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A Cost Effectiveness Analysis of Using Alternate Materials for Non-Skid in Shipboard Applications

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ABSTRACT

This MBA project investigated and evaluated the cost effectiveness of using alternative materials in shipboard construction, specifically in the area of non-skid application on surface ships. This project identified the costs and benefits of different alternatives to the currently used non-skid and identified whether these alternatives would be feasible for use onboard Navy ships. The analysis indicates that the Thermion alternative shows the potential for the most significant cost savings across the Surface Fleet, while the Liquidmetal alternative also shows potential for savings compared to the current status quo. It is recommended that both the Thermion and Liquidmetal alternatives be prototyped on Navy warships to better define their costs and benefits and evaluate their suitability for use.

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I. INTRODUCTION

The Navy has used an adhesive based compound as a deck covering on its ships for the last fifty years. The covering is intended to make walking and working on the deck safer at sea by making the deck very rough, rather than smooth and slick. Uncounted sailors' lives have been saved by the increased traction available as ships pitched and rolled on the open ocean. The only disadvantage to the non-skid covering used is its short useful life, which ranges from 6 months to 3 years, depending on the amount of traffic and abuse experienced. The costs involved in reapplying non-skid coatings are quite significant.

> Currently, the Navy applies over 100,000 gallons of organic based non-skid deck coatings per year. Application and removal of organic based non-skid coatings generates large quantities of hazardous materials and releases known carcinogens and crystalline silica into a ship's atmosphere and waste stream. Proper disposal of the hazardous materials places significant strain on budgets dedicated to environmental compliance. Life-cycle costs are also impacted due to increasing non-skid maintenance costs, including application, repair and removal of deck coatings. The Navy spends about $27 Million per year on non-skid deck coating maintenance for East Coast ships alone.[1]

In recent years, new technologies have emerged with the potential to provide more durable materials for use as non-skid. Among these materials are new aluminum-ceramic alloys and amorphous metal alloys. These materials could be applied once, and have an estimated service life of a decade or more in a shipboard environment. Their

[1] NAVSEA NSWC-Carderock, www.dt.Navy.mil/code60/code643/nonskid/nonskid.htm

disadvantages include a more technical application process and increased costs. They use metal spraying processes that are highly skilled evolutions; not a task for the ship's force to be attempting at sea.

Our goal was to investigate the cost effectiveness of using these new materials for non-skid coatings in place of the traditional adhesive based system in use today. The techniques for Cost Effectiveness Analysis (CEA) described in Office of Management and Budget (OMB) Circular A-94 were used to evaluate the costs of each possible alternative in present value terms.

The project report is divided into five chapters. After this introduction, the next chapter is a literature review addressing the major resources consulted for the project. Chapter III discusses the techniques analyzed for non-skid applications, including the current system, and the amorphous metal alloys and metal arc spray systems available today. Chapter IV is the CEA itself, including a sensitivity analysis of results. Chapter V is our recommendations for future action involving Navy non-skid applications.

II. LITERATURE REVIEW

Data regarding the use of amorphous metals in military applications are very limited. Currently, the Defense Advanced Research Projects Agency (DARPA) has commissioned the Structural Amorphous Metals (SAM) project to study and determine the future military uses of these materials. Data were also taken from two commercial sources; Liquidmetal Technologies and Thermion Inc.

Liquidmetal specializes in amorphous coatings to prevent industrial corrosion. This type of coating has the potential to reduce preservation and maintenance costs compared to the current Navy non-skid.[2] Data from Thermion were taken as a second alternative to the amorphous coating provided by Liquidmetal. Thermion uses an aluminum-ceramic based coating that shares many of the advantages of amorphous metals. The references collected for the cost effectiveness analysis of alternative non-skid materials are categorized into military, commercial, and financial selections.

A. Military References

1. Naval Ships Technical Manual, Chapter 634.

This reference outlines the standards of non-skid coatings for applications to weather decks, flight decks, and hangar decks of naval vessels.[3] Further, this reference breaks down the different types of currently used non-skid and their performance parameters. Chapter 634 does not account for the use of amorphous metals.

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[2] Liquidmetal Technologies web site (www.liquidmetal.com)
[3] NSTM 634, p.634-1.1.

NSTM 634 also outlines several specifications for the use of non-skid. These serve as benchmarks for all current and future materials used onboard naval vessels. Most notably are the coefficient of friction requirements. These requirements establish the basic parameters for deck resistance to friction in different environments. Next, the reference delineates specifications that outline weight, and the service life for each type of non-skid. These specifications are important in determining the selection of replacement materials for current Navy non-skid. The properties of the alternate materials considered must meet and exceed these standards in order for these materials to be considered as an acceptable alternative.

2. Structural Amorphous Metals Program Overview.

The second military reference is the "Structural Amorphous Metals Program Overview," a Microsoft PowerPoint presentation prepared by Dr. Leo Christodoulou, the director of the SAM program, for the purpose of communicating the DARPA project to each of the military services. The reference first establishes DARPA's interest in amorphous metals by explaining the science behind the unique material. This includes the comparison of crystalline (normal) metals with amorphous metals as described in Chapter III. The reference concludes that DARPA intends to explore the formation and evolution of these materials in military applications. Further, DARPA is investigating the feasibility of developing new fabrication processes that can produce these metals in bulk. As a result, the SAM project intends to develop amorphous metals that can be used in ship and aircraft construction to improve toughness and reduce life-cycle costs.

3. Navy Seaborne Materials Opportunities for Structural Amorphous Metals.

The third reference is the "Navy Seaborne Materials Opportunities for Structural Amorphous Metals," a Microsoft PowerPoint presentation prepared by Dr. William Messick under the guidance of Dr. Christodoulou. This reference was used in conjunction with the "Structural Amorphous Metals Program Overview" and specifically targets the use of amorphous metals in naval ship construction. Dr. Messick also concentrates on the corrosion resistance benefits of amorphous metals. The reference explains that the United States Navy spends an estimated $2 Billion annually on material preservation and maintenance. The use of amorphous metals in ship construction could reduce these costs significantly and extend the life of each ship.[4] Further, the reference outlines future project goals that will help the Navy achieve savings in total ownership costs.[5] These include reduced costs in metal fabrication, development, maintenance, and disposal. Finally, the reference closes with the future application opportunities of amorphous metals and recommends continued research to achieve these goals.

B. Commercial References

1. Thermion Ceramic Core Non-skid Presentation.

The second commercial reference is the "Ceramic Core Non-skid" PowerPoint presentation by Thermion, Inc. This

[4] Messick, W. Navy Seaborne Materials Opportunities for Structural Amorphous Metals. Arlington, VA. June 6, 2000.
[5] ibid.

reference opens with the discussion of the breakdown of the aluminum-ceramic composite, which is made up of 54% aluminum and 46% ceramic powder. This makes the substance extremely light, only 0.5 lb/ft^2, which exceeds NSTM 634's specifications for type I non-skid. The reference also discusses the method of application. This is done by using a 3/16" diameter twin wire arc-spray. This is the common industrial method for applying these coatings to steel, as well as the application of amorphous materials. The application process is illustrated below:

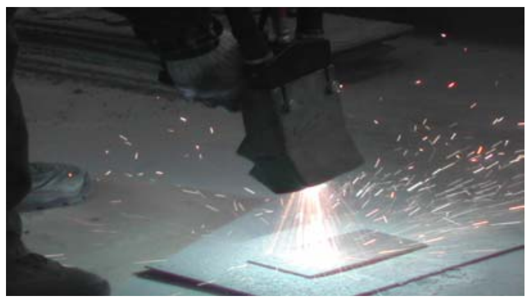

Figure 2.1 - Thermal spray application (From Thermion, Inc.)

The reference also discusses the benefits of using the ceramic non-skid as an industrial coating. The aluminum-ceramic material bonds with the steel to prevent corrosion from forming on, or under the non-skid application. The contractor's projected life expectancy of the material is 50 years. However, due to the high operational tempo of naval surface vessels and their extreme operating environment, the life expectancy will likely be significantly reduced. Even an 80% reduction would exceed the parameters set by NSTM 634.

2. Liquidmetal Technologies web site (www.liquidmetal.com).

Liquidmetal was created by researchers investigating new amorphous materials at the California Institute of Technology. Dr. William Johnson and Dr. Atakan Peker had been following amorphous research from its initial theoretical concepts in the 1950’s. In 1992, the two scientists were researching materials that could be useful in the defense and aeronautical industries. They discovered and patented several materials that they felt could be used successfully in commercial sectors. The two scientists then started their own company, which has evolved into Liquidmetal Technologies.

The web site describes the background of the company and outlines the different departments and products that Liquidmetal Technologies offers. This includes a complete summary on the fundamental differences between crystalline and amorphous metals. Next, the web site provides a breakdown of the different applications offered by the company. These include industrial coatings, defense applications, electronic casings, medical devices, sporting goods, and space projects.

The industrial coatings section is the point-of-interest for this project. Here, the web site describes the use of amorphous metals in coating boiler tubes, pumps, and heavy equipment. The web site finally describes the non-skid material (LMC-16), which is composed of various alloys in a proprietary mix. The non-skid alloy is applied using a 1/8” diameter twin wire arc-spray technique that bonds the material to a steel plate. This creates an amorphous non-skid that provides high stress abrasion resistance for both personnel and equipment.[6]

3. Mechanical Engineering Reference Manual for the PE Exam.

This reference is a study guide that is used by students to prepare for the Professional Engineer (PE) Exam. The book contains a section on metallic properties that explains the fundamentals of basic metallurgy. The section, Chapter 46: Material Properties and Testing, outlines the properties exhibited by conventional, crystalline metals. These include tensile strength, yield strength, ductility, and toughness. This chapter serves as the foundation for describing the scientific background of normal crystalline materials for this cost effectiveness analysis.

