Appendix 2C Structural Integrity of Spent Fuel Pool Structures Subject to Heavy Loads Drops

A heavy load drop into the spent fuel pool, or onto the spent fuel pool wall, can affect the structural integrity of the spent fuel pool. A loss-of-inventory from the spent fuel pool could occur as a result of a heavy load drop. The staff evaluated heavy loads as Generic Technical Activity A-36, which resulted in the publication of NUREG-0612 [Ref. 1]. Cask handling is expected to be the dominant heavy load operation at a decommissioning plant.

We revisited NUREG-0612 to review the evaluation and the supporting data then available. We identified two additional sources of information and used them to reassess the heavy load drop risk:

(1) 1990s Navy crane experiences for the period 1996 through mid-1999

(2) WIPP/WID-96-2196, "Waste Isolation Pilot Plant Trudock Crane System Analysis," October 1996 (WIPP).

The 1990s Navy data encompassed primarily bridge cranes with lift capacities of 20,000 lb to 350,000 lb, both at shipyards and at non-shipyard sites. The data are summarized in Table 2C-1 by incident type and incident cause. Improper operation caused 38% of the events, improper rigging 30%, procedures 20%, equipment failures 5%, and other causes 8%. Improper rigging was further sub-divided: (a) 70% were identified as rigging errors and (b) 30% were rigging-related failures resulting from the crane operation. Reported load drops occurred in about 9% of the accidents, 3% related to the crane and its operation and 6% to improper rigging. The fault trees used to assess a heavy load drop leading to a loss-of-inventory are shown in Figure 2C-1 (taken from NUREG-0612). Table 2C-1 includes the grouping of the incidents type for use in the fault tree quantification.

Based on the July 1999 SFP workshop, we assume that there will be a maximum of 100 cask lifts per year. Using the 1990s Navy database, for 100 lifts, about 3 lifts may lead to a load drop for the evaluation of the "failure of crane" event (CF). Using the new Navy database, for 100 lifts, about 6 lifts may lead to a load drop for the evaluation of the "failure of rigging" event (CR). In NUREG-0612, which was based on 200 lifts per year, the range of lifts leading to a load drop was estimated by the staff to be between 10 and 4 (5% to 2%).

The handling system failure rate was estimated in NUREG-0612 to be in the range of 1.5×10^{-4} to 1.0×10^{-5} incidents per year based on the 1970s Navy crane incident data and a staff estimate of the total number of lifts per year. The staff's evaluation included a factor of two reduction for the range estimate based on improved procedures and conformance with the guidelines presented in Section 5.1.1 of NUREG-0612.

In the NUREG-0612 evaluation it was assumed that the number of reported incidents could have represented only about one-half of the actual number of incidents due to unknown reporting requirements. The 1990s Navy data identified about twice as many incidents over the same time span. This may support the earlier assumption since the Navy reporting requirements are now well defined in NAVFAC P-307, U.S. Navy, June 1998. For this evaluation it was assumed that the handling system failure rate range was the same as used by the staff in NUREG-0612.

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The base data used in this evaluation considered a range of values comprised of a high estimate (V_H) and a low estimate (V_L) to represent an initiator rate or a demand rate. The data was generally expressed in exponents of 10 and a log normal distribution for a variable V was used for the evaluation. Use of the log normal distribution for V implies that the exponent has a normal distribution and that the exponent is viewed as the significant variable in the analysis.

The range of a value was considered to be the 90% confidence interval to account for uncertainty. There is a 5% chance that the high value may be higher than the estimate, and a 95% chance that the value is greater than the low estimate. This consideration provided a way to obtain the mean value for a range. A log normal distribution is, mathematically, a function of (μ,σ^2), where μ is the mean and σ^2 is the variance of the log normal distribution of V. μ and σ were calculated based on the 90% confidence interval consideration from the following two relationships:

$$V_H = \exp(\mu + 1.645\sigma) \qquad \text{and} \qquad V_L = \exp(\mu - 1.645\sigma)$$

The mean for the normal distribution of V was then calculated from the following relationship:

$$V_{mean} = \exp(\mu + \tfrac{1}{2}\sigma^2)$$

A heavy load drop could result from either the failure of the lifting equipment (mechanical or structural failures, or improper operation) or from failure to properly secure the load to the lifting device (human error). These two items are addressed separately.

