Annals of Nuclear Energy 81 (2015) 213–218

Contents lists available at ScienceDirect

Annals of Nuclear Energy

journal homepage: www.elsevier.com/locate/anucene

Methodology for analyzing risk at nuclear facilities

Hosik Yoo *, Nayoung Lee, Taekyu Ham, Janghoon Seo

Korea Institute of Nuclear Non-proliferation and Control, Expo-Ro 573, Yuseong, Daejeon 305-732, Republic of Korea

ARTICLE INFO

Article history:
Received 4 December 2014
Received in revised form 22 February 2015
Accepted 24 February 2015
Available online 12 March 2015

Keywords:
Risk assessment
NMAC
Consequences
Radiation damage

ABSTRACT

A methodology for evaluating risks at nuclear facilities is developed in this work. A series of measures is drawn from the analysis of factors that determine risks. Five measures are created to evaluate risks at nuclear facilities. These include the legal and institutional framework, material control, physical protection system effectiveness, human resources, and consequences. Evaluation attributes are developed for each measure and specific values are given in order to calculate the risk value quantitatively. Questionnaires are drawn up on whether or not a state has properly established a legal and regulatory framework (based on international standards). These questionnaires can be a useful measure for comparing the status of the physical protection regime between two countries. Analyzing an insider threat is not an easy task and no methodology has been developed for this purpose. In this study, attributes that could quantitatively evaluate an insider threat, in the case of an unauthorized removal of nuclear materials, are developed by adopting the Nuclear Material Accounting & Control (NMAC) system. The effectiveness of a physical protection system, $P(E)$, could be analyzed by calculating the probability of interruption, $P(I)$, and the probability of neutralization, $P(N)$. In this study, the Tool for Evaluating Security System (TESS) code developed by KINAC is used to calculate $P(I)$ and $P(N)$. Consequence is an important measure used to analyze risks at nuclear facilities. This measure comprises radiological, economic, and social damage. Social and economic damages are difficult to evaluate. Therefore, radiation levels and theft of nuclear materials that could be quantified are adopted as attributes for analyzing the consequences. Awareness of the nuclear security culture and physical protection resources such as staffing, capabilities, and cost required to provide PP should be considered when evaluating risks. In this study, these attributes are included in the measure of human resources. Human resources include such factors as trustworthiness, degree of nuclear security culture awareness, and frequency of psychiatric testing of employees. A case study performed on hypothetical facilities demonstrates that the developed methodology could be used to analyze innovative nuclear systems as well as existing facilities.

1. Introduction

Concerns over nuclear security have increased due to the potential of terrorist attacks. Nuclear terrorism is viewed as the worst-case scenario since its outcome could be catastrophic. There are three possible types of nuclear terrorism that could be carried out. These include the theft of nuclear materials, the sabotage of nuclear facilities, and the explosion of an atomic bomb. The explosion of an atomic bomb is considered as the most severe accident, although its probability is lower than the former two cases. A nuclear facility could be an attractive target to a terrorist since it houses nuclear materials. Damage to such a facility could bring about unacceptable radiological consequences. Measures should be set up in order to prevent the unauthorized removal of nuclear material and sabotage. An analysis of the risk at a facility is essential in order to develop new measures to prevent or mitigate a potential attack. There have been several studies on how to develop a methodology to evaluate risks at nuclear facilities. The Generation IV (Gen-IV) PR/PP (GIF/PRPPWG, 2011) and International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO) (IAEA, 2007) are well-known methodologies used to analyze risks at nuclear facilities. Both methodologies have the same objective, but they use very different measures to evaluate risks. In addition, the results obtained from the analysis have also been different. The Gen-IV methodology makes use of three measures to analyze risks, as well as allows quantitative results to be obtained. On the other hand, INPRO uses User Requirement (UR) and Criteria (CR) concepts for evaluation and the results of the analysis are qualitative.

Although these two methodologies are adequate tools for evaluating risks at nuclear facilities, there are some limitations to

* Corresponding author. Tel.: +82 42 860 9782; fax: +82 42 861 8819.
E-mail address: hsyoo@kinac.re.kr (H. Yoo).

http://dx.doi.org/10.1016/j.anucene.2015.02.041
0306-4549/

be considered carefully. Three measures that the Gen-IV methodology uses do not consider all factors affecting risks. In addition, they do not include the status of an individual nation's legal and institutional framework. This is important when comparing facilities that are located in different countries. INPRO is a useful tool for giving information on which areas of a physical protection system are weak at a facility. However, it can provide only qualitative results and comparison between two facilities is not possible. Therefore, a methodology which could evaluate nuclear facilities quantitatively and compare different facilities was needed. In order to do that, a new methodology called Integrated Code for Risk Assessment (INCORIA) was developed (Yoo, 2009). This method provides quantitative results by using five measures for evaluating risks, while allowing comparisons to be made between nuclear facilities. However, it has not reflected the attributes of the nuclear security culture and insider threat.