C. Financial References

1. Cost-Benefit Analysis: Concepts and Practice.

This reference provides background information on the theory behind cost-benefit analysis and its economic origins. The book discusses two types of analytical methods, cost benefit analysis (CBA), and cost effectiveness analysis (CEA). The book describes the CBA as an analysis that must monetize all pertinent variables.[7] By doing this, the CBA attempts to categorize all of the subject variables and assign some sort of monetary value to

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[6] Liquidmetal Technologies web site (www.liquidmetal.com)

[7] Boardman, A., Greenberg, D., Vining, A. and Weimer, D. Cost-Benefit Analysis, Concepts and Practice, Second Edition. Prentice Hall, 2001, p 2.

complete the analysis.[8] The CEA is described as an alternative to using the cost-benefit analysis. Here, the reference recommends the use of a CEA when the analysis seeks to monetarily quantify all of the cost variables, but is constrained by the data. The analysis is unable to assign a monetary value to all of the variables and instead, attempts to rank alternatives by holding benefits constant and comparing costs.[9]

2. Office of Management and Budget Circular A-94 Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs.

This reference acts as the foundation for financial analysis on all government programs. It covers such topics as net present value (NPV), the use of inflation, and the discount rate policy. The purpose of this reference is to educate government officials on the proper planning and execution of long term programs.[10] Further, this reference serves as a guide for proper financial planning by establishing well-informed, decision making processes.[11] As a result, the use of this guide provides the reader with the materials to conduct a proper cost effectiveness analysis.

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[8] ibid, p. 3.
[9] ibid, p. 5.
[10] OMB A-94 Circular, p 1.
[11] ibid, p.1.

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III. BACKGROUND AND ALTERNATIVES

A. Material Properties

In order to understand the benefits presented by the use of amorphous metal in ship construction, it is necessary to briefly describe how the atomic structure of a metal contributes to its material properties.

As do all alloys, steel used in shipbuilding contains several constituent components – iron, nickel, chromium, and molybdenum, for example. In these conventional alloys, the atoms arrange themselves in a repetitive or crystalline pattern. It is from this crystalline structure that metals and alloys derive their material properties. These three-dimensional patterns may take several forms, such as face-centered cubic, body-centered cubic, and hexagonal close-packed, as shown in Figure 3.1. Each of these patterns repeats itself throughout the entire material, such that when viewed through an electron microscope, it typically appears as in Figure 3.2.

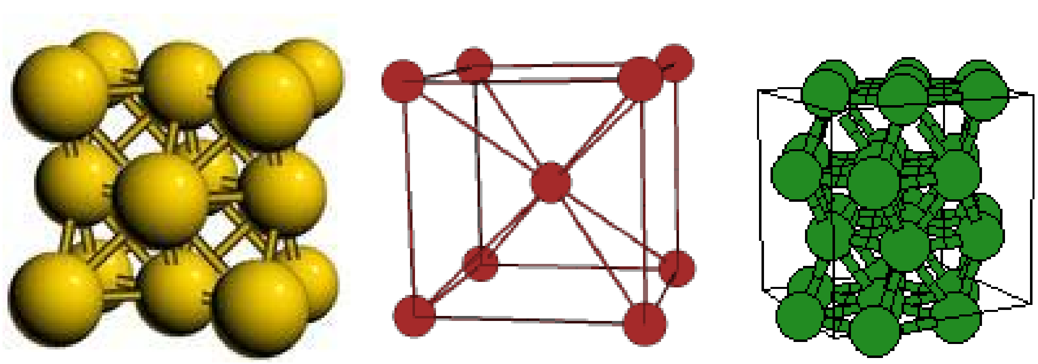

Figure 3.1 (left to right) - Face Centered Cubic, Body Centered Cubic, Hexagonal Close Packed. (From http://cst-www.nrl.navy.mil)

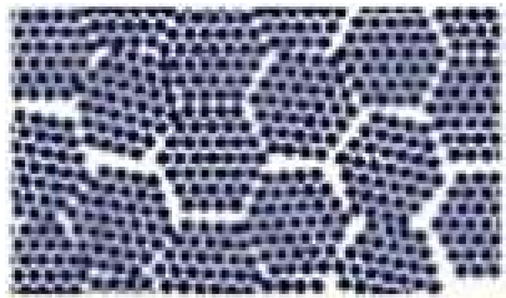

Figure 3.2 – Crystalline structure showing grain boundaries. (From Liquidmetal Technologies, Inc.)

During the formation of an alloy, the alloy's constituents will generally group themselves into patterns dependent upon their electrochemical compatibility with each other. This compatibility dictates the shape of the pattern the constituents will form. In the case of Figure 3.2 above, the constituent atoms have taken a hexagonal shape. These hexagonal groups are known as crystals.[12] The border between each crystal is a grain boundary.

In general, the size and shape of the crystal as well as the quantity and geometry of grain boundaries determine the material properties of a metal. These properties include:

> Tensile Strength – the maximum longitudinal stress a material can support without mechanical failure.[13]
>
> Yield Strength – the maximum stress a material can support before experiencing plastic, or non-reversible, deformation.[14]
>
> Ductility – the measure of a material's ability to plastically deform or elongate before failure

[12] In general, these crystals do not form a regular shape as shown in Figure 3.2.
[13] Lindberg, Michael R. Mechanical Engineering Reference Manual for the PE Exam, 10th Edition. Professional Publications: Belmont, CA, 1998. P. 46-2.
[14] ibid, p. 46-2.

relative to when the material first begins to plastically deform.[15] It is a measure of a material's "stretchiness."

Toughness – The ability to absorb energy and withstand high stresses without fracturing.[16]

Amorphous alloys differ from conventional ones in that instead of a repetitive, ordered crystal structure, the constituent atoms are in random orientations, as shown in Figure 3.3.

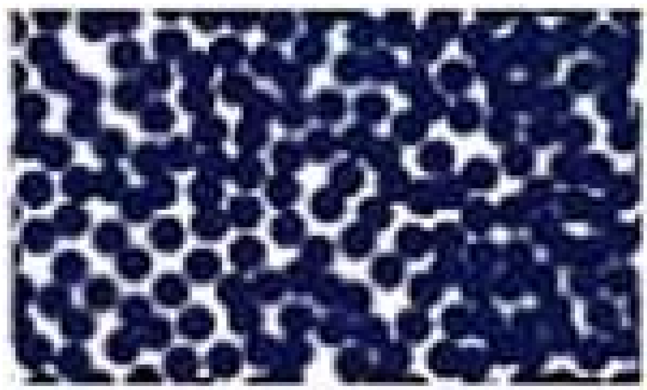

Figure 3.3 – Amorphous metal structure (From Liquidmetal Technologies, Inc.)

Amorphous metals have advantages over conventional materials due to their lack of grain boundaries. In conventional alloys, these grain boundaries are often the initiation sites for mechanical failure. The absence of these failure sites in amorphous alloys allows for very unique properties. For example, amorphous alloys exhibit superior strength and toughness compared to conventional alloys, whereas in conventional metals, strength and toughness are traded off for one another.[17]

[15] ibid, p. 46-5.
[16] ibid, p. 46-6.
[17] Christodolou, L. Structural Amorphous Metal Pre-Proposal Workshop. Arlington, VA. June 6, 2000.

Amorphous alloys also have a much higher corrosion and wear resistance than their conventional counterparts due to their unique atomic structure. This structure counters corrosion in two significant ways. First, the random atomic structure gives these alloys a significantly higher level of hardness, referring to a material's resistance to local deformation. This hardness precludes most macroscopic flaws in which oxidation may occur. Second, any surface defects are still resistant to oxidation, due to the behavior of valence electrons within the alloy's atoms. Essentially, the alloy's atoms do not readily "give up" their electrons, thus precluding the start of corrosion. These and other properties show some variation with the chemical composition of a specific amorphous alloy. As such, optimization of some properties can be achieved to a certain degree by varying chemical composition.

B. Applications

With their unique properties, amorphous alloys have potential for use in a wide array of naval applications. DARPA is currently sponsoring several projects to explore their potential use in naval applications.

1. Hull Construction Materials.

DARPA is conducting research into the exploration of novel ferrous base compositions, synthesis of bulk materials, measurement of magnetic properties, and investigation of glass formability using atomistic modeling validated by atomistic structure determination. The main goal of these university-led interdisciplinary projects is to discover and develop an entirely new generation of naval steels based on non-magnetic bulk ferrous metallic glasses(amorphous metals).[18] The Navy feels that this type of research could significantly reduce the magnetic signature of its surface ship and submarine hulls. Additionally, use of the lighter amorphous alloys versus standard HY-80 or HY-100 steels could significantly increase the amount of stores onboard, including equipment and fuel.

2. Acoustics.

Another study focuses on finding a new way to increase damping for acoustic signature reduction for ships, and the submarine fleet. There are several world navies such as India, Pakistan, China, and Korea that possess quiet diesel submarines. Amorphous alloy applications could help widen the narrowing advantage the United States holds in submarine stealth. The ultimate goal of this focus is to allow United States submarines to achieve optimal stealth without sacrificing speed and deployability.

3. Minesweeping.

In the minehunting (MCH) and minesweeping (MCM) community, DARPA is conducting research that focuses on the increased resistance of amorphous structures to underwater explosions. Currently, the Navy's mine sweeper and hunter hulls are made of wood or Glass Reinforced Plastic (GRP). This limits their overall deployability due to the wear and tear on the hulls as they cross the world's oceans. Large distance movement of minesweepers involves the use of Offshore Heavy Transport ships. Though the use of non-metallic hulls in modern-day mine hunting and sweeping

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[18] Messick, W. Navy Seaborne Materials Opportunities for Structural Amorphous Metals. Arlington, VA. June 6, 2000.

operations has been very effective, it has forced the Navy to transport, base, and forward deploy some of these ships to Bahrain. This has been done in order to mitigate damage to the ships as they transit to the Persian Gulf as well as avoiding the cost of transporting them there.

4. Corrosion Resistance.

The Naval Surface Warfare Center Carderock Division is evaluating iron-based bulk structural amorphous materials and coatings for corrosion resistance. As the Navy's manpower numbers continue to dwindle and its ships' hulls continue to age, the need for hull preservation and repair will steadily increase.

