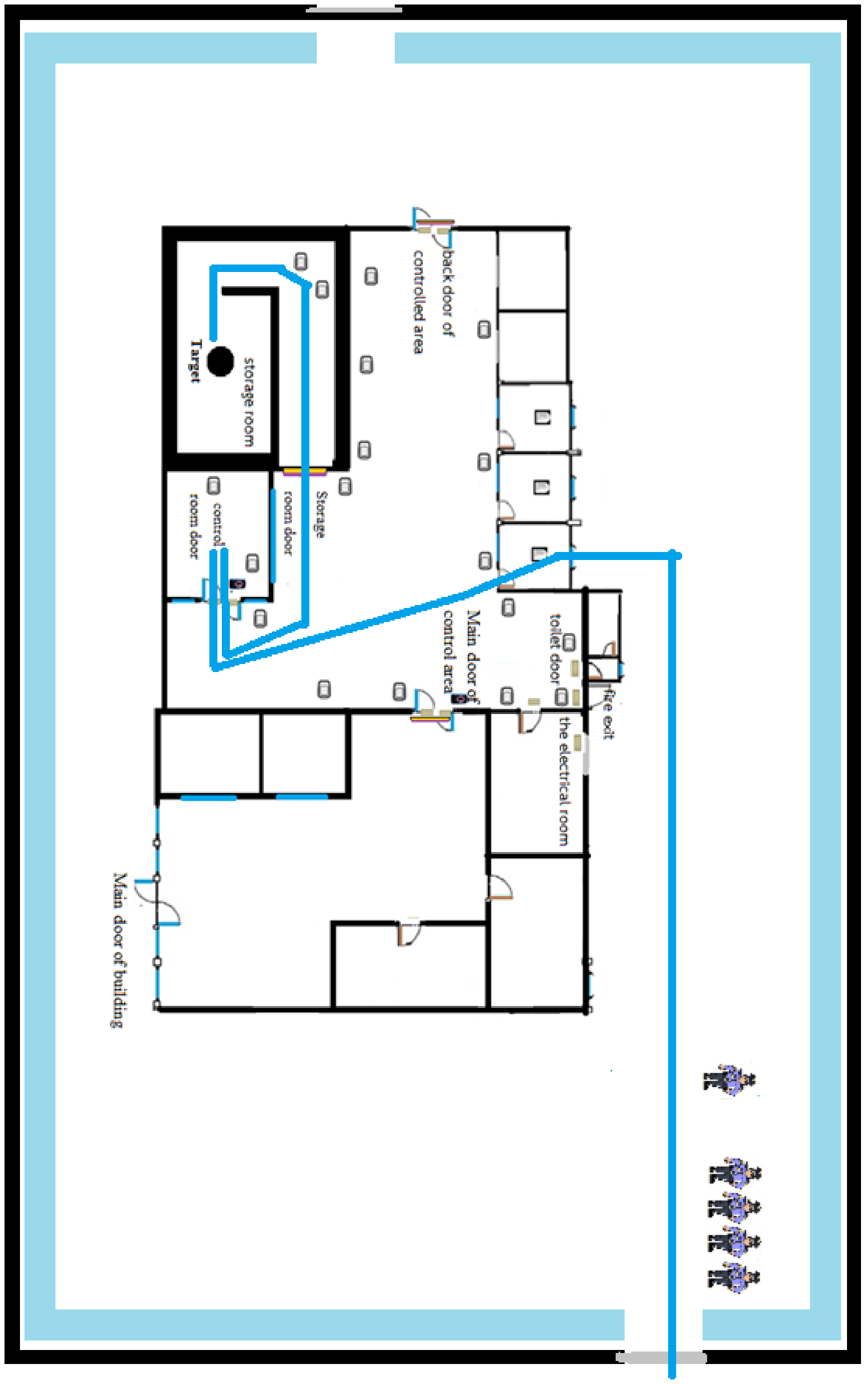

Figure 4.4 Diagram of adversary path ways in the category 1 gamma Irradiation Facility for the second scenario related to figure 4.2

In the third scenario, the pathway is shown in the green color in Figure 4.2. This scenario has been drawn as shown in Figure 4.5 and detail for each pathway shown in table 4.4.

Table 4.4 the detail of adversary travel time, penetrates time, and P_D for each pathway of adversary from offside to the target for the third scenario. (When R is Run, M is motorcycle, and T is truck)

Description	Adversary travel time (s)			Penetrates time for delay equipment (s)			P_D		
	R	M	T	R	M	T	R	M	T
1) Adversary penetrates the main gate of institute that had four guards at post and the gate is steel gate, 2.5 m high, with High Security Padlock, for adversary run they can used ladder to pass through this gate, for adversary take motorcycle they need to break High Security Padlock by Power saw to open the gate, and for adversary take truck, they can take the truck pass through the gate.	-	-	-	42	90	36	0.5	1	1
2) Adversary runs to the building by using different mode of transportation. This area is open area and had one guard at there, distance is 250 meter.	62.5	11.7	15	30	30	30	0.5	1	1

Table 4.4 the detail of adversary travel time, penetrates time, and P_D for each pathway of adversary from offside to the target for the third scenario. (When R is Run, M is motorcycle, and T is truck) (cont.)

Description	Adversary travel time (s)	Penetrates time for delay equipment (s)	P_D
3) Adversary passes through the back of the electrical room door, which is the one that rolls up by using Fire Ax, the door had BMS.	R	R	R
	-	132.00	0.80
4) Adversary runs to the wooden door, pathway have on sensor, distance is 4 meter.	1.00	-	0.00
5) Adversary penetrates the wooden door (5 cm thickness) by using Fire Ax	0.80	12.00	0.00
6) Adversary runs to the control room door, pathway have 4 motion sensors (1st sensor detect at the beginning, 2nd and 3rd sensor detect at the medium, and 4th detect at the end), distance is 6 meter	1.50	-	1-(1-0.9)*(1-0.45)*(1-0.45) = 0.97
7) Adversary break glass door 6 mm thickness of the control room, use no equipment, and MBS was install at this door	-	5.00	0.80
8) Open the storage room from the control room, in this room have 2 motion sensor (1st sensor detect at the beginning, and 2nd sensor detect at the medium), they need to take time around 3 minute to control the system and open the storage room	-	180.00	1-(1-0.9)*(1-0.45) = 0.95

Table 4.4 the detail of adversary travel time, penetrates time, and P_D for each pathway of adversary from offside to the target for the third scenario. (When R is Run, M is motorcycle, and T is truck) (cont.)

Description	Adversary travel time (s)	Penetrates time for delay equipment (s)	P_D
9) Adversary runs from control room to storage room door, this pathway have 3 motion sensor (1st sensor detect at the beginning, 2nd sensor detect at the medium, and 3rd detect at the end), distance is 5.5 meter	1.38	-	1-(1-0.9)*(1-0.45) = 0.95
10) Adversary open the steel cage door with High Security Padlock of storage room by using power saw, in front of the door have 1 motion sensor	-	60.00	0.90
11) Adversary runs to the target, pathway have 2 motion sensors (detect at the medium) and distance is 16 meter	4.00	-	1-(1-0.45)*(1-0.45) = 0.70
12) Adversary sabotage or theft the sources	-	-	-

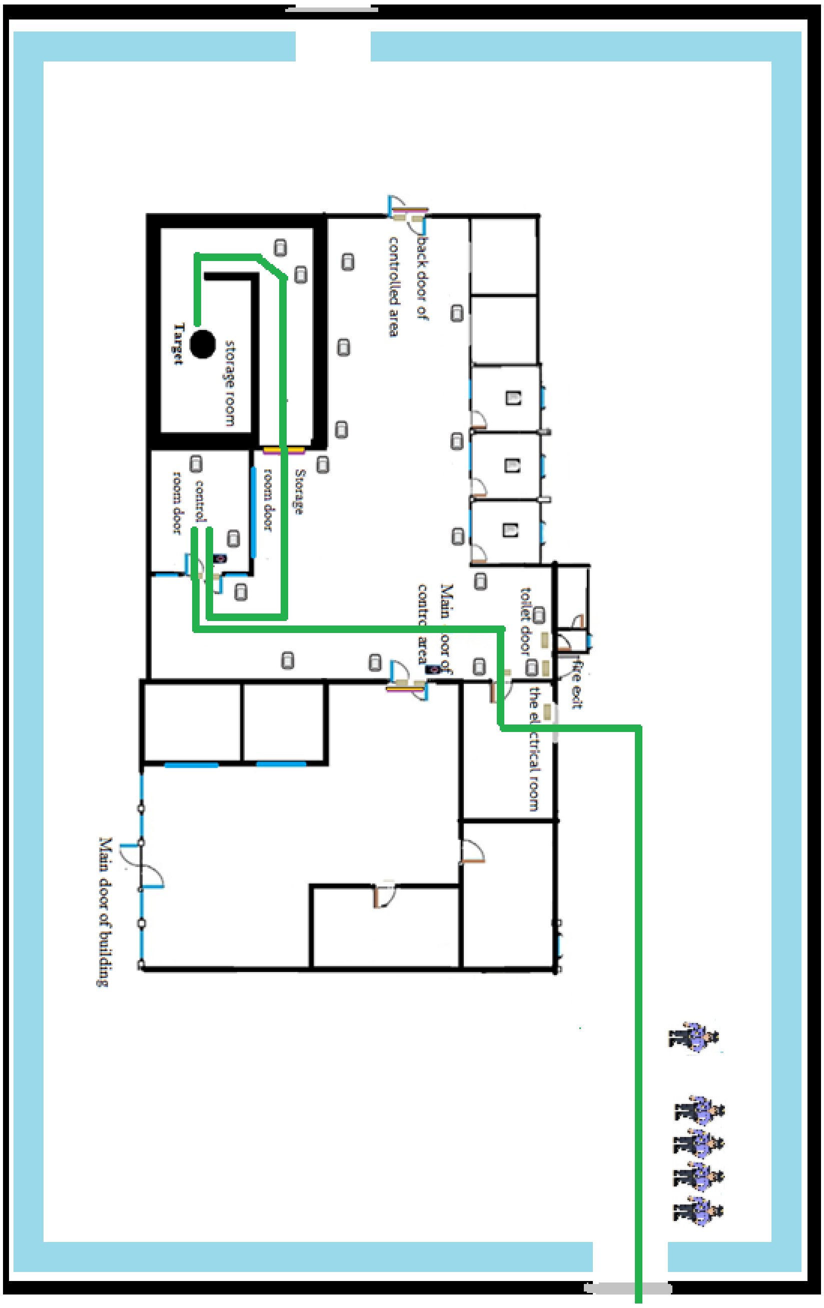

Figure 4.5 Diagram of adversary path ways in the Category 1 gamma Irradiation Facility for the third scenario related to figure 4.2

In the fourth scenario, the pathway is shown in the sky blue color in Figure 4.2. This scenario has been drawn as shown in Figure 4.6 and detail for each pathway shown in table 4.5.

