Appendix 9

Assessment of Heavy Loads

A heavy load drop onto the spent fuel pool wall, or into the spent fuel, can affect the structural integrity of the spent fuel pool. Heavy loads have been evaluated by the staff as Generic Technical Activity A-36, which resulted in the publication of NUREG-0612, "Control of Heavy Loads at Nuclear Power Plants," U.S. Nuclear Regulatory Commission, July 1980. Cask handling is the expected to be the dominate heavy load operation.

In NUREG-0612, we evaluated Navy data for cranes and hoists for the period February 1974 to October 1977. There were 74 load drop events identified. Of these, 23 percent were attributed to design and maintenance errors, 73 percent to operator (or human) error and 4 percent to rigging errors.

We also reviewed several, more recent studies concerning heavy load drops:

- Notice No. 125 - March 27, 1984, U.S. Department of the Interior, Minerals Management Service (MMS), Gulf of Mexico OCS Region

  The Risk and Safety Analysis Unit of the MMS reviewed 50 crane related accidents for the period January 1 1971 to June 30, 1983. The major findings included:

  1. The major contributing cause of crane accidents has been employee negligence and/or error.

  2. About 44 percent of the crane accidents involved some type of equipment failure due to poor maintenance and/or overloading of the crane.

- "Findings and Recommendation of the Crane Accident Workgroup" B. Hauser, B. Lewis, W. Rhome, Engineering & Operations Division, October 16, 1998 (U.S. Department of the Interior, MMS)

  The workgroup reviewed 34 incidents for the period 1995 to 1998.

  1. 17 incidents were listed as equipment failure (EF) and 12 listed as human error (HE).

  2. Fatalities were reported in 1 of the 12 HE incidents and in 5 of 17 EF incidents.

  3. Major property damage was reported in 1 of 12 HE incidents and in 6 of 17 EF incidents.

- "Independent Oversight Special Study of Hoisting and Rigging Incidents Within the Department of Energy," October 1996, Office of Oversite, Office of Environment, Safety and Health, U.S. Department of Energy

A/29

The DOE Occurrence Reporting and Processing System (ORPS) served as the principal information source for incidents relating to hoisting and rigging (H&R) operations. An initial set of 491 occurrence reports, corresponding to the October 1, 1993, to March 31, 1996, period, describing incidents related to H&R. There were 131 relevant hoisting and rigging incidents between October 1993 and March 1996. The data is summarized in Table 1 and Table 2.

Table 1 - Distribution of hoisting and rigging incidents and accidents

Equipment	Number of Incidents	Number of Accidents	Incidents as a Percent of Total*	Accidents as a Percent of Total*	Accidents as a Percent of Incidents*
Crane	66	49	50%	51%	74%
Forklift	40	36	31%	38%	90%
Other**	25	11	19%	11%	44%
Total	131	96	100%	100%	73%

* Rounded to the nearest whole number.
** Includes manual and power-operated hoists, chainfalls, and block and tackle.

Table 2 - Root cause of hoisting and rigging incidents by equipment type*

Root Cause	Crane	Forklift	Other
Inattention to Detail	20%	23%	8%
Work Organization and Planning	18%	3%	27%
Procedure Not Used or Used Incorrectly	9%	15%	0%
Policy Not Adequately Defined, Disseminated, or Enforced	9%	10%	4%
Inadequate or Defective Design	5%	5%	19%
Defective or Inadequate Procedure	9%	5%	0%
Inadequate Administrative Control	9%	0%	4%
Defective or Failed Part	5%	5%	8%
Other Management Problem	3%	3%	12%
Other Human Error	3%	3%	0%
Inadequate Work Environment	0%	10%	0%
Lack of Procedure	2%	3%	4%

Root Cause	Crane	Forklift	Other
Insufficient Refresher Training	3%	3%	0%
Insufficient Practice or Hands-On Experience	5%	0%	0%
Communication Problem	2%	3%	4%
Inadequate Supervision	0%	3%	4%
Error in Equipment or Material Selection	0%	3%	4%
Weather	0%	3%	0%
No Training Provided	0%	0%	4%

*Rounded to the nearest whole number.