A unique byproduct of this research is that since the iron-based systems will be designed to be very resistant to oxidation, this will allow processing them without atmosphere controls, which significantly reduces their cost. This cost reduction would result from a radical simplification of the techniques needed for handling hull plating in process. Traditional steels are highly prone to brittleness when welded in a normal atmosphere, requiring welding to be conducted in an artificial atmosphere of inert gases such as argon. By eliminating the need for this inert gas blanket, the welding process is simplified.

Ultimately, the production of iron-based structural amorphous metals in various forms may enable widespread incorporation of this new class of material into ship hulls in order to reduce upkeep costs, vastly extend system useful lives, and reduce total ownership costs.

5. Airframes.

DARPA has tasked several research laboratories to engage in the evaluation of aluminum and titanium-based structural amorphous materials for military airframes, specifically in applications for the F/A-18, as well as the Joint Strike Fighter. The greatest challenge to the designers of aerospace systems is to convert structural weight into performance. Reducing weight offers improved maneuverability, range and ceiling, and payload capacity.

One approach to achieving these improvements is through the introduction of new lightweight structural materials. This program seeks to develop and demonstrate a new class of aluminum alloys which can extend the operational capabilities of aluminum alloys well beyond the capability of current wrought products and replace heavier titanium in critical airframe and engine structure, achieving significant improvements in performance of advanced systems.

C. Life-Cycle Costs and the Status Quo

The Navy's operating environment is inherently unsafe and corrosive. These hazardous conditions affect all areas of the fleet, including various types of surface ships, aircraft, submarines, harbors, and docking facilities that are continuously exposed to marine environments. The primary defense against unsafe and slippery, weather-exposed areas has been the use of non-skid coatings applied on the deck. These non-skid coverings are textured, organic materials applied to steel, aluminum and GRP as a slip-resistant surface for personnel, vehicles and aircraft. This section will focus on the associated life-cycle costs of applying, maintaining, and resurfacing the decks of a Navy ship with the "status quo" non-skid coating.

The total annual direct cost of corrosion incurred by all of the military services for systems and infrastructure is estimated at $9.01 Billion in 2002. These can be broken down into the following components:

1. Increased manufacturing costs due to corrosion engineering and the use of corrosion-resistant materials ($2.56 Billion per year).
2. Repairs and maintenance necessitated by corrosion ($6.45 Billion per year).

In 1993, the Navy alone spent approximately $2 Billion on corrosion prevention and repair.[19]

The aging of Navy ships poses a unique challenge for personnel safety, deck maintenance, and corrosion prevention, with no immediate promise of replacement of ships or decks. Therefore, there is a need to develop corrosion prevention programs and systems that can carry the aging fleet well into the future.

Historically, the useful lives of procured deck coating systems have often taken a backseat to personnel safety, performance, quality, and quantity of procurement. Therefore, total life-cycle costing must also be considered when new coating systems are procured.[20] In recent years, more durable and longer lasting non-skid coating systems have been introduced as alternatives to the traditional coating method. Nonetheless, the Navy’s primary goal is for the acquisition of a non-skid system with better corrosion protection, a system that can be implemented into future Navy assets during initial construction.

[19] Koch, Gerhardous H., Ph D, Cost of Corrosion Study: Defense Department, U. S. DOT, 2002.
[20] Ibid.

The goal of this project is to conduct a cost effectiveness analysis to analyze the current costs associated with non-skid application and resurfacing (the status quo), versus the use of alternate coatings that can be applied directly to the weather decks of existing ships, and incorporated into new ship construction. To do this, all costs for the existing non-skid application process of a typical surface ship must be broken out. We will further narrow our focus to examine only the associated costs for a non-skid coating application, maintenance, and resurfacing job to the weather decks of an Arleigh Burke destroyer. The weather decks of an Arleigh Burke destroyer require 23,000 square feet of surface area to be coated with non-skid. [21]

During the current 18-month operational cycle of an Arleigh Burke destroyer, portions of the weather decks are completely stripped and resurfaced. (It is very rare when all surface areas requiring non-skid get resurfaced all at once). This process can be accomplished one of two ways. First, the job could be accomplished solely by using ship's force personnel, for which no cost data exist. Second, the job may be performed during a three-month Ship Refit Availability (SRA) at which point the job can be accomplished by contractors or the Intermediate Maintenance Activity (IMA). The contract price includes a full-application cost of $11 per square foot.[22] This price includes all of the associated material and labor costs to remove existing non-skid and install new non-skid.

[21] Losset, Mark. Email quote of Northrup Grumman Ship Systems Non-skid application contract, 2003.
[22] SHIPSUP, San Diego, CA. Phone conversation regarding Standard Cost Estimates for Non-skid replacement, 2003.

NSTM Chapter 634 requires the use of a high solid, two-part, non-slip deck coating designed to provide maximum wear and impact resistance for the decks. [23] Additionally, the coating must be resistant to fire, most acids, alkalis, solvents, grease, oil, salt water, detergents, alcohol, gasoline, jet fuels, cellulube and other hydraulic fluids. The Navy also requires that the coating bond to the underlying deck to prevent rust from creeping under the coating, if fractured. Lastly, depending on the required type and the grade of product being used, non-skid can be applied by spraying, rolling or troweling.

Non-skid products that meet Navy specifications are of the following basic types:

Type I - High durability, rollable deck coating.

Type II - Standard durability rollable or trowel deck coating.

Type III - Standard durability, rollable resilient deck coating for use on exterior wooden decks, GRP, or metal decks where flexibility is required and where increased weight is not a factor.

Type IV - Standard durability, sprayable deck coating. [24]

Each of these non-skid coating types is further broken down into two different composition grades depending on the area and class of ship where the coating is applied. The "G-grade", or general grade coating, is more commonly applied to walkways for pedestrian and heavy vehicular traffic. The "L-grade", or limited grade coating, is most

[23] Naval Ships' Technical Manual (NSTM), Chapter No. 634: Deck Coverings, 30 August 1999 page 634-3.24.2.
[24] MIL-PRF-24667A Performance Specification for Non-skid Coating Systems for Roll or Spray Application, Page 1.

commonly applied to flight decks and aircraft walkways, and also provides non-slip protection for aircraft, rolling equipment and personnel. The differences between the composition grades vary in their curing time, abrasiveness, protection (heavy/light duty) level, impact resistance, and primer undercoat requirements.[25]

The minimum service lives for these coatings are as follows:

Type	**Composition G (months)**	**Composition L (Landings)**
I	12	10,000
II	6	5,000
III	6	N/A
IV	6	N/A

Table 3.1 – Non-skid Minimum service lives (From NSTM 634)

The following paragraphs describe a standard non-skid replacement job performed by an independent contractor, at an average cost of $11, in accordance with existing regulation requirements and broken down by the individual steps and processes involved, costs, and associated testing methods: [26]

(1) Surface Preparation [$9/ft^2] - the coating must be applied to a clean, dry surface. All rust, mill scale, paint, dirt, grease, oil, etc. must be completely removed. Recommended methods for cleaning steel surfaces are as follows:

a. Grit blast the surface.

[25] Naval Ships' Technical Manual (NSTM), Chapter No. 634: Deck Coverings, 30 August 1999, p 634-3.25.1.1.
[26] SHIPSUP, San Diego, CA. Phone conversation regarding Standard Cost Estimates for Non-skid replacement, 2003.

b. Where grit-blasting is not feasible, power tool cleaning can produce a sufficiently clean surface.

c. If there is oil or grease on the surface, it must be removed prior to cleaning.

d. Prime steel surfaces immediately after the surface has been cleaned and before rust or oxidation has had a chance to form or surface becomes dirty or contaminated in any way.

(2) Materials [$\$2/ft^2$] - a two-part coating consisting of a base material and a hardener.

(a) Pre-mix base component.

(b) Pour entire contents of hardener can into base material. Material can be immediately applied since induction time is not required.

(c) Working pot life is approximately 2 hours at 70°F (21°C). The non-skid coating can be applied at ambient temperatures between 40°F and 90°F.

Unfortunately, the problem associated with existing coating systems is that their service life does not support most 6-month deployments, and the non-skid coatings continually require extensive maintenance to retain adequate appearance and effectiveness.

It is estimated that the total number of hours that sailors devote to painting and preservation of non-skid fleet-wide is equivalent to 6,500 sailors working full-time on ship maintenance each year.[27] These corrosion control measures include chipping, painting, and resurfacing existing non-skid areas on Navy ships, which consumes significant amounts of money and manpower resources. The latter also negatively affects our sailors' quality of life both while at-sea and in port.

D. Thermion Coating Process

Thermion, Inc. supplies a aluminum-ceramic core non-skid that is a promising alternative to current Navy non-skid. Thermion's purpose is to provide a wear resistant surface to steel and aluminum that is long lasting and protects against corrosion.[28] The Thermion coating is made up of 54% aluminum and 46% ceramic powder. This makes the coating extremely light, only 0.5 lb/ft^2, which exceeds the specifications for weight as set by NSTM chapter 634. When the non-skid is applied to a steel surface, the material forms a tough coating that bonds to the metal. The aluminum element in the coating acts as a binder for the ceramic powder, which results in a sealant that is extremely resistant to corrosion and wear.[29]

The theoretical life of the product, based on the properties of the material, is 50 years. However, Thermion's process has only been used commercially during the past 5 years. As a result, testing data on the useful life of the product are not available to support the contractor's claim. The contractor recommends a lifespan of 10 years based on the lack of testing data in a harsh naval environment. Therefore, it is recommended that this material be prototyped onboard a Navy surface vessel for testing and evaluation to verify the durability of the material.

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[27] Virmani, Paul. Pub No. FHWA:-RD-01-156: Corrosion Costs and Preventive Strategies in the U. S. Navy, 2002.
[28] Rodgers, Frank. Ceramic Core Non-skid. Thermion, Inc. Silverdale, WA. 2002.
[29] Ibid.

