

Probability of Neutralization Estimation for APR1400 Physical Protection System Design Effectiveness Evaluation

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1. Introduction

As the needs arose to enhance the Physical Protection System (PPS) design for nuclear power plants to promote international projects, Korea Hydro & Nuclear Power (KHNP) has conducted a project related to APR1400 PPS design. It is focusing on development of a new designing process which can be compatible to international standards such as IAEA¹ and NRC² suggest.

Evaluation for the design effectiveness was found as one of the areas to improve. If a design doesn't meet a certain level of effectiveness, it should be re-designed accordingly. The effectiveness can be calculated with combination of probability of Interruption and probability of neutralization. System Analysis of Vulnerability to Intrusion (SAVI) has been developed by Sandia National Laboratories for that purpose. With SNL's timely detection methodology, SAVI has been used by U.S. nuclear utilities to meet the NRC requirements for PPS design effectiveness evaluation. For the SAVI calculation, probability of neutralization is a vital input element that must be supplied³.

This paper describes the elements to consider for neutralization, probability estimation methodology, and the estimation for APR1400 PPS design effectiveness evaluation process.

2. Probability of Neutralization Estimation

2.1 Elements that effect response

The PPS at a nuclear facility consists of detection, delay, and response functions. The purpose of the response function is to prevent the adversary before completing his goal. The response function at a facility can be characterized by collecting the appropriate data. However, the analyst must still develop some measure of effectiveness for response. For response, the measure of effectiveness is probability of neutralization (P_N).

Probability of neutralization is defined as:

$$P_N = (\text{No. of wins}) / (\text{No. of engagements})$$

The term "win" means that the adversary force is killed, is captured, or abandons the attack and flees before his goal is accomplished.

The elements that can impact response force capability and should be considered are weapons, strategies, number of guards, transport, response times, etc. Strategies could include, but not limited to, deterrence, denial, containment, pursuit, recapture, and recovery. Each strategy should have an objective, which

may include observation, delay, interruption, neutralization, arrest, and backup.

2.2 Methodology for Numerical Calculations

To determine P_N , several methods can be categorized as below;

- Expert judgment, including tabletop analyses
- Simple numerical calculations
- Physical engagement exercise (force-on-force)
- Actual engagements

The first two can be grouped as "prediction", and the later two can be called physical "practice". Due to the cost and complexity for physical engagement exercise and actual engagements, they are difficult to apply. Also simple numerical calculation methods are often used in place of expert judgment.

Markov chain method and Monte Carlo simulation are most common mathematical solutions.

The Markov Chain method is a path-independent stochastic process in which probabilities of occurrence of future states depend only on the present state or the immediately preceding state. As shown in figure 1, a probability of transitioning from state (a, b) to (a, b-1) can be defined as λ (λ), while probability of transitioning to (a-1, b) can be defined as μ (μ). Either (a) or (b) can be number of adversaries or guards respectively. The states keep transitioning to reduce (a) or (b) until any of them becomes zero, which means one of the parties has been neutralized.

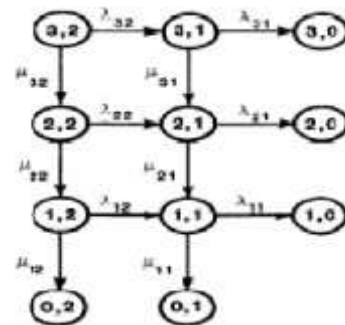


Fig.1. Markov chain state transition diagram

When adversaries and guards engage with equal capability, λ is determined as $a/(a+b)$ and μ is calculated as $b/(a+b)$ for each state. Note that the chance of winning for either side is 50% for a scenario in which the same number of people engage with this method.

Monte Carlo method uses random sampling techniques. Monte Carlo computer simulations are used to obtain approximate solutions to mathematical or physical problems involving a range of variables, not

only for this neutralization estimation but also for many engineering fields.