Table 4.5 the detail of adversary travel time, penetrates time, and P_D for each pathway of adversary from offside to the target for the fourth scenario. (When R is Run, M is motorcycle, and T is truck)

Description	Adversary travel time (s)			Penetrates time for delay equipment (s)			P_D		
	R	M	T	R	M	T	R	M	T
1) Adversary penetrates the main gate of institute that had four guards at post and the gate is steel gate, 2.5 m high, with High Security Padlock, for adversary run they can used ladder to pass through this gate, for adversary take motorcycle they need to break High Security Padlock by Power saw to open the gate, and for adversary take truck, they can take the truck pass through the gate.	-	-	-	42	90	36	0.5	1	1
2) Adversary runs to the building by using different mode of transportation. This area is open area and had one guard at there, distance is 250 meter.	62.5	11.68	15	30	30	30	0.5	1	1
3) Adversary passes through the back door is which made of 6 mm thick glass by using pliers, the door had BMS.	R			R			R		
	-			125			0.8		

Table 4.5 the detail of adversary travel time, penetrates time, and P_D for each pathway of adversary from offside to the target for the fourth scenario. (When R is Run, M is motorcycle, and T is truck) (cont.)

Description	Adversary travel time (s)	Penetrates time for delay equipment (s)	P_D
4) Adversary runs to the control room door, pathway have 8 motion sensors (1st sensor detect at the beginning, 2nd-7th sensor detect at the medium, and 8th detect at the end), distance is 24 meter	6.00	-	1-(1-0.9)* (1-0.45)* (1-0.45)* (1-0.45)* (1-0.45)* (1-0.45)* (1-0.45) = 0.99
5) Adversary break glass door 6 mm thickness of the control room, use no equipment, and MBS was install at this door	-	5.00	0.80
6) Open the storage room from the control room, in this room have 2 motion sensor (1st sensor detect at the beginning, and 2nd sensor detect at the medium), they need to take time around 3 minute to control the system and open the storage room	-	180.00	1-(1-0.9)* (1-0.45) = 0.95

Table 4.5 the detail of adversary travel time, penetrates time, and P_D for each pathway of adversary from offside to the target for the fourth scenario. (When R is Run, M is motorcycle, and T is truck) (cont.)

Description	Adversary travel time (s)	Penetrates time for delay equipment (s)	P_D
7) Adversary runs from control room to storage room door, this pathway have 3 motion sensor (1st sensor detect at the beginning, 2nd sensor detect at the medium, and 3rd detect at the end), distance is 5.5 meter	1.38	-	1-(1-0.9)*(1-0.45) = 0.95
8) Adversary open the steel cage door with High Security Padlock of storage room by using power saw, in front of the door have 1 motion sensor	-	60.00	0.90
9) Adversary runs to the target, pathway have 2 motion sensors (detect at the medium) and distance is 16 meter	4.00	-	1-(1-0.45)*(1-0.45) = 0.70
10) Adversary sabotage or theft the sources	-	-	-

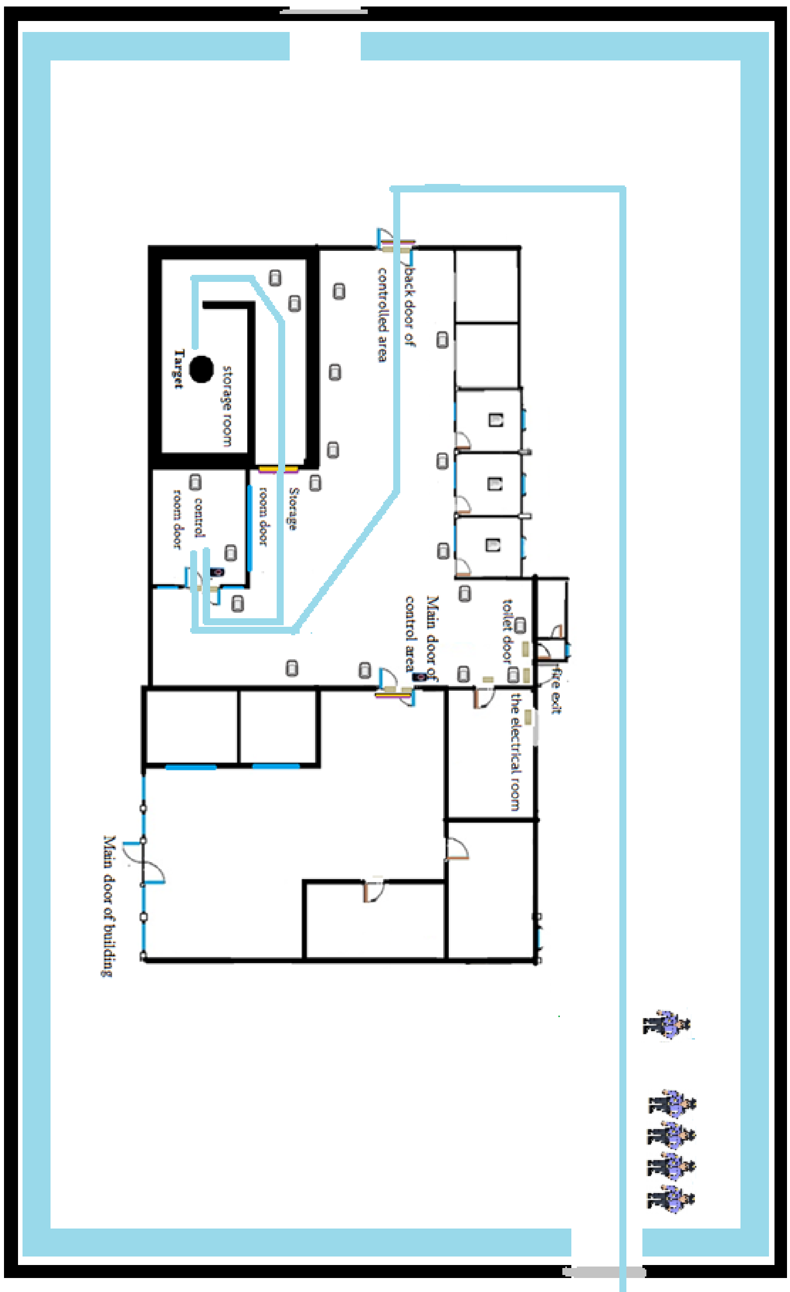

Figure 4.6 Diagram of adversary path ways in the category 1 gamma Irradiation Facility for the fourth scenario related to figure 4.2

In the fifth scenario, the pathway is shown in the orange color in Figure 4.2. This scenario has been drawn as shown in Figure 4.7 and detail for each pathway shown in table 4.6.

Table 4.6 the detail of adversary travel time, penetrates time, and P_D for each pathway of adversary from offside to the target for the fifth scenario. (When R is Run, M is motorcycle, and T is truck)

Description	Adversary travel time (s)			Penetrates time for delay equipment (s)			P_D		
	R	M	T	R	M	T	R	M	T
1) Adversary penetrates the main gate of institute that had four guards at post and the gate is steel gate, 2.5 m high, with High Security Padlock, for adversary run they can used ladder to pass through this gate, for adversary take motorcycle they need to break High Security Padlock by Power saw to open the gate, and for adversary take truck, they can take the truck pass through the gate.	-	-	-	42	90	36	0.5	1	1
2) Adversary runs to the building by using different mode of transportation. This area is open area and had one guard at there, distance is 250 meter.	62.5	11.7	15	30	30	30	0.5	1	1
3) Adversary passes through the fire exit door to go inside the controlled area by using Fire Ax, the door have BMS.	R			R			R		
	-			12.00			0.80		

Table 4.6 the detail of adversary travel time, penetrates time, and P_D for each pathway of adversary from offside to the target for the fifth scenario. (When R is Run, M is motorcycle, and T is truck) (cont.)

Description	Adversary travel time (s)	Penetrates time for delay equipment (s)	P_D
4) Adversary runs to the control room door, pathway have 7 motion sensors (1st-2nd sensor detect at the beginning, 3rd-6th sensor detect at the medium, and 7th detect at the end), distance is 8 meter	2.00	-	1-(1-0.9)* (1-0.9)* (1-0.45)* (1-0.45)* (1-0.45)* (1-0.45) = 0.99
5) Adversary break glass door 6 mm thickness of the control room, use no equipment and MBS was install at this door.	-	5.00	0.80
6) Open the storage room from the control room, in this room have 2 motion sensor (1st sensor detect at the beginning, and 2nd sensor detect at the medium), they need to take time around 3 minute to control the system and open the storage room	-	180.00	1-(1-0.9)* (1-0.45) = 0.95

Table 4.6 the detail of adversary travel time, penetrates time, and P_D for each pathway of adversary from offside to the target for the fifth scenario. (When R is Run, M is motorcycle, and T is truck) (cont.)

Description	Adversary travel time (s)	Penetrates time for delay equipment (s)	P_D
7) Adversary runs from control room to storage room door, this pathway have 3 motion sensor (1st sensor detect at the beginning, 2nd sensor detect at the medium, and 3rd detect at the end), distance is 5.5 meter	1.38	-	1-(1-0.9)* (1-0.45) = 0.95
8) Adversary open the steel cage door with High Security Padlock of storage room by using power saw, in front of the door have 1 motion sensor	-	60.00	0.90
9) Adversary runs to the target, pathway have 2 motion sensors (detect at the medium) and distance is 16 meter	4.00	-	1-(1-0.45)* (1-0.45) = 0.70
10) Adversary sabotage or theft the sources	-	-	-

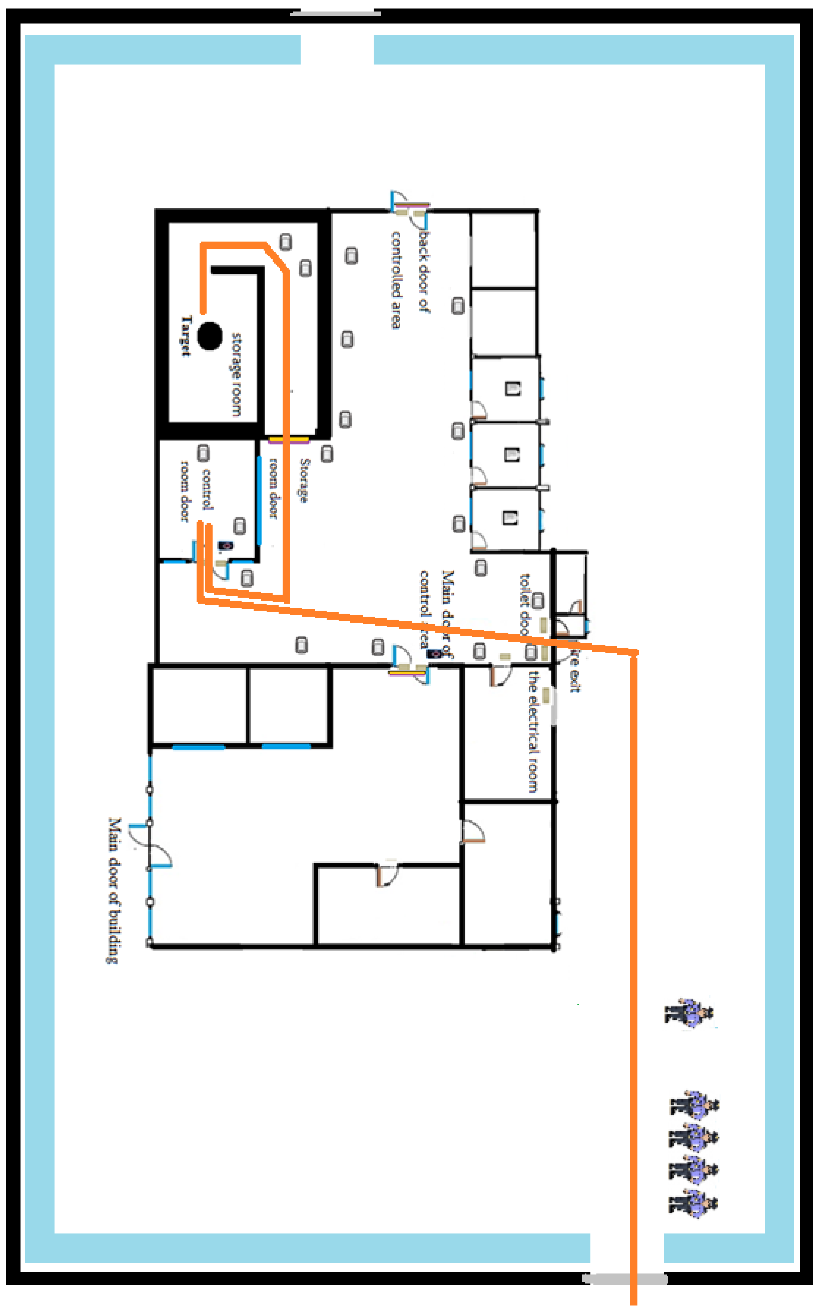

Figure 4.7 Diagram of adversary path ways in the category 1 gamma Irradiation Facility for the fifth scenario related to figure 4.2

In the sixth scenario, the pathway is shown in the purple color in Figure 4.2. This scenario has been drawn as shown in Figure 4.8 and detail for each pathway shown in table 4.7.