The application of the aluminum-ceramic non-skid to a steel surface is accomplished using a twin wire arc-spray. This method uses a 3/16th inch diameter wire to apply the ceramic material to the desired surface. The ceramic wire is fed through a spray gun that creates an electrical arc between two electrically charged wires to melt the coating material.[30] Compressed air is used as an atomizer and propels the material through the spray gun at a uniform speed. The components of the twin-wire system consist of an air compressor, D.C. power supply, wire guides, and a spray gun. Figure 3.4 illustrates a typical twin-wire arc system:

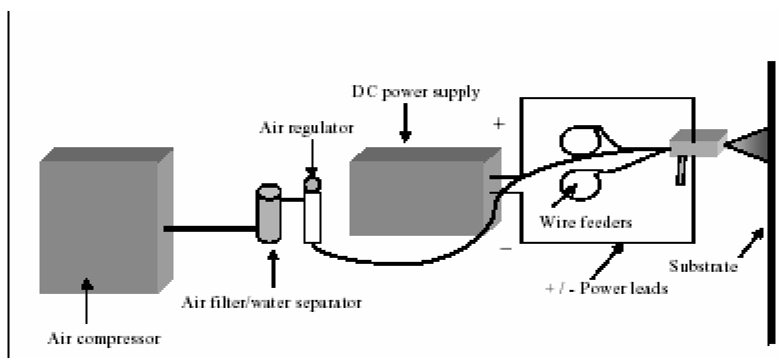

Figure 3.4 - Twin-wire Arc Spray Unit

Figure 3.5 illustrates a typical Thermion spray gun:

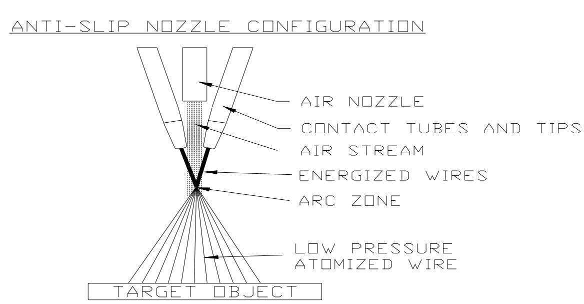

Figure 3.5 - Thermion Spray Nozzle (From Thermion, Inc.)

[30] ibid.

The current arc method used by Thermion is considered to be the industry standard of depositing aluminum materials because of its ability to provide high adhesive and cohesive strengths.[31] This type of application is also considered to be the most economical method within the industry. The coating rate can reach up to 300 ft^2/hr per application machine. As a result, the twin-wire arc-spray is both simple and effective for applying ceramic core non-skid to any surface vessel.

Thermion's ceramic core non-skid meets and exceeds the Navy's specifications on non-skid as set by NSTM Chapter 634. The Navy publication classifies non-skid into four categories based on their parameters as listed in Table 3.1.

These types of non-skid reflect the current materials that are used to coat surface vessels. Due to the toughness of the material, Thermion's ceramic core non-skid should have a high durability rating.

Furthermore, NSTM, 634 establishes a minimum life-span for the four types of non-skid, also shown on Table 3.1. These specifications are exceeded by Thermion's ceramic material. The maximum life for a high durability, rollable non-skid is 12 months. The projected life of the ceramic alternative is 10 years.[32] However, Thermion's non-skid life is only a projection based on the properties of the material and would need to be tested in an operational environment. Next is the comparison of weight specifications. Table 3.2 lists the weight specifications for non-skid:

[31] ibid.
[32] ibid.

Type I	.99 lbs/ft^2
Type II & IV	.44 lbs/ft^2
Type III	1.66 lbs/ft^2

Table 3.2 - Non-skid Weight Parameters (From NSTM Chapter 634)

These specifications are also exceeded by Thermion's ceramic non-skid. The maximum weight for class I non-skid, the class of interest, is set at 0.99 lbs/ft^2. Thermion's weight is 0.5 lb/ft^2. This provides the potential advantage of reducing topside weight and its effects on a ship's calculated stability. Finally, the coefficient of friction standard is exceeded by the ceramic non-skid. Table 3.3 establishes the requirement for friction aboard surface vessels:

	Dry	Wet	Oily
Initial Coating	.95	.90	.80
After Wear	.90	.85	.75

Table 3.3 - Non-skid Coefficient of Friction (From NSTM Chapter 634)

Thermion's coefficient of friction is 1.1, which surpasses the NSTM minimum dry specification of .95. As a result of these comparisons, Thermion's ceramic core non-skid meets and exceeds the NSTM standards and serves as an alternative for lowering the preservation and maintenance costs of surface vessels.

A total cost of $13.50 is applied to the Thermion coating to include all equipment, labor and preparation. The materials cost for Thermion is $2.83 per square foot plus an estimated $10.67 for surface preparation and topcoat.[33] This estimate is based on historical data for typical surface preparation costs for the status quo.

E. Liquidmetal Coating Process

The Liquidmetal process for application of its amorphous metal coating is similar in principle to the Thermion process above. Both systems use a similar arc-spray technology with minor changes in how the coating is presented to the arc and applied to the base metal surface. The major differences between the two are the cost per square foot of application and no need to apply a topcoat over the amorphous coating, as is the case for Thermion.

[33] Rodgers, Frank. Ceramic Core Non-skid. Thermion, Inc. Silverdale, WA. 2002.

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IV. COST EFFECTIVENESS ANALYSIS

A. Evaluating Costs

In order to fully understand the subject matter at hand, a useful place to start is a description of the methods typically used in a cost analysis. There are two useful approaches to be considered for the analysis of the cost effectiveness of amorphous alloys. They are Cost Benefit Analysis (CBA) and Cost Effectiveness Analysis (CEA). Both approaches offer a method to determine the relative merits of possible alternatives to a given problem. The major difference between the two is how rigorous the concepts of monetized value are applied to the possible alternatives. Both methods are valuable when considering alternatives to resolve a problem. Choosing which method to apply depends largely on the amount of data available to the analyst.

1. Cost-Benefit Analysis

A Cost-Benefit analysis (CBA) has been defined as "a policy assessment method that quantifies in monetary terms the value of all policy consequences to all members of society." [34] A CBA takes the possible alternatives for a given problem and determines the value of all aspects of those alternatives to determine the best approach to take. The CBA approach leads to a set of absolute costs of each alternative considering all aspects of the alternative and its effects on society. There are several types of CBA, primarily dependant on when the analysis is performed. These include:

[34] Boardman, A., Greenberg, D., Vining, A. and Weimer, D. Cost-Benefit Analysis, Concepts and Practice, Second Edition. Prentice Hall, 2001, p 2.

Ex Ante: a CBA that is performed while a project or policy is under consideration, before it is started or implemented. This type of CBA assists in the decision about whether scarce resources should be allocated to a specific project or policy.

Ex Post: a CBA that is conducted at the end of a project. All costs are considered "sunk." This type of CBA is used by managers to help learn if a particular class of project is feasible or worthwhile.

In Medias Res: a CBA that is performed during the life of a project. This type of CBA has elements of both the Ex Ante and Ex Post methods. These may be used when, during ongoing projects, shifting funds from the ongoing project to an alternative is possible. [35]

In this study, the *Ex ante* approach is most appropriate because our evaluation was conducted to determine which alternative is best for application of scarce resources. The outcome of our analysis is intended to provide a potential best solution for future Navy spending.

A CBA calls for a specific progression of steps to determine the net benefit of each alternative. The procedure provides a repeatable path for evaluation of the overall problem, and all realistically possible alternatives to solve that problem.

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[35] ibid, p 5.

The necessary steps to be conducted to perform a CBA are:

1. Specify the set of alternative projects.
2. Decide whose benefits and costs matter (standing).
3. Catalogue the impacts and select measurement indicators (units).
4. Predict the impacts quantitatively over the life of the project.
5. Monetize all impacts.
6. Discount benefits and costs to obtain present values.
7. Compute the net present value (NPV) of each alternative.
8. Perform sensitivity analysis.
9. Make a recommendation based on the NPV and sensitivity analysis. [36]

A rigorous application of the above procedure is necessary to get useful data out of a CBA. Without paying adequate attention to the detail of the analysis, it is impossible to reach a definitive conclusion. Each step will be discussed in detail below, drawing from the definitions in the Boardman text[37].

Step 1 is the foundation of the analysis. A problem statement must be stated that allows for a solution. The possible alternative paths to reach a resolution of that problem are then determined. One option is always to do nothing: the *status quo*, the baseline from which all other alternatives provide relative net benefit. All options to be considered must be feasible. There is no point to

[36] ibid, p 7.
[37] ibid, pp 7-17.

attempting to evaluate impossible alternatives. Once the possible courses of action have been determined, the CBA can continue.

Step 2 establishes what viewpoint shall be used to evaluate all alternatives. The relative standing of all parties impacted by the problem must be considered to obtain the greatest net benefit for all stakeholders. All future steps of the analysis will be conducted considering the choices of standing made here. In many cases limits must be placed on the level of standing to permit evaluation of the alternatives without bogging down the effort unnecessarily.

Step 3 determines the critical variables of the analysis. The beneficial and detrimental aspects of all alternatives must be determined, and useful units of the measure applied. There must be a way to relate the impact of a given measure to the benefit of those with standing. An impact that cannot be stated quantitatively cannot provide any useful addition to the CBA. There must also be a balance between the resources available to perform the analysis and the level of detail to be used in determining the impacts. There must be a limit applied to what impacts are to be considered in the analysis, largely determined by the standing arrived at in step 2.

Step 4 takes the impacts of step 3 and applies quantitative values to them for the life of the project. This might take the form of service life for a component, or the injury rate to operating personnel, and so on. The correct estimate of each impact is performed using the available data. These estimates are the most difficult step of the analysis. The data available for arriving at these estimates are usually incomplete or estimates themselves, radically increasing the uncertainty and error of the valuation. All impacts to be considered must have a value applied to them for further analysis.

Step 5 converts the quantified impacts of step 4 and reduces them to monetary terms. The impacts are converted into a common form to prevent apples-to-oranges comparison of the impacts. Some impacts are easy to convert while others can be very difficult to state in monetary terms. The value of a life is an example of a difficult conversion. There are tables of monetized values available in the literature that can simplify the process of conversion. Another important consideration is that an impact that no one would pay for has no value to the analysis, and should not be used as an impact of concern. Once all impacts are converted into monetary terms for the life of the project, the analysis can continue.

