A

THESIS

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# An Investigation of an Alternative High Efficiency Lighting Solution for Naval Use

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**Abstract**

**Because of high costs in installing and providing energy to current light systems, the Navy is searching for ways to reduce the costs of security lighting while maintaining current or greater levels of security. A comparison was made between the current lighting system and newer products to see if new technologies could be utilized to improve upon the system. In the end, the newer lighting system was unable to produce the same levels of lighting.**

Military Sealift Command (MSC) has strict procedures on what must be included and not included on lighting products that are installed upon their ships. Light fixtures must be secure and sea-worthy, and most important of all, must provide at minimum 5 foot-candles of luminance around a 30 foot perimeter of the hull of the ships upon which they are installed. The purpose of these lights upon MSC ships is to assist other security products on the ship to create an atmosphere where each ship both prepares itself for any threat and initiates threat deterrence. To ignore the security benefit of deterrence that mounted lighting provides is to neglect the security of each ship, so it is the job of the individual companies that provide the lighting to these ships to insure that the light levels do not fall below the minimum required by naval code. At the same time, these lights must be used in a cost-efficient and energy friendly way. The purpose of this study was to determine whether or not a third party lighting system would be able to meet the standards set forth by the Navy, and be a cost-effective alternative to the system that was already in use.

## -Introduction-

The light study in question was a comparison between the currently used Phoenix Lighting System that incorporated High Pressure Sodium lights that provided ample light but used a large amount of power, and a third party design that by using a much cheaper light source with new age technology, had the potential to provide the necessary light with more fixtures but a greatly decreased amount of energy usage.

The Navy's standard for ships under Military Sealift Command is to have a 30 foot perimeter that have a level of light that does not fall under 5 foot-candles at the surface of the water. In addition, all light fixtures must be seaworthy. To be seaworthy on a Military Sealift Command ship, a light fixture must be completely sealed on the inside to keep it waterproof and it must not exceed the flashpoint of any hazardous or explosive material that may be onboard. For most ships, this means that the temperature of the light must not be greater than 200 degrees Fahrenheit, although this number is lower for oil tankers and other special exceptions.

To understand the physics behind the illuminance and light intensity, we first need to define the basic principles behind the physics of light. We define the power emitted by a light source in a given direction as the luminous intensity. That is to say, it is a measurement of the power that is being given off by a light source for each unit of solid angle. It is measured in units of candela and in monochromatic light and is calculated from the radiant intensity (That is, the work done per steradian) multiplied by the standard luminosity function (a measurement of the average sensitivity of the human eyes to light), and then taken times a constant of 683.

$$\mathbf{I_v = 683\ I\ y(\square)}$$

**$I_v$** = luminous intensity (candelas)

**I** = radiant intensity (work per steradian)

**y(□)** = standard luminosity function

However, the luminous intensity is different from the luminous flux, which is the perceived power of light at a given distance. Where the luminous intensity measures the power emitted for only a certain solid angle, the luminous flux measures the power that is present at some distance from the light source throughout a measurement of angles. To convert luminous intensity to luminous flux, we must take the luminous intensity and multiply it by the steradian. The steradian is the commonly used unit that defines a solid angle. The steradian is found simply by squaring the distance from the light source to the measurement point, and it corresponds to the area that is created from the radius taken out through some solid angle.

$$\Omega = \frac{S}{r^2}$$

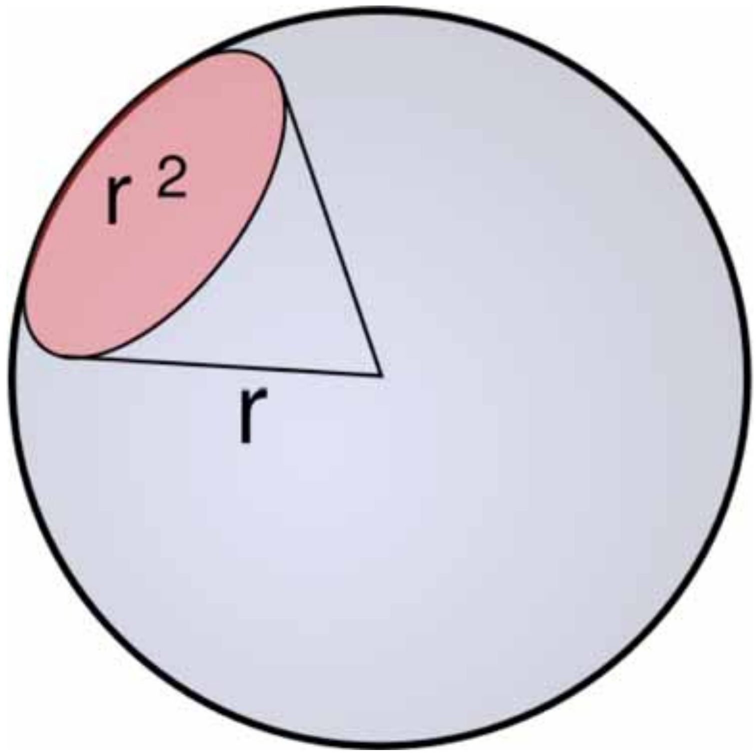


**Figure 1: Steradian[3]**

From the luminous flux, we can finally derive the illuminance, which is defined as the luminous flux in lumens per square meter. Illuminance typically uses units of lux, which is the SI unit of choice in lighting. However, the Navy currently uses foot-candles as the preferred unit for measuring illuminance. One foot-candle is equivalent to 10.8 lux, although most American light meters (all tests done were made with a Fluke digital light meter) will measure both lux and foot-candles.

Currently, the ships of the MSC are using High Pressure Sodium lights in order to provide the security needed on ship while at port or while anchored. High Pressure Sodium lights work by forcing a current through an arc of sodium and mercury vapor, or amalgam. The main source of light is the Sodium D-line that comes from the sodium vapor in the amalgam (the liquid material suspended inside of the bulb of the lamp). A current is forced through the tube, which excites the vapor inside of it increasing the pressure and temperature inside of the lamp.

Current can be controlled by means of electronic ballast, which is a device is primarily inductive, to control the current that passes through it. Unfortunately, sometimes situations do arise where the lamp can receive too large a current. This leads to a cycle of increasing the current and decreasing the resistance each cycle, which will result in failure of the product. The average expected life of our specific Phoenix products is around 22,000 lamp hours, but in reality this is shorter due to the harsh environment in which they are placed.

