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Light Water Reactor Sustainability Program

# Economic Analysis of Physical Security at Nuclear Power Plants

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# ABSTRACT

The overall operation and management (O&M) costs to operate a nuclear power plant in the U.S. have increased to a point that many utilities may not be able to continue to operate these important assets. The Department of Energy established the Light Water Reactor Sustainability Program with the mission to support the current fleet of nuclear power plants with research to facilitate lowered O&M costs. The Physical Security Pathway aims to lower the cost of physical security through directed research into modeling and simulation, application of advanced sensors or deployment of advanced weapons. Modeling and simulation are used to evaluate the excessive margin inherent in many security postures and to identify ways to maintain overall security effectiveness while lowering costs. This effort presents the economic analysis models developed with the aim of optimizing the physical security program at nuclear power plants.

This report describes the development of a framework that integrates results from Force on Force analysis with economic assessment to achieve two closely linked objectives: (1) Estimation of effectiveness of components of the physical security posture, and (2) Evaluation of investments in physical security using an estimated cash flow analysis. An econometric model is used for incorporating the success and failure of the physical security posture as determined from Force on Force models. The economic model incorporates various costs associated with physical security posture at a typical commercial nuclear power plant, such as labor and personnel costs, non-labor costs, equipment capital costs and operating costs. An investment assessment analysis is illustrated using a case study of performance and cost effectiveness of remotely operated weapons system in a hypothetical scenario. The framework provides a proof of concept towards achieving performance and cost effectiveness in design and operation of physical security posture at nuclear power plants.

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# ACRONYMS

| | |
|---|---|
| CDF | Cumulative distribution function |
| CROWS | Common Remotely Operated Weapon Station |
| DBT | Design basis threat |
| EDG | Emergency Diesel Generator |
| EUCG | Electric Utility Cost Group |
| FoF | Force-on-Force |
| FTE | Full time equivalent |
| GHG | greenhouse gas emission |
| INL | Idaho National Laboratory |
| IRR | Internal Rate of Return |
| LWRS | Light Water Reactor Sustainability |
| NEI | Nuclear Energy Institute |
| NPV | Net Present Value |
| NRC | Nuclear Regulatory Commission |
| O&M | Operation and management |
| PHPK | Probability hit probability kill |
| ROWS | Remotely operated weapon systems |

# ECONOMIC ANALYSIS OF PHYSICAL SECURITY AT NUCLEAR POWER PLANTS

## 1. INTRODUCTION

The overall operation and management (O&M) costs to operate a nuclear power plant in the U.S. have increased to a point that many utilities may not be able to continue to operate these important assets. The continued low cost of natural gas and the added generation of increased wind and solar development in many markets have significantly lowered the price that utilities charge for electricity. Utilities are working hard to modernize plant operations to lower the cost of generating electricity with nuclear power. The Department of Energy established the Light Water Reactor Sustainability Program (LWRS) with the mission to support the current fleet of nuclear power plants with research to facilitate lowered O&M costs. Due to the use of nuclear materials, nuclear power plants have an additional cost burden in protecting fuel against theft or sabotage. The overall O&M cost to protect nuclear power plants accounts for approximately 7% of the total cost of power generation, with labor accounting for half of this cost (Pacific Gas & Electric Company, 2018). In the current research, from interaction with utilities and other stakeholders, it was determined that physical security forces account for nearly 20% of the entire workforce at several nuclear power plants. Labor costs continue to rise in the U.S., so any measures to reduce the cost of operating a nuclear power plant will need to include a reduction in labor.

To support this mission, a new pathway for physical security research was established within the LWRS Program. The Physical Security Pathway aims to lower the cost of physical security through directed research into modeling and simulation, application of advanced sensors or deployment of advanced weapons. Modeling and simulation will be used to evaluate the excessive margin inherent in many security postures and to identify ways to maintain overall security effectiveness while lowering costs. This effort presents the economic analysis models developed with the aim of optimizing the physical security program at nuclear power plants. The models are developed to incorporate input from the physical security performance assessment models, such as Force-on-Force (FoF) models that provide the performance effectiveness of a physical security posture. When implemented together, the economic models, and the FoF models will provide a utility with technical basis to enable an optimized physical security program that is both cost and performance effective.

### 1.1 Background

In the United States, nuclear energy has historically supplied a substantial portion of the country's energy needs. Against the backdrop of climate change and the need for meeting the world's current and future energy needs without adding to greenhouse gas emissions (GHG), development of clean energy sources has received substantial attention in recent decades. While renewable energy sources such as solar and wind have witnessed significant growth; proponents of nuclear energy, given its low contribution to GHG emissions, contend that it can continue to be an important contributor to the overall energy mix. Yet, the nuclear industry is facing substantial headwinds and the next decade will be crucial for its future (Barkatullah & Ahmad, 2017). A decline in nuclear power generation could also diminish the potential for decarbonizing the energy sector.

The leading factor portending a bleak outlook for the nuclear energy sector is cost. The total generating costs for nuclear energy comprise capital, fuel, and operating costs (NEI, 2019). The Nuclear Energy Institute's (NEI) report estimated that energy generation from nuclear sources cost $31.88/MWh in 2018, of which fuel costs comprised $5.98 (18.7%), capital costs $6.21 (19.5%), and operating costs $19.69 (61.8%). Capital costs had peaked in 2012 owing to equipment replacement and upgrades, whereas fuel costs experienced an upward trend between 2009 and 2013 owing to rising costs for uranium. Barring 2018, operating costs have remained relatively flat over the past decade (NEI, 2019). Between 2012 and 2018, the total generating cost for nuclear power plants operating in the U.S. declined by 25%. While capital costs declined 46%, fuel costs fell 25%, and operating costs were 14% lower. The decline in costs is promising, however, lower gas prices over sustained periods, mandates for renewable energy, and negative electricity prices present a disadvantage for nuclear power plants. This is also because nuclear power plants are better suited for baseload operations given their relatively low fuel costs. Furthermore, operating costs, which comprise most overall generating costs for a nuclear power plant, have experienced the least decline, thereby limiting the economic advantage of nuclear power plants.