Step 6 takes the monetary values of step 5 over the life of the project and reduces them to present values. The discount rate used in the reduction can depend on who has standing in the problem. Frequently, a governing body such as the Office of Management and Budget (OMB) determines the required discount rate to be used.

Step 7 determines the net present value (NPV) of each alternative. The values of all costs and benefits determined in step 6 are combined to reach a total net benefit of each alternative. The alternatives can then be ranked in terms of that net benefit.

Step 8 evaluates the level of uncertainty present in the analysis due to unknown and estimated values assigned to impacts, or due to the difficulties in assigning monetary values to some impacts. Sensitivity analysis is conducted to determine the amount of variability in the final outcome of the study based on changes in the valuation of the impacts.

Step 9 is the culmination of the analysis. The NPV and sensitivity of each alternative are compared, and a recommended course of action is selected. The analyst must make a determination on which alternative has the greatest benefit to those with standing, while considering the effects of the uncertainty in the analysis of each alternative.

The discussion above is predicated on the framework of the Boardman text. For CBA work in the government theater, the specific guidelines published by government agencies must be considered. The primary source of this guidance is The Office of Management and Budget (OMB) Circular A-94. A-94 is intended to provide a common framework that can be used and interpreted by all levels of government. Common terms and format are used to allow any informed viewer to understand the process used in the analysis. The format used in A-94 varies from the Boardman approach in wording, but not in content. A-94 also calls for evaluation of alternatives based on quantifying all variables, conversion of all impacts into monetary terms and evaluation of variability and sensitivity of that conversion. The NPV of each alternative is still the primary analysis outcome. A-94 states the appropriate discount rates to be used in analyses, using 2.5% as the real value for the discount rate, including the effects of inflation.[38] The approach of A-94 is otherwise similar to the Boardman method.

2. Cost Effectiveness Analysis

A CBA is not always possible given the impacts and resources available for consideration. In cases where major impacts cannot be reduced to monetary terms, a different approach is necessary to reach a recommended course of action. One of the primary alternatives to a CBA is Cost effectiveness Analysis (CEA). A CEA is used when the major variables involved in a problem cannot be reduced into monetary terms or as in our case, when all benefits are considered equal.[39,40]

A CEA compares alternatives to a given problem by comparing costs and effectiveness of each. The costs are determined as they would be in a CBA. The benefits of each alternative are compared in terms of a non-monetized quantified variable. In other words, a variable is selected that best captures the benefit of all alternatives and each alternative is ranked in terms of how well it meets that measure. The effectiveness of each alternative can then be determined by determining the amount of benefit achieved per unit of cost.

A CEA runs into difficulties when the scale of the alternatives differs enough that it is possible to skew the relative merits of the alternatives out of proportion. The usual method to deal with this issue is to apply a constraint to either cost or benefit of the project.

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[38] OMB Circular A-94, Appendix B, p 20.

[39] Boardman, A., Greenberg, D., Vining, A. and Weimer, D. Cost-Benefit Analysis, Concepts and Practice, Second Edition. Prentice Hall, 2001, p 437.

[40] OMB Circular A-94, Appendix B, p 20.

It is possible to have a meaningful comparison of radically different alternatives if they are constrained to have the same benefit or cost. In OMB Circular A-94, a CEA is also seen as an acceptable method of analysis when the benefits to be seen from all alternatives are the same, or a requirement to meet a certain minimum level of benefit has been set.[41]

For this project, a CEA was conducted because of the data available for analysis.

B. Assumptions

A full, rigorous CBA requires access to data detailing all aspects of standing for all alternatives. One must be able to isolate and place a numerical value on all benefits and costs associated with all alternatives. The cost side of the equation is relatively easy to enumerate. One takes the estimates of costs available based on historical data or on future projections, and assigns them to the cost drivers of the alternatives. There is almost always some sort of cost data available for any reasonable alternative that can be used to provide the cost side of the CBA equation. Benefits, however, are far more difficult to place a value on. Some aspects are relatively easy to resolve: how long a part will last, based on testing projections, or how much faster a new processor might complete a computing job than the legacy systems currently in use. It is far more difficult to determine the exact relationship of relative benefit between alternatives when there is no hard data about the relative merit of each alternative.

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[41] OMB Circular A-94, p 4.

In this project, we were attempting to determine the relative costs and benefits of different alternative coatings for Navy surface ships. Important variables are listed below and in Appendix A. These are valuable tools, but they do not tell the whole story about the actual relative benefits of each covering. We were unable to monetize all benefits associated with each alternative because we did not have the necessary data to conduct a full, rigorous CBA.

As discussed above, a CEA captures many of the salient points of the CBA, but allows for analysis without all of the pertinent benefit data. We shall discuss the assumptions we made about the relative merits of each alternative to allow us to focus on the cost and benefit data that were available. For the purposes of this CEA, all benefits have been assumed to be equal across all alternatives. In other words, we found the cost of each alternative per unit of benefit, where the benefits were held constant and canceled when comparing alternatives.

The technology behind the alternatives is relatively new and the data that do exist do not directly pertain to the application being studied. The Liquidmetal alternative has been in use since 1991 in the oil and power generation industries and Thermion's process has been in use for several years in a variety of commercial applications. These processes have never been used as non-skid coverings; therefore the testing required by MIL-PRF-24667A (Performance specification for non-skid) has not been conducted.

To the deck plate sailor, the person who depends on non-skid deck covering to give him a safer environment to work in, it is likely that all alternatives have the same benefits. Of all the metrics reviewed in Appendix A, the only one that would likely be differentiated on the basis of net benefit to the end user is coefficient of friction. If one alternative has a significantly higher coefficient of friction, long-term testing may be able to quantify this benefit as reduced injury to crewmembers. This could in turn be monetized and it would then be possible to expand this study into a CBA. The existing data do not support this and it is reasonable to assume the same benefits among the different alternatives.

Because of the lack of required data we were forced to make several assumptions in analyzing the costs and benefits of the various alternatives. The following metrics from Appendix A were considered the same among the alternatives for the purpose of this Cost Effectiveness Analysis.

- Appearance of dried coating.
- Application properties
- Coefficient of friction
- Coverage
- Drying time
- Fire resistance
- Immersion resistance
- Impact resistance
- Resistance to accelerated aging by light and water
- Resistance to accelerated corrosion
- Resistance to wear
- Thickness
- Weight

Based on the available data we chose to evaluate the alternatives on two metrics: cost per application and frequency of application. We chose an Arleigh Burke guided missile destroyer as the platform on which to compare the alternatives. It has 23,000 ft^2 of deck with non-skid applied. In this case, an application is defined as the total cost to remove the old deck covering, prep the deck and apply the new deck covering.

The following table lists the application costs and life expectancy of the various alternatives. Additionally, a discount rate of 2.5% was used to adjust all costs over the ten year period. This rate was derived from Appendix C of OMB Circular A-94. The real interest rate on treasury notes and bonds for a 10 year maturity is 2.5%.[42]

Alternatives	Cost per ft^2	Normal Case Cost per Application	NPV over 10 years	Life Expectancy
ALT 0 – Status Quo	$11.00 [43]	$253,000	$1,346,468	2 Years [44]
ALT 1 – Thermion	$13.50 [45]	$310,500	$310,500	10 Years [46]
ALT 2 – Liquidmetal	$40.00 [47]	$920,000	$920,000	10 Years [48]

Table 4.1 – CEA Alternatives Consolidated Data

C. Results

We determined the cost of a single application of each alternative. Appendix C contains the spreadsheet data for the three alternatives. We amortized the costs of each

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[42] OMB Circular A-94, Appendix C, revised January 2003. Located on the Internet at: www.whitehouse.gov/omb/circulars/a094/a94_appx-c.html
[43] SHIPSUP, San Diego, CA. Phone conversation regarding Standard Cost Estimates for Non-skid replacement, 2003.
[44] ibid.
[45] Rodgers, Frank. Ceramic Core Non-skid. Thermion, Inc. Silverdale, WA. 2002.
[46] Ibid.
[47] Liquidmetal Technologies, Tampa, FL Phone conversation regarding cost estimates for Non-skid replacement, 2003.
[48] ibid.

application over a ten year period. Alternatives 1 and 2 had a life of 10 years. Our amortization was done by applying the status quo non-skid five times over the 10 year period and taking the Net Present Values of all three alternatives. Our results are compiled in Table 4.1.

Comparing the ten year costs of each application, reduced to net present value, it is clear that Alternative 1, the Thermion case, is significantly lower in costs than the status quo or Alternative 2. Alternative 2 shows significant cost savings over the status quo as well. Alternative 1 is less expensive than the status quo by a factor of four over the 10 year period, despite a somewhat larger initial investment, and less expensive by a factor of three than Alternative 2 over the same period.

A better feel for how significant the potential savings are can be seen by applying our results to the Surface Fleet as a whole. For this purpose and for ease of analysis, we limited our analysis to surface combatant vessels (frigates, destroyers and cruisers) and the 12 Aircraft Carriers currently in service. There are a total of 114 surface combatants considered, from five ship types: the Arleigh Burke DDG used thus far in our analysis, the Perry class FFG, Spruance class DD, Ticonderoga CG, and the 12 Carriers, which have equivalent flight deck areas. There are 188 other ships currently in the Fleet which could potentially benefit from the new non-skid technology which were not considered for our analysis.

We chose to conduct our analysis based on a snapshot as it exists in 2003, with the understanding that the actual savings achieved will vary based on the changes in fleet composition as ships are commissioned and decommissioned. The current Perry and Spruance class ships are currently being decommissioned, but are scheduled to be replaced by the CG-X, DD-X and LCS classes of ships currently in development. Our methodology for computing the deck areas of each class covered by non-skid used a ratio of the contract non-skid area of the Arleigh Burke DDG (23,000ft^2), divided by the product of the ship's length and beam (505ft long, 66ft beam, product 33,330 ft^2). [49] This resulted in 69% of the area described by the length and beam calculation being covered in non-skid. This ratio was applied to the length-beam calculations for the other three classes of ships to obtain non-skid application areas for each class. These areas were multiplied by the number of ships of each class to achieve the total non-skid area of the Surface Fleet. Table 4.2 shows the calculated non-skid area of each class, and the total area for each class. The non-skid area of each Aircraft Carrier is 4.5 Acres[50], or 196,000ft^2 per ship, leading to a total of 2,352,240ft^2 for the carrier fleet. The total aggregate non-skid area of all ships considered was 4,429,194ft^2.