In this study, a new methodology called Comprehensive Methodology for PR&PP Evaluation (COMPRE) is developed by incorporating all requirements. The developed methodology is composed of five measures, including legal and institutional frameworks. Quantitative results can be obtained if a numerical value is given to each attribute. A comparison of risks between facilities is also possible by using this methodology. This paper illustrates each measure and details a case study on hypothetical facilities. It is expected that the risk of both existing facilities and innovative nuclear systems could be analyzed by using this methodology.

2. Determining measures

Based on the traditional definition of risk (Arnold, 2002), risk is composed of three measures. These measures include the likelihood of adversary attack (P_A), adversary success (1-P_E, where P_E is security system effectiveness), and consequence (C). Risk could be obtained by multiplying these three measures. The methodology developed by the Gen-IV PR/PP group used similar measures as those employed in the traditional equation (probability of adversary success, consequences, and physical protection resources). The Gen-IV methodology adopted physical protection resources as a measure, instead of incorporating the likelihood of an adversary attack. Physical protection resources include costs related to staffing and staff capabilities. On the other hand, the INPRO methodology uses very different measures, such as legislative and regulatory frameworks, and a fundamental principle with 12 requirements including trustworthiness, confidentiality, and threat. Yoo developed a methodology consisting of five measures, which is called INCORIA. INCORIA comprises measures such as fissile material type, probability of interruption, probability of neutralization, effectiveness of physical protection resources, and consequences. Essential measures in previous studies included security system effectiveness, resources effectiveness, and consequences. A new methodology developed in this study also adopts these measures, as shown in Table 1. In this study, attributes for each measure are developed and numerical values are assigned to them.

2.1. Legislative and institutional framework

A national physical protection regime is an important factor when evaluating the risk of facilities. Whether legal and institutional systems on physical protection are well established or not is a basis for comparing two facilities located in different countries. There are many attributes that should be considered when evaluating a legal and institutional framework. These attributes comprise factors such as a national legal system, competent authority, ratification of international norms, and the establishment of a national Design Basis Threat (DBT). INPRO methodology was the only one in which measures on legal and regulatory frameworks were incorporated, as shown in Table 1. In this study, nine questionnaires are developed to evaluate attributes related to national legislative and institutional frameworks, as shown in Table 2.

2.2. Material control

Nuclear material is considered as a main target for terrorists. Its attractiveness as a target varies depending on material type and its level of enrichment. Other methodologies such as Gen-IV and INPRO do not include measures on materials. INCORIA only uses material types as attributes for evaluation. Recently, the Nuclear Material Accountancy & Control (NMAC) system, which has been used as a tool for international safeguards, is considered as an attribute for evaluating the risk of an insider attack. The NMAC could be used as an effective way to prevent an insider from illegally transferring nuclear materials. Therefore, evaluating the potential threat of insiders could be performed by using those attributes from the NMAC system. In this study, six attributes are developed for analyzing the NMAC system based on an IAEA document (IAEA, to be published), as shown in Table 3. A categorization table on nuclear material developed by Yoo is used.

2.3. Physical protection system effectiveness

The effectiveness of a physical protection system is an important measure for evaluating a nuclear facility. A physical protection system is defined by the IAEA as "An integrated set of physical protection measures intended to prevent the completion of a malicious act" (IAEA, 2011). The effectiveness of a physical protection system can be calculated by using the following equation:

Table 1
Comparison of methodologies for evaluating risk.

	Gen-IV PR/PP	INPRO	INCORIA	COMPRE
Measures	• Probability of adversary success • Consequences • Physical protection resources	• Legislative and regulatory framework • Integration of PP • Trustworthiness • Confidentiality • Threat • Graded approach • Quality assurance • Security culture • PP consideration in siting • Layout and design • Design of PPS • Contingency plans	• Probability of interruption • Probability of neutralization • Fissile material type • Effectiveness of physical protection resources • Consequences	• Legislative and institutional framework • Material control • Physical protection system effectiveness • Consequences • Human resources