Crane Safety: Lessons from the Nuclear Industry

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Abstract

Fatalities and injuries involving crane operations on U.S. construction sites have not appreciably changed over the last 20 years. Incidents causing injuries and fatalities occur due to events such as crane boom contact with overhead power lines, workers struck by a crane load, and cranes collapses. Recently, a study was completed on construction crane operations on or near U.S. nuclear power plants. Safe and effective crane operation is critical for operational use and construction processes in and around active nuclear power plants. Construction activities near active nuclear sites require that crane operations are well planned in advance, monitored to consider all potential adverse impacts to nuclear operation, and reviewed with all key personnel. The U.S. Nuclear Regulatory Commission (NRC) has documented numerous crane related incidents and conducted exhaustive studies on the root cause of the incidents. The NRC has also made numerous regulations and inspection procedures, and provided guidance to reduce the risk of a crane incident. Many of the concepts and procedures developed for both operational crane use and construction use would benefit crane operations on a general construction site. To determine if some of the unique requirements for nuclear crane operation would benefit the general construction industry, a review of procedures and requirements in the nuclear industry was completed. A series of case studies where then examined to determine if additional safety features may have assisted in preventing the incidents. For the particular case studies shown there was evidence that increased requirements may have prevented an incident, however, following proper protocol for general crane operations would also have assisted in preventing the incident. The nuclear crane requirements would be considered excessive in the general construction industry, however, general concepts such as redundancy, thorough planning of lift operations, load monitoring, and specially designed lifting mechanism and lift points could be implemented or already are implemented in the general construction industry. To improve safety of crane use, it may be appropriate to turn to crane requirements that have very low probability of failure, such as in the nuclear industry.

Keywords: Crane, Safety, Nuclear, Redundancy

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1. Introduction

The operation of cranes on the construction site has long been a source of injuries and fatalities in the workplace. In order to reduce the number of crane incidents on construction sites, construction firms have developed more advanced planning procedures and training materials to ensure the safe and effective operation of cranes. Crane manufacturers have also improved safety by providing improved and easy to understand crane operation information and developing new systems to detect when cranes are beyond their operational capability. Despite all of these efforts, incidents involving cranes are still common on the construction site. The focus of this study was to review the very stringent operational requirements for crane operation on a U.S. nuclear power plant site and to determine if there are operational requirements in this industry that may help improve crane safety in the general construction industry.

In nuclear power plant operation there are numerous activities in which heavy loads need to be moved and hoisted. If these loads were to impact critical nuclear systems because of a failure of the equipment or human error, a serious nuclear incident could result which would endanger the lives of many people. In order to prevent such incidents, the U.S. Nuclear Regulatory Commission (NRC) provides regulations for safe crane operation in and around active nuclear power plants. These regulations exceed typical safe crane construction operational requirements and focus on the critical nature of load and what may impact the load versus the safety of the worker. While these regulations may be excessive for the general construction industry and only utilized on facilities with hazardous material or expensive industrial equipment, they provide insight into potential areas where further crane operational safety measures could be improved.

This paper provides an overview of crane operations on U.S. nuclear power plants through a review of regulations and pertinent literature. The operational requirements for the NRC are then compared with a typical crane lift procedure on a construction site that is well planned and documented. For the purpose of this study, a general construction industry “critical lift” plan is used for the comparison. The stringent NRC requirements are then used to evaluate documented cases of crane operational failures to determine if the additional NRC requirements would have reduced the probability of the injury or fatality.

2. Background

2.1 U.S. Crane Injuries and Fatalities

The operation of cranes on construction sites in the U.S. is a source of numerous injuries and fatalities. In 2011, there were 680 non-fatal injuries involving cranes where workers spent a day or more away from work (BLS 2010). Additional information about crane fatalities is shown in Table 1. Based on this data, there are a significant numbers of workers injured or killed in crane related incidents. The majority of incidents are caused by being struck by an object, which includes a falling object. Being caught in the equipment and being electrocuted by power lines are also common causes of injuries involving cranes.