Failure of the Lifting Equipment

The fault tree (Figure 2C-1) describing the failure of a crane comes from NUREG-0612. When heavy loads were evaluated in NUREG-0612, low density storage racks were in use and after 30 to 70 days (a time frame of about 0.1 to 0.2 per year) no release was expected if the pool were drained. After this time frame, the fuel gap noble gas inventory had decayed and no zircaloy fire would have occurred. To be consistent with the high density storage racks now in use, this evaluation presents the results for a time frame of 1.0 per year, to represent the probability of a zicraloy fire if the pool were drained.

Figure 2C-1 represents the "Releases exceed guidelines due to loads handled over spent fuel," the event 3.1(A) branch of Figure B-3 in NUREG-0612. The companion branch, "Releases exceed guidelines due to loads handled near spent fuel," the event 3.1(B) branch, was not considered in this evaluation for cask handling. Branch 3.1(B) considered movement of heavy loads near the spent fuel pool and the load drop would have resulted in damage to the spent fuel but not to the spent fuel pool.

The mean failure frequency of a component without a secondary device (for example, a crane cable/hook failure) was estimated in NUREG-0612 to be $1.2\text{x}10^{-6}$ per demand. This estimate was further reduced by the staff, based on conformance with NUREG-0554 [Ref. 2] and the expected increase in design safety factors to reduce the failure probability, by an additional factor of 10. It is noted that the 1990s Navy data supports the NUREG-0612 estimate of 1-in-44 events being the result of equipment failure (2% versus about 1% for the 1990s Navy data).

Failure to Secure the Load

The improper rigging evaluation as presented in NUREG-0612 was based on an estimate of a common mode effect resulting in failure of the redundant rigging 25% to 5% of the time. The frequency of improper rigging incidents identified in the 1990s Navy data may not be representative of a single-failure proof load handling design which conforms to the guidelines in NUREG-0612. A literature search performed by the staff identified a WIPP report study [Ref. 3] which included a human error evaluation for improper rigging. This study was used to re-evaluate the contribution of rigging errors to the overall heavy load (cask) drop rate and to address both the common mode effect estimate and the 1990s Navy data.

Failure to secure a load was evaluated in the WIPP report for the Trudock crane. It was determined that failure to attach the load to the lifting mechanism, considering two trained personnel, numerous feedbacks and verifications, was incredible. The more probable human error was for attaching the lifting legs to the lifting fixture using locking pins. In Appendix 4 of the WIPP report, the failure to secure the load (based on a 2-out-of-3 lifting device) was estimated (a mean point estimate) based on redundancy, procedures and a checker. It was assumed that the load could be lowered without damage if only one of the three connections was not properly made. Using NUREG/CR-1278 [Ref. 4] information, the mean failure rate due to improper rigging was estimated in the WIPP report to be 8.7×10^{-7} per lift. The re-quantification of the fault tree using the WIPP improper rigging failure rate is summarized in Table 2C-2. The WIPP evaluation for the human error probabilities is summarized in Table 2C-3.

Heavy Load Drop Summary

The staff evaluation, based on the 1990s Navy crane data with the WIPP improper rigging evaluation as summarized in Table 2C-2, provides the basis for developing the estimate of a loss-of-inventory from a heavy load (cask) drop into a decommissioning plant's spent fuel pool.

The estimated mean value for a heavy load drop was 2.3×10^{-6} per year for 100 lifts (FHLS) for a single-failure proof handling system. The range was 1.0×10^{-5} to 9.5×10^{-7} per year. The mean crane failure contribution was 1.4×10^{-6} per year (CRANE), with the operator-related contribution estimated to be 3.0×10^{-8} per year (CF1 + CF3). The mean improper rigging contribution was estimated to be 8.7×10^{-7} per year (RIGGING). For the non-single failure proof handling system the estimated mean value for a heavy load drop was 1.0×10^{-3} per year for 100 lifts, with a range of 1.2×10^{-3} to 2.0×10^{-5} per year.