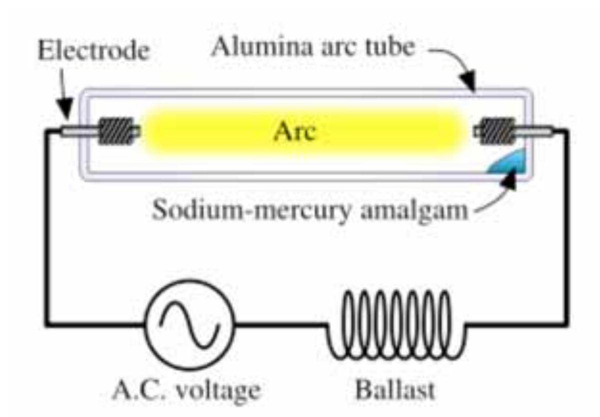


**Figure 2: Diagram of High Pressure Sodium Light[2]**

**Figure 3: Phoenix HPS Light - 400 watt[1]**

The Phoenix Lighting System comes from a company called Phoenix in Milwaukee, WI. Phoenix has many products, but we specifically use the MS400 and MS1000 series of lights because of their powerful lighting capabilities and their resistance to marine environments. These two lights are 400 watts and 1000 watts respectively per light. This amount of power is necessary in order to light entire areas 40-70 feet below where the lights must be placed. Currently, the lights are mounted on to extended arm brackets so that they can be swiveled out beyond the edge of the ship to light it while making port, and can be brought back in while at sea.

**Figure 4: PAR Bulb**

The alternate lighting system in question was one developed by David Dettimer using the much cheaper and far more energy efficient Parabolic Aluminized Reflector (PAR) lighting system. The PAR lights use a lens and a reflector in combination to produce a more focused beam than the Phoenix lights at much lower energies. Where the Phoenix system was using 400 watt and 1000 watt systems, the PAR system had four 35 watt bulbs with a 50 watt bulb in the center. While this was substantially less energy, it was known that the spread of the lighting would not be as wide reaching as the Phoenix system, so the purpose of the experiment was to try and find out exactly how many more PAR lights we would need to install in order to get the same effective lighting as the Phoenix.

Cost and value of the product in question were the main reasons for pursuing a comparison of these two products. First off, one of the main goals of the study was to see if the system could be made any more energy efficient. A ship only has so much power that it can draw upon, and reducing that amount of energy would allow for other components to be added to the ship with greater ease. Second, we were looking to see if there were any products out in the market that could be comparable to the Phoenix Lights in ability but could be obtained at a lower price when valuing in both the cost of the light itself with the potential energy savings. It would be beneficial to either install it on all future ships or even return to previous ships and reinstall a better model that cost less. Finally, Crane was looking for a solution to the problem that the Phoenix Lights had a high turnover rate because of the extremely harsh environments that MSC ships go through. If it was possible to also have the newer light in question be more sea-worthy than our current product then it could reduce the repair calls that are made which would save both Crane and the MSC ships time and effort.

-Measurements-

To compare the two products on a basis of lighting power, it was determined that the best method would be to create computer simulations of the light output based on the lamp's output. Two computer programs were to be used here for the comparisons. First, AGI32 was the program that was already in place to determine the setup of the lights on each ship, as it takes a file that describes the light output and can map the luminous flux at any given point. Secondly, we were to use 3DS Max 8, a primarily graphics based simulation program, to create better three-dimensional images of what the light would actually look like on the ship. However, both of these programs required IES files (the naming convention for photometric data). For the Phoenix lights, this was simple as the files were requested from the company as they had done tests to create the files previously. It was not so easy for the PAR light however, as the light was still in development with little data available on the output of light. So, the first task was to create a basic IES file for the light.

IES files contain the following information. The first few lines are optional and contain the line "[TEST]" followed by the name of the person or company performing the test, "[DATE]" followed by the date, and the name of the company whom the test is being performed for with the prefix "[MANUFACT]".

There may then be any number of lines stating "[OTHER]" with any other notes about the test or product as determined by the tester or manufacturer. Next is the required line stating the name of the lamp in question, in the format "[LAMP]" followed by the lamp name, be followed by the word "TILT" proceeded by the degree that the lamp is tilted from the observation axis because of the design of the product. For the vast majority of commercial products, this will be "TILT = NONE".