Nuclear power plants represent critical infrastructure both from the perspective of the overall energy system and the private and public infrastructure. Protection of such critical assets is paramount, and disruptions or damage to this infrastructure systems can present an enormous threat to public safety and impose massive costs on the overall economy through direct and indirect pathways (Brown, Carlyle, Salmerón, & Wood, 2006). Physical protection systems integrate personnel, procedures, and equipment for the protection of assets against theft or other malevolent actions (Bowen et al., 2018; Garcia, 2007).

To adhere to the requirements of the Nuclear Regulatory Commission and conduct operations safely, nuclear power plants are required to maintain state-of-the art intrusion detection systems, highly trained personnel, equipment, and other infrastructure. These requirements are one of the most important contributors to a nuclear power plants O&M costs. Meanwhile, cost and performance analysis is frequently used for evaluating strategic and tactical decisions to manage physical security systems (Hicks et al., 1999). Since nuclear power plants are faced with unfavorable economic prospects, evaluating the efficacy of their expenditures on O&M to identify areas for improvement is a critical research gap.

## 1.2 Current Physical Security Posture

While the U.S. commercial nuclear power industry is among the most robust and well-protected critical infrastructures in the world, increased costs of regulation in nuclear security threaten the long-term operation and future of the existing fleets. The US NRC and the industry approach to maintaining effective security at a plant includes various security programs, each with its own individual objectives that, when combined provide a holistic approach to maintaining effective security of the plant. There has been a continued buildup within these various security programs for commercial nuclear power producing what is widely considered to be the most robustly fortified and protected commercial critical infrastructure in the world.

As part of the research within this effort, the cost of physical security at U.S. commercial nuclear power plants were studied. The cost data is obtained from the Electric Utility Cost Group (EUCG), which is a group of energy companies from around the world participating with the objective of sharing information to help individual companies improve their operating, maintenance, and construction performance (EUCG, 2020). In the current effort, a non-disclosure agreement is executed between EUCG and Idaho National Laboratory (INL) enabling EUCG to share proprietary cost data of physical security at U.S. commercial nuclear power plants. The cost data comprises of four parts: 1) Labor cost, 2) Service cost, 3) Material cost, and 4) Others. Due to proprietary nature of the cost data, dollar values of the cost are not published here. Figure 1 shows the evolution over the last twenty years the percentage contribution of the four costs towards the total cost of physical security at U.S. commercial nuclear power plants. It is interesting to note the rapid increase in the contribution from labor cost since year 2008, indicating the shift of physical security posture towards labor-intensive approach. Labor costs account for more than 60% of the total physical security budget, and its contribution continues to rise.

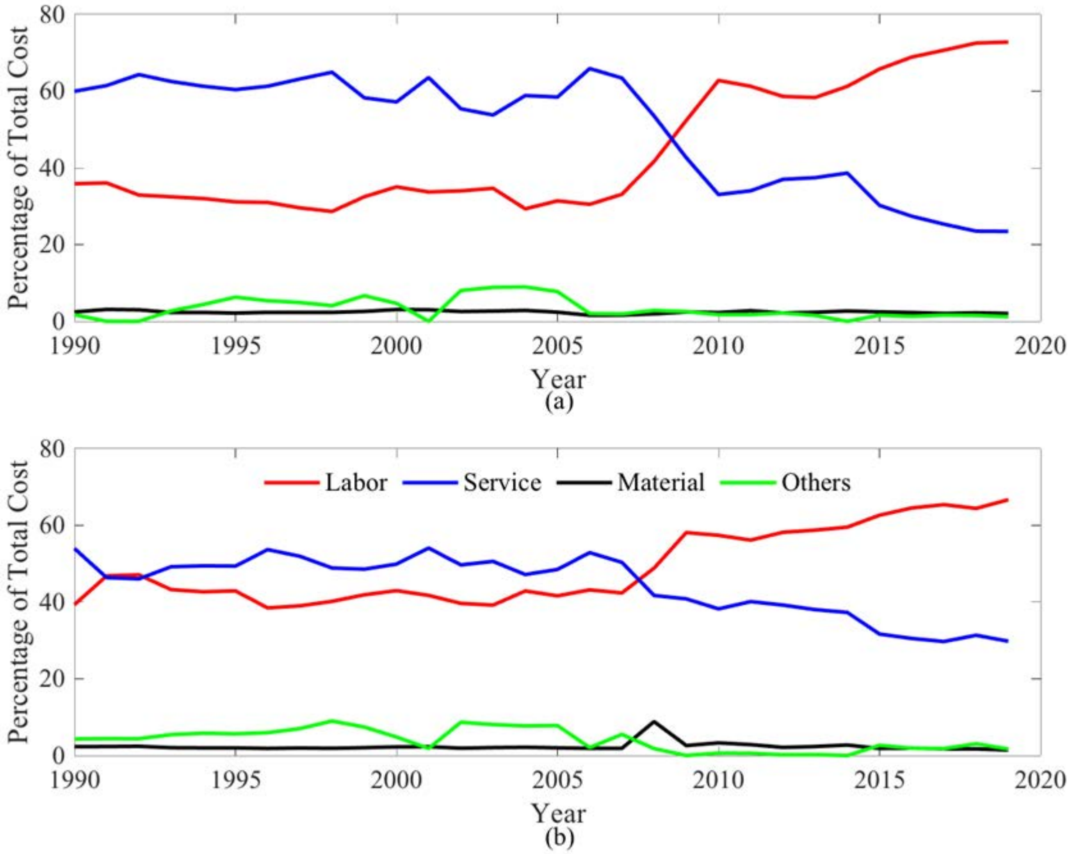


Figure 1. Evolution from 1990 to 2019 of percentage of total cost for the four types of physical security costs: Labor, Service, Material and Others at (a) Single Unit nuclear power plants and (b) Dual Unit nuclear power plants. Notice the continued increase in contribution of labor costs since 2008. Data source: EUCG.