Table 4.7 the detail of adversary travel time, penetrates time, and P_D for each pathway of adversary from offside to the target for the sixth scenario. (When R is Run, M is motorcycle, and T is truck)

Description	Adversary travel time (s)			Penetrates time for delay equipment (s)			P_D		
	R	M	T	R	M	T	R	M	T
1) Adversary penetrates the main gate of institute that had four guards at post and the gate is steel gate, 2.5 m high, with High Security Padlock, for adversary run they can used ladder to pass through this gate, for adversary take motorcycle they need to break High Security Padlock by Power saw to open the gate, and for adversary take truck, they can take the truck pass through the gate.	-	-	-	42	90	36	0.5	1	1
2) Adversary runs to the building by using different mode of transportation. This area is open area and had one guard at there, distance is 250 meter.	62.5	11.7	15	30	30	30	0.5	1	1
3) Adversary passes through the 6 mm thick glass window in front of the toilet room with no equipment, this window has no sensor	R			R			R		
	-			5.00			0.00		

Table 4.7 the detail of adversary travel time, penetrates time, and P_D for each pathway of adversary from offside to the target for the sixth scenario. (When R is Run, M is motorcycle, and T is truck) (cont.)

Description	Adversary travel time (s)	Penetrates time for delay equipment (s)	P_D
4) Adversary runs to the wooden door, pathway have on sensor, distance is 4 meter.	1.00	-	0.00
5) Adversary break the 5 cm thick wooden door by using Fire Ax, BMS was installed at this door	-	12.00	0.80
6) Adversary runs to the control room door, pathway have 7 motion sensors (1st-2nd sensor detect at the beginning, 3rd-6th sensor detect at the medium, and 7th detect at the end), distance is 8 meter	2.00	-	$1-(1-0.9)*(1-0.9)*(1-0.45)^4 = 0.99$
7) Adversary break glass door 6 mm thickness of the control room, use no equipment, and MBS was install at this door	-	5.00	0.80
8) Open the storage room from the control room, in this room have 2 motion sensor (1st sensor detect at the beginning, and 2nd sensor detect at the medium), they need to take time around 3 minute to control the system and open the storage room door	-	180.00	$1-(1-0.9)*(1-0.45) = 0.95$

Table 4.7 the detail of adversary travel time, penetrates time, and P_D for each pathway of adversary from offside to the target for the sixth scenario. (When R is Run, M is motorcycle, and T is truck) (cont.)

Description	Adversary travel time (s)	Penetrates time for delay equipment (s)	P_D
9) Adversary runs from control room to storage room door, this pathway have 3 motion sensor(1^{st} sensor detect at the beginning, 2^{nd} sensor detect at the medium, and 3^{rd} detect at the end), distance is 5.5 meter	1.38	-	1-(1-0.9)* (1-0.45) = 0.95
10) Adversary open the steel cage door with High Security Padlock of storage room by using power saw, in front of the door have 1 motion sensor	-	60.00	0.90
11) Adversary runs to the target, pathway have 2 motion sensors (detect at the medium) and distance is 16 meter	4.00	-	1-(1-0.45)* (1-0.45) = 0.70
12) Adversary sabotage or theft the sources	-	-	-

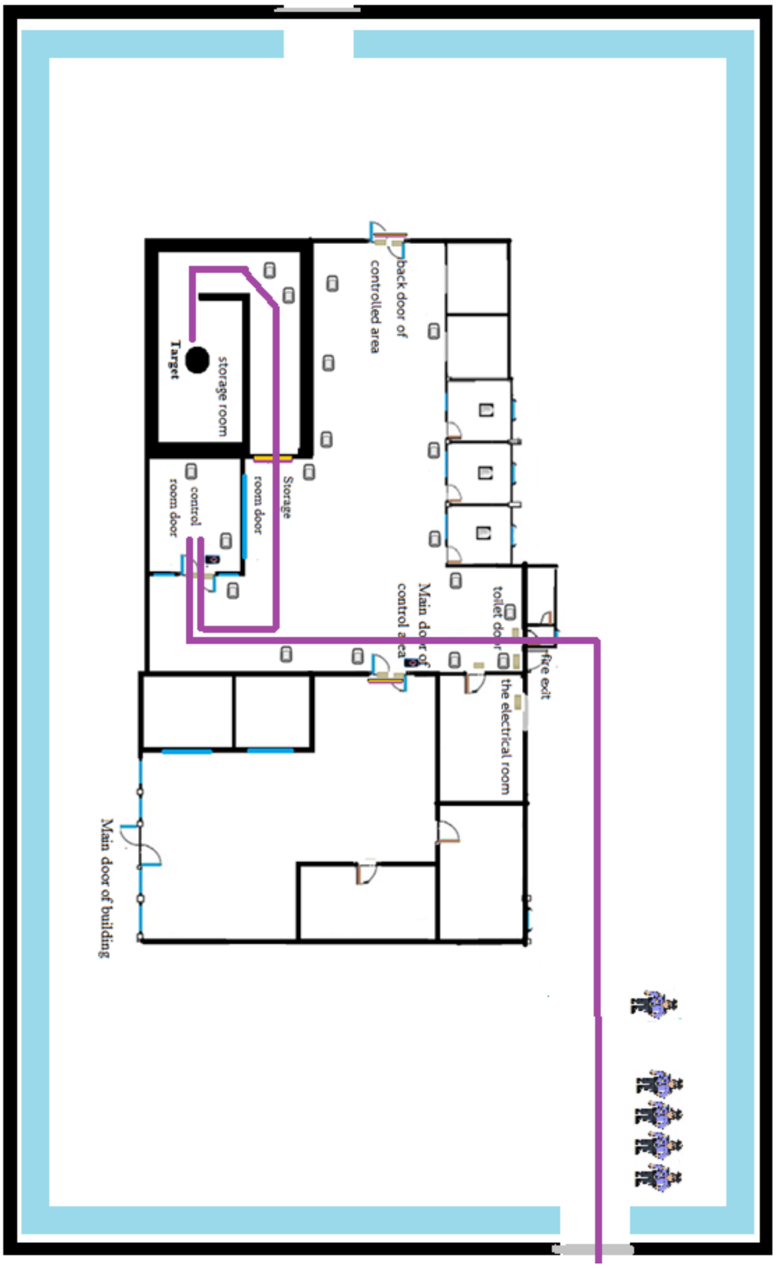

Figure 4.8 Diagram of adversary path ways in the category 1 gamma Irradiation Facility for the fifth scenario related to figure 4.2.

Using the pathway of adversary and detail for each scenarios and the Estimation of Adversary Sequence Interruption (EASI) model, potential scenarios can be evaluated against the existing PPS. These scenarios include sabotage and theft; using various modes of transportation (running, motorcycles and trucks). Detection, delay, response, and communication values of the security elements along the pathway are used to compute the probability of interruption P_I. The probability of detection or delay time for each event or component is derived from experiment performed by Sandia National Laboratories. The response force time of the police patrol in area is within 5 minute of receiving notification from the guard. The probability of guard communication is set to 0.95, the common value used. The standard deviations (SD) for the response force time and the adversary mean delay time are approximately 30% of the corresponding mean value [2]. In case of sabotage from diagram of the source in Figure 3.3, the exposure tube shield by 1.2 cm lead thickness, adversary use 3 kg explosives and, so adversary could be set explosion time of 30 second to break the exposure tube. The results for adversary running to sabotage the target using various modes of transportation (running, motorcycles and trucks) are shown in Tables 4.8 to 4.13 for running, Tables 4.14 to 4.19 for motorcycles, and Table 4.20 to 4.25 for trucks. In each of mode of transportation, there are six scenarios.

Table 4.8 results from EASI model Analysis of sabotage of category 1 gamma irradiation facility for running: the first scenario in pink line from figure 4.3

	Estimate of Adversary Sequence Interruption	Probability of Interruption: 0.91			
		Probability of Alarm Communication: 0.95		Response Force Time (in Seconds)	
				Mean: 300	Standard Deviation: 90
				Delays (in Seconds):	
Task	Description	P_D	Location	Mean:	Standard Deviation
1	Break main entrance	0.50	B	42.00	12.60
2	Run to the building	0.50	B	92.50	27.80
3	Break the doors of building	0.00	B	5.00	1.50

Table 4.2 results from EASI model Analysis of sabotage of category 1 gamma irradiation facility for running: the first scenario in pink line from figure 4.3 (cont.)