Since crane and hoisting operations are governed by U.S. Occupational Safety and Health Administration (OSHA) requirements, accident data is generally available however there is only limited data available on the number of operations, or lifts, for developing load drop per operation data.

In NUREG-0612, we evaluated the Navy data for the period February 1974 to October 1977. Based on some assumptions regarding the number of cranes and hoist in service, the number of lift per year and the 74 load drops identified in the period studied, we estimated that frequency of a heavy load drop to be in the range of $2.5\text{x}10^{-5}$ to $3.0\text{x}10^{-4}$ per operation.

In NUREG/CR-4982, "Severe Accidents in Spent Fuel Pools in Support of Generic Safety Issue 82," Brookhaven National Laboratory, July 1987, we estimated the human error contributor to a heavy load drop as $6.0\text{x}10^{-4}$ per lift, based on data concerning human reliability in the positioning heavy objects.

A more recent study on heavy load drops was performed for the DOE Savannah River Site to quantify human errors, "Savannah River Site Human Error Data Base Development for Nonreactor Nuclear Facilities," Westinghouse Savannah River Co., WSRC-TR-93-581, February 28. 1994. The likelihood of a heavy load drop, when using cranes or hoists, was quantified using a generic data base. An operation was defined as "lift, move and setting down" the load. Based on 200 drops in 2,000 crane years of operation and additional crane data from nuclear power plants, the drop rate was estimated as $1.5\text{x}10^{-4}$ per operating-hour. No error factor information was provided in the study.

If it is assumed that it takes 1-hour for an operation (lift, move and setting down) and using a factor of 10 from the nominal value ($1.5\text{x}10^{-4}$), then the recommended values for a human error resulting in a heavy load drop are provided in Table 1.

Table 1 - DOE recommend heavy load drop frequencies

	Frequency	Error Factor	Type of Load
Low mean value	1.5x10-5 / operation	10	Standard
Nominal man value	1.5x10-4 / operation	10	Typical
High mean value	1.5x10-3 / operation	10	Unusual

The DOE nominal mean value for the heavy load drop frequency is a factor of 2 to 4 lower than the values we reported in previous evaluations, however the supporting data base is believed to be representative of the expected cask handling operations in a spent fuel pool, or movement of heavy loads near the spent fuel pool. DOE recommends that the high value be used for unusual, unevenly balanced loads with standard construction or industrial equipment and that the low value be applied to standardized loads with a spotter present.

The number of cask operations per year and the time span during which a drop may impact the spent fuel pool wall or fall into the spent fuel pool need to be considered as part of a risk-informed evaluation. The numerical values presented in Table 1 have an implied time duration of 1 hour per operation.

For heavy loads not involving cask operations, we expect that a "safe load-path" procedure will be followed. If movement of objects over the spent fuel pool, other than casks, are to be considered, then a description of the assumptions used for this risk-informed evaluation need to be document, including items such as weight, number of movements, potential spent fuel pool failure mode (for example, crush or fail the wall or puncture the bottom of the pool) and the drop rate frequency assigned to the particular movement.

In reviewing the drop per lift data, we determined that the range of values presented in the 1994 DOE study were nearly identical to those used in the 1980 NUREG-0612 study. Therefore we have used NUREG-0612 as the bases for developing estimates of heavy load drop frequencies.

Non-single-failure-proof load handling system

Figure B-2 (pg B-16) in NUREG-0612 provides a quantified fault tree for load handling over a spent fuel pool for a load handle system which is not single-failure-proof. We estimated the handling system failure rate to be $1.0x10^{-4}$ to $1.5x10^{-3}$ per lift. We based this value on a nuclear power plant estimate expected to be in the $1.0x10^{-5}$ to $1.5x10^{-4}$ per lift range, including a factor-of-2 improvement over the Navy data evaluated (reported to be in the $2.5x10^{-5}$ to $3.0x10^{-4}$ per lift range), and included an assumption that failure of the interlocks and/or failure to follow an approved load path lead to a factor-of-10 reduction in the load handling system reliability (we estimated the interlock/load path failure range to be $2.0x10^{-3}$ to $1.0x10^{-1}$ per year.). The per lift range from the DOE Savannah River study,$1.5x10^{-5}$ to $1.5x10^{-4}$ for this type of load handling, is nearly the same as the expected NUREG-0612 range.