Evaluation of the Load Path

The path of the lift, and the portion of the path interval over which significant damage is likely to occur in a cask drop, need to be factored into an overall estimate of a loss-of-inventory.

The load path assessment is plant specific. In NUREG-0612 it was estimated that the heavy load was near, or over, the spent fuel pool for between 25% and 5% (event P in Table 2C-2) of the total path needed to lift, move and set down the load. It was further estimated that if the load were dropped over 25% and 10% (event P' in Table 2C-2) of each respective path length, a release could occur. If the cask is dropped from its maximum height (about 40 feet above the pool floor — with a range of between 30 feet to 36 feet) it is felt likely that, without a specific load drop analysis, damage to the pool floor could occur resulting in a loss-of-inventory. Therefore a heavy load (cask) drop over between 6.25% and 0.5% of the path length could result in a loss-of-inventory. If the cask is dropped on the pool wall (from a height of 6 to 10 inches above the wall), there is a 10% likelihood that damage to the wall could result in a loss-of-inventory based on Generic Safety Issue 82 studies NUREG-1353 [Ref. 5].

Heavy Load Drop Leading to a Loss-of-Inventory

The heavy load drop evaluation was based on the method and fault trees developed in NUREG-0612. New 1990s Navy data was used to quantify the failure of the lifting equipment. The WIPP human error evaluation was used to quantify the failure to secure the load. The mean probability of a loss-of-inventory was estimated to be 2.0×10^{-7} per year for 100 lifts for a single-failure proof handling system (Table 2C-2, LOI-S). The range was estimated to be between 2.1×10^{-6} to 2.8×10^{-8} per year. Table 2C-2 presents the results for a heavy load drop on or near the spent fuel pool. If the load is dropped on the spent fuel pool floor, the likelihood of a loss-of-inventory, given the drop, is 1.0. If the load is dropped on the spent fuel pool wall, the likelihood of a loss-of-inventory, given the drop, is 0.1. Therefore the likelihood of a loss-of-inventory from a dropped load for a single-failure proof handling system was estimated to be 2.2×10^{-7} per year (for 100 lifts). The range was estimated to be between 2.3×10^{-6} to 3.1×10^{-8} per year.

For a non-single failure proof handling system, the mean probability of a loss-of-inventory was estimated based on NUREG-0612. In NUREG-0612, an alternate fault tree (Figure B-2, page B-16 of NUREG-0612) was used to estimate the probability of exceeding the release guidelines (loss-of-inventory) for a non-single failure proof system. The mean value was estimated to be about 2.1×10^{-5} per year (event 2.1.1) when corrected for the new Navy data and 100 lifts per year (Table 2C-2, LOI-N). The range was estimated to be between 7.5×10^{-5} to 1.0×10^{-7} per year. Table 2C-2 presents the results for a heavy load drop on or near the spent fuel pool. If the load is dropped on the spent fuel pool floor, the likelihood of a loss-of-inventory, given the drop, is 1.0. If the load is dropped on the spent fuel pool wall, the likelihood of a loss-of-inventory, given the drop, is 0.1. Therefore the likelihood of a loss-of-inventory from a dropped load for a non-single failure proof handling system was estimated to be 2.3×10^{-5} per year (for 100 lifts). The range was estimated to be between 8.3×10^{-5} to 1.1×10^{-7} per year.

Assessment of the Incident Rate

The incidents per year range was estimated to be on the order of 1.5×10^{-4} to 1.0×10^{-5} incidents per year. This range was based on Navy data and was used in the NUREG-0612 evaluation and in the current evaluation. The incident rate contains uncertainty because it is not well known how many crane operations occurred without a reportable incident. There is also some uncertainly in using the Navy data for nuclear power plant operations.

At nuclear power plants, dry cask storage has provided some additional information useful in assessing the incident rate. There have been about 150 casks loaded for dry storage at commercial reactor sites (LWRs) in the past 14 years. There have been about 250 cask loaded at the Fort St. Vrain gas-cooled reactor site (GCR). There have been no reportable incidents related to heavy loads per 10CFR 72.75, "Reporting requirements for special events and conditions."