[49] Naval Vessel Register, www.nvr.navy.mil/nvrships
[50] NAVSEA NSWC-Carderock, www.dt.Navy.mil/code60/code643/nonskid/nonskid.htm

Ship Type	Length (ft)	Beam (ft)	Non-skid Area (est.)(ft^2)	Number of ships in class	Total Non-skid Area (ft^2)
FFG 7 Perry	453	47	14,690	25	367,250
DD 963 Spruance	563	55	21,365	13	277,745
DDG 51 Burke	505	66	23,000	37	851,000
CG 47 Ticonderoga	567	55	21,517	27	580,959
Aircraft Carrier	N/A	N/A	196,020	12	2,352,240
				Total Aggregate Area	4,429,194

Table 4.2 Non-skid Areas for Surface Combatants and Carriers

The normal case cost of our three alternatives was then determined over a ten year period to determine the potential cost savings of Alternatives 1 and 2. Table 4.3 below shows the costs and cost savings over 10 years for our chosen sample.

Alternatives	NPV of costs for Sample Fleet over 10 years	Cost savings for sample Fleet
ALT 0 – Status Quo	$259,294,210	N/A
ALT 1 – Thermion	$59,794,119	$199,500,091
ALT 2 – Liquidmetal	$177,167,760	$82,126,450

Table 4.3 - Aggregate Fleet Costs and Savings

It is clear from table 4.3 that the potential savings by using either alternative non-skid are significant, and the potential of Alternative 1 is substantial. Our results indicate a potential average savings of almost $20 Million per year.

In our analysis, we have used a 10 year life for Alternative 1 based on the recommendation of Thermion about the probable life of their coating in the naval environment. Thermion predicts a theoretical life of 50 years for their coating based on its material properties. Therefore, in the best case, it is possible for a single application of the Alternative 1 non-skid to last 50 years. The average life of a naval combatant for the purposes of our analysis is assumed to be 30 years, with the carriers staying in commission for 50 years. Using the 12 ship carrier fleet, we calculated a NPV savings of over $356 Million for using the Alternative 1 non-skid with a 50 year life in lieu of the status quo non-skid. We performed a similar calculation over a 30 year period using the entire sample fleet determined above, including surface combatants and carriers and achieved at total savings of $492 Million over those 30 years with a single application of Alternative 1 non-skid. Table 4.4 shows the NPV costs over 30 and 50 years of our sample fleets using the status quo and Alternative 1.

Alternatives	NPV of costs for Sample Fleet over 30 years	Cost savings for Sample Fleet over 30 years	NPV of costs for Carrier Fleet over 50 years	Cost savings for Carrier Fleet over 50 years
ALT 0 – Status Quo	$552,300,191	N/A	$388,276,914	N/A
ALT 1 – Thermion	$59,794,119	$492,506,072	$31,755,240	$356,521,674

Table 4.4 - Cost Savings using Thermion Non-skid over 30 and 50 years with Sample and Carrier Fleets

There is a significant difference in the relative magnitude of the savings achieved in our results on Tables 4.1 and 4.4. Table 4.1 shows the savings over a 10 year period of using our alternative materials. We used a useful life of 10 years for the Thermion and Liquidmetal coatings to determine these savings, as recommended by the manufacturers. In Table 4.4, we explored the potential savings from using the theoretical useful life of the coating as predicted by Thermion. For the ships considered in our analyses, the coating would be applied once for the life of the ship, set at 30 years for our analysis. Therefore the magnitude of the savings when the alternative coating had a useful life of 30 years was significantly higher. We conducted the same analysis on the aircraft carriers alone, using their designed life of 50 years and the theoretical life of 50 years for the Thermion coating. The magnitude of savings is even higher in this case. In all three analyses, we used a useful life of 2 years for the status quo coating, leading to 15 applications over 30 years, and 25 applications over 50 years.

D. Sensitivity Analysis

The results obtained by our CEA are highly dependent on the values assigned for the lifecycle and cost parameters of each alternative. OMB Circular A-94 calls for sensitivity analysis to be conducted to determine how much of an effect changing the variables has on the overall outcome of the analysis.[51]

After completion of the original calculation for the cost effectiveness of each alternative, a factor of 25% was used to establish best and worst case cost values and 30% was used for lifecycle values for each alternative. Thermion and Liquidmetal were unable to provide us with data to establish the level of variation in the cost and useful life data used. Therefore, we chose our 25% cost

[51] OMB Circular A-94, Page 10

variation to allow a reasonable spread in per-application costs of each alternative. It is our opinion that the real world cost of the two new alternatives would fall into the range predicted by our cost variation. The 30% useful life variation was used to show how the costs varied with the life of the coating. We varied the useful life of the status quo by 50% and varied the useful life of Alternatives 1 and 2 by 30% to simplify our calculations by keeping the useful life values in whole years. We then analyzed the alternatives based on the resulting best case and worst case situations to determine if any significant changes in our results became apparent.

Applying the changes in lifespan to each alternative made the comparison between best and worst case situations much more challenging to analyze. To reduce the analysis to a common time period, we used the concept of straight line depreciation to show the total NPV of each alternative and its best and worst cases over a useful life of 10 years. Any residual life left in current application of each alternative coating was subtracted from the total present value cost of that alternative. Thus, the best case for Alternatives 1 and 2, with a life of 13 years, had three years of that nominal life removed from the analysis at the 10 year point, reducing the total cost of those two alternatives. A similar process was used for the worst case analysis, deducting the last four years of the 14 year life of the second application to determine the 10 year NPV. The resulting NPVs are shown in Table 4.5.

Alternatives	Best Case NPV for 10 years	Worst Case NPV for 10 years
ALT 0 - Status Quo	$632,100	$3,084,090
ALT 1 - Thermion	$190,987	$533,577
ALT 2 - Liquidmetal	$565,609	$1,580,500

Table 4.5 Sensitivity Analysis NPV over 10 Year Period

Figure 4.1 shows the indifference curves for the three cases of the status quo non-skid. The three lines represent the progression of costs for that case over time, given the cost per application and application lifetime for each case. The plotted points for the cases of Alternatives 1 and 2 show the cost and lifetime of that case of each alternative. When comparing options, the dominant position is to be lower and to the right of the applicable indifference line.

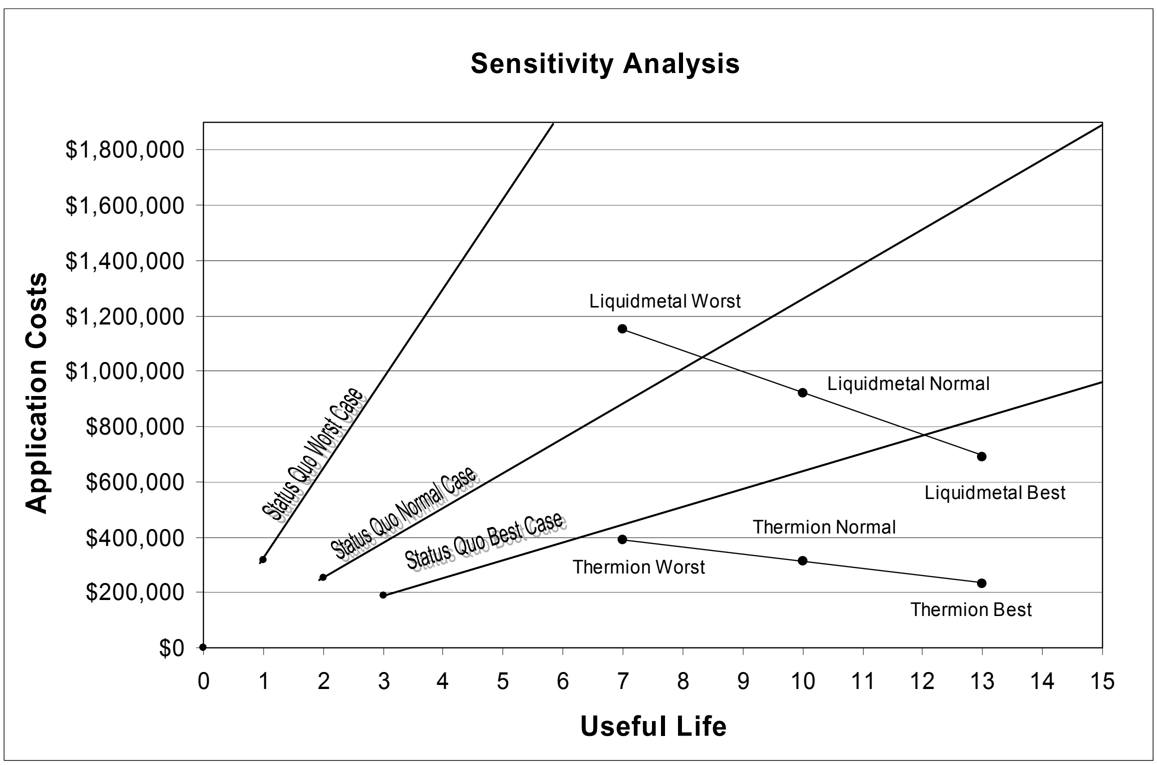

Figure 4.1 Sensitivity Analysis of Alternatives

It is clear that the Thermion alternative is superior across all cases considered. Alternative 1 is a robust, best choice, even with its worst case compared to the best cases of the other two options. Alternative 2 is better than the status quo, in the normal case, but dominance is less clear when the costs of Alternative 2 rise to the worst case. In best case conditions for the status quo, it is less costly than the normal case for Alternative 2. These results are presented graphically in Figure 4.1.

It is also clear from Figure 4.1 that there is a much smaller difference between the status quo option and Alternative 2, especially when we allow one alternative to be in a more disadvantaged case than the other. When both have the same characteristics, Alternative 2 is superior to the status quo.