Only some fraction of the load drops will lead to significant spent fuel pool damage. In NUREG-0612 we assumed that the only 10 percent of the critical load path was over the spent fuel. We

estimated that between 2 to 10 drops would occur for 200 lifts per year resulting in an estimate of 2.0×10^{-3} to 1.0×10^{-1} drops per year into the spent fuel pool. Therefore we estimate the load drop to be in the range 2.0×10^{-7} to 1.5×10^{-4} per year (applying the NUREG-0612 methods and assumptions). If the NUREG-0612 assumption on the load handling system reliability is not considered (for example, the load drop is not related to failure of the interlock or the load path) then we estimate the load drop to be in the range 2.0×10^{-8} to 1.5×10^{-5} per year.

Single-failure-proof load handling system

Figure B-3 (pg B-17) of NUREG-0612 provides a quantified fault tree for load handling over spent fuel pool for a single-failure-proof handling system. We estimated the failure of the handling system to be in the range of 4.0×10^{-7} to 1.0×10^{-4} per year. We estimated the likelihood of the drop occur over spent fuel to be 5.0×10^{-2} to 2.5×10^{-1} per event (using an estimate of between 5 percent to 25 percent of the load path - based on the 10 percent estimate of the total path). The resulting range is 2.0×10^{-8} to 2.5×10^{-5} per year, a reduction from the non-single-failure-proof load handling system range of 2.0×10^{-7} to 1.5×10^{-4} per year. The single-failure-proof handling system reduced a load drop by a factor of 10.

Calculated values for risk-informed assessment of spent fuel pool

We estimate the likelihood of a load drop into the spent fuel pool to be in the range of 2.0×10^{-7} to 1.5×10^{-4} per year for a non-single-failure-proof load handling system. For a single-failure-proof load handling system the range is reduced by about a factor of 10 (2.0×10^{-8} to 2.5×10^{-5} per year). An estimate of the likelihood of substantial damage (rapid pool draining) given the drop is needed.

For the failure of the pool wall, we assume that the load is over the wall 2 percent (0.02) of the time (10 percent of the 5 to 25 percent of the total load path) and we assume a one-in-ten (0.1) chance of significant damage. We estimate a failure rate in the 2.0×10^{-7} to 3.0×10^{-6} per year for the non-single-failure-proof system and 8.0×10^{-10} to 2.0×10^{-7} per year for the single-failure-proof system. (The NUREG/CR-4982 value for wall failure was 3.7×10^{-7} per year.)

For failure of the pool floor, we assume one-in-ten events (0.1) will result in significant damage. We estimated a failure rate range of 2.0×10^{-8} to 1.5×10^{-5} per year for the non-single-failure-proof system and 2.0×10^{-9} to 2.5×10^{-6} per year for the single-failure-proof system.

Insights to be considered

In assigning a drop rate to a particular operation, the following information should be considered.

It appears that the human error contribution to heavy load drops has not changed since the original work documented in NUREG-0612 in 1980. The following conclusions were reported in the 1996 DOE, Office of Oversite, study:

- Human error is the major cause of hoisting and rigging (H&R) incidents.

Human error, whether directly associated with supervisors or equipment operators, is the principal cause of H&R incidents. Factors not related to human performance, such as equipment failure and weather, are responsible for only 6 percent of H&R incidents—management (35 percent) and personnel errors (33 percent) collectively account for 68 percent of all H&R incidents, as reported into ORPS.

- Management shortcomings and workers' inattention to detail account for a large proportion of incidents.

Further analysis shows that deficient work planning (43 percent) and inadequate definition, dissemination, and enforcement of policy (24 percent) are responsible for two thirds of the incidents attributable to management deficiencies. Inattention to detail (56 percent) and not following procedures (28 percent) account for 84 percent of H&R incidents caused by personnel error. Furthermore, inattention to detail is the most prevalent cause of all 131 H&R incidents, accounting for about one in every five incidents. Additionally, there are no indications that certain root causes are becoming less frequent over time, are being remedied, or are being replaced with other causal factors.