	Estimate of Adversary Sequence Interruption	Probability of Interruption: 0.91			
		Probability of Alarm Communication: 0.95		Response Force Time (in Seconds)	
				Mean: 300.00	Standard Deviation: 90.00
				Delays (in Seconds):	
Task	Description	P_D	Location	Mean:	Standard Deviation
4	Run to controlled area	0.00	B	3.00	0.90
5	Break the control area door	0.80	B	125.00	37.50
6	Run to the control room	0.95	B	2.00	0.60
7	Break the control room door	0.80	B	5.00	1.50
8	Open the storage room from the control room	0.95	B	180.00	54.00
9	Run to the storage room door	0.95	B	1.38	0.40
10	Open the steel cage door	0.90	B	60.00	18.00
11	Run to the target	0.70	B	4.00	1.20
12	Target	0.00	B	30.00	9.00

Table 4.9 results from EASI model Analysis of sabotage of category 1 gamma irradiation facility for running: the second scenario in blue line from figure 4.4

	Estimate of Adversary Sequence Interruption	Probability of Interruption: 0.76			
		Probability of Alarm Communication: 0.95		Response Force Time (in Seconds)	
				Mean: 300.00	Standard Deviation: 90.00
				Delays (in Seconds):	
Task	Description	P_D	Location	Mean:	Standard Deviation
1	Break main entrance	0.50	B	42.00	12.60
2	Run to the building	0.50	B	92.50	27.80
3	Break the glass windows	0.90	B	5.00	1.50
4	Run to the wooden doors	0.00	B	1.00	0.30
5	Break the wooden doors	0.00	B	12.00	3.60
6	Run to the control room	0.97	B	2.00	0.60
7	Break the l control room door	0.80	B	5.00	1.50
8	Open the storage room from the control room	0.95	B	180.00	54.00
9	Run to the storage room door	0.95	B	1.38	0.40
10	Open the steel cage door	0.90	B	60.00	18.00
11	Run to the target	0.70	B	4.00	1.20
12	Target	0.00	B	30.00	9.00

Table 4.10 results from EASI model Analysis of sabotage of category 1 gamma irradiation facility for running: the third scenario in green line from figure 4.5

	Estimate of Adversary Sequence Interruption	Probability of Interruption: 0.92			
		Probability of Alarm Communication: 0.95		Response Force Time (in Seconds)	
				Mean: 300.00	Standard Deviation: 90.00
				Delays (in Seconds):	
Task	Description	P_D	Location	Mean:	Standard Deviation
1	Break main entrance or fence	0.50	B	42.00	12.60
2	Run to the building	0.50	B	92.50	27.80
3	Break the electrical room door	0.80	B	132.00	39.60
4	Run to the wooden doors	0.00	B	1.00	0.30
5	Break the wooden doors	0.80	B	12.00	3.60
6	Run to the control room	0.97	B	1.50	0.50
7	Break the control room door	0.80	B	5.00	1.50
8	Open the storage room from the control room	0.95	B	180.00	54.00
9	Run to the storage room door	0.95	B	1.38	0.40
10	Open the steel cage door	0.90	B	60.00	18.00
11	Run to the target	0.70	B	4.00	1.20
12	Target	0.00	B	30.00	9.00

Table 4.11 results from EASI model Analysis of sabotage of category 1 gamma irradiation facility for running: the fourth scenario in sky blue line from figure 4.6

	Estimate of Adversary Sequence Interruption	Probability of Interruption: 0.87			
		Probability of Alarm Communication: 0.95		Response Force Time (in Seconds)	
				Mean: 300.00	Standard Deviation: 90.00
				Delays (in Seconds):	
Task	Description	P_D	Location	Mean:	Standard Deviation
1	Break main entrance	0.50	B	42.00	12.60
2	Run to the building	0.50	B	92.50	27.80
3	Break the back door of control area	0.80	B	125.00	37.50
4	Run to the control room	0.99	B	6.00	1.80
5	Break the control room door	0.80	B	5.00	1.50
6	Open the storage room from the control room	0.95	B	180.00	54.00
7	Run to the storage room door	0.95	B	1.38	0.40
8	Open the irradiation steel cage door	0.90	B	60.00	18.00
9	Run to the target	0.70	B	4.00	1.20
10	Target	0.00	B	30.00	9.00

Table 4.12 results from EASI model Analysis of sabotage of category 1 gamma irradiation facility for running: the fifth scenario in orange line from figure 4.7

	Estimate of Adversary Sequence Interruption	Probability of Interruption: 0.74			
		Probability of Alarm Communication: 0.95		Response Force Time (in Seconds)	
				Mean: 300.00	Standard Deviation: 90.00
				Delays (in Seconds):	
Task	Description	P_D	Location	Mean:	Standard Deviation
1	Break main entrance	0.50	B	42.00	12.60
2	Run to the building	0.50	B	92.50	27.80
3	Break firer exit	0.80	B	12.00	3.60
4	Run to the control room	0.99	B	2.00	0.60
5	Break the control room door	0.80	B	5.00	1.50
6	Open the storage room from the control room	0.95	B	180.00	54.00
7	Run to the storage room door	0.95	B	1.38	0.40
8	Open the irradiation steel cage door	0.90	B	60.00	18.00
9	Run to the target	0.70	B	4.00	1.20
10	Target	0.00	B	30.00	9.00

Table 4.13 results from EASI model Analysis of sabotage of category 1 gamma irradiation facility for running: the sixth scenario in purple line from figure 4.8

	Estimate of Adversary Sequence Interruption	Probability of Interruption: 0.75			
		Probability of Alarm Communication: 0.95		Response Force Time (in Seconds)	
				Mean: 300.00	Standard Deviation: 90.00
				Delays (in Seconds):	
Task	Description	P_D	Location	Mean:	Standard Deviation
1	Break main entrance	0.50	B	42.00	12.60
2	Run to the building	0.50	B	92.50	27.80
3	Break the glass windows in front of toilet of control room	0.00	B	5.00	1.50
4	Run to the wooden doors	0.00	B	1.00	0.30
5	Break the wooden doors	0.80	B	12.00	3.60
6	Run to the control room	0.99	B	2.00	0.60
7	Break the control room door	0.80	B	5.00	1.50
8	Open the storage room from the control room	0.95	B	180.00	54.00
9	Run to the storage room door	0.95	B	1.38	0.40
10	Open the irradiation steel cage door	0.90	B	60.00	18.00
11	Run to the target	0.70	B	4.00	1.20
12	Target	0.00	B	30.00	9.00

Table 4.14 results from EASI model Analysis of sabotage of category 1 gamma irradiation facility for motorcycle: the first scenario in pink line from figure 4.3

	Estimate of Adversary Sequence Interruption	Probability of Interruption: 0.98			
		Probability of Alarm Communication: 0.95		Response Force Time (in Seconds)	
				Mean: 300.00	Standard Deviation: 90.00
				Delays (in Seconds):	
Task	Description	P_D	Location	Mean:	Standard Deviation
1	Break main entrance	1.00	B	90.00	27.00
2	Run to the building	1.00	B	41.70	12.50
3	Break the doors of building	0.00	B	5.00	1.50
4	Run to controlled area	0.00	B	4.00	0.90
5	Break the control area door	0.80	B	125.00	37.50
6	Run to the control room	0.95	B	2.00	0.60
7	Break the control room door	0.80	B	5.00	1.50
8	Open the storage room from the control room	0.95	B	180.00	54.00
9	Run to the storage room door	0.95	B	1.38	0.40
10	Open the steel cage door	0.90	B	60.00	18.00
11	Run to the target	0.70	B	4.00	1.20
12	Target	0.00	B	30.00	9.00

Table 4.15 results from EASI model Analysis of sabotage of category 1 gamma irradiation facility for motorcycle: the second scenario in blue line from figure 4.4

	Estimate of Adversary Sequence Interruption	Probability of Interruption: 0.87			
		Probability of Alarm Communication: 0.95		Response Force Time (in Seconds)	
				Mean: 300.00	Standard Deviation: 90.00
				Delays (in Seconds):	
Task	Description	P_D	Location	Mean:	Standard Deviation
1	Break main entrance	1.00	B	90.00	27.00
2	Run to the building	1.00	B	41.70	12.50
3	Break the glass windows	0.90	B	5.00	1.50
4	Run to the wooden doors	0.00	B	1.00	0.30
5	Break the wooden doors	0.00	B	12.00	3.60
6	Run to the control room	0.97	B	2.00	0.60
7	Break the control room door	0.80	B	5.00	1.50
8	Open the storage room from the control room	0.95	B	180.00	54.00
9	Run to the storage room door	0.95	B	1.38	0.40
10	Open the steel cage door	0.90	B	60.00	18.00
11	Run to the target	0.70	B	4.00	1.20
12	Target	0.00	B	30.00	9.00

Table 4.16 results from EASI model Analysis of sabotage of category 1 gamma irradiation facility for motorcycle: the third scenario in green line from figure 4.5

	Estimate of Adversary Sequence Interruption	Probability of Interruption: 0.98			
		Probability of Alarm Communication: 0.95		Response Force Time (in Seconds)	
				Mean: 300.00	Standard Deviation: 90.00
				Delays (in Seconds):	
Task	Description	P_D	Location	Mean:	Standard Deviation
1	Break main entrance or fence	1.00	B	90.00	27.00
2	Run to the building	1.00	B	41.70	12.50
3	Break the electrical room door	0.80	B	132.00	39.60
4	Run to the wooden doors	0.00	B	1.00	0.30
5	Break the wooden doors	0.80	B	12.00	3.60
6	Run to the control room	0.97	B	1.50	0.50
7	Break the control room door	0.80	B	5.00	1.50
8	Open the storage room from the control room	0.95	B	180.00	54.00
9	Run to the storage room door	0.95	B	1.38	0.40
10	Open the steel cage door	0.90	B	60.00	18.00
11	Run to the target	0.70	B	4.00	1.20
12	Target	0.00	B	30.00	9.00

Table 4.17 results from EASI model Analysis of sabotage of category 1 gamma irradiation facility for motorcycle: the fourth scenario in sky blue line from figure 4.6

	Estimate of Adversary Sequence Interruption	Probability of Interruption: 0.98			
		Probability of Alarm Communication: 0.95		Response Force Time (in Seconds)	
				Mean: 300.00	Standard Deviation: 90.00
				Delays (in Seconds):	
Task	Description	P_D	Location	Mean:	Standard Deviation
1	Break main entrance	1.00	B	90.00	27.00
2	Run to the building	1.00	B	41.70	12.50
3	Break the back door of control area	0.80	B	125.00	37.50
4	Run to the control room	0.99	B	6.00	1.80
5	Break the control room door	0.80	B	5.00	1.50
6	Open the storage room from the control room	0.95	B	180.00	54.00
7	Run to the storage room door	0.95	B	1.38	0.40
8	Open the irradiation steel cage door	0.90	B	60.00	18.00
9	Run to the target	0.70	B	4.00	1.20
10	Target	0.00	B	30.00	9.00

Table 4.18 results from EASI model Analysis of sabotage of category 1 gamma irradiation facility for motorcycle: the fifth scenario in orange line from figure 4.7

	Estimate of Adversary Sequence Interruption	Probability of Interruption: 0.86			
		Probability of Alarm Communication: 0.95		Response Force Time (in Seconds)	
				Mean: 300.00	Standard Deviation: 90.00
				Delays (in Seconds):	
Task	Description	P_D	Location	Mean:	Standard Deviation
1	Break main entrance	1.00	B	90.00	27.00
2	Run to the building	1.00	B	41.70	12.50
3	Break firer exit	0.80	B	12.00	3.60
4	Run to the control room	0.99	B	2.00	0.60
5	Break the control room door	0.80	B	5.00	1.50
6	Open the storage room from the control room	0.95	B	180.00	54.00
7	Run to the storage room door	0.95	B	1.38	0.40
8	Open the irradiation steel cage door	0.90	B	60.00	18.00
9	Run to the target	0.70	B	4.00	1.20
10	Target	0.00	B	30.00	9.00

Table 4.19 results from EASI model Analysis of sabotage of category 1 gamma irradiation facility for motorcycle: the sixth scenario in purple line from figure 4.8

	Estimate of Adversary Sequence Interruption	Probability of Interruption: 0.88			
		Probability of Alarm Communication: 0.95		Response Force Time (in Seconds)	
				Mean: 300	Standard Deviation: 90
				Delays (in Seconds):	
Task	Description	P_D	Location	Mean:	Standard Deviation
1	Break main entrance	1.00	B	90.00	27.00
2	Run to the building	1.00	B	41.70	12.50
3	Break the glass windows in front of toilet of control room	0.00	B	5.00	1.50
4	Run to the wooden doors	0.00	B	1.00	0.30
5	Break the wooden doors	0.80	B	12.00	3.60
6	Run to the control room	0.99	B	8.00	2.40
7	Break the control room door	0.80	B	5.00	1.50
8	Open the storage room from the control room	0.95	B	180.00	54.00
9	Run to the storage room door	0.95	B	1.38	0.40
10	Open the irradiation steel cage door	0.90	B	60.00	18.00
11	Run to the target	0.70	B	4.00	1.20
12	Target	0.00	B	30.00	9.00