Point estimates of the incident rate may be calculated with the following equations for those events not observed (zero occurrence — no drops or any other reportable event) in C number of components (lifts) for T years:

$$\lambda_{95\%\ \text{confidence limit}} = 3.0/(C \times T) \text{ incidents per year}$$

$$\lambda_{50\%\ \text{confidence limit}} = 0.69/(C \times T) \text{ incidents per year}$$

For the current experience base for LWRs, $\lambda_{95\%} = 7.1\text{x}10^{-4}$ incidents per year (assuming each cask load requires two lifts). At the 50% confidence limit, $\lambda_{50\%} = 1.6\text{x}10^{-4}$ incidents per year. If the GCR data is considered and added to the LWRs data, then $\lambda_{95\%} = 2.7\text{x}10^{-4}$ incidents per year and $\lambda_{50\%} = 6.2\text{x}10^{-5}$ incidents per year. The actual cask handling data indicates that the incident rate range used in this assessment was reasonable.

Summary of Other Heavy Load Drop Studies

Heavy load drops were evaluated as part of Generic Safety Issue 82. In NUREG/CR-4982 [Ref. 6] the total human error rate associated with cask movement was estimated to be $6.0\text{x}10^{-4}$ incidents per lift. It was further assumed that only 1-in-100 human errors would result in a cask drop. It was also estimated that the cask was above the pool edge (wall) about 25% of the lift time. Based on two shipment per week with two lifts per shipment (208 lifts), the estimate for a load drop on the spent fuel pool wall was $3.1\text{x}10^{-4}$ per year. Damage to the pool wall sufficient to cause a loss-of-inventory was further estimated to have a 1-in-10 probability, for an estimate of a loss-of-inventory from a heavy load drop on the spent fuel pool wall of $3.1\text{x}10^{-5}$ per year (for a non-single-failure proof handling system). Based on 100 lifts per year, the NUREG/CR-4982 evaluation would estimate the loss-of-inventory from a heavy load drop on the spent fuel pool wall to be about $1.5\text{x}10^{-5}$ per year (for a non-single-failure proof handling system).

In NUREG-1353, conformance with NUREG-0612 was estimated to reduce the probability of a load drop as presented in NUREG/CR-4982 by a factor of 1,000. Based on Table 2C-2, the fault tree method indicated that the expected reduction was in the 10 to 100 range. For 100 lifts per year, the NUREG/CR-4982 evaluation would estimate the loss-of-inventory from a heavy load drop on the pool wall to be $1.5\text{x}10^{-8}$ per year. This value should be increased by a factor of 10, to $1.5\text{x}10^{-7}$ per year, for use for comparison to this current evaluation for a load drop on the pool floor (a drop onto the pool floor may likely cause sufficient damage to result in a loss-of-inventory). Based on the fault tree quantification (Table 2C-2), the mean probability for the loss-of-inventory from a heavy load drop was estimated to be $2.0\text{x}10^{-7}$ per year for 100 lifts (for a single-failure proof handling system) for a drop on the spent fuel pool wall and $2.0\text{x}10^{-8}$ per year for a drop on the spent fuel pool wall.

Conclusion

This generic assessment of a heavy load (cask) drop which may result in significant damage to the spent fuel pool indicates that the likelihood of a loss-of-inventory from the spent fuel pool is in the range of $2.3\text{x}10^{-6}$ to $3.1\text{x}10^{-8}$ per year for 100 lifts with a mean value of $2.2\text{x}10^{-7}$ per year for a single-failure proof handling system. These value include the contribution from a heavy load drop on the spent fuel pool floor and a heavy load drop on the spent fuel pool wall. A heavy load (cask) drop leading to the uncovery of spent fuel in a decommissioning plant's spent fuel pool appears to be a credible event, even for a plant with a single-failure proof handling system.

A segregated cask transfer area, a plant specific load drop analysis confirming acceptable consequences, or a load drop limiter (for example, cask crash pads) would most likely demonstrate that the heavy loads event need not be considered as a significant contributor to the risk.