Table 1 shows an example of a Monte Carlo calculation to estimate the engagement consequence.

Table 1. Monte Carlo Simulation of 1 vs. 1 Engagement

Case	1		2		3		4	
	G	A	G	A	G	A	G	A
Coin	Head-Head		Tail-Head		Head-Tail		Tail-Tail	
Shot	Hit-Hit		Miss-Hit		Hit-Miss		Miss-Miss	
Result	Win		Win		Lost		Do it again	

Two coins are flipped to determine the results of a guard(G) and an adversary(A) both shooting at each other. A coin flip result “head” is used for “hit”, meaning a guard or an adversary got shoot to kill. In this coin flipping case, the probability of showing each face is 50%, which means the probability of shooting somebody successfully are the same for each case. As shown in case 4, if both miss each shot or they both have tail face of the coin, they shot (or flip) again until they have the result like case 1, 2, or 3 which involves death of any side. When a statistically significant number of engagements are made in this way, the probability of neutralization for this type of engagement can be calculated⁴.

It is interesting to find that the probability of neutralization for this engagement is 66.7%, which is higher than the result from Markov chain method (50%). The reason for the difference is that Markov chain method does not count for the transitioning of two states at once like case 1 from table 1.

2.3 P_N Estimation for APR1400

To calculate the estimation of PPS effectiveness for APR1400, P_N value was generated with Markov chain method. Table 2 shows that the estimation for the probability when both guards and adversaries have the same capability during engagements. Two more states were considered to reflect the advantage of guards and adversaries.

Table 2. P_N Estimation for Even Match Situation

	1	2	3	4	5	6	7	8
1	0.50	0.17	0.04	0.01	0.00	0.00	0.00	0.00
2	0.83	0.50	0.22	0.08	0.02	0.01	0.00	0.00
3	0.96	0.77	0.50	0.26	0.11	0.04	0.01	0.00
4	0.99	0.92	0.74	0.50	0.28	0.14	0.06	0.02
5	1.00	0.98	0.89	0.72	0.50	0.30	0.16	0.08
6	1.00	0.99	0.96	0.86	0.70	0.50	0.32	0.18
7	1.00	1.00	0.99	0.94	0.84	0.68	0.50	0.33
8	1.00	1.00	1.00	0.98	0.92	0.82	0.67	0.50

To extend the number of guards and adversaries that engage at the same time, the values in table 2 were reviewed and transformed into a graph shown in figure 2, even reflecting advantage to any side.

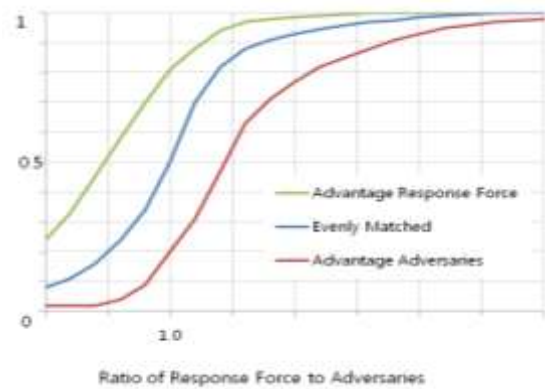


Fig. 2. Estimated Probability of Neutralization

3. Conclusions

Probability of neutralization (P_N) is an important input for PPS effectiveness evaluation process. Response force capability could be affected by many elements such as weapons, strategies, number of guards, transport, response times, etc. Markov chain and Monte Carlo simulation are often used for simple numerical calculation to estimate P_N . The results from both methods are not always identical even for the same situation. P_N values for APR1400 evaluation were calculated based on Markov chain method and modified to be applicable for guards/adversaries ratio based analysis.

Acknowledgement

This work was support by the Korea Institute of Energy Technology Evaluation and Planning(KETEP) grant funded by the Korea government(Ministry of Trade, Industry & Energy) (No.2012T1002011558)

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