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Review

More efficient integrated safeguards by applying a reasonable detection probability for maintaining low presence probability of undetected nuclear proliferating activities

Naoto Otsuka

University of Tokyo, School of Engineering, Department of Nuclear Engineering and Management, 7-4-1 Hongo, Bunkyo-ku, Tokyo 113-8656, Japan

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A B S T R A C T

A theoretical foundation is presented for implementing more efficiently the present International Atomic Energy Agency (IAEA) integrated safeguards (ISs) on the basis of fuzzy evaluation of the probability that the evaluated nation will continue peaceful activities. It is shown that by determining the presence probability of undetected nuclear proliferating activities, nations under IS can be maintained at acceptably low proliferation risk levels even if the detection probability of current IS is decreased by dozens of percentage from the present value. This makes it possible to reduce inspection frequency and the number of collected samples, allowing the IAEA to cut costs per nation. This will contribute to further promotion and application of IS to more nations by the IAEA, and more efficient utilization of IAEA resources from the viewpoint of whole IS framework.

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1. Introduction

There are many nations currently planning on developing nuclear energy because of its advantages in terms of global warming and energy security. Indeed, the IAEA's "Vision 20/20" (2008) predicts that the number of nuclear power reactors will increase by up to 60% and associated fuel cycle facilities up to 45% by 2030. However, the March 11 earthquake and tsunami in Japan might have had a significant impact on the estimated expansion of nuclear energy in the future. For example,

E-mail address: naoto830@hotmail.com

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several nations such as Germany, Italy, and Switzerland have, on the one hand, clearly decided to abandon nuclear energy. However, there are many nations that have clearly declared a continued interest in nuclear energy as an important energy source for the future. These include not only the U.S., France, and Russia, but also Vietnam and Jordan. Thus, although several international agencies have reduced their estimates for future expansion since the March 11 disaster, the use of nuclear energy will still continue.

With continued interest in nuclear energy, there is significant possibility for cooperation among nations, allowing for nuclear materials and related technology to spread all over the world. In such a case, concerns regarding nuclear proliferation are exacerbated, especially by the spread of nuclear explosive devices (hereinafter referred to as "NED").

The International Atomic Energy Agency (hereinafter referred to as "IAEA") has promoted an integrated safeguards (hereinafter referred to as "IS") program to prevent proliferation to non-nuclear weapons nations. IS is a combination of both INFCIRC/153 and INFCIRC/540, and is expected to be more effective and efficient than previous safeguards. There is, however, no guarantee that the IAEA will always have a sufficient budget for these safeguards activities. It is, therefore, beneficial to develop a method for enhancing the efficiency of IS implementation.

Previous studies on the efficiency of IAEA safeguards ocused on material control and accountancy, and on the technical methods involved in implementing inspection activities such as remote monitoring. Recently, however, some have insisted on further improvements in efficiency (Biaggio and Marzo, 2001; Carlson, 2004; Albert, 2001). However, few studies have employed quantitative methods to support their arguments on efficiency. Although several studies (Seward et al., 2008; Kwon and Ko, 2009) have tried to develop a method to quantitatively evaluate nations' nuclear nonproliferation credibility, they have not focused on the efficiency of IAEA safeguards.

This article proposes that it is possible to considerably decrease the detection probability of safeguards while maintaining a satisfactorily low presence probability that a nation's proliferation activities can occur without being detected through the safeguards. This article provides a theoretical foundation for enabling more efficient IS in the future.

2. Presence probability of undetected nuclear proliferating activities as an objective function

2.1. Importance of presence probability of undetected nuclear proliferating activities

The IAEA IS is implemented in many nations and the results are published annually in the safeguards implementation report. According to the safeguards statement for 2009, the IAEA implemented IS in 36 nations through the year and concluded that all the nuclear materials and activities remained peaceful in these nations.

Member states of the IAEA can express their dissatisfaction or concerns with nuclear proliferation in nations under IS to the Board of Governors if necessary. However, no such concerns have been expressed. This fact implies that the IAEA judges that the presence probability of undetected nuclear proliferating activities in the nations under IS is low enough to be accepted by international society, although the probability is not zero. This chapter considers the presence probability of undetected proliferating activities.

2.2. Two factors determining the presence probability of undetected nuclear proliferating activities

The IAEA has promoted the application of its combined safeguards, INFCIRC/153 and INFCIRC/540, for detection of undeclared activities in non-nuclear weapon nations. This article proposes the use the presence probability of undetected nuclear proliferating activities as an objective function to determine the necessary degree of implementation for IS. The presence probability for the evaluated nation "j" can be expressed in terms of two factors "αj" and "βj" as follows:

$$Pj = (1 - aj) \times (1 - \beta j), \quad (1)$$

where Pj is the presence probability of undetected nuclear proliferating activities in the evaluated nation j, i.e. the probability that nuclear proliferation activities are occurring in the evaluated nation j for one year without being detected by the IS; αj is the probability that the evaluated nation j remains peaceful for one year, i.e. the probability that the evaluated nation j does not start NED acquisition activities within a year; and βj is the detection probability of the IS applied to the evaluated nation j, i.e. the probability that the IAEA can detect indications of diversions arising from nuclear proliferation activities when the nation j starts NED acquisition activities.

2.3. Graph of the presence probability of undetected nuclear proliferating activities

As shown in Fig. 1, when $\alpha j = 1$ or $\beta j = 1$ in Eq. (1), Pj equals zero. In this case, the international society has no doubts that nation j is maintaining peaceful use of nuclear energy since there are no undetected nuclear proliferating activities. If this is true, the IAEA will not need to carry out inspection activities in such nations. Therefore, the case that $(0 \leqslant)\ \alpha j < 1$ and $(0<)\ \beta j < 1$ are considered as essential, where $Pj > 0$.

3. Quantitative evaluation of αj

3.1. Relationship between nuclear nonproliferation credibility and αj

Kwon and Ko (2009) evaluated the nuclear nonproliferation credibility of some nations by creating a criteria tree of many factors influencing nonproliferation credibility. They defined nuclear nonproliferation credibility as other nations' subjective perception of the given nation's propensity for nuclear nonproliferation. In other words, it is how much other nations believe that the given nation adheres to international standards for nuclear nonproliferation and does not have any intention to build weapons even if it has the requisite technological capabilities. Such a perception is formulated and accumulated over a period of time by factual reasoning, but is based on the biased interpretations of various factors surrounding the nation. They used an integrated multi-criteria analysis method to evaluate quantitatively a nation's nuclear nonproliferation credibility level. This concept is useful for calculating αj because it can be determined in an identical manner. In other words, this article assumes that the degree of nuclear nonproliferation credibility is proportional to αj from Eq. (1).

3.2. Use of fuzzy analysis

It would be possible to calculate αj to a certain degree in accordance with the method of Kwon and Ko. However, given the many international and domestic factors influencing a nation's decision and differences in persons' value judgments, it is difficult to provide an exact numerical value for αj. The fuzzy method resolves