The uncertainties is this evaluation are as follows:

(1) Incident rate

The range used in this evaluation ($1.5x10^{-4}$ to $1.0x10^{-4}$ incidents per year) was based on the Navy data originally assessed by the staff in NUREG-0612. The 1999 Navy data, like the 1980 data, did not include the number of lifts made and only provided information about the number of incidents. The cask loading experience at LWRs and the GCR tends to support use of the incident range.

(2) Drop rate

The drop rate, about 1-in-10, was based on the 1999 Navy data. Previous studies used engineering judgement to estimate the drop rate to be as low as 1-in-100.

(3) Load path

The load path fraction over which a load drop may cause sufficient damage to the spent fuel pool to result in a loss-of-inventory was estimated to be between 6.25% and 0.5% of the total path needed to lift, move and set down the load. This range was developed by the staff for the NUREG-0612 evaluation.

(4) Load handling design

The benefit of a single-failure proof load handing system to reduce the probability of a load drop was estimated to be about a factor of 10 to 100 improvement over a non-single failure proof load handling system, based on the fault tree quantifications in this evaluation. Previous studies have used engineering judgement to estimate the benefit to be as high as 1,000.

The guidelines for the control of heavy loads, Section 5 of NUREG-0612, should be followed for a decommissioning plant. Specifically, if a decommission plant does not have a single-failure proof handling system then a plant specific load drop analysis should be performed to demonstrate Item III of Section 5.1 of NUREG-0612, "Damage to the reactor vessel or the spent fuel pool based on calculations of damage following accidental dropping of a postulated heavy load is limited so as not to result in water leakage that could uncover the fuel, (makeup water provided to overcome leakage should be from a borated source of adequate concentration if the water being lost is borated); ..." Alternatively, mitigation of damage with load impact limiters (for example, cask crush pads) to reduce the likelihood of the uncovery of spent fuel should be considered, as appropriate, on a plant specific basis.

References:

(1) George, H., "Control of Heavy Loads at Nuclear Power Plants," NUREG-0612, July 1980.

(2) Porse, L.,"Single-Failure Proof Cranes for Nuclear Power Plants," NUREG-0554, May 1979.

(3) Pittsburgh, Westinghouse, P.A., and Carlsbad, WID, N.M., "Waste Isolation Pilot Plant Trudock Crane System Analysis," WIPP/WID-96-2196, October 1996.

(4) Swain, A.D., and H.E. Guttmann, "Handbook of Reliability Analysis with Emphasis on Nuclear Power Plant Applications," NUREG/CR-1278, August 1983.

(5) Throm, E.D., Regulatory Analysis for the Resolution of Generic Issue 82, Beyond Design Basis Accidents in Spent Fuel Pools, NUREG-1353, April 1989.

(6) Sailor, V.L., et.al.,"Severe Accidents in Spent Fuel Pools in Support of Generic Safety Issue 82," NUREG/CR-4982, July 1987.

Table 2C-1 Summary of the 1996-1999 Navy Crane Data

	Summary by Incident Type (fraction of events)	ID	Non-rigging Fraction	Rigging Fraction	Total Traction
	Crane collision	CC	0.17	0.00	0.17
	Damaged crane	DC	0.20	0.08	0.27
	Damaged load	DL	0.02	0.03	0.05
	Dropped load	DD	0.03	0.06	0.09
	Load collision	LC	0.11	0.03	0.14
	Other	OO	0.02	0.00	0.02
	Overload	OL	0.08	0.05	0.12
	Personnel injury	PI	0.03	0.05	0.08
	Shock	SK	0.00	0.02	0.02
	Two-blocking	TB	0.05	0.00	0.05
	Unidentified	UD	0.02	0.00	0.02
	Totals		0.70	0.30	1.00
	Summary by Incident Cause (fraction of total events)	ID	Fraction		
	Improper operation	IO	0.38		
	Procedures	PROC	0.20		
	Equipment failure	EQ	0.05		
	Improper rigging(1)	IR	0.30		
	Others	OTHER	0.08		
	Totals		1.00		
Fault Tree ID(2)	**Application of new Navy data to heavy load drop evaluation**	Fraction		NUREG-0612 Fraction	
F1	OL + 0.5*(DL+LC)	0.14		0.05	
F2	CC + DC + 0.5(DL+LC) + DD + OO + PI + SK + UD + 0.3*IR	0.61		0.53	
F3	TB	0.05		0.35	
F4	Assume next incident	(0.01)		(1/44)	
F5	Rigging 0.7*IR	0.21		0.07	
	Totals	1.00		1.00	