# 2. ANALYTICAL FRAMEWORK

This section provides the background on two analytical frameworks of FoF modeling and the Econometric analysis. The two frameworks have been popular individually, FoF for physical security performance effectiveness evaluations and econometric models for various applications.

## 2.1 Force-on-Force Model

The design and analysis of physical protection systems constitute 1) identification of critical assets, 2) identification of threats that might undermine capability 3) identifications of the consequences/impacts of impairment these assets, and 4) analysis of effectiveness of the elements used for physical protection (Hicks, Snell, Sandoval, & Potter, 1999). FoF inspections are used to assess and verify the preparedness of a nuclear power plant to protect against an adversarial attack (NRC, 2019). The inspections are intended to provide a realistic assessment of the security posture of a nuclear power plant against a threat consistent with the design basis threat, which also helps identify any deficiencies that require to be addressed.

There are several levels and tools available for FoF modeling. The most basic level of modeling considered Table Top. There are several ways that a Table Top exercise can be conducted, but in its basic form, a group of Subject Matter Experts using a map or diagram of a facility simply postulate many attack scenarios and develop possible adversary attack paths and possible protective force responses. From these scenarios, the planers can determine what types of terrain and obstacles will have to be traversed and overcome. Once this has been determined, resources such as the Sandia developed Access Delay Technical Transfer Manual can be used to:

1. Determine what tools, ranging from mechanical to explosives, can be used to defeat the obstacle
2. For each tool, what will be the weight, and size
3. For each tool, what will be the time requirements to defeat the obstacle
4. And finally, for each tool, what will be the signature of the action, i.e., will it make a lot of noise over a longer period of time, will it have a bright light and heat signature, will it produce a loud explosion and shock wave that will be easily heard and felt by people inside the facility. Any of these signatures could affect the probability of detection and the probability of assessment.

Once the path and tool requirements have been determined, the planers can start to determine the number of adversaries required, the total adversary tool kit, including each adversary's individual part of the tool kit, and the basic adversary steps and corresponding rough timeline. Once this has been accomplished, more advanced computer modeling tools are used to refine and analyses the attack scenario.

Another version of the "Table Top" is often used in actual FoF exercises. When a situation is reached during the exercise that would be unsafe or cause damage to the facility, the exercise is usually put on hold at that stage, and the participants verbally step through the sequence. The expected outcome is determined by using accepted standards, such as the Sandia Access Delay Technical Manual, Computer modeling or performance testing that has been conducted and documented. Examples of this type of action are breaching of an obstacle. Whereas it is not possible, or wise, to actual detonate the explosives and destroy part of the plant's protective system, the adversaries would simulate many of the steps required to conduct the attack. The responding force would be verbally told what type of events they would be detecting; i.e., a loud noise, a bright flash, sensors or cameras going out. A hold is then placed on the exercise, while the adversary team is moved to the other side of the barrier. Once this has occurred, the exercise is resumed. This type of forced delays imposes a certain level of artificiality to the exercise. It is important that every step be taken to try and reduce this level of artificiality. The adversaries should be required to carry the equivalent weight of materials that would have been required and go through simulated actions to carry out the attack. Responding force personnel, should not be allowed to look around or observe actions during this time that would give them an advantage when the exercise resumes. Two phenomena that are difficult or impossible to account for during these delays are (1) during these forced delays, people are able to recover from physical exercise, and the human brain will remain active, reviewing the actions that have occurred, and (2) formulating possible scenarios that might be occurring, and formulating appropriate responses to these actions. The above two phenomena underline the extent to which FoF exercise can accurately simulate a real-life attack scenario.

More advanced tools are now being used by industry which use path analysis algorithms, human response models and Monte-Carlo simulation runs to evaluate attack scenarios and defense strategies. The main tools used by industry are AVERT by ARES Security (Ares Security Corp, 2020) and Simajin by RhinoCorps (RhinoCorps Ltd. Co, 2020). These tools allow utilities to model their facility in a 3D environment with detection and protection equipment such as the PIDAS, BRE's, vehicles, etc. (Figure 2). The modeler can also input time requirements for movement, delays, probability hit probability kill, cover protection, firearms, equipment, etc. After a model is complete it has several uses, such as evaluating likely attack routes; evaluating current defense measures; or testing specific scenarios. Results from these tools can give a statistical analysis or the probability of success for attacks.