Following this is a line of numbers, with the most important for our purposes being the first three numbers. A number "1" at the beginning of the line signifies to read the line and the second number signifies the lumens present at the point source of the light. The third line is used later and is a value in meters that tells the distance between each line of measurement in the last set of lines. The rest of the line refers to color and reflectance values of the light, which although important to the light, were not deemed necessary to calculate for our initial survey. The next line will have two number 1's in a row (these signify constants for measuring the angles through which the light passes, which thanks to standard practices have now been set to be 1 for virtually all new lighting products). Following those numbers will be a number that signifies the power in watts that the light uses. The following line begins the actual data that the software programs use. It contains a list of values that show what angles the measurements were taken at. This list corresponds to all following lines in that the first entry in each proceeding line will match the corresponding angular value. These numbers will vary widely depending upon the use of the light, as higher intensity beams will use smaller variations in the lower angles while floodlights will typically have a fairly standard spread of angles. After this line, all lines will be the measurement of the luminous flux at the corresponding angles with each line being separated by a distance equal to the third number on the first line of numbers. The following is an example of the Phoenix IES file.

```
[OTHER] MSD1000 W/HAMMERTONE REFLECTOR

[LAMP] LU 1000 HPS

TILT=NONE

1 140000 1 000019 000019 2 1 0.5 1.58 0

1 1 1147

0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90

0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90

23261 23289 23029 22527 21709 20607 19270 17764 15969 14132 12246 10146 7475 5130 3041 1614 692 299 128

23680 23679 23444 22945 22151 20988 19537 18045 16280 14322 12406 10224 7540 5139 3026 1636 706 301 129

25520 25544 25283 24690 23791 22531 20993 19244 17276 15129 12991 10503 7650 5152 3006 1679 741 308 129

28224 28262 27908 27263 26184 24807 22893 20948 18672 16322 13803 10956 7805 5164 2985 1669 765 317 131

31956 31993 31738 30779 29399 27676 25494 23146 20496 17732 14661 11266 7838 5031 2972 1659 804 330 132

34748 34784 34403 33398 31788 29831 27304 24617 21688 18603 15296 11482 7804 4909 2935 1677 828 338 133

38837 38846 38227 37107 35452 33091 30281 27337 23860 20042 15941 11751 7710 4808 2842 1674 846 342 133

40359 40308 39610 38362 36526 34106 31141 27890 24189 20064 15663 11315 7513 4705 2751 1633 895 348 132
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35637 35640 34998 33911 32431 30340 27842 25020 21584 17866 14011 10093 6798 4233 2577 1538 1179 341 130

