

From: Edward Throm, *NRA*
To: Brian Thomas, Diane Jackson, George Hubbard, Gl...
Date: Monday, August 09, 1999 07:58 AM
Subject: Re: Reminder: Heavy loads meetings

Attached is the current draft re-assessment of the heavy loads issue - you may wish to review it prior the meeting tomorrow at 1:30 pm in O 10B2. However, here is a brief summary.

The estimate of a load drop is about $4.5E-5$ per year (for 100 lifts per year) for a single-failure proof crane, comprised of a crane failure rate of $4.0E-5$ per year a rigging failure rate of $5.0E-6$ per year. The crane failure value comes from NUREG-0612 which included a factor of 10 reduction in failures based on expected improvements resulting from conformance with NUREG-0612 guidelines. The rigging failure comes from the a human error study for a 2-out-of-3 lifting device. If it is assumed that the NUREG-0612 improvements are a factor 10 again better, the estimate of a load drop is about $1.0E-5$ per year (for 100 lifts per year).

The load path assessment is plant specific. Based on NUREG-0612 it was estimated that the heavy load is near, or over, the spent fuel pool between 5% and 25% of the time. It is therefore assumed that 1-in-10 (or 10% of the load path) drops will be over the spent fuel pool at a height sufficient to damage the pool floor if dropped. The estimate for loss of inventory from a heavy load drop event is of the order $1.0E-6$ per year, and appears to be a credible event.

If a plant specific evaluation (for a plant without a load drop analysis) cannot show that the crane/rigging failure is significantly lower than this generic assessment, then a load drop analysis should be required - even for a plant with a single-failure proof crane (if either the frequency or the consequences are judged to be unacceptable). It may be appropriate to re-visit the NUREG-0612 conclusion that a single-failure proof crane itself is sufficient. That study included a factor of 10 reduction in the release rate estimates to account for the expected short time frame needed with low-density storage racks to preclude a release if water was lost (or a fuel bundle were damaged).

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Reassessment of Heavy Loads

The staff has revisited NUREG-0612 ("Control of Heavy Loads at Nuclear Power Plants") and identified two additional sources of information:

- (1) Navy crane experiences for the period 1996 through mid-1999, and
- (2) WIPP/WID-96-2196, "Waste Isolation Pilot Plant Trudock Crane System Analysis," October 1996 (WIPP).

The Navy data encompassed primarily bridge cranes with lift capacities of 20,000 lb. to 350,000 lb., at both shipyards and non-shipyard sites. The data is summarized in Table 1. Improper operation caused 44% of the events, improper rigging 26%, procedures 18%, equipment 5%, and other causes 7%.

Based on the Navy data, it will be assumed that only 1-in-10 "crane failures" will result in a dropped load. Failures of some components, for example limit switches, do not necessarily lead to a dropped load. Further, based on the July 1999 SFP workshop, it will be assumed that there will be a maximum of 100 cask lifts per year.

(Note: Since some of the estimates are "of the order of magnitude" the log-mean value is also presented.)

Failure of Lifting Equipment

The only available fault tree describing the failure of a crane comes from NUREG-0612, and the staff's previous evaluation is summarized in Table 2. (Note: The WIPP report does contain fault trees but they are illegible. The Trudock crane appears to be a non-single failure proof handling system.) It is noted that the dominant contributor to the "Failure of crane" is the "Failure due to random component failure," with a backup component, event CF2. The staff's evaluation was based on an estimate of errors or failures "per year." The staff's evaluation was also based on the 1970s Navy data and included a factor of 0.5 reduction for the estimates range of drops per lift based on improved procedures and conformance with the guidelines presented in Section 5.1.1 of NUREG-0612.

The identical fault tree was requantified for the Trudock crane (WIPP), as shown in Table 3, but the estimate of errors or failures was recast in "per lift," based on the NUREG-0612 evaluation. It is again noted that the dominant contributor to failure is the "Failure due to random component failure," with a backup component, event CF2. The probability of a handling system failure was estimated (in NUREG-0612) to be in the range of 1.5×10^{-4} to 1.0×10^{-5} per lift (mean value of 8.0×10^{-5} per lift, log-mean value of 3.9×10^{-5} per lift) for a non-single failure proof handling system. Based on the 1970s Navy data these value were reduced (by a factor of 23/43 to account for the number of events resulting from crane component failures) to 8.0×10^{-5} to 5.3×10^{-6} per lift (mean value of 4.3×10^{-5} per lift, log-mean value of 2.1×10^{-5} per lift). An 0.1 to 0.01 conditional

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probability of failure of the backup component was used to evaluate a single-failure proof handling system. The CF2 probability was therefore in the range of 8.0×10^{-6} to 5.3×10^{-8} per lift (mean value of 4.0×10^{-6} per lift, log-mean value of 6.5×10^{-7} per lift).

The WIPP evaluation (based on demand or per lift instead of per year) was used by the staff to reevaluate the cask drop frequency based on 100 lifts per year and assumed that 1-in-10 "crane failures" leads to a dropped load (based on the 1990s Navy data). This evaluation is summarized in Table 4. A comparison of Table 2 to Table 4 shows, with some minor differences, the NUREG-0612 and WIPP estimates to be about the same. From Table 4, the range is 8.5×10^{-5} to 7.7×10^{-7} per year of a crane failure (event CF) leading to a dropped load for 100 lifts. The mean value is 4.3×10^{-5} per year, and the log-mean value is 8.0×10^{-6} per year.