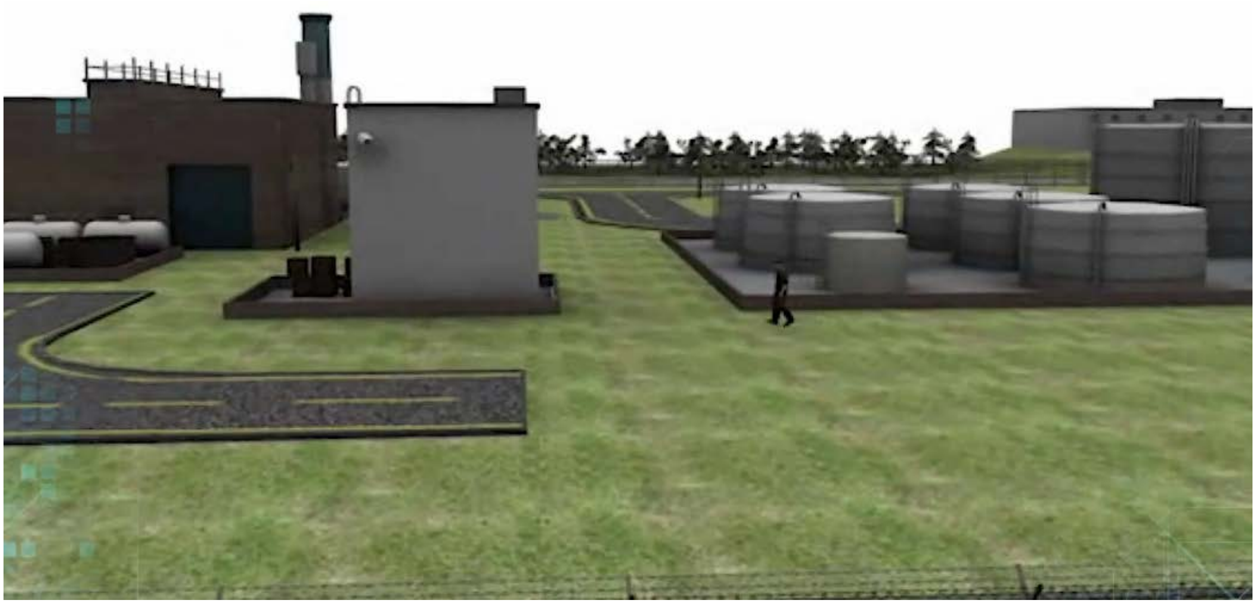

Figure 2. 3D model of a nuclear power plant in AVERT software

These modeling tools provide accurate modeling of scenarios and probable outcomes but focus on the attack itself. They do not include or vary the probability of attack, alert levels, environmental conditions, current plant conditions, operator actions during or after the attack, etc.

## 2.2 Econometric Analysis

Security risk models have empirically evaluated security threats in the context of burglary and auto theft (Schechter, 2005). For example, researchers assessed the efficacy of home security measures to predict the likelihood of break-ins at homes with different attributes and safety measures (Hakim, Rengert, & Shachmurove, 2000; O'Shea, 2000). However, such empirical assessments are not common in the literature for assessing security of critical assets. We utilize econometric tools to evaluate the effectiveness of the physical security at a nuclear power plant. Our analysis enables the identification of the relative importance of each component of the physical security posture included in the model. The objective is to evaluate tradeoffs between the components to identify potential opportunities to optimize physical security components while maintaining a specific level of system effectiveness.

The dependent variable (Y) for this analysis is the "effectiveness" of the nuclear power plant's FoF security posture. Effectiveness is represented as a binary variable that takes the value of '1' when the security posture successfully defends against an adversarial attack, and '0' when the posture is deemed ineffective and fails to protect core assets of the nuclear power plant. We use the logistic regression framework to analyze the data as the model can be used to estimate the probability of a "success" occurring given the values of the independent variables (Xs)(Wooldridge, 2016). The probability of an effective security posture, P(Y), can be expressed as:

$$P(Y) = \frac{1}{1 + e^{-(\beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_n X_x)}}$$

the X's represent the variables included in the FoF security posture classified as personnel, weapons and barriers, and locations. Using the logit model ensures that the estimated probabilities are always between 0 and 1, and following from (Agresti & Kateri, 2011; Greene, 2003) the link function G(z), has a cumulative distribution function given by:

$$G(z) = \frac{e^z}{1 + e^z}$$

where z is the composite index of all the explanatory variables.

The ratio of the probability of successes over the probability of failure, commonly called the odds ratio, indicates the resulting change in odds due to a one-unit change in the predictor (Field, Miles, & Field, 2012). The odds ratio is expressed as:

$$\text{Odds} = \frac{\text{P(Y)}}{1 - \text{P(Y)}}$$

and is equivalent to the exponential of the β coefficients from the logistic regression. The odds ratio is useful to indicate the direction of influence on the dependent variable. However, in models with non-linear transformations of the independent variables, the interpretability of the odds-ratio is not straightforward. We estimate the average marginal effects of the covariates on the outcome in order to provide a more intuitive interpretation into the relationship between the variables (Hosmer Jr, Lemeshow, & Sturdivant, 2013; Leeper, 2017).

# 3. ASSESSMENT OF INVESTMENT

The analysis of investment is performed based on a specified level of security posture effectiveness as determined by the FoF analysis. The FoF analysis determines the effectiveness of the physical security posture given a range of system components, for example security guards, intrusion detection system, remotely operated weapon systems (ROWS), active and passive barriers etc.

Given a level of security effectiveness, we evaluate the cost efficiencies arising from incorporating ROWS into a hypothetical physical security posture. The characteristics of ROWS such as acquisition costs, installation, useful life, and system performance are incorporated into the analytical framework. Figure 3 provides an illustration of the steps involved for evaluating the impact of including ROWS into the security posture.