Table 1. United States Fatal Occupational Injuries where a Crane was the Primary Incident Source (BLS 2010)						
Year	Total Fatalities	Struck By Object	Caught in or Compressed by Equipment	Contact With Electrical Current	Transportation Incidents	Non-Categorized
2010	17	5 29%	6 35%	3 18%	0 0%	3
2009	23	16 30%	6 26%	3 13%	3 13%	4
2008	45	16 36%	9 20%	9 20%	0 0%	11
2007	30	11 37%	9 30%	5 17%	5 17%	0
2006	28	10 36%	6 21%	6 21%	6 21%	0
2005	43	10 23%	12 28%	13 30%	8 19%	0
2004	39	20 51%	5 13%	10 26%	0 0%	4
Total	225	88 39%	53 24%	49 22%	22 10%	22

2.2 Crane Operation in the Nuclear Industry

For nuclear reactor safety, it is important that heavy loads hoisted by a crane are done properly to ensure plant safety and security. The focus of crane regulations are the protection of equipment and critical systems, however, inherently the regulations also protect the workers. One of the main regulations for crane use inside the facility is the NRC regulation, NUREG 0612, “Control of Heavy Loads at Nuclear Power Plants” (George 1980). This report provides guidelines for managing heavy loads and the additional redundancies that are required in order to prevent a load drop or other damage that may release radioactive material. The main strategy employed by the NRC is entitled “Defense-in-Depth”. The NRC provides the following definition:

> *“Defense-in-Depth: An approach to designing and operating nuclear facilities that prevents and mitigates accidents that release radiation or hazardous materials. The key is creating multiple independent and redundant layers of defense to compensate for potential human and mechanical failures so that no single layer, no matter how robust, is exclusively relied upon. Defense-in-depth includes the use of access controls, physical barriers, redundant and diverse key safety functions, and emergency response measures”. (NRC 2012)*

The NRC and the Department of Energy (DOE) also provide guidelines for construction operations on or near nuclear power plants. During the construction of nuclear power plants in the United States there were significant crane related incidences that prompted the NRC to do an in-depth look at construction cranes. Reports that provide additional information on safe use of cranes include: 1) NUREG -1774, "A Survey of Crane Operating Experience at U.S. Nuclear Power Plants from 1968 through 2002" (Lloyd 2003); 2) NRC Inspection Manual 2515 Appendix F, "Reactor Construction Activities Near Operating Units" (NRC 2008); 3) Department of Energy Report, "Independent Oversight Special Study of Hoisting and Rigging Incidents within the Department of Energy" (Neubauer 1992).

2.3 General Construction Crane Operation

Information on crane operations in the commercial sector was gathered in order to allow a comparison between crane operations on nuclear sites and general construction project sites. For operational and safety issues involving cranes on a typical construction site the American Society of Civil Engineers (ASCE), "Crane Safety Training for Engineers and Supervisors" (ASCE 2009) provides extensive crane safety information. A more condensed set of guidelines for critical lifts is provided by The Hartford Loss Control Department report, "Crane Critical Lifts" (The Hartford 2008). Figure 1 shows an example of a crane critical lift plan. These references provide detailed information on planning and executing a critical lift.

3. Results

Based on a comparison of guidelines for nuclear crane operation and general industry crane operation, a number of operational variances were found. As expected, the crane operation for the nuclear industry contains more detailed requirements and more specialized equipment. A select few of the requirements are discussed along with case studies on how these requirements may assist in reducing the number of crane incidents.

3.1 Comparison of Nuclear Crane Operation and General Industry Crane Operation

3.1.1 Single-Failure-Proof

A notable equipment requirement for the nuclear industry is that certain cranes be required to be "Single-Failure-Proof". The cranes that handle nuclear material must be equipped such that a single failure will not result in a crane dropping a load or cause a system failure during a critical lift (Porse 1979). The concept of single-failure proof requires significant redundancy in the crane lifting system and additional control requirements. Single-failure-proof crane features may include (Whiting 2012):

- Creep speeds on one or more motions
- Area or zone restrictive limit switches
- Redundant mechanical drives
- Cameras mounted at various locations

- Motion and position indicating lights or readout
- Remote operation

Crane Critical Lift Plan

General Information

Scheduled Lift Date:	**Scheduled Lift Time:**
Jobsite:	
Specific Lift Location:	
Lift Height:	
Description of Lift:	

Personnel

Crane Operator:	**Qualifications:**
Lift Supervisor:	**Qualifications:**
Rigger:	**Qualifications:**
Hoisted Personnel (if applicable):	