32633 32614 31902 30940 29674 27788 25466 22949 19777 16323 12618 8920 5838 3543 2178 1311 687 277 123

24049 23989 23589 22900 21833 20401 18770 16974 14606 11794 9610 6398 3820 2383 2297 1293 544 211 119

15010 15107 14876 14555 14021 13267 12333 11222 10279 8681 6030 4508 2880 1795 1131 791 454 182 114

6395 5804 5324 5220 5366 5074 5104 4557 3801 2997 2510 1960 1424 952 789 576 348 158 115

2235 2239 2218 2165 2081 1960 1812 1649 1450 1252 1073 906 701 601 492 351 200 146 116

1101 1101 1103 1094 1066 1022 965 895 806 719 602 490 439 365 287 191 159 130 111

662 663 666 662 648 628 528 499 455 413 392 371 316 276 219 156 132 120 111

338 336 339 336 330 321 353 336 316 292 265 235 207 179 151 119 112 114 111

191 190 193 194 193 190 186 181 176 166 154 140 128 119 109 91 96 108 111

100 101 103 105 106 107 108 108 109 105 97 93 90 90 87 84 93 106 111

From this data we are also able to see how the light falls off as we would expect it to, that is, as $1/R^2$. It is because of this that we are able to take one line of data for the light we are testing and expand it based upon using the $1/R^2$ equation for luminous intensity. Figure 5 shows the data taken from the Phoenix Light as compared to $1/R^2$.

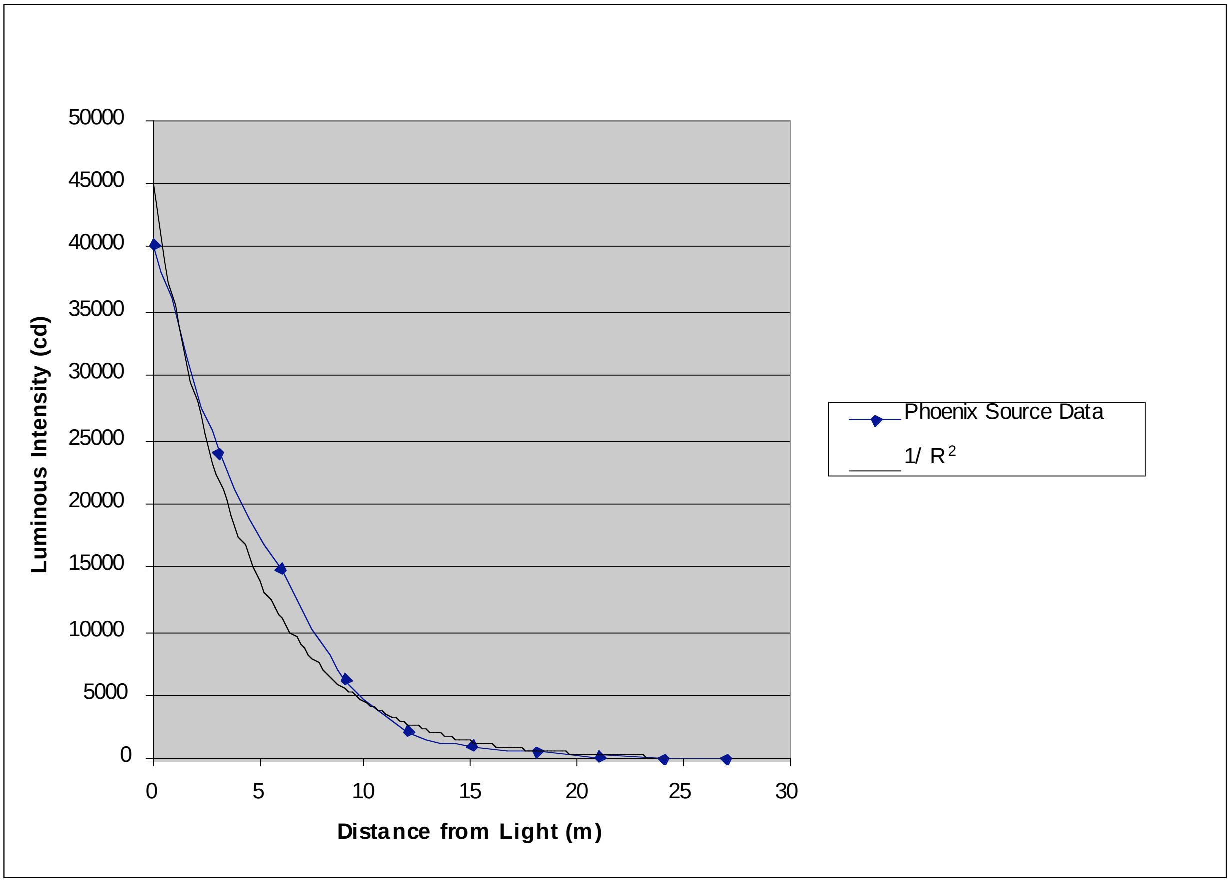


**Figure 5: IES Data versus expected values**

So, to make a file of this type, there were two options. First, separate companies can take the light and perform the test for us at the cost of ten thousand dollars in approximation. Or, we could develop a crude file ourselves to use as a starting point. Since this was just an initial foray into the product, it was determined that getting a rough basis from which we could justify more expensive tests would be the best course of action. To create this file, we would need a broad spread of the light at the angles we could use and from the data we collected, we would be able to create a useable IES file that we could load into the computer simulation to gauge the ability of the PAR light to provide sufficient lighting.

The experiment was conducted in a warehouse on base. The warehouse was our most optimal location because we were able to tape cardboard over the windows that were in the warehouse and create an atmosphere with a non-detectable amount of ambient light. The light meter that we used was reading around 0.2 foot-candles with the lights off and windows sealed. This baseline was subtracted from all measurements. The light meter that was used was only accurate to 0.1 foot-candles, but that was deemed to be acceptable for our purposes.