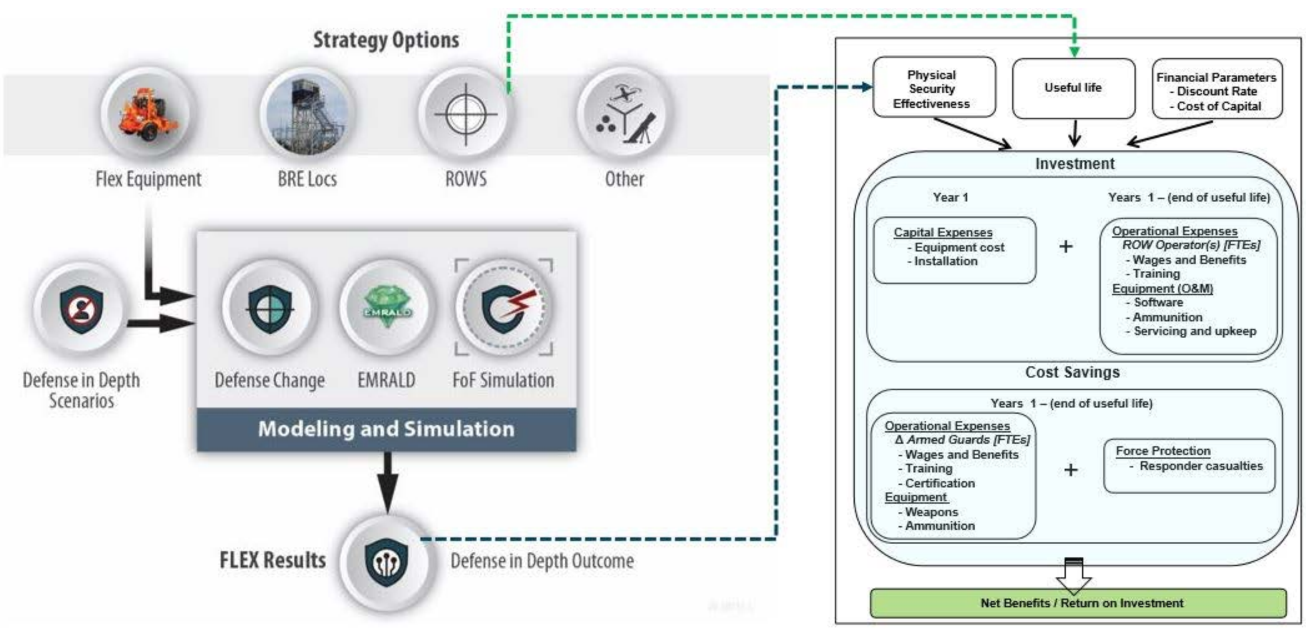


Figure 3. Economic Analysis of including ROWS into security posture

If the cost savings (benefits) arising from the incorporation of ROWS outweigh the costs (investment) over the life of the asset, the Benefit-Cost (B/C) ratio will exceed 1. For long-term investments, a financial metric called the Net Present Value (NPV) us useful for evaluating an investment when the benefits and costs accrue over multiple and disparate time periods. The calculation for NPV discounts all the benefits and costs to a common time period expressed as a monetary unit (Bojanc & Jerman-Blažič, 2013).

$$NPV = \sum_{t=0}^{n} \frac{B_t - C_t}{(1+i)^t}$$

where $B_t$ and $C_t$ are the benefits and costs, respectively, $i$ is the discount rate and $t$ is time period, typically in years. While the NPV calculation is useful for evaluating multiple investment alternatives, the Internal Rate of Return enables as assessment of the discount rate that makes the NPV of an investment equal zero, i.e. the present value of the outflows is equal to the present value of the inflows.

$$0 = \sum_{t=0}^{n} \frac{B_t - C_t}{(1+IRR)^t}$$

# 4. MODEL VARIABLES AND COST DATA

A nuclear power plant can incur nearly $600 million in O&M related expenditures on an annual basis, of which security related O&M can account for over $34 million (approximately 6%). Payroll and overtime subcategories of O&M costs are typically the two most significant costs from a physical security standpoint. As a result, reduction in manpower at a nuclear power plant can translate into a sizeable cost savings on an O&M budget.

## 4.1 PERSONNEL AND PERSONNEL COSTS

The number of security personnel at a nuclear power plant would typically depend on the size of the premises to be protected and safety requirements, both regulatory and operational. The physical security team at a nuclear power plant comprises of a personnel team with officers across various ranks including captains, lieutenants, security officers, shift emergency communicators, management staff and relief staff. Security officers constitute the largest portion of the security team, nearly 40%. In addition, relief security officers are around 20% of the security team. Lieutenants make up less than 10% and have an equal number of positions in relief staff. Finally, the proportion of captains to lieutenants in terms of full time equivalent (FTE) staff is approximately 1:4. And captains to security officers is approximately 1:5. Management staff can be stationed at the nuclear power plant or at the headquarters and can be shared between two or more nuclear power plants. Figure 4 shows a comparison between the proportion of FTEs by position/rank for a physical security team at a nuclear power plant.