Table 4.20 results from EASI model Analysis of sabotage of category 1 gamma irradiation facility for trucks: the first scenario in pink line from ASD figure 4.3

	Estimate of Adversary Sequence Interruption	Probability of Interruption: 0.95			
		Probability of Alarm Communication: 0.95		Response Force Time (in Seconds)	
				Mean: 300.00	Standard Deviation: 90.00
				Delays (in Seconds):	
Task	Description	P_D	Location	Mean:	Standard Deviation
1	Break main entrance	1.00	B	36.00	10.80
2	Run to the building	1.00	B	45.00	13.50
3	Break the doors of building	0.00	B	5.00	1.50
4	Run to controlled area	0.00	B	3.00	0.90
5	Break the control area door	0.80	B	125.00	37.50
6	Run to the control room	0.95	B	2.00	0.60
7	Break the control room door	0.80	B	5.00	1.50
8	Open the storage room from the control room	0.95	B	180.00	54.00
9	Run to the storage room door	0.95	B	1.38	0.40
10	Open the steel cage door	0.90	B	60.00	18.00
11	Run to the target	0.70	B	4.00	1.20
12	Target	0.00	B	30.00	9.00

Table 4.21 results from EASI model Analysis of sabotage of category 1 gamma irradiation facility for trucks: the second scenario in blue line from figure 4.4

	Estimate of Adversary Sequence Interruption	Probability of Interruption: 0.77			
		Probability of Alarm Communication: 0.95		Response Force Time (in Seconds)	
				Mean: 300.00	Standard Deviation: 90.00
				Delays (in Seconds):	
Task	Description	P_D	Location	Mean:	Standard Deviation
1	Break main entrance	1.00	B	36.00	10.80
2	Run to the building	1.00	B	45.00	13.50
3	Break the glass windows	0.90	B	5.00	1.50
4	Run to the wooden doors	0.00	B	1.00	0.30
5	Break the wooden doors	0.00	B	12.00	3.60
6	Run to the control room	0.97	B	2.00	0.60
7	Break the control room door	0.80	B	5.00	1.50
8	Open the storage room from the control room	0.95	B	180.00	54.00
9	Run to the storage room door	0.95	B	1.38	0.40
10	Open the steel cage door	0.90	B	60.00	18.00
11	Run to the target	0.70	B	4.00	1.20
12	Target	0.00	B	30.00	9.00

Table 4.22 results from EASI model Analysis of sabotage of category 1 gamma irradiation facility for trucks: the third scenario in green line from figure 4.5

<table>
<tr><td></td><td rowspan="4">Estimate of Adversary Sequence Interruption</td><td colspan="4">Probability of Interruption: 0.96</td></tr>
<tr><td></td><td colspan="2" rowspan="3">Probability of Alarm Communication: 0.95</td><td colspan="2">Response Force Time (in Seconds)</td></tr>
<tr><td></td><td>Mean: 300.00</td><td>Standard Deviation: 90.00</td></tr>
<tr><td></td><td colspan="2">Delays (in Seconds):</td></tr>
<tr><td>Task</td><td>Description</td><td>P_D</td><td>Location</td><td>Mean:</td><td>Standard Deviation</td></tr>
<tr><td>1</td><td>Break main entrance or fence</td><td>1.00</td><td>B</td><td>36.00</td><td>10.80</td></tr>
<tr><td>2</td><td>Run to the building</td><td>1.00</td><td>B</td><td>45.00</td><td>13.50</td></tr>
<tr><td>3</td><td>Break the electrical room door</td><td>0.80</td><td>B</td><td>132.00</td><td>39.60</td></tr>
<tr><td>4</td><td>Run to the wooden doors</td><td>0.00</td><td>B</td><td>1.00</td><td>0.30</td></tr>
<tr><td>5</td><td>Break the wooden doors</td><td>0.80</td><td>B</td><td>12.00</td><td>3.60</td></tr>
<tr><td>6</td><td>Run to the control room</td><td>0.97</td><td>B</td><td>1.50</td><td>0.50</td></tr>
<tr><td>7</td><td>Break the control room door</td><td>0.80</td><td>B</td><td>5.00</td><td>1.50</td></tr>
<tr><td>8</td><td>Open the storage room from the control room</td><td>0.95</td><td>B</td><td>180.00</td><td>54.00</td></tr>
<tr><td>9</td><td>Run to the storage room door</td><td>0.95</td><td>B</td><td>1.38</td><td>0.40</td></tr>
<tr><td>10</td><td>Open the steel cage door</td><td>0.90</td><td>B</td><td>60.00</td><td>18.00</td></tr>
<tr><td>11</td><td>Run to the target</td><td>0.70</td><td>B</td><td>4.00</td><td>1.20</td></tr>
<tr><td>12</td><td>Target</td><td>0.00</td><td>B</td><td>30.00</td><td>9.00</td></tr>
</table>

Table 4.23 results from EASI model Analysis of sabotage of category 1 gamma irradiation facility for trucks: the fourth scenario in sky blue line from figure 4.6

	Estimate of Adversary Sequence Interruption	Probability of Interruption: 0.95			
		Probability of Alarm Communication: 0.95		Response Force Time (in Seconds)	
				Mean: 300.00	Standard Deviation: 90.00
				Delays (in Seconds):	
Task	Description	P_D	Location	Mean:	Standard Deviation
1	Break main entrance	1.00	B	36.00	10.80
2	Run to the building	1.00	B	45.00	13.50
3	Break the back door of control area	0.80	B	125.00	37.50
4	Run to the control room	0.99	B	6.00	1.80
5	Break the control room door	0.80	B	5.00	1.50
6	Open the storage room from the control room	0.95	B	180.00	54.00
7	Run to the storage room door	0.95	B	1.38	0.40
8	Open the irradiation steel cage door	0.90	B	60.00	18.00
9	Run to the target	0.70	B	4.00	1.20
10	Target	0.00	B	30.00	9.00

Table 4.24 results from EASI model Analysis of sabotage of category 1 gamma irradiation facility for trucks: the fifth scenario in orange line from figure 4.7

	Estimate of Adversary Sequence Interruption	Probability of Interruption: 0.75			
		Probability of Alarm Communication: 0.95		Response Force Time (in Seconds)	
				Mean: 300.00	Standard Deviation: 90.00
				Delays (in Seconds):	
Task	Description	P_D	Location	Mean:	Standard Deviation
1	Break main entrance	1.00	B	36.00	10.80
2	Run to the building	1.00	B	45.00	13.50
3	Break firer exit	0.80	B	12.00	3.60
4	Run to the control room	0.99	B	2.00	0.60
5	Break the control room door	0.80	B	5.00	1.50
6	Open the storage room from the control room	0.95	B	180.00	54.00
7	Run to the storage room door	0.95	B	1.38	0.40
8	Open the irradiation steel cage door	0.90	B	60.00	18.00
9	Run to the target	0.70	B	4.00	1.20
10	Target	0.00	B	30.00	9.00

Table 4.25 results from EASI model Analysis of sabotage of category 1 gamma irradiation facility for trucks: the sixth scenario in purple line from figure 4.8

	Estimate of Adversary Sequence Interruption	Probability of Interruption: 0.77			
		Probability of Alarm Communication: 0.95		Response Force Time (in Seconds)	
				Mean: 300.00	Standard Deviation: 90.00
				Delays (in Seconds):	
Task	Description	P_D	Location	Mean:	Standard Deviation
1	Break main entrance	1.00	B	36.00	10.80
2	Run to the building	1.00	B	45.00	13.50
3	Break the glass windows in front of toilet of control room	0.00	B	5.00	1.50
4	Run to the wooden doors	0.00	B	1.00	0.30
5	Break the wooden doors	0.80	B	12.00	3.60
6	Run to the control room	0.99	B	2.00	0.60
7	Break the control room door	0.80	B	5.00	1.50
8	Open the storage room	0.95	B	180.00	54.00
9	Run to the storage room door	0.95	B	1.38	0.40
10	Open the irradiation steel cage door	0.90	B	60.00	18.00
11	Run to the target	0.60	B	4.00	1.20
12	Target	0.00	B	30.00	9.00

Table 4.26 P_I from EASI model using various modes of transportation, the security system range for running of 0.74 to 0.92, range for using motorcycle to be vehicle is 0.86 to 0.98 and range of 0.75 to 0.96 for using truck to be vehicle.

Scenarios	Color	Probability of Interruption (P_I)		
		Running	Motorcycle	Truck
1		0.91	0.98	0.95
2		0.76	0.87	0.77
3		0.92	0.98	0.96
4		0.87	0.98	0.95
5		0.74	0.86	0.75
6		0.75	0.88	0.77

In Table 4.26, the security system can handle most scenarios, and better when the adversary travels by motorcycle than by truck. When the adversary runs, however, the EASI results are the smallest for all scenarios since the P_D of the guard is reduced to 0.5; in case of motorcycle and truck, the P_D equals to 1.

The P_I's are separated in three ranges. The first range is from 0.5 to 0.75 (red color), which is a medium range, and is too low and unacceptable. Something should be done to improve the PPS in this range. The second range is from 0.76 to 0.89 (yellow color), which is not high, but may be acceptable and easier to improve the security than the previous range. The third range is above 0.9 (white color), which is acceptable and means that the PPS has high security [8, 10].

In case of the adversary running, the results show that the P_I's are in range between 0.74-0.92 as shown in Table 4.26. In the fifth and sixth scenarios, the security systems P_I are in the 0.50-0.75 range. In the second and fourth scenario, the security systems P_I are between 0.76 and 0.89. For the first and third scenario, the security system P_I is high, above 9.0. The fifth scenario has small P_I because the adversary spends shorter time than other cases passing through the fire exit door to directly go inside the controlled area. The sixth scenario has small P_I because of the adversary can pass through the 6 mm thick glass window in front of the toilet and run to the wooden door in the controlled area using small amount of time, and the window and pathway have no sensor to detect the adversary.

In case of the adversary using motorcycle, the results from table 4.26 show that the P_I's are in the range of 0.86 to 0.98. All scenarios show P_I above medium range (0.5-0.57) because when the adversary uses motorcycle, the P_D of the guard is 1. To pass through the main gate, the adversary needs to take time to break the High Security Padlock to open the gate to go inside the institute. Thus, the value of P_I becomes high. However, the second, fifth, and sixth scenarios still have P_I under 0.9, The P_I's of these scenarios are not quite high. Thus, the PPS should be further improving.

In case of the adversary using truck, the results from Table 4.26 show that the P_I's are in the range of 0.75 to 0.96. In the fifth scenario, the security systems P_I is 0.75. In the second and sixth scenarios, the security systems P_I are between 0.76 and 0.89. For the first, third, and fourth scenarios, the security system P_I's are high, above 9.0. The fifth scenario has small P_I because when the adversary uses truck, the delay time is reduced; and from outside facility, the adversary can pass through the fire exit door to directly go inside the controlled area. This requires less time than other cases, and makes the P_I small.