The light itself was suspended from the ceiling with rope and was tied off onto steel beams to secure it from falling. Below it, the area was marked off with a piece of tape directly below the light using a plumb line held from the center of the front window on the light. Other pieces of tape were then placed every six inches using a standard ruler, so that it would be easy to go from point to point with the light meter and make the measurement. The lamp was measured to be suspended 13 feet, 10 inches above the ground. Using a protractor, the tilt of the light was found to be 2.41 degrees. This meant that some basic trigonometry would have to be used to determine the luminous flux in the planes parallel to the lamp. Below is an Excel spreadsheet of the data that was taken. The measurements are in six-inch increments. The outlined box in the center is the spot underneath the lamp.

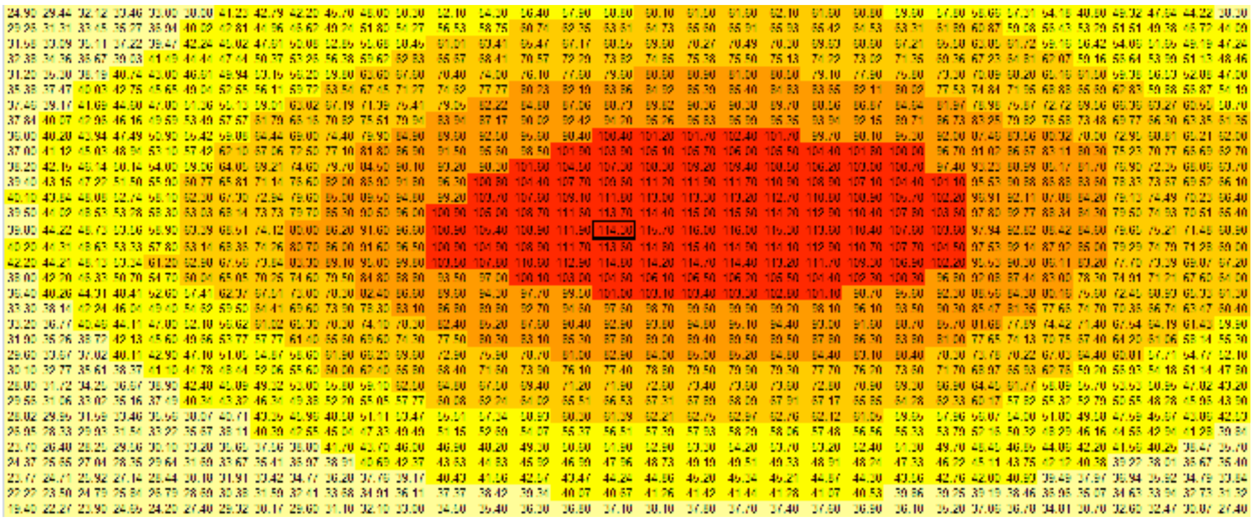

**Figure 6: Graph of Luminous Intensity test**

Measurements beyond 4 feet in each direction were then taken only at each foot, so the measurements in between are calculated through a series of averaging. The color in the graph is only to help distinguish the pattern that is being made by the lamp, with each shade being 20 foot-candles less than the previous, with the highest luminous flux near the middle (between 100-120 foot-candles) and the lowest being on the outside corners (around 20-40 foot-candles). From this graph, we were able to extrapolate enough information to make an IES file to make simulations from. We do this by taking the values found as though they were one line of values on the IES files. Then, the values for the other lines are calculated using $1/R^2$, and added in. The AGI32 files matched up with the expected values.

The AGI32 software takes multiple types of files, depending on what purpose you are using the program for. In our case, we were using IES files that we had to upload into the program's "Luminaire definition". Once we had given the program our definition of the light patterns that were produced by the light we imported an AutoCAD representation of the lamp that was created by another person within our department. The program gives great freedom in allowing one to edit each light to their liking, as it was very simple to take the CAD (Computer Aided Design) lamp and virtually "screw in the light bulb" by placing the point source for the lamp inside of the luminaire.

To work with AGI32 requires some basic CAD knowledge, and since we also need to know how to interact with the three dimensional model of the ship in each program, it is wise to have some familiarity with AutoCAD and its nuances. AutoCAD is a computer design program that is used for a wide variety of engineering and modeling purposes, because it allows for both artistic use and has a precise set of mathematical rigors that can be used to position each part of a drawing wherever it is needed. The basic parts of AutoCAD are much like any graphical design program, it has lines, shapes and camera features to allow one to view the object from many points of view.