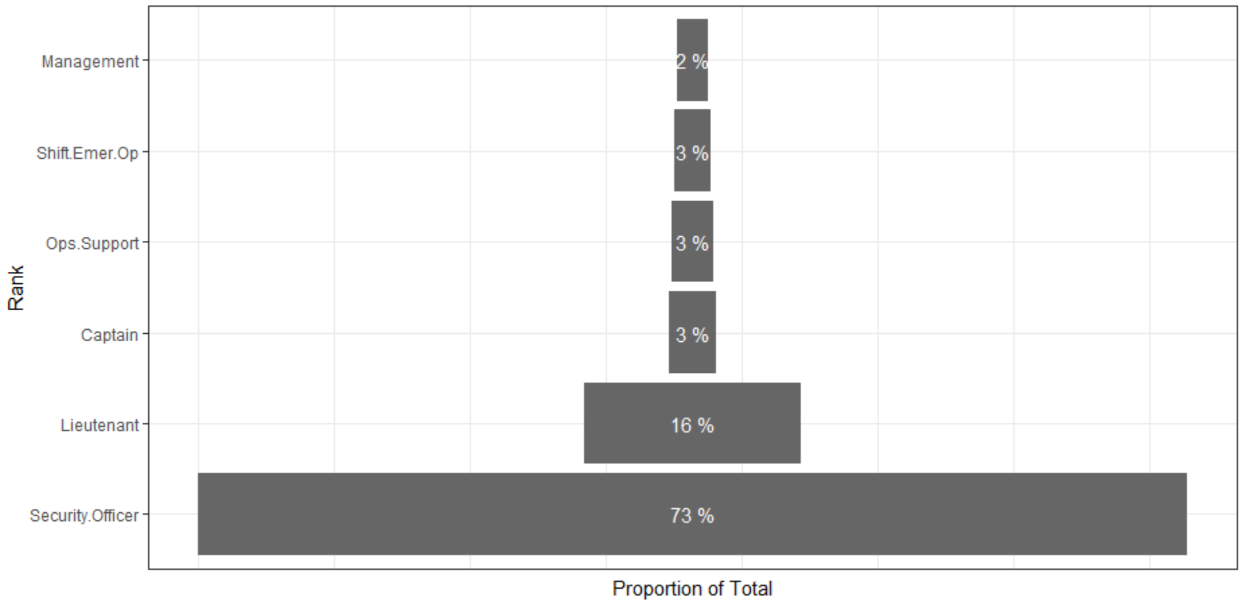


Figure 4. Proportion of FTEs by position/rank within a security team at a nuclear power plant

Delving deeper into the physical security budget provides insights into its various components. Security budgets comprise of labor costs, non-labor costs, general and administrative costs, as well as provisions for taxes and performance improvements.

*Labor Expenses*

Labor related expenses account for nearly 2/3rd of physical security budget expenses. The two major components of this category are wage-related expenses and contributions under the Federal Insurance Contributions Act, Federal and State Unemployment Insurance, Worker's compensation, and general liability. The total wage expenses typically allocate for wage payments, overtime premium, training pay, as well as provides for vacation pay, personal time, holiday pay and funeral payments. Out of the overall expenses incurred on labor, wage related expenses account for nearly 91% whereas non-wage expenses constitute the remaining 9%. Not surprisingly, labor expenses depend on the size of the workforce and can range between $7-11 million per year.

*Non-Labor Expenses*

Non-labor expenses at nuclear power plants include provisions for life and health insurance, 401(k) contributions, bonuses, expenses on medical examinations, as well as costs incurred for procuring uniforms, travel, and vehicles as well as allowances for boots and equipment. Together the non-labor expenses account for nearly 20% of total budget expenses. Within this category however, health insurance-related expenses comprise over 82% of all non-labor expenses with the next highest category being 401(k) contributions which are under around 7%. The other categories combined account for around 10-11% of non-labor expenses. From a physical security budget standpoint, non-labor expenses could range between $2-3 million on an annual basis for labor expenses for a workforce size delineated in the section above.

*Management Fee*

Management fees constitute a relatively small portion of the total budget expenses on physical security. Typically, these are shared between two or more power plants under the same operator. Management fees constitute general and administrative fees and provisions for profit (in case of subcontractors) and are between 6 and 6.25% of the total budget. Additionally, nuclear power plants make provisions for taxes as part of their overall earmarked expenses for physical security operations.

## 4.2 Other Equipment/Costs

ROWS can be equipped for lethal denial wherein the system can be operated by an officer located in a remote, well-secured location (Garcia, 2007). ROWS provide the benefit of accuracy, higher lethality, force protection, capability to zoom in or targets and utilize high powered sensors, as well as ability to detect thermal emissions to improve performance in darkness and bad weather (Hoffman, 2007). These systems have been utilized in conflict zones. Common Remotely Operated Weapon Station (CROWS) are estimated to cost over $200,000, not including the weapon (Hoffman, 2007). Information on cost of installation, O&M costs, training requirements for personnel to operate the equipment (for example simulators), training for maintenance and repair of equipment, as well as any other costs incurred to ensure successful deployment of ROWS within the nuclear power plants physical security posture are difficult to estimate.

Other non-lethal delay mechanisms including foam dispensers, smoke generators, entanglement devices, millimeter wave systems are potential candidates to modify the physical security posture (Garcia, 2007).

# 5. CASE STUDY AND DISCUSSION

A hypothetical attack scenario is considered for this analysis that comprises of an attempt to destroy two Emergency Diesel Generators (EDGs) by 5 adversaries. The potential variables that are part of the security posture of the nuclear power plant include armed guards, a smoke generator (non-lethal denial technology), tower guards, and two ROWS. The variables are coded as zeros and ones based on their presence or absence in the posture for each scenario. Similarly, the effectiveness of the security posture is also binary, classified as a success if the security posture is able to neutralize the attackers before the cause any damage to the EDG and failure if at least one of the EDGs is damaged. Based on the 5 variables included in the security posture, the possible combinations are 31. Each scenario was simulated 1,00,000 times to collect 3,100,000 observations.

The results presented in Table 1 indicate that ROWS had the largest influence on the effectiveness of the security posture. The odds ratio indicates that in the presence of ROWS the odds of achieving an effective physical security posture are over 11 times as compared to the odds in the case of a physical security posture without rows. Similarly, inclusion of ROWS increases the probability of attaining an effective physical security posture by approximately 0.32.