In case of sabotage of the Category 1 gamma sources facility, there are several scenarios that have P_I's in the range of 0.5 to 0.75. These values are considered too low and unacceptable. So something should be done to improve the PPS.

If the adversary's goal is to steal the source from the facility, it would need at least additional 30 minutes to get the source because the source has safety and security system by-design in itself. That is, the Category 1 source has high activity, and needs to have shielding to transport it out. The shielding is usually made of high density and heavy material such as a 140 cm diameter lead as shown in Figure 3.3. The adversary will also need to have a truck to transport the source from the facility. In case that the adversary uses truck, the security system P_I's in all scenarios are equal to 1.00. Thus, the adversary will definitely be interrupted in its path before completing its objective. The results are shown in Tables 4.27 to 4.32

Table 4.27 results from EASI model Analysis of theft of category 1 gamma source in facility for trucks: the first scenario in pink line from figure 4.3.

	Estimate of Adversary Sequence Interruption	Probability of Interruption: 1			
		Probability of Alarm Communication: 0.95		Response Force Time (in Seconds)	
				Mean: 300.00	Standard Deviation: 90.00
				Delays (in Seconds):	
Task	Description	P_D	Location	Mean	Standard Deviation
1	Break main entrance	1.00	B	36.00	10.8
2	Run to the building	1.00	B	45.00	13.5
3	Break the doors of building	0.00	B	5.00	1.5
4	Run to controlled area	0.00	B	3.00	0.9
5	Break the control area door	0.80	B	125.00	37.5
6	Run to the control room	0.95	B	2.00	0.6
7	Break the control room door	0.80	B	5.00	1.5
8	Open the storage room	0.95	B	180.00	54.0
9	Run to the storage room door	0.95	B	1.38	0.4
10	Open the steel cage door	0.90	B	60.00	18.0
11	Run to the target	0.70	B	4.00	1.2
12	Target	0.00	B	1800.00	540

Table 4.28 results from EASI model Analysis of theft of category 1 gamma source in facility for trucks: the second scenario in blue line from figure 4.4

	Estimate of Adversary Sequence Interruption	Probability of Interruption: 1			
		Probability of Alarm Communication: 0.95		Response Force Time (in Seconds)	
				Mean: 300	Standard Deviation: 90
				Delays (in Seconds):	
Task	Description	P_D	Location	Mean:	Standard Deviation
1	Break main entrance	1.00	B	36.00	10.80
2	Run to the building	1.00	B	45.00	13.50
3	Break the glass windows	0.90	B	5.00	1.50
4	Run to the wooden doors	0.00	B	1.00	0.30
5	Break the wooden doors	0.00	B	12.00	3.60
6	Run to the control room	0.97	B	2.00	0.60
7	Break the control room door	0.80	B	5.00	1.50
8	Open the storage room from the control room	0.95	B	180.00	54.00
9	Run to the storage room door	0.95	B	1.38	0.40
10	Open the steel cage door	0.90	B	60.00	18.00
11	Run to the target	0.70	B	4.00	1.20
12	Target	0.00	B	1800.00	540.00

Table 4.29 results from EASI model Analysis of theft of category 1 gamma source in facility for trucks: the third scenario in green line from figure 4.5

	Estimate of Adversary Sequence Interruption	Probability of Interruption: 1			
		Probability of Alarm Communication: 0.95		Response Force Time (in Seconds)	
				Mean: 300.00	Standard Deviation: 90.00
				Delays (in Seconds):	
Task	Description	P_D	Location	Mean:	Standard Deviation
1	Break main entrance or fence	1.00	B	36.00	10.80
2	Run to the building	1.00	B	45.00	13.50
3	Break the electrical room door	0.80	B	132.00	39.60
4	Run to the wooden doors	0.00	B	1.00	0.30
5	Break the wooden doors	0.80	B	12.00	3.60
6	Run to the control room	0.97	B	1.50	0.50
7	Break the control room door	0.80	B	5.00	1.50
8	Open the storage room from the control room	0.95	B	180.00	54.00
9	Run to the storage room door	0.95	B	1.38	0.40
10	Open the steel cage door	0.90	B	60.00	18.00
11	Run to the target	0.70	B	4.00	1.20
12	Target	0.00	B	1800.00	540.00

Table 4.30 results from EASI model Analysis of theft of category 1 gamma source in facility for trucks: the fourth scenario in sky blue line from figure 4.6

	Estimate of Adversary Sequence Interruption	Probability of Interruption: 1			
		Probability of Alarm Communication: 0.95		Response Force Time (in Seconds)	
				Mean: 300.00	Standard Deviation: 90.00
				Delays (in Seconds):	
Task	Description	P_D	Location	Mean:	Standard Deviation
1	Break main entrance	1.00	B	36.00	10.80
2	Run to the building	1.00	B	45.00	13.50
3	Break the back door of control area	0.80	B	125.00	37.50
4	Run to the control room	0.99	B	6.00	1.80
5	Break the control room door	0.80	B	5.00	1.50
6	Open the storage room from the control room	0.95	B	180.00	54.00
7	Run to the storage room door	0.95	B	1.30	0.40
8	Open the irradiation steel cage door	0.90	B	60.00	180
9	Run to the target	0.70	B	4.00	1.20
10	Target	0.00	B	1800.00	540.00

Table 4.31 results from EASI model Analysis of theft of category 1 gamma source in facility for trucks: the fifth scenario in orange line from figure 4.7

Task	Description	P_D	Location	Mean:	Standard Deviation
	Estimate of Adversary Sequence Interruption	Probability of Interruption: 1			
		Probability of Alarm Communication: 0.95		Response Force Time (in Seconds)	
				Mean: 300.00	Standard Deviation: 90.00
				Delays (in Seconds):	
1	Break main entrance	1.00	B	36.00	10.80
2	Run to the building	1.00	B	45.00	13.50
3	Break firer exit	0.80	B	12.00	3.60
4	Run to the control room	0.99	B	2.00	0.60
5	Break the control room door	0.80	B	5.00	1.50
6	Open the storage room from the control room	0.95	B	180.00	54.00
7	Run to the storage room door	0.95	B	1.38	0.40
8	Open the irradiation steel cage door	0.90	B	60.00	18.00
9	Run to the target	0.70	B	4.00	1.20
10	Target	0.00	B	1800.00	540.00

Table 4.32 results from EASI model Analysis of theft of category 1 gamma source in facility for trucks: the sixth scenario in purple line from figure 4.8

	Estimate of Adversary Sequence Interruption	Probability of Interruption: 1			
		Probability of Alarm Communication: 0.95		Response Force Time (in Seconds)	
				Mean: 300.00	Standard Deviation: 90.00
				Delays (in Seconds):	
Task	Description	P_D	Location	Mean:	Standard Deviation
1	Break main entrance	1.00	B	36.00	10.80
2	Run to the building	1.00	B	45.00	13.50
3	Break the glass windows in front of toilet of control room	0.00	B	5.00	1.50
4	Run to the wooden doors	0.00	B	1.00	0.30
5	Break the wooden doors	0.80	B	12.00	3.60
6	Run to the control room	0.99	B	2.00	0.60
7	Break the control room door	0.80	B	5.00	1.50
8	Open the storage room	0.95	B	180.00	54.00
9	Run to the storage room door	0.95	B	1.38	0.40
10	Open the irradiation steel cage door	0.90	B	60.00	18.00
11	Run to the target	0.70	B	4.00	1.20
12	Target	0.00	B	1800.00	540.00

4.2 Design additional PPS

The results based on the calculation using the EASI model show that the existing security system still cannot perform well in several scenarios as shown in Table 4.26. To improve, the following changes are suggested.

1. Move one guard from the main entrance of institute to the facility. This process has no additional cost, and the P_D will increase to 0.5 for the adversary running, and to 1 for the adversary using motorcycle and truck, and the delay time will increase to 30 seconds. The P_I's of all scenarios increase, as shown in Table 4.33, to above the medium range. These values are acceptable. In case of the adversary using motorcycle, the P_I's for all scenarios are above 0.9, which is considered high and acceptable. However, in case of the adversary running and using truck in several scenarios, the P_I's are in the range of 0.76 to 0.89. These values are not high, but can be acceptable. However, the PPS should still be improved to have higher value of P_I.

Table 4.33 Sum of P_I from EASI model using various modes of transportation, after improving PPS system by moving one guard from the main entrance of institute to the facility

Scenarios	Color	Probability of Interruption (P_i)		
		Running	Motorcycle	Truck
1		0.94	0.99	0.97
2		0.82	0.92	0.84
3		0.95	0.99	0.98
4		0.91	0.99	0.97
5		0.81	0.91	0.83
6		0.81	0.93	0.84

2. Install more sensors inside and outside the facility and fence. For example, install ported coax, microwave sensor, fiber optic cable, or break wire sensor. The P_D from the sensor will help increase the effectiveness, depending on the type of

sensor used. In case of installing Active IR, 1m High along the fence and the main gate, the P_D will be increased to 0.8. In case the adversary uses motorcycle and truck, installing more sensors at the fence or the main gate of institute has no effect on the P_I because at the main gate the P_D of the guard is equal to 1. In case the adversary running.

The P_D of this sensor can help increase the P_I to higher value. If a video motion sensor is installed outside the facility, P_D will be increased to 0.8. Appropriate position of sensor installing in the facility should help increase the P_I's to higher value. From Table 4.26, the appropriate position for installation are in front of the glass window of the room in the controlled area (the position of window as shown in Figure 4.4), in front of back door of controlled area (the position of the door as shown in Figure 4.6), and in front of firer exit (the position of firer exit as shown in Figure 4.7). Installing glass break sensor at the glass window in front of the toilet room will increase the P_D to 0.9 (the position of window as shown in Figure 4.7). The P_I's of all scenarios increase as shown in Table 4.34

Table 4.34 sum of P_I from EASI model using various modes of transportation, after improve PPS system by Install more sensors inside and outside the facility and fence.

Scenarios	Color	Probability of Interruption (P_I)		
		Running	Motorcycle	Truck
1		0.91	0.98	0.95
2		0.85	0.87	0.77
3		0.92	0.98	0.96
4		0.94	0.98	0.95
5		0.84	0.86	0.75
6		0.85	0.88	0.77

The results show that in case of the adversary running, the P_I's for all scenarios increase to above the medium range (0.5-0.75). However, several scenarios have the P_I's that are still in the range of 0.78 to 0.89. In case the adversary using motorcycle and truck, installing more sensors has no effect on the P_I. It should also be kept in mind that some sensors have weakness and are sensitive to environment which can lead to a nuisance alarm from things like dust and small animal. More sensors also mean that the cost for maintenance will rise. This process, therefore, may not be worth the investment [8].

3. Install the delay equipment to delay the adversary. The method can increase the P_I to high range. For instance, installing a steel cage door with 4-mm thickness, 5 x 10 cm rectangle, at the control room door to replace the current door which is made from normal glass. This room has a control system that can open the storage room that houses the gamma sources. This process increases the delay time to 120 second, and improves the security system P_I for all scenarios to above 0.90. The P_I's of some scenarios, for the adversary using motorcycle and truck, are equal to 1. In such case, the adversary will definitely be interrupted in its path before completing its objective as shown in Table 4.35.