Lift Criteria

- ☐ Lifting greater than 75% of the rated capacity
- ☐ Lift involving more than one crane
- ☐ Lift over occupied structures or in tight quarters
- ☐ Blind lift (out of the view of the operator)
- ☐ Lift near power lines
- ☐ Hoisting personnel
- ☐ Lift involving non-routine rigging techniques
- ☐ Lift where the center of gravity may change
- ☐ Lifting high value, hazardous, or explosive loads
- ☐ Lifting submerged loads
- ☐ Other (describe): ______________________

Crane Critical Lifts
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Figure 1. Example Page of a Critical Lift Plan from Hartford (The Hartford 2008)

In the general construction industry, rarely are there requirements to have a redundant mechanical lift system or rigging to prevent a dropped load. The single-failure-proof concept also requires additional systems to monitor load location, confirm location visibly, and have very low speed (creep) capability. Some of these features may be found on newer cranes in the general construction industry. With the advancement of load sensors and position detection equipment, many of these systems are becoming more affordable options for all types of cranes, not just those servicing the nuclear industry.

3.1.2 Safe Load Path with Mechanical or Electrical Interlocks

Another difference between nuclear crane operations and general crane operations is the extent to which a safe load path is designed and implemented (George 1980). In the general construction industry, it is recommended that a diagram of the intended load path be identified and that other hazards be noted, such as proximity to power lines and other workers. However, in the nuclear industry, the load path is clearly prescribed for each lift and the crane may be incapable of going near any potential hazards because of mechanical and/or electrical interlocks; this load path requirement for the nuclear operation exceed requirements for a typical lift in the general construction industry.

Advanced cranes in the general industry have the capability to limit crane movement areas. For example, collision monitoring is important when working with multiple tower cranes. Large construction sites may have multiple cranes, with moving booms and varying loads throughout the day. The cranes may be equipped with an internal system to prevent movement in certain areas or collision monitoring systems. Figure 2 shows two cranes on a job site in China outfitted with a collision monitoring system.

Figure 2. Tower Cranes in China with Collision Monitoring

3.1.3 Special Lifting Devices

In the nuclear industry special lifting devices are required for heavy loads (greater than 10,000 pounds or 5 tons) containing nuclear material (George 1980). These lifting devices interface with specific designated lifting points on the load. Specific lifting points and special lifting devices are becoming more prevalent in the general construction industry. These devices tend to be more common when repetitive lifts are required of a specialized nature. Figure 3 shows a specially designed lifting rig for a wind turbine blade. The lifting device positions the turbine blades and hub on the generator and reduces the need for a second crane. The construction industry is also starting to use more prefabricated units. The prefabricated units often come with specific lifting points and special lifting instruction.

Figure 3. Customized Crane Attachment for Hoisting Main Hub into Place

3.2 Case Study Review

In this section, case studies are presented to explore whether the additional crane requirements in the nuclear industry would reduce the probability of an incident occurring. The case studies were chosen as an example of how nuclear crane operation concepts such as redundancy, thorough planning of lift operations, load monitoring, and specially designed lifting mechanism and lift points may have assisted in preventing an incident.

3.2.1 Crane Load Dropped

In 2000, a construction worker died after the rigging carrying a steel beam failed. A lifting procedure had been developed and implemented. Multiple lifts had been performed without incident. The construction workers deviated from the original plan and lifted a much heavier load. The nylon slings failed, dropping the load on a construction worker. In addition to the overloaded slings, no devices were provided to protect the nylon slings from the sharp edges of the steel beams (FACE 2000).

An analysis by the National Institute for Occupational Safety and Health (NIOSH) Fatality Assessment and Control Evaluation (FACE) provided the following review of the incident:

- “Ensure that nylon slings are not overloaded.
- Ensure chafing material is used to protect nylon slings from sharp edges.
- Ensure that all elevated loads are controlled with tag lines.
- Ensure crane operators making lifts are aware of the rating capacity of the rigging devices used to lift the load. “(FACE 2000)

The review of the incident indicates that many of the general construction guidelines for crane operation were not followed and the incident could possibly be prevented following standard crane operational procedures. For example, careful attention to the load rating of the slings would have to be accounted for in the lifting plan. If this crane operation was being performed on a nuclear construction facility near hazardous material, additional requirements may have prevented the incident. The single-failure-proof crane would have redundant systems that may have prevented the rigging failure when one of the straps failed. In this case, the redundant system could have been additional straps to support the load.