- Work planning is a significant factor in non-forklift incidents, while the work environment has more effect on forklift incidents.

Work organization and planning require more attention in operations involving cranes and "Other" hoisting equipment than when forklifts are utilized. This is evident by the fact that inadequate work planning was the cause of 18 percent of all incidents involving cranes, 27 percent of the incidents involving "Other" hoisting (i.e., non-forklift) equipment, and only 3 percent of all forklift incidents. Similarly, the work environment (i.e., the characteristics of the area in which H&R equipment is operated) has a significantly greater influence on the frequency of forklift incidents than non-forklift incidents. As noted earlier, this is largely due to the mobility of forklifts and the increased likelihood of an incident when forklifts are used to transport loads over routes that are not protected from obstacles or other risks.

- Training-related deficiencies were not identified as a major problem.

Training-related deficiencies were not identified as a significant problem. Procedure-related problems, including applying procedures incorrectly, defective or inadequate procedures, or procedures not used, are responsible for 18 and 20 percent of crane and forklift incidents, respectively. They were not found as causal factors for incidents involving "Other" equipment. Communication, lack of procedures, and defective or failed parts cause incidents with approximately equal frequency for all equipment type categories, although it is the greatest for "Other" equipment (e.g., hoists, chainfalls, block and tackle).

- The use of mobile cranes by subcontractors is expected to increase, heightening the need for effective oversight of subcontractors' safety performance.

Discussions with H&R experts within the DOE (Federal workers, contractors, and subcontractors) indicate that as production-related operations are curtailed and superseded with activities directed at waste management, environmental restoration, and facility dismantlement, the need for stationary or overhead cranes will be reduced, and mobile units will be in more demand. Mobile cranes owned and operated by subcontractors are often used to perform material handling tasks of varying complexity, whereas overhead cranes are generally operated by contractors and are used to perform maneuvers that are relatively simple and often routine. Independent evaluations performed by the Office of Oversight, in addition to information reported into ORPS and the Department's Computerized Accident/Incident Reporting System (CAIRS), have highlighted deficiencies in oversight of subcontractor activities. Therefore, the additional risks posed as more H&R tasks involving cranes are performed by subcontractor personnel heightens the concern over H&R safety and the need for effective oversight of subcontractor performance. Information contained in ORPS does not explicitly and formally identify whether an H&R incident is associated with a contractor or subcontractor activity. While it was possible in this review to make this determination for some of the 131 incidents analyzed, it was not possible to resolve this issue for the entire sample.

The following standards describe the guidelines currently in use based on requirement of the U.S. Occupational Safety and Health Administration (OSHA) and the American National Standards Institute (ANSI):

- DOE-STD-1090-99, "Hoisting and Rigging (Formerly Hoisting and Rigging Manual)," U.S. Department of Energy, March 1999.
- MIL-HDBK-1038, "Weight Handling Equipment," Department of Defense Handbook, March 06, 1998.
- NAVFAC P-307, U.S. Navy, June 1998.

The DOE standard occasionally goes beyond the minimum general industry standards established by OSHA and ANSI; and also delineates the more stringent requirements necessary to accomplish the extremely complex, diversified, critical, and oftentimes hazardous hoisting and rigging work found within the DOE complex. In doing so, it addresses the following items which are not covered in detail in the general industry standards:

1. Management responsibility and accountability
2. Operator/inspector training and qualification requirements
3. Definition of critical lifts and the additional requirements for making them
4. The need and responsibilities of a person-in-charge for critical lifts
5. The need and responsibilities of a designated leader for ordinary lifts

6. The definition and special requirements for preengineered production lifts

7. Special requirements for the testing, inspection, and maintenance of hoisting equipment in hostile environments

8. Nondestructive testing/nondestructive examination requirements for such items as hooks, welds, and spreader bars

9. Special requirements for inspection and load-testing of hoisting and rigging equipment/accessories

10. Hook latch requirements for cranes, slings, and rigging accessories

11. Design standards for such equipment as cranes, forklifts, and hooks

12. Operating practices for hoisting and rigging operations

13. Rigging information and load tables

14. Good and bad rigging practices.