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V. CONCLUSION AND RECOMMENDATIONS

While our analysis concludes that the Thermion alternative is superior because it exhibits the least cost incurred, it potentially has several other advantages. Thermion has the advantage of reducing topside weight and its effects on a ship’s calculated stability and its coefficient of friction is greater than the standard set forth in NSTM 634. Whenever a naval architect is able to reduce topside weight, a ships stability and seakeeping ability is improved. Thermion’s coefficient of friction is 1.1, which surpasses the NSTM minimum dry specification of .95. Thermion’s improved coefficient of friction has the potential of reducing shipboard injuries and improving the efficiency of topside operations.

Based on our analysis, we propose that Alternative 1 be adopted as a potential replacement for the status quo non-skid on Navy Surface ships. We recommend that the Thermion process non-skid be prototyped on a surface ship to test the durability characteristics in the real world environment. We recommend a two year test of the Thermion coating in a real world environment, with application of both the new coating and the status quo coating on the same ship. The results of that test could be extrapolated to reflect the full useful life of the Thermion coating.

Despite the superiority of Alternative 1 in our analysis, we feel that there is sufficient merit to Alternative 2’s costs to warrant a similar prototyping plan for the amorphous metal coating under similar conditions to those recommended above for Alternative 1.

In addition, the data for the alternatives that do exist are provisional in nature. We believe that the initial data for Alternative 2 merit further testing and it should be tested in conjunction with Alternative 1. Field testing will yield data that would further refine our CEA.

APPENDIX A

Discussion of Performance Specification MIL-PRF-24667A, Coating System, Non-Skid, For Roll or Spray Application

Military Specification MIL-PRF-24667A was written by Naval Sea Systems Command (NAVSEA) to specify the requirements for applying non-skid coating systems to weather decks, flight decks and hangar decks of ships. This specification was not written to account for the unique characteristics of the alternatives being analyzed. Due to the twin wire arc-spray technique used to apply these alternative materials, the Type IV (sprayable deck coating) discussed in the MIL-SPEC best fits these alternatives. Ideally, a new MIL-SPEC, including a fifth type of deck coatings, should be written to take into account the vastly different characteristics of these alternatives.

While many of the specifications of MIL-PRF-24667A do not apply to alternatives 1 & 2 of this CEA, some of them do apply and would probably remain unchanged in any new MIL-SPEC. This appendix will briefly go through the characteristics identified in MIL-PRF-24667A and discuss their applicability.

Testing of non-skid systems IAW MIL-PRF-24667A require that they meet the following general requirements (only applicable requirements listed):

Appearance of dried coating: Specifies a uniformly coarse, rough appearance over the entire surface. Any alternative should be able to satisfy this.

Application properties: Requires material to flow evenly without running, dripping, spattering or cob-webbing. Alternatives would have to meet similar requirements.

Coefficient of friction: Requires a minimum coefficient of friction between .90 and .65 depending on surface conditions such as amount of wear and if it is dry or not. For the Thermion based Alternative 1, the company claims an average of 1.1. The coefficient of friction for Alternative 2 based on Liquidmetal Corporation's technology is not specified. Any alternative would have to meet the existing requirement of the MIL-SPEC.

Coverage: The specification requires not less than 60 ft^2/gal. Alternative 1 specifies coverage of 8-12ft^2/lb of wire. Alternative 2 is unknown. This requirement would have to be re-written to take into account the twin wire arc spray process.

Drying time: Allows a maximum of 72 hours drying time. Both alternatives have the advantage of being immediately usable with no cure time.

Fire resistance: Both alternatives have the advantage of being non-flammable.

Immersion resistance: Specifies that coating systems shall show no softening, loss of adhesion, discoloration or other signs of deterioration. Capabilities of the alternatives are unknown but would have to meet the same requirements.

Impact resistance: Requires impact resistance between 90 – 70%. Alternatives have not been tested to this spec but data suggest that the alternatives have superior impact resistance.

Resistance to accelerated aging by light and water: Specifies no loss of adhesion when exposed to ultraviolet light and condensation of water. Also specifies amount of cracking, checking and discoloration allowed. Alternatives have not been tested to this spec but data imply superior resistance.

Resistance to accelerated corrosion: Requires that coating system show no loss of adhesion or corrosion of the steel substrate beyond a 9 mm radius. Alternatives have not been tested to this spec but data imply superior resistance.

Resistance to wear: Testing IAW MILSPEC specifies weight loss shall not exceed 40%. Alternatives have not been tested to this spec but data imply superior resistance.

Thickness: Specifies a minimum thickness of 0.75 mm (30 mils). Alternatives would exceed this requirement using normal application process.

Weight: Specifies a maximum of .99 lb/ft^2 for Type I non-skid. Alternative 1 weighs between .125 and .50 lb/ft^2. Alternative 2 would weigh approximately .959 lb/ft^2. While both alternatives meet the specification, Alternative 1 has the benefit of reducing topside weight in this application.

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Appendix B
Analysis Data

Alternative 0 – Status Quo:

Normal Case **Discount Rate:** 2.5%

Itemized Recurring Costs

Description	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Contractor application of non - skid	(253,000)	0	(253,000)	0	(253,000)	0	(253,000)	0	(253,000)	0	(253,000)
Discount Rate	1.0000	0.9756	0.9518	0.9286	0.9060	0.8839	0.8623	0.8413	0.8207	0.8007	0.7812
PV of Costs:	($253,000)	$0	($240,809)	$0	($229,206)	$0	($218,161)	$0	($207,649)	$0	($197,643)
NPV Of All Costs:	($253,000)	($253,000)	($493,809)	($493,809)	($723,015)	($723,015)	($941,176)	($941,176)	($1,148,825)	($1,148,825)	($1,346,468)

Overall NPV: **($1,346,468)**

Best Case **Discount Rate:** 2.5%

Itemized Recurring Costs

Description	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Contractor application of non - skid	(189,750)	0	0	(189,750)	0	0	(189,750)	0	0	(189,750)	0
Remaining Life											$ 63,250
Discount Rate	1.0000	0.9756	0.9518	0.9286	0.9060	0.8839	0.8623	0.8413	0.8207	0.8007	0.7812
PV of Costs:	($189,750)	$0	$0	($176,202)	$0	$0	($163,621)	$0	$0	($151,938)	$0
PV of Remaining Life											$ 49,411
NPV Of All Costs:	($189,750)	($189,750)	($189,750)	($365,952)	($365,952)	($365,952)	($529,573)	($529,573)	($529,573)	($681,511)	($632,100)

Overall NPV: **($632,100)**

Worst Case **Discount Rate:** 2.5%

Itemized Recurring Costs

Description	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Contractor application of non - skid	(316,250)	(316,250)	(316,250)	(316,250)	(316,250)	(316,250)	(316,250)	(316,250)	(316,250)	(316,250)	(316,250)
Discount Rate	1.0000	0.9756	0.9518	0.9286	0.9060	0.8839	0.8623	0.8413	0.8207	0.8007	0.7812
PV of Costs:	($316,250)	($308,537)	($301,011)	($293,670)	($286,507)	($279,519)	($272,701)	($266,050)	($259,561)	($253,230)	($247,054)
NPV Of All Costs:	($316,250)	($624,787)	($925,798)	($1,219,467)	($1,505,974)	($1,785,493)	($2,058,195)	($2,324,245)	($2,583,806)	($2,837,036)	($3,084,090)

Overall NPV: **($3,084,090)**

Alternative 1 - Thermion, Inc.

Normal Case **Discount Rate:** **2.5%**

Itemized Recurring Costs

Description	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Contractor application of non - skid	(310,500)	0	0	0	0	0	0	0	0	0	0
Discount Rate	1.0000	0.9756	0.9518	0.9286	0.9060	0.8839	0.8623	0.8413	0.8207	0.8007	0.7812
PV of Costs:	($310,500)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
NPV Of All Costs:	($310,500)	($310,500)	($310,500)	($310,500)	($310,500)	($310,500)	($310,500)	($310,500)	($310,500)	($310,500)	($310,500)
										Overall NPV:	**($310,500)**

Best Case **Discount Rate:** **2.5%**

Itemized Recurring Costs

Description	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Contractor application of non - skid	(232,990)	0	0	0	0	0	0	0	0	0	0
Remaining Life											$ 53,767
Discount Rate	1.0000	0.9756	0.9518	0.9286	0.9060	0.8839	0.8623	0.8413	0.8207	0.8007	0.7812
PV of Costs:	($232,990)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
PV of Remaining Life											$ 42,003
NPV Of All Costs:	($232,990)	($232,990)	($232,990)	($232,990)	($232,990)	($232,990)	($232,990)	($232,990)	($232,990)	($232,990)	($232,990)
										Overall NPV:	**($190,987)**

Worst Case **Discount Rate:** **2.5%**

Itemized Recurring Costs

Description	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Contractor application of non - skid	(388,240)	0	0	0	0	0	0	0	(388,240)	0	0
Remaining Life											$ 221,851
Discount Rate	1.0000	0.9756	0.9518	0.9286	0.9060	0.8839	0.8623	0.8413	0.8207	0.8007	0.7812
PV of Costs:	($388,240)	$0	$0	$0	$0	$0	$0	$0	($318,647)	$0	$0
PV of Remaining Life											$ 173,310
NPV Of All Costs:	($388,240)	($388,240)	($388,240)	($388,240)	($388,240)	($388,240)	($388,240)	($388,240)	($706,887)	($706,887)	($706,887)
										Overall NPV:	**($533,577)**

Alternative 2 - Liquidmetal Technologies

Normal Case

Discount Rate: 2.5%

Itemized Recurring Costs

Description	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Contractor application of non - skid	(920,000)	0	0	0	0	0	0	0	0	0	0
Discount Rate	1.0000	0.9756	0.9518	0.9286	0.9060	0.8839	0.8623	0.8413	0.8207	0.8007	0.7812
PV of Costs:	($920,000)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
NPV Of All Costs:	($920,000)	($920,000)	($920,000)	($920,000)	($920,000)	($920,000)	($920,000)	($920,000)	($920,000)	($920,000)	($920,000)