Notes:

(1) Based on database description, 30% or "improper rigging" by incident cause were rigging failures during crane movement, and 70% of "improper rigging" by incident cause were rigging errors.

(2) F1 - Load hangup resulting from operator error (assume 50% of "damaged load" and "load collision" lead to hangup)
F2 - Failure of component with a backup component (assume 50% of "damaged load" and "load collision" lead to component failure)
F3 - Two-blocking event
F4 - Failure of component without a backup
F5 - Failure from improper rigging

Table 2C-2 Summary of NUREG-0612 Heavy Loads Evaluation (For Cask Drop) with New 1990s Navy Crane Data Values and WIPP Rigging HEP Method

Event	Description	Units	High	Low	Mean
N0	Base range of failure of handling system	/year	1.5e-04	1.0e-05	5.4e-05
	Crane Failure				
F1	Fraction of load hangup events (new 1990s Navy data)	---	0.14	0.14	0.14
CF11	Operator error leading to load hangup (N0*F1))	/year	2.0e-05	1.4e-06	7.4e-06
CF12	Failure of the overload device	/demand	1.0e-02	1.0e-03	4.0e-03
CF1	Load hangup event (CF11*CF12)	/year	**2.0e-07**	**1.4e-09**	**3.0e-08**
F2	Fraction of component failure events (new 1990s Navy data)	---	0.61	0.61	0.61
CF21	Failure of single component with a backup (N0*F2)	/year	9.1e-05	6.1e-06	3.3e-05
CF22	Failure of backup component given CF21	/demand	1.0e-01	1.0e-02	4.0e-02
CF2	Failure due to random component failure (CF21*CF22)	/year	**9.1e-06**	**6.1e-08**	**1.3e-06**
F3	Fraction of two-blocking events (new 1990s Navy data)	---	0.05	0.05	0.05
CF31	Operator error leading to Two-blocking (N0*F3)	/year	6.8e-06	4.5e-07	2.5e-06
CF32	Failure of lower limit switch	/demand	1.0e-02	1.0e-03	4.0e-03
CF33	Failure of upper limit switch	/demand	1.0e-01	1.0e-02	4.0e-02
CF3	Two-blocking event (CF31*CF32*CF33)	/year	**6.8e-09**	**4.5e-12**	**4.0e-10**
F4	Fraction of single component failure (new 1990s Navy data)	---	0.01	0.01	0.01
F4'	Credit for NUREG-0554	/demand	0.10	0.10	0.10
CF4	Failure of component that doesn't have backup (N0*F4*F4')	/year	**2.2e-07**	**1.5e-08**	**8.1e-08**
CRANE	**Failure of crane (CF1+CF2+CF3+CF4)**	**/year**	**9.5e-06**	**7.7e-08**	**1.4e-06**
D1	Lifts per year leading to drop (100 lifts per year, drops from non-rigging)	No.	3	3	3
CF	**Failure of crane leading to load drop (CRANE*D1)**	/year	**2.9e-05**	**2.3e-07**	**4.4e-06**
	Rigging failure - Based on WIPP method				
F5	Fraction of improper rigging events (new 1990s Navy data)	---	0.21	0.21	0.21
CR11	Failure due to improper rigging, mean from WIPP study	/year	8.7e-07	8.7e-07	8.7e-07
CR12	Failure of redundant/alternate rigging	N/A			
RIGGING	**Failure due to improper rigging (CR11)**	**/year**	**8.7e-07**	**8.7e-07**	**8.7e-07**
D2	Lifts per year leading to drop (100 lifts per year, drops from rigging)	No.	6	6	6
CR	**Failure of rigging leading to a load drop (RIGGING*D2)**	**/year**	**5.3e-06**	**5.3e-06**	**5.3e-06**
FHLS	**Failure of heavy load (crane and rigging) system (CRANE+RIGGING)**	**/year**	**1.0e-05**	**9.5e-07**	**2.3e-06**
CFCR	**Total failures (crane and rigging) leading to a load drop (CF+CR)**	**/year**	**3.4e-05**	**5.5e-06**	**9.6e-06**
	Loss-of-inventory for a single-failure proof crane				
RF	Fraction of year over which a release may occur	---	1.00	1.00	1.00
P	Fraction of path near/over pool	---	0.25	0.05	0.13
P'	Fraction of path critical for load drop	---	0.25	0.10	0.16
LOI-S	**(CFCR) * P * P' * RF**	**/year**	**2.1e-06**	**2.8e-08**	**2.0e-07**
	Loss-of-inventory for a non single-failure proof crane				
CFCRNON	Total failures leading to a dropped load (est. from NUREG-0612)	No.	7.5e-05	1.0e-07	2.1e-05
RF	Fraction of year over which a release may occur	---	1.00	1.00	1.00
LOI-N	**(CFCRNON) * P * P' * RF**	**/year**	**7.5e-05**	**1.0e-07**	**2.1e-05**
	Risk reduction for a single-failure proof crane (LOI-N /LOI-S)	—	**35**	**4**	**104**