The thing that separates it from a typical drawing program, however, is the fact that each point that is drawn can be accessed via a simple right click and can be adjusted to any other point within the drawing space mathematically, either through x,y,z coordinate systems (the height, width and depth of the drawing) or by R, theta and z (the radius, angle and depth). This functionality transfers over to AGI32, where after editing the luminaire to your liking it is possible to place it wherever it is needed without messing up by putting it slightly in the wrong place.

The main use of AutoCAD within the group I was working with was to create and modify drawings of the MSC ships themselves. There were a base set of ship schematics that could be brought up and from them it was possible to plan out where to place either the Shipboard Security System or the Hull Perimeter Lighting system, depending upon which installation was needed. The way that ships in the past had been fitted for lights within the Hull Perimeter Lighting system was that the luminaries in the AGI32 program were placed in various locations around the ship so that they could be modified and adjusted until they were able to cover the locations for each other that they could not light well enough on their own, and this cycle of propagating each light and adjusting the location was the main method to determine how to place the lights.

The following graph was used to the USNS Pathfinder, a transport vessel. The study was to show the output that the Phoenix Lights should have if properly place upon the vessel, with an optimal output being that all space within 30 feet would be up to the 5 foot-candle output. The most exterior line that surrounds the ship is the 30 foot perimeter for compliance. All space within the lines that are shaded with small boxes shows lack of compliance, while all outside are greater than 5 foot-candles. The main reason for the areas that are of less intensity is that certain areas on the rear of the ship are confined due to the ship's crane, and so only certain areas were even allowed for the lights to be placed.

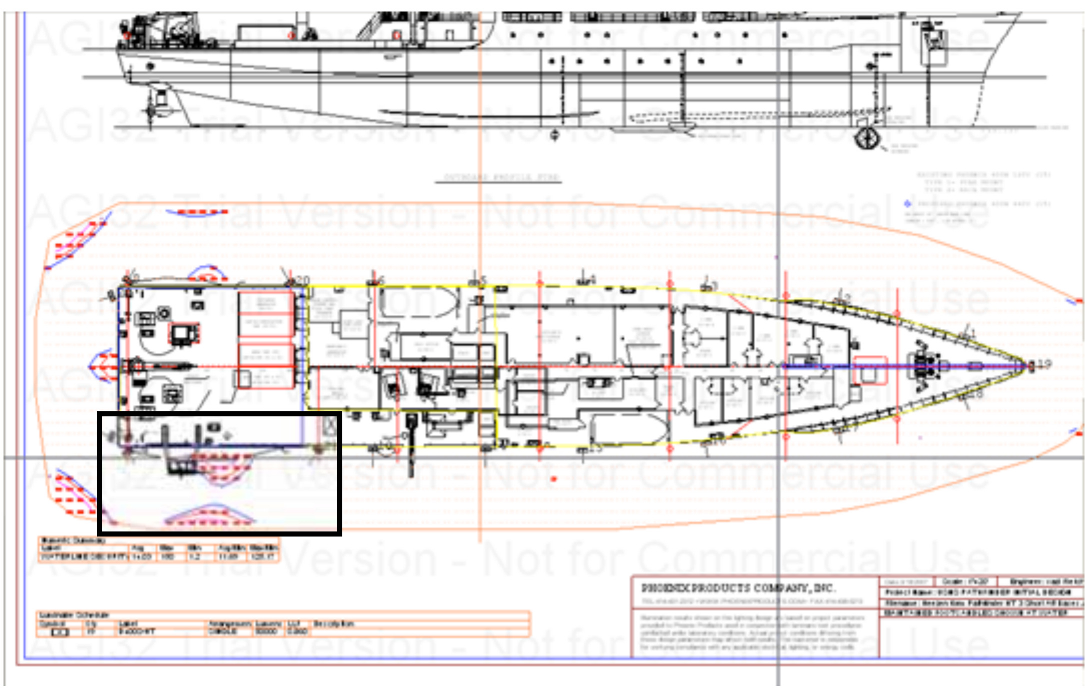


**Figure 7: USNS Pathfinder with Phoenix Lighting**

The poor lighting in the stern of the ship can be attributed to a couple of factors. Primarily, it is much harder to light the back as it is where the ship docks and as such the majority of systems for making port are already located back there, leaving little space to include lights. Also, the stern of the ship is at a higher elevation than the bow of the ship, so it is harder to get that same luminous flux at the surface of the water at the stern than at the bow.

The next graph is a close-up of the stern, starboard side, and the values associated with it. The shaded numbers are not in compliance with Navy standards, but exceptions have to be made because the safety risks involved with placing non-essential systems near the mooring line and crane was not an acceptable risk. Notice however that the lights are located as close as they can be in order to maintain the highest level of luminous flux possible in that area.

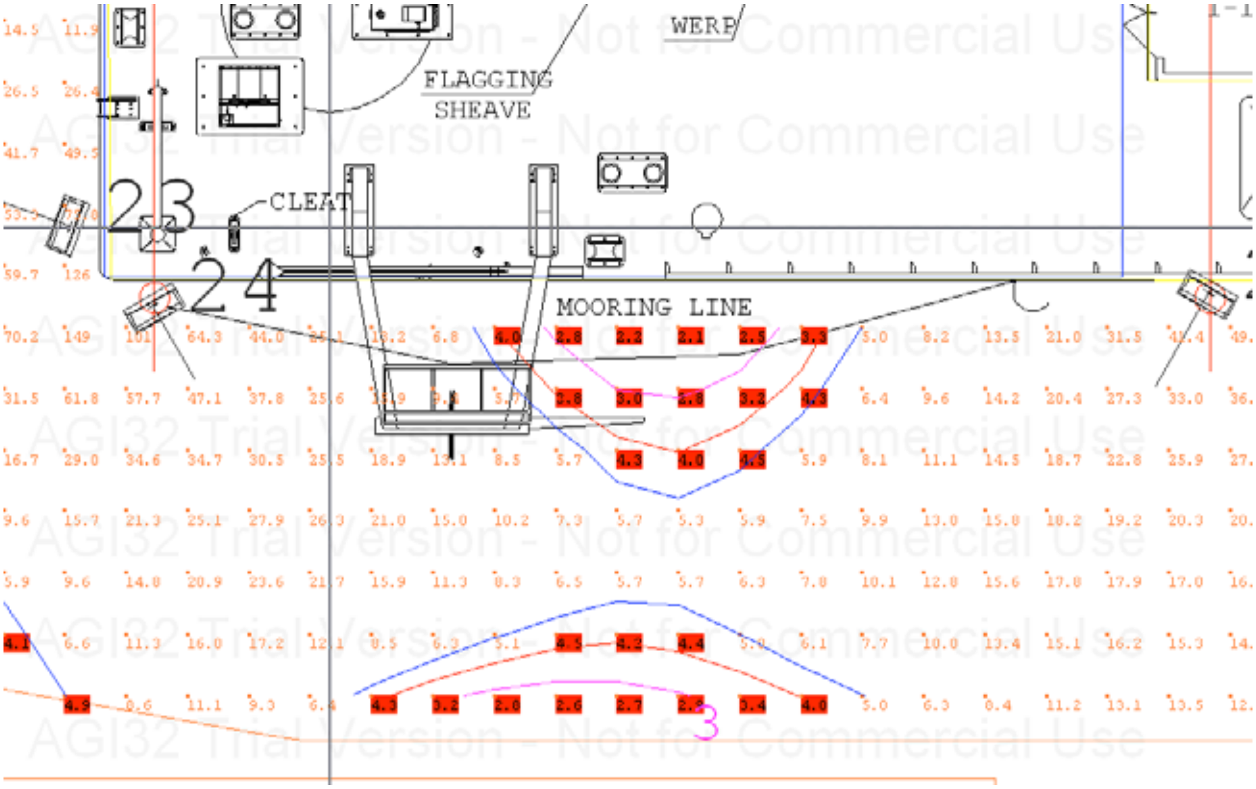