3.2.2 Crane in Contact with Electrical Current

In 2004, two heavy equipment mechanics were electrocuted by overhead power lines while operating a truck mounted crane. The two men had been sent out to work on a piece of road construction equipment that was parked under 12kv lines. The mechanics used a truck-mounted crane to replace a component on the equipment. The crane was controlled with a portable unit that was connected to the truck by an electrical cable. Once the component was replaced, one of the mechanics remotely operated the controls to move the boom out of the way. The boom hit the overhead power lines, causing the fatalities. (FACE 2004)

The NIOSH FACE report provided the following review of the incident:

- “Ensure heavy equipment mechanics know the safety and health hazards specific to their job assignments.”
- “Ensure all employees perform safety and health inspections prior to starting their job assignments in order to find, eliminate, or control safety and health hazards as well as unsafe working conditions and practices, and to comply fully with the safety and health standards.”
- “Ensure all employees are provided with mechanical and physical safeguards to the maximum extent possible in order to perform their job assignments safely.”
- “Ensure heavy equipment mechanics are properly trained on machine operation and safety and their achievement of skills is verified through a testing program. “(FACE 2004)

Cranes coming in contact with electrical power lines is one of the main causes of fatalities in the construction industry. Based on the fatality data in table one, over the last seven years, 22% of crane fatalities were due to crane contact with electrical current. Many crane safety guidelines for the general construction industry crane operation were not followed based on the FACE assessment. If the workers had followed these guidelines, this incident may have been avoided. If some of the more stringent nuclear guidelines had been implemented, the probability of the incident would have been significantly reduced. For example, the path a crane is allowed to take during an operation is clearly defined to avoid potential hazards. If there is a significant hazard, the crane may be unable to operate in this sector. The crane used for the operation would probably not be advanced enough to have this capability, but as technology advances, this may be something that can be implemented on even simple pieces of equipment. In addition to the safe path nuclear criteria, guidelines for working around active nuclear power plants require an assessment of potential damage to electrical lines entering into the power plant. These electrical systems may support vital systems on the power plant site.

3.2.3 Crane Load Lifting Point Failure

In 1994, a construction worker died when a 10,000 pound (5 ton) concrete slab being hoisted by a crane was dropped. The concrete slab was being used to cap a 10,000 gallon commercial septic tank. The worker was killed when two steel re-bar eyelets, embedded in the concrete slab that supported the crane rigging failed. (FACE 1994)

The NIOSH FACE report provided the following review of the incident:

The manufacturers of pre-cast concrete products should:

- "Install lifting inserts in their products that are suitable for use at the time of installation.
- Ensure that load lifting anchor points and rigging accessories are capable of carrying the intended load.
- Design, develop and implement a comprehensive safety program for all employees that includes, but is not limited to, safety training and hazard recognition for septic tank construction and, particularly, rigging operations" (FACE 1994)

In the lifting of nuclear material over 10,000 pounds special lifting points are required along with a special lifting device. Based on information from the nuclear industry, lifting points have to be specially designed and redundant to avoid a load drop. As noted in the regulations:

"Provide redundancy or duality such that a single lift point failure will not result in uncontrolled lowering of the load; lift points should have a design safety factor with respect to ultimate strength of five (5) times the maximum combined concurrent static and dynamic load after taking the single lift point failure." (George 1980)

4. Conclusions

This paper provides an overview of crane operations in the nuclear industry and examples of requirements that may useful in preventing crane incidents in the general construction industry. These requirements are compared to three crane fatality case studies to see how more stringent crane requirements may have affected the outcome of crane incidents in the

U.S. For the particular case studies shown there was evidence that increased requirements may have prevented an incident, however, following proper protocol for general crane operations would also have assisted in preventing the incident. Many of the nuclear crane requirements would be considered excessive in the general construction industry, however, general concepts such as redundancy, thorough planning of lift operations, load monitoring, and specially designed lifting mechanism and lift points could be implemented or already are implemented in the general construction industry. To improve safety of crane use, it may be appropriate to turn to crane requirements that have very low probability of failure, such as in the nuclear industry.

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