Table 2C-3 WIPP Evaluation for Failure to Secure Load (Improper Rigging Estimate)

Symbol	HEP	Explanation of error	Source of HEP (NUREG/CR-1278)
A_1	$3.75x10^{-3}$	Improperly make a connection, including failure to test locking feature for engagement	Table 20-12 Item 13 Mean value (0.003, EF[1] = 3)
B_1	0.75	The operating repeating the actions is modeled to have a high dependency for making the same error again. It is not completely independent because the operator moves to the second lifting leg and must physically push the locking balls to insert the pins	Table 20-21 Item 4(a) High dependence for different pins. Two opportunities (the second and third pins) to repeat the error is modeled as 0.5+(1-0.5)*0.5 = 0.75
C_1	$1.25x10^{-3}$	Checker fails to verify proper insertion of the connector pins, and that the status affects safety when performing tasks	Table 20-22 Item 9 Mean value (0.001, EF = 3)
D_1	0.15	Checker fails to verify proper insertion of the connector pins at a later step, given the initial failure to recognize error. Sufficient separation in time and additional cues to warrant moderate rather than total or high dependency.	Table 20-21 Item 3(a) Moderate dependency for second check
F_1	$5.2x10^{-7}$	Failure rate if first pin improperly connected	$A_1 * B_1 * C_1 * D_1$
a_1	0.99625	Given first pin was improperly connected	
A_2	$3.75x10^{-3}$	Improperly make a connection, including failure to test locking feature for engagement	Table 20-12 Item 13 Mean value (0.003, EF = 3)
B_2	0.5	The operating repeating the actions is modeled to have a high dependency for making the same error again. It is not completely independent because the operator moves to the second lifting leg and must physically push the locking balls to insert the pins	Table 20-21 Item 4(a) High dependence for different pins. Only one opportunity for error (third pin)
C_2	$1.25x10^{-3}$	Checker fails to verify proper insertion of the connector pins, and that the status affects safety when performing tasks	Table 20-22 Item 9 Mean value (0.001, EF = 3)
D_2	0.15	Checker fails to verify proper insertion of the connector pins at a later step, given the initial failure to recognize error. Sufficient separation in time and additional cues to warrant moderate rather than total or high dependency.	Table 20-21 Item 3(a) Moderate dependency for second check
F_2	$3.5x10^{-7}$	Failure rate if first pin improperly connected	$a_1 * A_2 * B_2 * C_2 * D_2$
F_T	$8.7x10^{-7}$	Total failure due to human error	F1 + F2

(1) Note: The EF (error factor) is the 95th percentile/50th percentile (median). For an EF of 3, the mean-to-median multiplier is 0.8.