Table 1. Estimated Coefficients and Odds Ratios from Regression Model

| **Variable** | **Dependent Variable: effective** | **Odds Ratio** |
|---|---|---|
| Armed Responders | 0.359*** (0.003) | 1.4320 |
| Active Barriers | 0.218*** (0.003) | 1.2432 |
| Tower Guards | 0.175*** (0.003) | 1.1914 |
| ROW 1 | 2.417*** (0.004) | 11.2070 |

| Variable | Dependent Variable: effective | Odds Ratio |
|---|---|---|
| ROW 2 | 2.421*** (0.004) | 11.2611 |
| Constant | -1.462*** (0.004) | 0.2318 |
| Observations | 3,100,000 | |
| Log Likelihood | -1,308,295.0 | |
| Akaike Inf. Crit | 2,616,603.0 | |
| Note: *p<0.1; **p<0.05; ***p<0.01 | | |

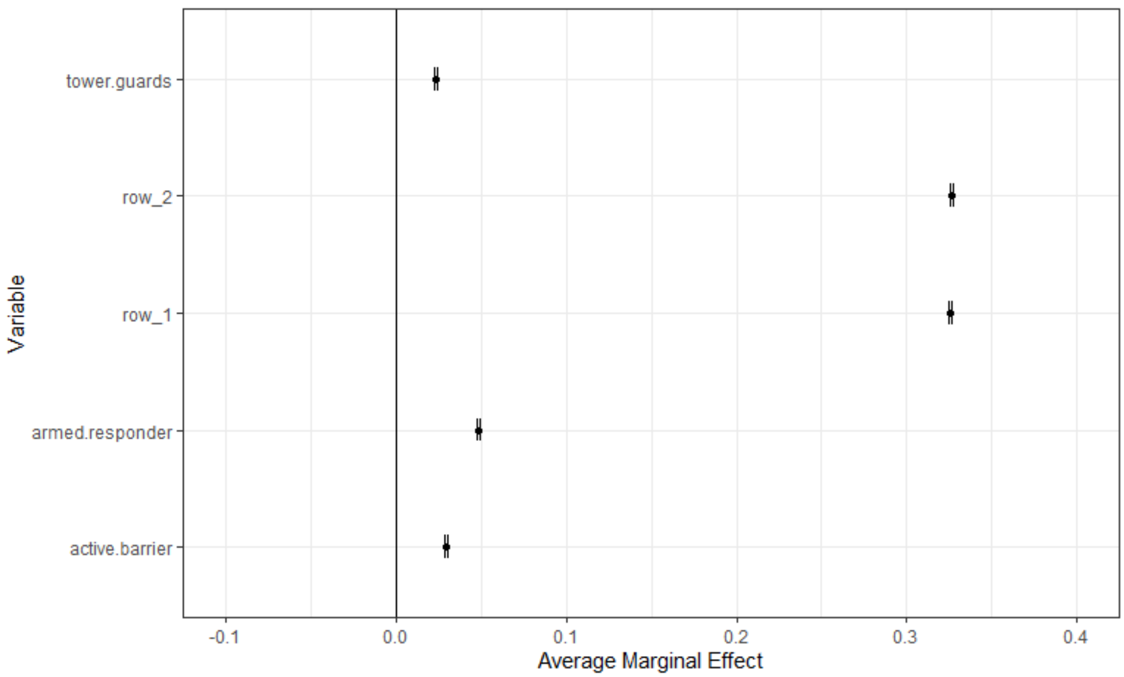


Figure 5. Average Marginal Effects for components of physical security posture

Figure 5 illustrates the values of average marginal effects corresponding to the five variables modeled. The high values of average marginal effects for the two ROWs indicate the high significance of ROWs in the physical security posture, compared to other variables. The analysis of investments in physical security encompass capital costs incurred on exterior protection systems (perimeter fences and sensors), passive barriers (bullet resistant enclosures, hardened doors and barriers), and active barriers (ROWS, foam dispensers, smoke generators, vehicle barriers). Costs related to the installation to make the components deployment ready are also part of the capitalized costs. Specific information pertaining to the useful life of assets and end-of-life salvage value are inputs for the cash flow analysis. The second component of costs pertain to O&M costs associated with the modified physical security posture including personnel costs, software and servicing costs, and other costs such as ammunition.

These costs are compared with the benefits/cost savings arising from the modified security posture such as those pertaining to reduced staffing needs, reduced need for training and other avoided costs, as well as benefits from reducing potential casualties of staff owing to reductions in combat roles. The specifics of the components of the modified posture are informed by the F-o-F analysis results. Finally, financial parameters such as discount rate assumptions, inflation, taxes, and depreciation are also incorporated to perform the cash flow analysis.

A spreadsheet-based modeling framework is shown in Appendix A. The framework presents an aggregated overview of the different components that can be used to evaluate the investments in physical security. Based on the availability of data, the framework can accommodate for greater levels of granularity to account for more detailed breakdowns of components and associated costs. In the current framework, the dollar values presented are to illustrate the workings of the model and are purely hypothetical.

# 6. CONCLUSION

This report describes the development of a framework that integrates results from Force on Force analysis with economic assessment to achieve two closely linked objectives: (1) Estimation of effectiveness of components of the physical security posture, and (2) Evaluation of investments in physical security using an estimated cash flow analysis. An econometric model is used for incorporating the success and failure of the physical security posture as determined from FoF models. The economic model incorporates various costs associated with physical security posture at a typical commercial nuclear power plant, such as labor and personnel costs, non-labor costs, equipment capital costs and operating costs. An investment assessment analysis is illustrated using a case study of performance and cost effectiveness of remotely operated weapons system in a hypothetical scenario. The framework provides a proof of concept towards achieving performance and cost effectiveness in design and operation of physical security posture at nuclear power plants.