Table 4.35 sum of P_I from EASI model using various modes of transportation, after improve PPS system by install steel cage door with 4-mm thickness, 5 x 10 cm rectangle at the control room door

Scenarios	Color	Probability of Interruption (P_i)		
		Running	Motorcycle	Truck
1		0.98	1.00	1.00
2		0.94	0.98	0.96
3		0.98	1.00	1.00
4		0.97	1.00	0.99
5		0.94	0.98	0.95
6		0.94	0.98	0.96

CHAPTER 5
CONCLUSION

The possibility that nuclear or other radioactive material could be used for malicious purposes cannot be ruled out in the current global situation. The goal of a PPS is to prevent the accomplishment of overt and covert malevolent actions [9]. This study has applied an analytical methodology for PPS evaluation to an actual gamma radiation facility in Thailand with a Category I gamma source to assess the existing security system against various attack scenarios. For security reason, the name and detailed information of the facility are omitted in this Thesis. All models have been redrawn to different configuration and scaling, but information vital to the calculation is still kept relatively the same. Such evaluation can be used to support security assessment and provide the basis for demonstration of security for licensing to ensure that the facility has been secured and can protect against malicious act or adversary action effectively. The effectiveness of the physical protection system in the facility has been determined using the computerized Estimation of adversary Sequence Interruption (EASI) model to calculate the probability of interruption (P_I). Six scenarios have been assessed. The adversary's modes of transportation are assumed to be running, motorcycle, or truck, based on the current design and DBT.

In case of sabotage the P_I of the second, fifth and sixth scenarios, in the case that the adversary runs, are in the range of low security system, and the PPS should be improved. Several improvements in the PPS design have been discussed. They are

1) Moving the guard from the main entrance of the institute into the facility. This process requires no additional cost, but the improvement may not be very high.

2) Installing more sensors inside and outside the facility and fence. This process can increase the P_I only in the case of the adversary running, but has no effect when the adversary uses motorcycle and truck. It also has addition cost for installing and maintaining the sensor.

3) Adding/replacing the delay equipment such as using steel cage door in place of the existing control room door. This process has additional cost for installing and maintaining the equipment, but the improvement can be substantial.

In case of theft, the adversary's goal is to steal the source from the facility. The security systems P_I's in all scenarios are equal to 1.00. Thus, the adversary will definitely be interrupted in its path before completing its objective.

For this facility to have more PPS effectiveness, it should also aim to improve the followings:

Detection: along the fence or main gate of institute should install line or volume sensors, such as microwave sensor, passive infra-red (PIR) sensors, video motion sensor, and glass break sensor to detect adversary entering the facility. The facility should also have a guard to detect the adversary and if move the guard from the main gate to facility will have no additional cost

Delay: more delay equipment should be installed in the facility. For have more system effectiveness, steel cage door should be installed at the control room door. It can increase delay time for all scenarios and the system has more security system effectiveness.

Response: a Memorandum of Understanding (MOU) between the facility operator and the local police force should be established; regular force-on-force exercises between all response forces should be performed; authorized security devices can be implemented to permit fast response.

REFERENCES

[1] International Atomic Energy Agency. Implementing Guide of Security of Nuclear Information. IAEA Nuclear Security Series No. 23-G. Vienna : International Atomic Energy Agency, 2015.

[2] International Atomic Energy Agency. Exercise Data for the General Hypothetical Facility and PTR Data. IAEA nuclear Security Training Material NS6.2. Vienna : International Atomic Energy Agency, 2014.

[3] International Atomic Energy Agency. Security of Radioactive Sources. IAEA Nuclear Security Series No. 11. Vienna : International Atomic Energy Agency, 2009.

[4] International Atomic Energy Agency. Objective and Essential Elements of a State's Nuclear Security Regime. IAEA Nuclear Security Series No. 20. Vienna : International Atomic Energy Agency, 2009.

[5] Australian Radiation Protection and Nuclear Safety Agency. Codes of Practice the Security of Radioactive Sources. Radiation Protection Series Publication No. 11. Yallambie : Australian Radiation Protection and Nuclear Safety Agency, 2007.

[6] International Atomic Energy Agency. Nuclear Security Recommendations on Physical Protection of Nuclear Material and Nuclear Facilities. IAEA Nuclear Security Series No. 13. Vienna : International Atomic Energy Agency, 2009.

[7] International Atomic Energy Agency. Code of Conduct on the Safety and Security of Radioactive Sources. Vienna : International Atomic Energy Agency, 2004.

[8] Mary Lynn Garcia. The Design and Evaluation of Physical Protection Systems. Burlington : Butterworth-Heinemann, 2001.

[9] M.C. Echeta, and others. PPS Evaluation Of An Oil Refinery Using EASI Model. Physical Security 7 (2014) : 30-41.

[10] O. D. Oyeyinka, and others. Determination of System Effectiveness for Physical Protection Systems of a Nuclear Energy Centre. Science and Technology 4 (2014) : 9-16.

[11] Lukas Ludek, and Hromada. Critical Infrastructure Protection and the Evaluation Process. Disaster Recovery and Business Continuity 3 (November 2012) : 37-46.

[12] Jingjing Dai, and others. Benefit-Cost Analysis of Security Systems for Multiple Protected Assets Based on Information Entropy. Entropy 14 (March 2012) : 571-580.

[13] Lukas Ludek, and Hromada Martin. Simulation and Modelling in Critical Infrastructure Protection. MATHEMATICS AND COMPUTERS IN SIMULATION 5 (2011) : 389-394.

[14] Sung Soon Jang, and others. Development of a Vulnerability Assessment Code foe a Physical Protection System Analysis of Physical Protection Effectiveness. Nuclear Engineering and Technology 41 (January 2009) : 747-754.

[15] W.F.Bakr, and A.A.Hamed. Upgrading the Physical Protection System (PPS) To Improve the Response to Radiological Emergencies Involving Malevolent Action. Physical Security 3 (2009) : 9-16.

[16] D. W. Whitehead, and others. Nuclear Power Plant Security Assessment Technical Manual. California : Sandia National Laboratories, 2007.

[17] Lukas Ludek, and Hromada. Utilization of the EASI model in the matters of critical infrastructure protection and its verification via the OTB SAF simulation tool. the 13th WSEAS International Conference on AUTOMATIC CONTROL,

MODELLING & SIMULATION (ACMOS '11) 131-136. Lanzarote: World Scientific and Engineering Academy and Society, 2011.

[18] U.S.NCR. Physical protection of category 1 and category 2 quantities of radioactive material [online]. 2013. Available from: http://www.nrc.gov/reading-rm/doc-collections/cfr/part037/ [12 January 2015]

[19] Ryan Bedoe. Part B EASI Model [online]. 2001. Available from: http://booksite.elsevier.com/9780750683524/casestudies/EASI%20Model.pdf [8 March 2015]

[20] สำนักงานปรมาณูเพื่อสันติ. ระเบียบคณะกรรมการพลังงานปรมาณูเพื่อสันติ ว่าด้วย วิธีการรักษาความมั่นคงปลอดภัยของวัสดุพลอยได้ พ.ศ. ๒๕๕๔ [ออนไลน์]. 2554. แหล่งที่มา: http://www.ratchakitcha.soc.go.th/DATA/PDF/2555/E/056/6.PDF [9 มกราคม 2558]

APPENDIX

Appendix A

Table A.1 Recommended measures for security level A [7]

Security function	Security objective	Security measures
Detect	Provide immediate detection of any unauthorized access to them secured area/source location.	Electronic intrusion detection system and/or continuous surveillance by operator personnel
	Provide immediate detection of any attempted unauthorized removal of the source, including by an insider.	Electronic tamper detection equipment and/or continuous surveillance by operator personnel.
	Provide immediate assessment of detection.	Remote monitoring of CCTV or assessment by operator / response personnel.
	Provide immediate communication to response personnel.	Rapid, dependable, diverse means of communication such as phones, cell phones, pagers, radios.
	Provide a means to detect loss through verification.	Daily checking through physical checks, CCTV, tamper indicating devices, etc.
Security function	Security objective	Security measures
Delay	Provide delay after detection sufficient for response personnel to interrupt the unauthorized removal.	System of at least two layers of barriers (e.g. walls, cages) which together provide delay sufficient to enable response personnel to interdict

Table A.1 Recommended measures for security level A (cont.)

Security function	Security objective	Security measures
Response	Provide immediate response to assessed alarm with sufficient resources to interrupt and prevent the unauthorized removal.	Capability for immediate response with size, equipment, and training to interdict.
Security management	Provide access controls to source location that effectively restrict. Access to authorized persons only.	Identification and verification, for example, lock controlled by swipe card reader and personal identification number, or key and key control.
	Ensure trustworthiness of authorized individuals	Background checks for all personnel authorized for unescorted access to the source location and for access to sensitive information.
	Identify and protect sensitive information.	Procedures to identify sensitive information and protect it from unauthorized disclosure
	Provide a security plan.	A security plan which conforms to regulatory requirements and provides for response to increased threat levels.
	Ensure a capability to manage security events covered by security contingency plans.	Procedures for responding to security-related scenarios.
	Establish security event reporting system.	Procedures for timely reporting of security events.

Appendix B

EASI Model

From the Design and Evaluation of Physical Protection Systems book [8], the EASI method calculates the probability of interruption of an adversary action sequence aimed at theft or sabotage. This is the probability that the response force will be notified when there is sufficient time remaining in the sequence for the force to respond. The notification of the response force is called an alarm, and the probability of alarm is:

$$P_A = P_D * P_C$$

Where: P_D = probability of detection and P_C = probability of communication to the response force.

In the case of a single detection sensor (or other possible means of detection), the probability of an adversary action sequence interruption is given by:

$$P_I = P(R|A)\ P_A$$

Where: P(RIA) = probability of response force arrival prior to the end of the adversary's action sequence, given an alarm. An adversary action sequence takes place along a path consisting of a starting point, a sequence of detection

sensors, transit and barrier delays, and a terminal point. The transits and barriers can be thought of as tasks the adversary must perform. Current versions of EASI allow specification of where the detection sensors are located

with respect to the task delays before, after, or during the task delay.

If TR is the time remaining for the adversary to reach the terminal point when a sensor activates, and RFT is the response time of the security force, then for adversary interruption it is necessary that

$$TR - RFT > 0$$

The random variables TR and RFT are assumed to be independent and normally distributed* and thus the random variable

$$X = TR - RFT$$

Is normally distributed with mean

$$\mu_x = E(TR - RFT) = E(TR) - E(RFT)$$

Variance

$$\sigma_x^2 = Var(TR - RFT) = Var(TR) + Var(RFT)$$

* The normal distribution requirement may be approximated by letting TR and RFT be sums of random variables which satisfy the conditions of the Central Limit Theorem.

And

$$P(R|A) = P(X > 0)$$

$$= \int_0^\infty \frac{1}{\sqrt{2\pi\sigma_x^2}} exp\left[\frac{-(X-\mu_x)^2}{2\sigma_x^2}\right] dx$$

In EASI, P(RIA) is approximated using the NormSDist function found in Excel®. Because the method is concerned with the time remaining in the sequence, evaluation of E(TR) and E(RFT) at point p along a path of interest must be with respect to the terminal point. The penetration time through each barrier and the transit time between barriers are considered to be random variables with values corresponding to the level of adversary resources. Then, the expected time from any point p to the terminal point n is

$$E(TR) \text{ at point } P = E(\text{Time After Detection at point } p) + \sum_{i=p+1}^{n} E(T_i)$$

Where: $E(T_i)$ = the expected time to perform Task I and

E(Time After Detection at point p) =

$E(T_i)$ if detection is at the beginning (B)

$E(T_i)/2$ if detection is in the middle (M)

0 if detection is at the end (E).