Figure 2C-1 (sheet 1 of 2) Heavy Load Drop Fault Trees

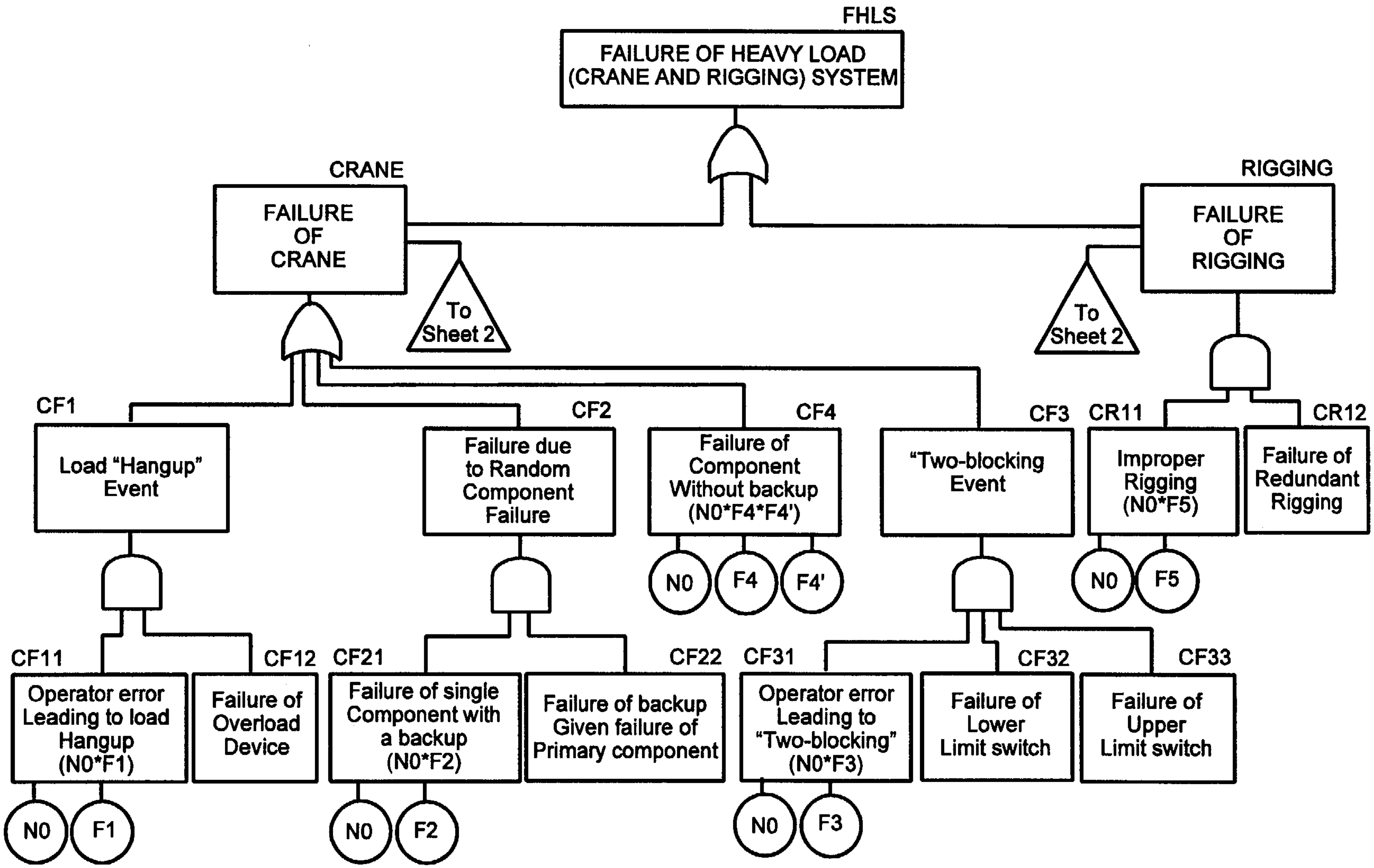

Figure 2C-1 (sheet 2 of 2) Heavy Load Drop Fault Trees