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# Appendix A
# Spread-sheet Model for Evaluating Investments in Physical Security

**Model Inputs**

| *Cost/Investments* | |
|---|---|
| Capital Costs | $ 700,000 |
| Equipment | $ 200,000 |
| Installation | $ 500,000 |
| Project Life | 15 |
| Salvage Value | 0 |

| *Operational Costs* | |
|---|---|
| Personnel | $ 311,230 |
| # of personnel | 1 |
| Equipment O&M | $ 212,000 |
| Software and Servicing | $ 200,000 |
| Ammunition | $ 12,000 |

| Benefits/Cost Savings | |
|---|---|
| Avoided Personnel Costs | $ 622,460 |
| # of personnel reduced | 2 |
| Other Avoided costs | $ 20,000 |
| O&M | $ 10,000 |
| Ammunition | $ 10,000 |
| Avoided Casualties | $ 20,000 |

| | |
|---|---|
| Discount Rate | 0.08 |
| Inflation | 0.025 |
| Tax rate | 0.35 |
| Depreciation | 0.15 |

| | Years | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
| Cashflow Analysis | | | | | | | | | | | | | | | | |
| Revenues/Benefits | | $ 652,460 | $ 668,772 | $ 685,491 | $ 702,628 | $ 720,194 | $ 738,199 | $ 756,654 | $ 775,570 | $ 794,959 | $ 814,833 | $ 835,204 | $ 856,084 | $ 877,486 | $ 899,423 | $ 921,909 |
| Costs | $ (700,000) | $ 511,230 | $ 524,011 | $ 537,111 | $ 550,539 | $ 564,302 | $ 578,410 | $ 592,870 | $ 607,692 | $ 622,884 | $ 638,456 | $ 654,418 | $ 670,778 | $ 687,548 | $ 704,736 | $ 722,355 |
| EBITDA | | $ 141,230 | $ 144,761 | $ 148,380 | $ 152,089 | $ 155,892 | $ 159,789 | $ 163,784 | $ 167,878 | $ 172,075 | $ 176,377 | $ 180,786 | $ 185,306 | $ 189,939 | $ 194,687 | $ 199,554 |
| Depreciation | | $ 30,000 | $ 25,500 | $ 21,675 | $ 18,424 | $ 15,660 | $ 13,311 | $ 11,314 | $ 9,617 | $ 8,175 | $ 6,949 | $ 5,906 | $ 5,020 | $ 4,267 | $ 3,627 | $ 3,083 |
| EBIT | | $ 111,230 | $ 119,261 | $ 126,705 | $ 133,666 | $ 140,231 | $ 146,478 | $ 152,469 | $ 158,261 | $ 163,900 | $ 169,428 | $ 174,880 | $ 180,286 | $ 185,671 | $ 191,060 | $ 196,471 |
| Taxes | | $ 38,931 | $ 41,741 | $ 44,347 | $ 46,783 | $ 49,081 | $ 51,267 | $ 53,364 | $ 55,391 | $ 57,365 | $ 59,300 | $ 61,208 | $ 63,100 | $ 64,985 | $ 66,871 | $ 68,765 |
| EBIT(1-Taxes) | | $ 72,300 | $ 77,520 | $ 82,358 | $ 86,883 | $ 91,150 | $ 95,211 | $ 99,105 | $ 102,870 | $ 106,535 | $ 110,129 | $ 113,672 | $ 117,186 | $ 120,686 | $ 124,189 | $ 127,706 |
| Add Depreciation | | $ 30,000 | $ 25,500 | $ 21,675 | $ 18,424 | $ 15,660 | $ 13,311 | $ 11,314 | $ 9,617 | $ 8,175 | $ 6,949 | $ 5,906 | $ 5,020 | $ 4,267 | $ 3,627 | $ 3,083 |
| Net Cash Flow | $ (700,000) | $ 102,300 | $ 103,020 | $ 104,033 | $ 105,306 | $ 106,811 | $ 108,522 | $ 110,419 | $ 112,487 | $ 114,710 | $ 117,077 | $ 119,578 | $ 122,206 | $ 124,954 | $ 127,816 | $ 130,789 |
| Discount Factor | 1 | 0.926 | 0.857 | 0.794 | 0.735 | 0.681 | 0.630 | 0.583 | 0.540 | 0.500 | 0.463 | 0.429 | 0.397 | 0.368 | 0.340 | 0.315 |
| Discounted CF | $ (700,000) | $ 94,722 | $ 88,323 | $ 82,585 | $ 77,403 | $ 72,693 | $ 68,387 | $ 64,429 | $ 60,773 | $ 57,384 | $ 54,229 | $ 51,285 | $ 48,530 | $ 45,945 | $ 43,516 | $ 41,230 |

| | |
|---|---|
| NPV | 251435 |
| IRR | 13% |

| Depreciation Calculation | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Beginning Value | | $ 200,000 | $ 170,000 | $ 144,500 | $ 122,825 | $ 104,401 | $ 88,741 | $ 75,430 | $ 64,115 | $ 54,498 | $ 46,323 | $ 39,375 | $ 33,469 | $ 28,448 | $ 24,181 | $ 20,554 |
| Depreciation | | $ 30,000 | $ 25,500 | $ 21,675 | $ 18,424 | $ 15,660 | $ 13,311 | $ 11,314 | $ 9,617 | $ 8,175 | $ 6,949 | $ 5,906 | $ 5,020 | $ 4,267 | $ 3,627 | $ 3,083 |
| Ending Value | $ 200,000 | $ 170,000 | $ 144,500 | $ 122,825 | $ 104,401 | $ 88,741 | $ 75,430 | $ 64,115 | $ 54,498 | $ 46,323 | $ 39,375 | $ 33,469 | $ 28,448 | $ 24,181 | $ 20,554 | $ 17,471 |

EBITDA: Earnings Before Interest, Taxes, Depreciation, and Amortization
EBIT: Earnings Before Interest and Taxes