**Figure 8: USNS Pathfinder (Fig. 7), zoomed**

The next set of graphs is the same ship, the USNS Pathfinder, but now it is using the PAR lights instead of the Phoenix lights to light the perimeter. One important thing to notice between this graph and the one before it is the number of luminaries on each. The Phoenix system required 19 lamps in order to obtain sufficient lighting levels, while the PAR lights needed double that in order to have adequate lighting levels.

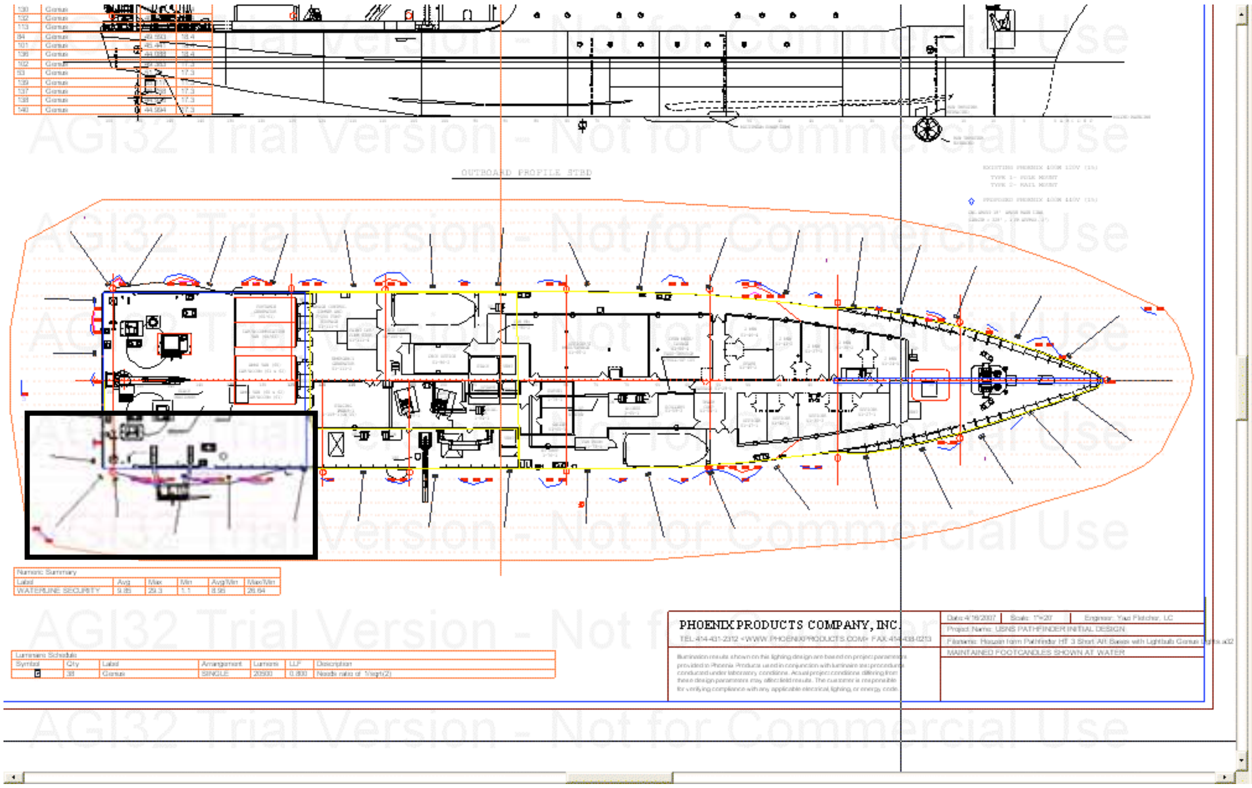


**Figure 9: USNS Pathfinder with PAR lighting**

Another small detail of importance to note in this image is how each lamp seems to have a longer line attached to it than in the Phoenix system. This is because of the PAR lamps poor luminous flux through large angles. If left pointed at the same position as the Phoenix lamps, the PAR lamps don't even reach sufficient lighting levels at 20 feet, let alone make adequate lighting at 30 feet. Because of this, the lamps are pointed at a slightly more horizontal angle, which causes the edge of the ship near the water to suffer somewhat. This next image is the same location as the first, but once again showing the numbers closer up for better inspection.

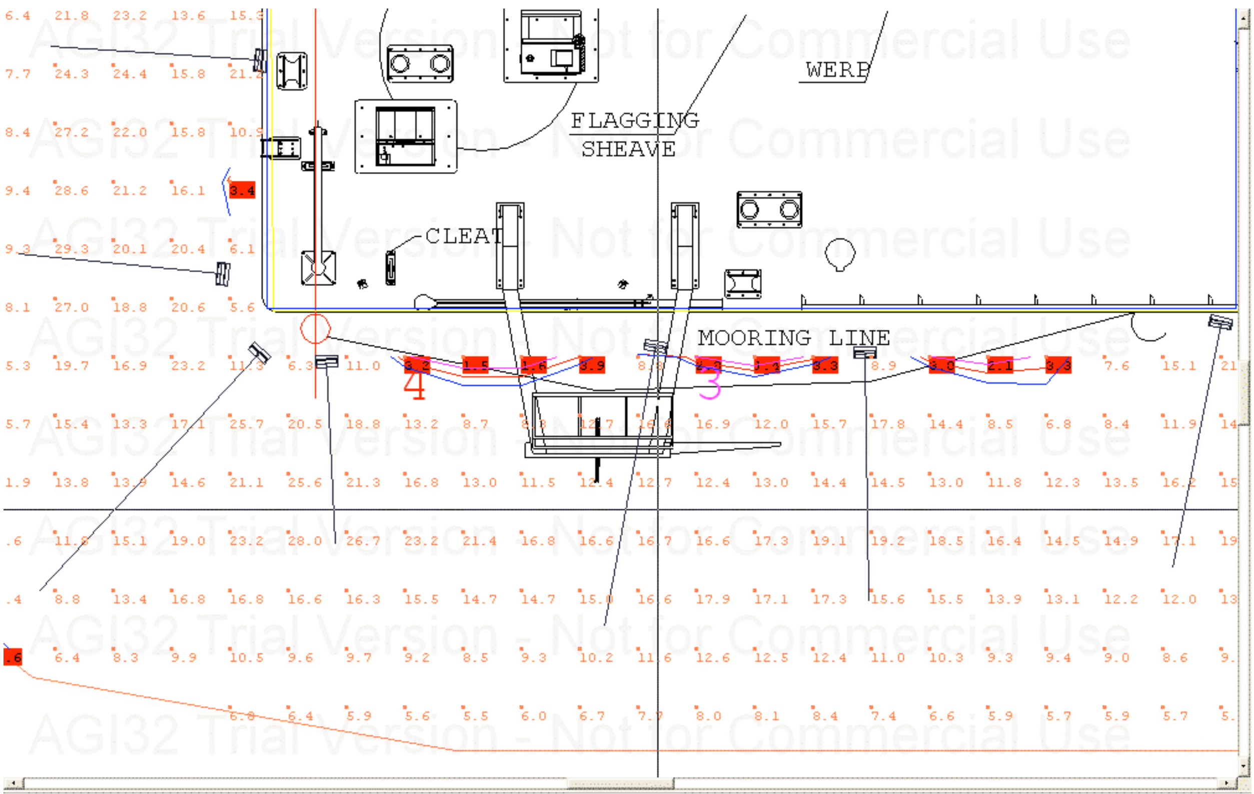


**Figure 10: USNS Pathfinder (Fig 9.), zoomed**

-Comparison between the two-

The lines separating the shaded portion with the rest represent where the actual cutoff point would be for Navy compliance. The space between each point on the following graphs is 5 feet. These graphs are a simulation of what the lighting effects would be if the lights were placed in a completely dark room and turned on while pointing straight down at a fixed height. The first set of graphs is placed at 45 feet above the surface. The PAR light is on the left with the Phoenix on the right. Notice how the PAR light doesn't even cover a 10' by 10' square of light, while the Phoenix adequately fills much of the area (the sample area is a 30' by 40' rectangle). For such a long distance above the ground like 45 feet, the Phoenix lights are superior in that they provide light throughout a much broader area, while the PAR lights require that many bulbs would have to be placed close to each other in order to produce the same amount of light on the ground.

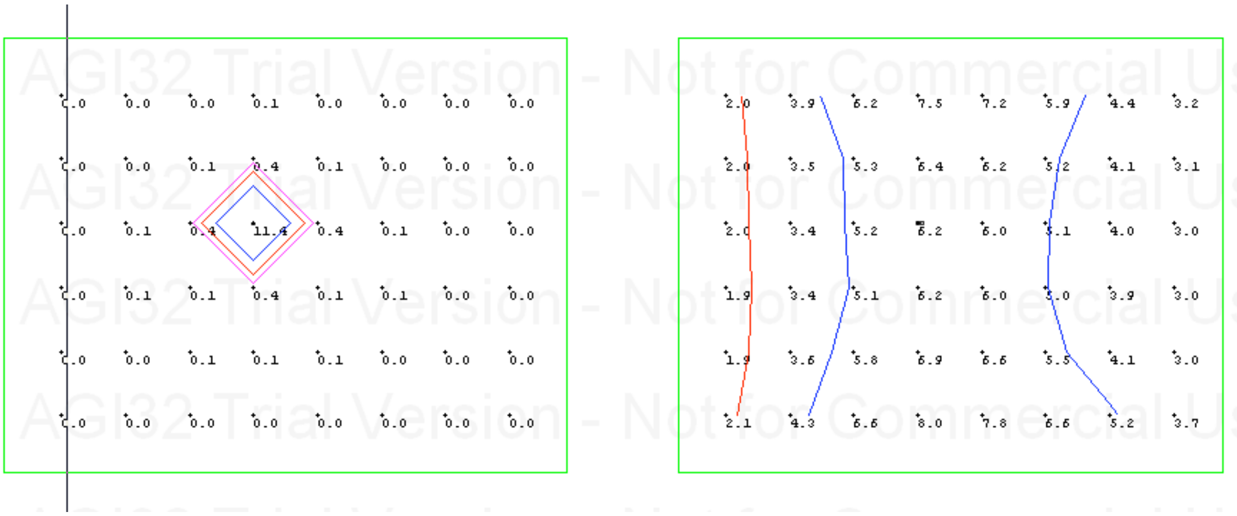


**Figure 11: PAR Lighting System (left) versus Phoenix (right) (45 feet)**

The next graph now shows both lights suspended 15 feet above the ground. In this, we notice that the PAR light comes much closer to mimicking the results of the Phoenix light. This means that if we needed to lights to be some smaller distance above the ground while on board the ship, then the effects of the PAR light would not be much different than that of the Phoenix light. This would allow for the cheaper PAR lights to be set in the same pattern as the Phoenix, allowing for their inexpensive nature to compensate for the need to have more of them.