Assuming each task to be independent, the variance of the path time remaining between point p and the terminal point n is

$$Var(TR) \text{ at point } p = Var(\text{Time After Detection at point } p) + \sum_{i=p+1}^{n} Var(T_i)$$

Where: Var(Time After Detection at point p) =

Var(Tj) if detection is at the beginning (B)

Var(Tj)/4 if detection is in the middle (M)

0 if detection is at the end (E).

For two or more sensors the conditional probability of response force arrival, P(R|A), for each sensor must be calculated as previously described. Then the formula for P(I), the cumulative probability of sequence interruption calculated along the adversary's path from the starting point, must consider detection at the first location, at the second, and so on. For example, for a path with two detection locations:

$$P_I = P_{D1}*P_{C1}*P(R|A_1) + (1-P_{D1})* P_{D2}*P_{C2}*P(R|A_2)$$

Notice that P_{C1} is included in the first term but not the second. This is because if we do detect at the first location, but do not communicate to the response force based on that detection (due to jamming, etc.), we will probably not get a second chance to communicate at the second location just by the virtue of being detected there.

$$P_I = P_{D1}*P_{C1}*P(R|A_1) + \sum_{i=2}^{n} P(R|A_i)P_{Di} \prod_{i=1}^{i=1}(1 - P_{Di})$$

Additional Notes on EASI Excel Model

The next pages are printouts of the Excel model. This can be used to create the application if the user has no Internet access to download the model. The EASI computer model in Excel exists as an excel worksheet with embedded macros. Due to the presence of the macros, when the file is first opened an alert warning of possible virus infection may be presented. Choose "Enable macros" to continue running the file. The following instructions can be used to re-enter the necessary information to build the EASI file. The file is comprised of three tabs—the user interface (XL Easi), the calculations (EASI2.XLS), and the macro (EASIO.XLM). Questions concerning the creation of a worksheet file in Excel may require use of the Excel Users Manual.

The bold letters and numbers in the first column and row of each table represent column and row numbers in Excel. The first tab in the Excel file (XL Easi) is a table formatted to look like Figures A.1. This can be formatted using whichever font or line widths desired, but the data must reside in the appropriate column/row. The data inside the table is entered for a specific path.

	A	B	C	D	E	F	G
1							
2			***Estimate of***	Probability of			
3			***Adversary***	Guard		Response Force Time (in Seconds)	
4			***Sequence***	Communication		Mean	Standard Deviation
5			***Interruption***	0.95		300	90
6							
7						Delays (in Seconds):	
8		Task	Description	P(Detection)	Location	Mean:	Standard Deviation
9		1	Cut Fence	0	B	10	3
10		2	Run to Building	0	B	12	3.6
11		3	Open Door	0.9	B	90	27
12		4	Run to Vital Area	0	B	10	3
13		5	Open Door	0.9	B	90	27
14		6	Sabotage Target	0	B	120	36
15		7					
16		8					
17		9					
18		10					
19		11					
20		12					
21							
22			Probability of Interruption:	0.476040779			
23							

Second tab (EASI2.XLS):

Figures A.1 EASI model example

All of the information must appear exactly as shown, in the appropriate cell.

	A	B	C	D	E	F	G
1							
2							
3							
4							
5		1		='XL Easi'!F5	='XL Easi'!G5		
6	PC	='XL Easi'!D5					
7							
8				mean	sdev	pad	1-pd
9		='XL Easi'!D9	='XL Easi'!E9	='XL Easi'!F9	='XL Easi'!G9	=$B$5*B9	=1-F9
10		='XL Easi'!D10	='XL Easi'!E10	='XL Easi'!F10	='XL Easi'!G10	=$B$5*B10	=(1-F10)*G9
11		='XL Easi'!D11	='XL Easi'!E11	='XL Easi'!F11	='XL Easi'!G11	=$B$5*B11	=(1-F11)*G10
12		='XL Easi'!D12	='XL Easi'!E12	='XL Easi'!F12	='XL Easi'!G12	=$B$5*B12	=(1-F12)*G11
13		='XL Easi'!D13	='XL Easi'!E13	='XL Easi'!F13	='XL Easi'!G13	=$B$5*B13	=(1-F13)*G12
14		='XL Easi'!D14	='XL Easi'!E14	='XL Easi'!F14	='XL Easi'!G14	=$B$5*B14	=(1-F14)*G13
15		='XL Easi'!D15	='XL Easi'!E15	='XL Easi'!F15	='XL Easi'!G15	=$B$5*B15	=(1-F15)*G14
16		='XL Easi'!D16	='XL Easi'!E16	='XL Easi'!F16	='XL Easi'!G16	=$B$5*B16	=(1-F16)*G15
17		='XL Easi'!D17	='XL Easi'!E17	='XL Easi'!F17	='XL Easi'!G17	=$B$5*B17	=(1-F17)*G16
18		='XL Easi'!D18	='XL Easi'!E18	='XL Easi'!F18	='XL Easi'!G18	=$B$5*B18	=(1-F18)*G17
19		='XL Easi'!D19	='XL Easi'!E19	='XL Easi'!F19	='XL Easi'!G19	=$B$5*B19	=(1-F19)*G18
20		='XL Easi'!D20	='XL Easi'!E20	='XL Easi'!F20	='XL Easi'!G20	=$B$5*B20	=(1-F20)*G19

Figure A.2 formula of EASI model in Excel file

	H	I	J	K
1				
2				
3	dddd			
4				
5				
6				
7				
8	P(first detn)	cum delays	Cum Var	True Mean
9	=F9	=D9+I10	=(E9*E9)+J10	=IF(C9="B",D9,IF(C9="M",0.5*D9,0))+I10
10	=F10*G9	=D10+I11	=(E10*E10)+J11	=IF(C10="B",D10,IF(C10="M",0.5*D10,0))+I11
11	=F11*G10	=D11+I12	=(E11*E11)+J12	=IF(C11="B",D11,IF(C11="M",0.5*D11,0))+I12
12	=F12*G11	=D12+I13	=(E12*E12)+J13	=IF(C12="B",D12,IF(C12="M",0.5*D12,0))+I13
13	=F13*G12	=D13+I14	=(E13*E13)+J14	=IF(C13="B",D13,IF(C13="M",0.5*D13,0))+I14
14	=F14*G13	=D14+I15	=(E14*E14)+J15	=IF(C14="B",D14,IF(C14="M",0.5*D14,0))+I15
15	=F15*G14	=D15+I16	=(E15*E15)+J16	=IF(C15="B",D15,IF(C15="M",0.5*D15,0))+I16
16	=F16*G15	=D16+I17	=(E16*E16)+J17	=IF(C16="B",D16,IF(C16="M",0.5*D16,0))+I17
17	=F17*G16	=D17+I18	=(E17*E17)+J18	=IF(C17="B",D17,IF(C17="M",0.5*D17,0))+I18
18	=F18*G17	=D18+I19	=(E18*E18)+J19	=IF(C18="B",D18,IF(C18="M",0.5*D18,0))+I19
19	=F19*G18	=D19+I20	=(E19*E19)+J20	=IF(C19="B",D19,IF(C19="M",0.5*D19,0))+I20
20	=F20*G19	=D20	=E20*E20	=IF(C20="B",D20,IF(C20="M",0.5*D20,0))

Figure A.3 formula of EASI model in Excel file (cont.)

	L	M
1		
2		
3		
4		
5		
6		
7		
8	True Var	z-values
9	=IF(C9="B",E9*E9,IF(C9="M",0.25*E9*E9,0))+J10	=(K9−$D$5)/SQRT(L9+$E$5*$E$5)
10	=IF(C10="B",E10*E10,IF(C10="M",0.25*E10*E10,0))+J11	=(K10−$D$5)/SQRT(L10+$E$5*$E$5)
11	=IF(C11="B",E11*E11,IF(C11="M",0.25*E11*E11,0))+J12	=(K11−$D$5)/SQRT(L11+$E$5*$E$5)
12	=IF(C12="B",E12*E12,IF(C12="M",0.25*E12*E12,0))+J13	=(K12−$D$5)/SQRT(L12+$E$5*$E$5)
13	=IF(C13="B",E13*E13,IF(C13="M",0.25*E13*E13,0))+J14	=(K13−$D$5)/SQRT(L13+$E$5*$E$5)
14	=IF(C14="B",E14*E14,IF(C14="M",0.25*E14*E14,0))+J15	=(K14−$D$5)/SQRT(L14+$E$5*$E$5)
15	=IF(C15="B",E15*E15,IF(C15="M",0.25*E15*E15,0))+J16	=(K15−$D$5)/SQRT(L15+$E$5*$E$5)
16	=IF(C16="B",E16*E16,IF(C16="M",0.25*E16*E16,0))+J17	=(K16−$D$5)/SQRT(L16+$E$5*$E$5)
17	=IF(C17="B",E17*E17,IF(C17="M",0.25*E17*E17,0))+J18	=(K17−$D$5)/SQRT(L17+$E$5*$E$5)
18	=IF(C18="B",E18*E18,IF(C18="M",0.25*E18*E18,0))+J19	=(K18−$D$5)/SQRT(L18+$E$5*$E$5)
19	=IF(C19="B",E19*E19,IF(C19="M",0.25*E19*E19,0))+J20	=(K19−$D$5)/SQRT(L19+$E$5*$E$5)
20	=IF(C20="B",E20*E20,IF(C20="M",0.25*E20*E20,0))	=(K20−$D$5)/SQRT(L20+$E$5*$E$5)

Figure A.4 formula of EASI model in Excel file (cont.)

	N	O
1		
2		
3		
4		
5		
6		
7		
8	Normal values	prod h?*n?
9	=EASI2.XLS!fornorm__a(M9)	=H9*N9
10	=EASI2.XLS!fornorm__a(M10)	=H10*N10
11	=EASI2.XLS!fornorm__a(M11)	=H11*N11
12	=EASI2.XLS!fornorm__a(M12)	=H12*N12
13	=EASI2.XLS!fornorm__a(M13)	=H13*N13
14	=EASI2.XLS!fornorm__a(M14)	=H14*N14
15	=EASI2.XLS!fornorm__a(M15)	=H15*N15
16	=EASI2.XLS!fornorm__a(M16)	=H16*N16
17	=EASI2.XLS!fornorm__a(M17)	=H17*N17
18	=EASI2.XLS!fornorm__a(M18)	=H18*N18
19	=EASI2.XLS!fornorm__a(M19)	=H19*N19
20	=EASI2.XLS!fornorm__a(M20)	=H20*N20
21		=SUM(O9:O20)*B6

Third tab in file (EASI0.xlm):

Figure A.5 formula of EASI model in Excel file (cont.)

	A
1	fornorm (a)
2	=RESULT(1)
3	=ARGUMENT("z_value",1)
4	=z_value
5	=NORMSDIST(z_value)
6	=RETURN(A5)

Figure A.6 formula of EASI model in Excel file (cont.)

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