Overall NPV: **($920,000)**

Best Case

Discount Rate: 2.5%

Itemized Recurring Costs

Description	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Contractor application of non - skid	(690,000)	0	0	0	0	0	0	0	0	0	0
Remaining Life											$ 159,231
Discount Rate	1.0000	0.9756	0.9518	0.9286	0.9060	0.8839	0.8623	0.8413	0.8207	0.8007	0.7812
PV of Costs:	($690,000)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
PV of Remaining Life											$ 124,391
NPV Of All Costs:	($690,000)	($690,000)	($690,000)	($690,000)	($690,000)	($690,000)	($690,000)	($690,000)	($690,000)	($690,000)	($690,000)

Overall NPV: **($565,609)**

Worst Case

Discount Rate: 2.5%

Itemized Recurring Costs

Description	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Contractor application of non - skid	(1,150,000)	0	0	0	0	0	0	0	(1,150,000)	0	0
Remaining Life											$ 657,143
Discount Rate	1.0000	0.9756	0.9518	0.9286	0.9060	0.8839	0.8623	0.8413	0.8207	0.8007	0.7812
PV of Costs:	($1,150,000)	$0	$0	$0	$0	$0	$0	$0	($943,859)	$0	$0
PV of Remaining Life											$ 513,359
NPV Of All Costs:	($1,150,000)	($1,150,000)	($1,150,000)	($1,150,000)	($1,150,000)	($1,150,000)	($1,150,000)	($1,150,000)	($2,093,859)	($2,093,859)	($2,093,859)

Overall NPV: **($1,580,500)**

Analysis of Alternatives over 30 years:

Normal Case **Discount Rate:** 2.5%

Itemized Recurring Costs

Status Quo	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Contractor application of non - skid	(48,721,134)	0	(48,721,134)	0	(48,721,134)	0	(48,721,134)	0	(48,721,134)	0	(48,721,134)
Remaining Life											
Discount Rate	1.0000	0.9756	0.9518	0.9286	0.9060	0.8839	0.8623	0.8413	0.8207	0.8007	0.7812
PV of Costs:	($48,721,134)	$0	($46,373,477)	$0	($44,138,943)	$0	($42,012,081)	$0	($39,987,704)	$0	($38,060,872)
PV of Remaining Life											
NPV Of All Costs:	($48,721,134)	($48,721,134)	($95,094,611)	($95,094,611)	($139,233,554)	($139,233,554)	($181,245,635)	($181,245,635)	($221,233,338)	($221,233,338)	($259,294,210)

Year 20	Year 21	Year 22	Year 23	Year 24	Year 25	Year 26	Year 27	Year 28	Year 29	Year 30
(48,721,134)	0	(48,721,134)	0	(48,721,134)	0	(48,721,134)	0	(48,721,134)	0	(48,721,134)
0.6103	0.5954	0.5809	0.5667	0.5529	0.5394	0.5262	0.5134	0.5009	0.4887	0.4767
($29,733,092)	$0	($28,300,385)	$0	($26,936,714)	$0	($25,638,752)	$0	($24,403,334)	$0	($23,227,444)
($423,793,561)	($423,793,561)	($452,093,946)	($452,093,946)	($479,030,661)	($479,030,661)	($504,669,413)	($504,669,413)	($529,072,747)	($529,072,747)	($552,300,191)

Overall NPV: **($552,300,191)**

Normal Case **Discount Rate:** 2.5%

Itemized Recurring Costs

Thermion	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Contractor application of non - skid	(59,794,119)	0	0	0	0	0	0	0	0	0	0
Discount Rate	1.0000	0.9756	0.9518	0.9286	0.9060	0.8839	0.8623	0.8413	0.8207	0.8007	0.7812
PV of Costs:	($59,794,119)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
											$ -
NPV Of All Costs:	($59,794,119)	($59,794,119)	($59,794,119)	($59,794,119)	($59,794,119)	($59,794,119)	($59,794,119)	($59,794,119)	($59,794,119)	($59,794,119)	($59,794,119)

Year 20	Year 21	Year 22	Year 23	Year 24	Year 25	Year 26	Year 27	Year 28	Year 29	Year 30
0	0	0	0	0	0	0	0	0	0	0
0.6103	0.5954	0.5809	0.5667	0.5529	0.5394	0.5262	0.5134	0.5009	0.4887	0.4767
$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
$ -		$ -		$ -		$ -		$ -		$ -
($59,794,119)	($59,794,119)	($59,794,119)	($59,794,119)	($59,794,119)	($59,794,119)	($59,794,119)	($59,794,119)	($59,794,119)	($59,794,119)	($59,794,119)

Overall NPV: **($59,794,119)**

Savings of using Thermion over Status Quo **$492,506,072**

Analysis of Alternatives over 50 years:

Normal Case **Discount Rate:** 2.5%

Itemized Recurring Costs

Status Quo	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Contractor application of non - skid	(25,874,640)	0	(25,874,640)	0	(25,874,640)	0	(25,874,640)	0	(25,874,640)	0	(25,874,640)
Remaining Life											
Discount Rate	1.0000	0.9756	0.9518	0.9286	0.9060	0.8839	0.8623	0.8413	0.8207	0.8007	0.7812
PV of Costs:	($25,874,640)	$0	($24,627,855)	$0	($23,441,147)	$0	($22,311,621)	$0	($21,236,522)	$0	($20,213,227)
PV of Remaining Life											
NPV Of All Costs:	($25,874,640)	($25,874,640)	($50,502,495)	($50,502,495)	($73,943,642)	($73,943,642)	($96,255,263)	($96,255,263)	($117,491,785)	($117,491,785)	($137,705,012)

	Year 40	Year 41	Year 42	Year 43	Year 44	Year 45	Year 46	Year 47	Year 48	Year 49	Year 50
Contractor application of non - skid	(25,874,640)	0	(25,874,640)	0	(25,874,640)	0	(25,874,640)	0	(25,874,640)	0	(25,874,640)
Discount Rate	0.3724	0.3633	0.3545	0.3458	0.3374	0.3292	0.3211	0.3133	0.3057	0.2982	0.2909
PV of Costs	($9,636,508)	$0	($9,172,167)	$0	($8,730,201)	$0	($8,309,531)	$0	($7,909,131)	$0	($7,528,025)
NPV Of All Costs	($346,627,859)	($346,627,859)	($355,800,026)	($355,800,026)	($364,530,227)	($364,530,227)	($372,839,758)	($372,839,758)	($380,748,889)	($380,748,889)	($388,276,914)

Overall NPV: **($388,276,914)**

Normal Case **Discount Rate:** 2.5%

Itemized Recurring Costs

Thermion	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Contractor application of non - skid	(31,755,240)	0	0	0	0	0	0	0	0	0	0
Discount Rate	1.0000	0.9756	0.9518	0.9286	0.9060	0.8839	0.8623	0.8413	0.8207	0.8007	0.7812
PV of Costs:	($31,755,240)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
											$ -
NPV Of All Costs:	($31,755,240)	($31,755,240)	($31,755,240)	($31,755,240)	($31,755,240)	($31,755,240)	($31,755,240)	($31,755,240)	($31,755,240)	($31,755,240)	($31,755,240)

	Year 40	Year 41	Year 42	Year 43	Year 44	Year 45	Year 46	Year 47	Year 48	Year 49	Year 50
Contractor application of non - skid	0	0	0	0	0	0	0	0	0	0	0
Discount Rate	0.3724	0.3633	0.3545	0.3458	0.3374	0.3292	0.3211	0.3133	0.3057	0.2982	0.2909
PV of Costs	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
	$ -		$ -		$ -		$ -		$ -		$ -
NPV Of All Costs	($31,755,240)	($31,755,240)	($31,755,240)	($31,755,240)	($31,755,240)	($31,755,240)	($31,755,240)	($31,755,240)	($31,755,240)	($31,755,240)	($31,755,240)

Overall NPV: **($31,755,240)**

Savings of using Thermion over Status Quo **$356,521,674**

Aggregate Costs for all alternatives:

Normal Case **Discount Rate:** 2.5%

Itemized Recurring Costs

Status Quo	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Contractor application of non - skid	(48,721,134)	0	(48,721,134)	0	(48,721,134)	0	(48,721,134)	0	(48,721,134)	0	(48,721,134)
Discount Rate	1.0000	0.9756	0.9518	0.9286	0.9060	0.8839	0.8623	0.8413	0.8207	0.8007	0.7812
PV of Costs:	($48,721,134)	$0	($46,373,477)	$0	($44,138,943)	$0	($42,012,081)	$0	($39,987,704)	$0	($38,060,872)
NPV Of All Costs:	($48,721,134)	($48,721,134)	($95,094,611)	($95,094,611)	($139,233,554)	($139,233,554)	($181,245,635)	($181,245,635)	($221,233,338)	($221,233,338)	($259,294,210)

Overall NPV: **($259,294,210)**

Normal Case **Discount Rate:** 2.5%

Itemized Recurring Costs

Thermion	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Contractor application of non - skid	(59,794,119)	0	0	0	0	0	0	0	0	0	0
Discount Rate	1.0000	0.9756	0.9518	0.9286	0.9060	0.8839	0.8623	0.8413	0.8207	0.8007	0.7812
PV of Costs:	($59,794,119)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
											$ -
NPV Of All Costs:	($59,794,119)	($59,794,119)	($59,794,119)	($59,794,119)	($59,794,119)	($59,794,119)	($59,794,119)	($59,794,119)	($59,794,119)	($59,794,119)	($59,794,119)

Overall NPV: **($59,794,119)**

Normal Case **Discount Rate:** 2.5%

Itemized Recurring Costs

Liquidmetal	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Contractor application of non - skid	(177,167,760)	0	0	0	0	0	0	0	0	0	0
Discount Rate	1.0000	0.9756	0.9518	0.9286	0.9060	0.8839	0.8623	0.8413	0.8207	0.8007	0.7812
PV of Costs:	($177,167,760)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
NPV Of All Costs:	($177,167,760)	($177,167,760)	($177,167,760)	($177,167,760)	($177,167,760)	($177,167,760)	($177,167,760)	($177,167,760)	($177,167,760)	($177,167,760)	($177,167,760)

Overall NPV: **($177,167,760)**

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