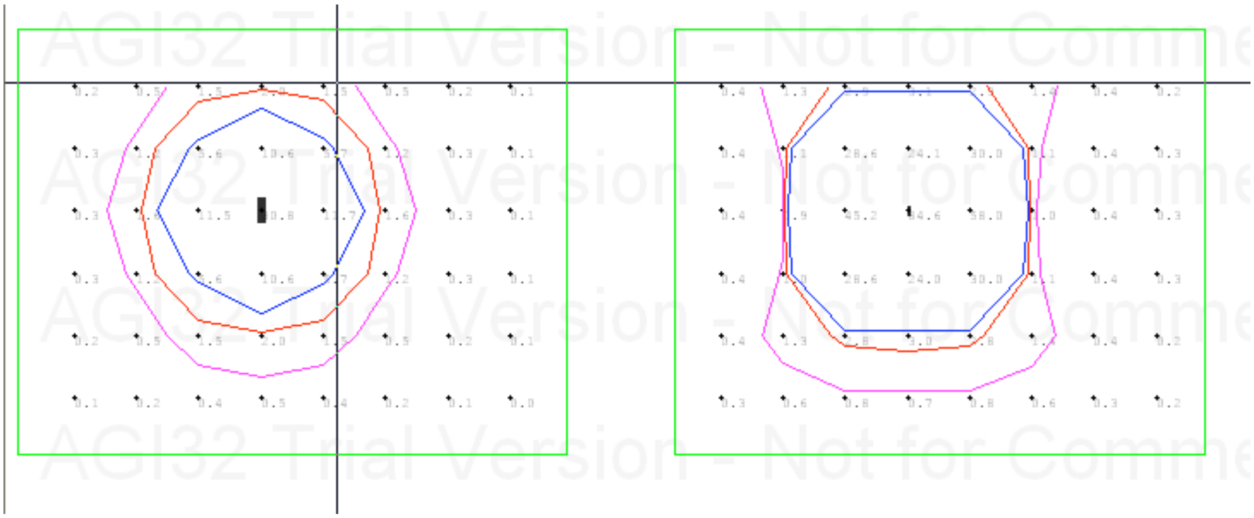


**Figure 12: PAR Lighting System (left) versus Phoenix (right) (15 feet)**

-3DS Max renderings-

The following renderings were made with 3DS Max 8, a computer graphics and animation program that is used for simulations and moviemaking. For the final part of the project, it was requested to have some idea of what both lighting systems would look like on board a MSC ship. 3DS Max can take a CAD file from AutoCAD, similarly to AGI32, and can place this file within any sort of background required. This specific model was of the USNS Lopez and was placed in a nighttime setting in ocean water.

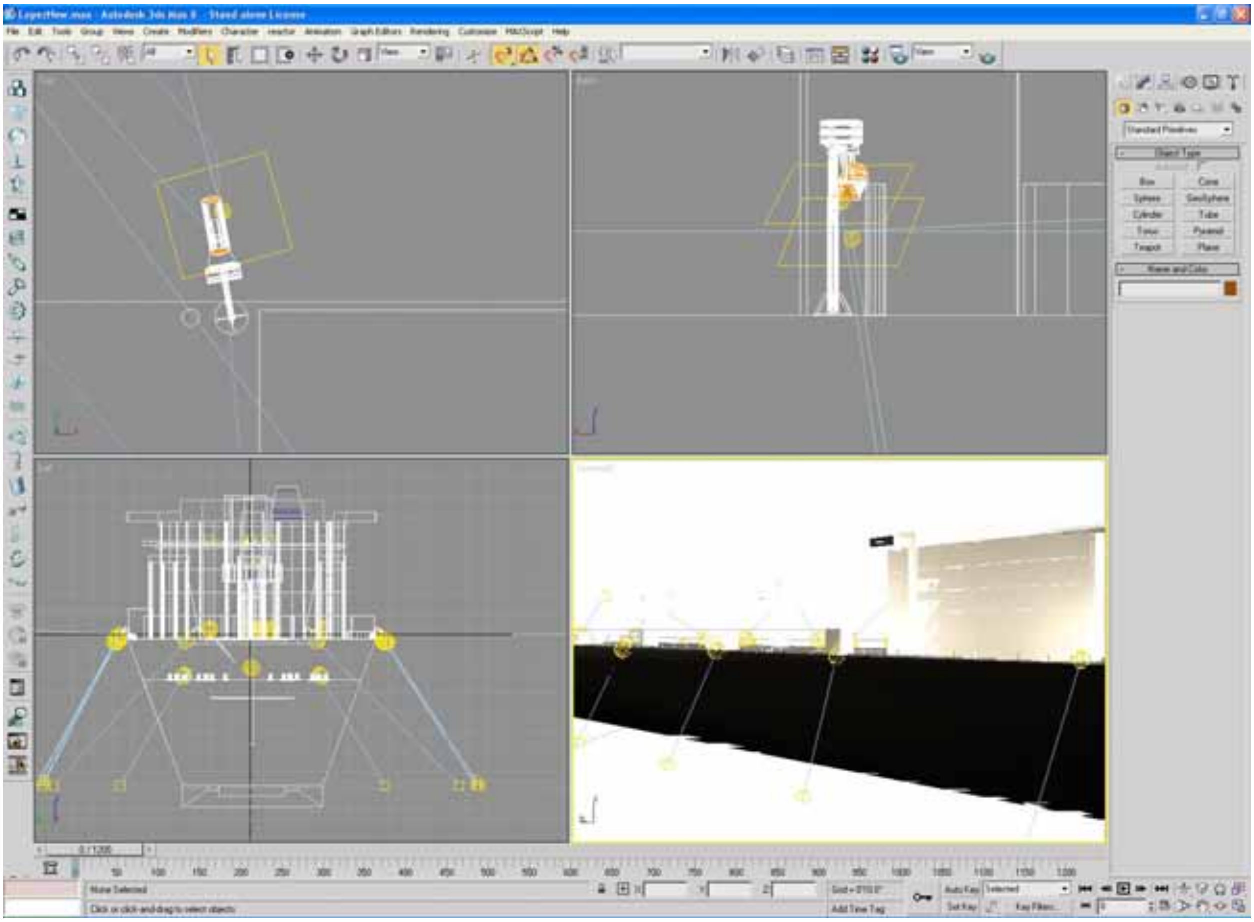

**Figure 13: 3DS Max 8**

In addition to placing the ship where you want it, the program also allows for any sort of lighting one would desire to be placed in the scene. It also allows for moonlight, ambient light, and reflectivity from the surface of the water, and allows for short “clips” of animation to be created by adding cameras that move over time and can dynamically change both position and shooting angle. The specific movie that we created made a complete trip around the ship to show lighting levels for each position, and then zoomed in on a single light to show exactly what the product looked like and what lighting levels could be expected in its immediate vicinity.

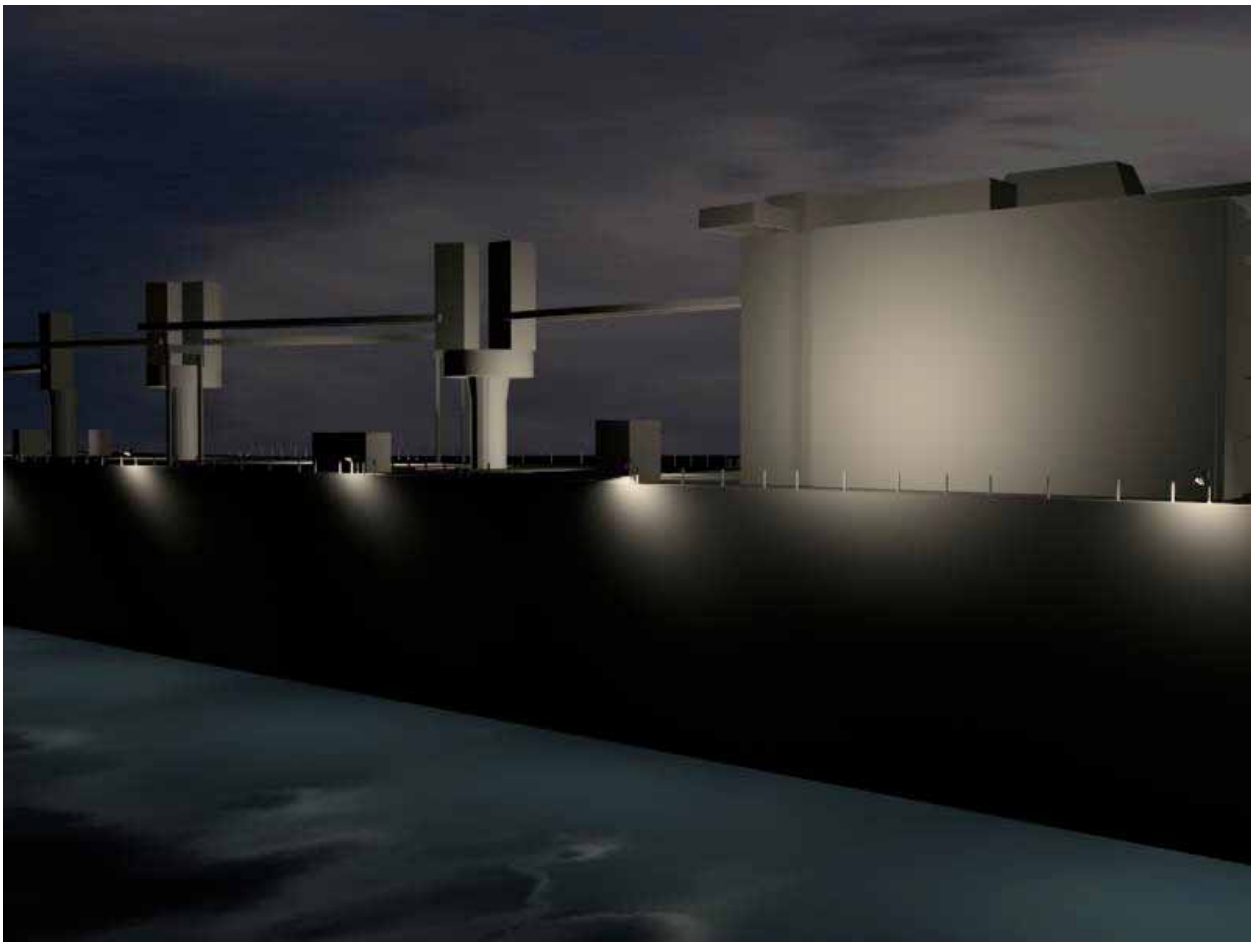

**Figure 14: USNS Lopez with Phoenix Lighting**

**Figure 15: USNS Lopez with PAR Lighting**

As can be seen from the images, the PAR lighting system was not nearly as bright on the surface of the water as the Phoenix system was, which is the major problem in providing lighting security as deterrence for these ships.

-Results and Conclusions-

In the end, the problem with the PAR lighting system was that it produced too high of a focused beam of light to be of any real use for our goals. Whereas the Phoenix system used a few lights with a high spread at high energy costs, the PAR system would have required more than twice the number of Phoenix lights to produce the same spread. While this would actually have produced a savings in the energy used on board ship, the logistics of doubling the number of lighting fixtures onboard was a large problem, as space is already tightly conserved on each ship and the extra cost of purchasing and installing the fixtures would outweigh the energy that would be saved. The PAR models could have been much cheaper and they still would not have been the optimal solution, as time it would have taken to install such a huge project would have also doubled, and by doubling the work time that the Navy would have to pay for installing this system there would be no real benefit. So, the Phoenix lights would stay and continue to be the lighting system that will be installed on future MSC ship installations.

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