Failure to Secure Load

The second cause of a dropped load is failure of the load rigging. In NUREG-0612, this was estimated to be 3.0×10^{-5} to 1.0×10^{-7} per year (mean value 1.5×10^{-5} per year, log-mean value 1.7×10^{-6} per year). Based on the 1970s Navy data, and included a factor of 0.5 reduction based on improved procedures and conformance with the guidelines presented in Section 5.1.1 of NUREG-0612, the estimated rigging failure leading to a load drop was 1.0×10^{-5} (0.07 times 1.5×10^{-4}) to 7.0×10^{-7} (0.07 times 1.0×10^{-5}) per lift (mean value of 5.4×10^{-6} per lift, log-mean value of 2.6×10^{-6} per lift). The 1970s Navy data indicated that about 7% of failures (drops) were from improper rigging. The 1990s Navy data indicates that 25% of failures are from rigging with 6% leading to a dropped load.

Failure to secure a load was evaluated in the Trudock (WIPP) report. 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 the WIPP report (Appendix 4), 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 information, the mean failure was estimated in the WIPP report to be 8.7×10^{-7} per lift, similar to lower bound value of 7.0×10^{-7} per lift in NUREG-0612. Assuming 100 lift per year, the mean failure of rigging leading to a load drop is estimated to be on the order of 5.0×10^{-6} per year (100 times 8.7×10^{-7} times 0.06 — 6% or rigging failures leads to a load drop). The WIPP evaluation, including the human error probabilities, is summarized in Table 5.

Summary

Current studies for the failure of a crane are dominated by the "Failure due to random component failure," with a backup component, event CF2 in the fault trees summarized in Tables 2 and 4. The estimated mean value is about 4.0×10^{-5} per year for 100 lifts, assuming 1-in-10 failures leads to a dropped load. The crane failure contribution from operator error is estimated to have a mean value of 6.0×10^{-7} per year (CF1 + CF3) for 100 lifts, assuming 1-in-10 failures leads to a dropped load. These two values are based on an estimate of 1.5×10^{-4} to

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1.0×10^{-5} drops per lift as evaluated in NUREG-0612. The drop per lift values are consistent with the Savannah River study ("Savannah River Site Human Error Data Base Development for Nonreactor Nuclear Facilities," Westinghouse Savannah River Co., WSRC-TR-93-581, February 28, 1994), 1.5×10^{-4} to 1.5×10^{-5} for the expected load characteristics.

Failure of the rigging leading to a dropped load is estimated to have a mean value of about 5.0×10^{-6} per year for 100 lifts, based on 6% of rigging failures leading to a drop load. The WIPP Trudock report and the 1990s Navy data were used as the basis for this estimate.

Operator errors (CF1 and CF3) are secondary contributors based on the current studies, accounting for less than 5% of the overall frequency of "Failure of crane."

The purpose of the WIPP reevaluating of NUREG-0612 was to estimate the crane cable/hook failure contribution to the overall failure of the crane. It was determined that this contribution was less than of 2.5×10^{-6} per lift. It was further stated in the WIPP report that "there appears to be sufficient evidence to demonstrate that the design conservatism and operating environments associated with the WIPP cranes is much better than that of the Navy cranes which formed the databases for the NUREG-0612 analysis. However, the impact of this evidence is extremely difficult to quantify and no additional credit has been taken for this potential improvement."

The mean frequency of a crane cable/hook failure (a component without a secondary device, event CF4) was estimated in NUREG-0612 to be 1.8×10^{-7} per demand (lift) (see Table 3). This estimate was based on conformance with NUREG-0554 ("Single-Failure-Proof Cranes for Nuclear Power Plants") and included a reduction by a factor of 10 based on the expected increase in design safety factors to reduce the failure probability. 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 3 to 5% for the 1990s Navy data). If it is assumed that rigging errors will not lead to a dropped load into or onto the spent fuel pool (error or failure found at onset of lift) resulting in damage to the pool, and that other hardware or operator errors are substantially reduced based on conformance with NUREG-0554 and Section 5.1.1 of NUREG-0612, the likelihood of a dropped load for 100 lifts per year is could be as low as 1.8×10^{-5} per year (compared to a total estimate of 4.0×10^{-5} per year). With a backup or if the improved design safety factors yields a greater reduction in the failure probability, this value could drop to 1.8×10^{-6} or to 1.8×10^{-7} per year.

Based on the revised evaluation using the WIPP report and the new Navy data (Table 4), the mean crane failure rate leading to a dropped load is about 4.0×10^{-5} per year (given 100 lifts per year, and 1-in-10 failures leads to a dropped load). The log-mean value is 8.0×10^{-6} per year.

Rigging failure leading to a dropped load, is estimated using the new Navy data and the WIPP report. The WIPP report indicates that the mean rigging failure rate is about 8.7×10^{-7} per lift. Given 100 lift per year with 6% leading to a dropped load, the mean failure rate for improper rigging is estimated to be 5.0×10^{-6} per year (the log-mean value would be the same).

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The mean estimate for a dropped load is 4.5×10^{-5} for 100 lifts per year (mean crane failure plus mean rigging failure). The log-mean estimate for a dropped load is 1.3×10^{-5} per year (log-mean crane failure plus mean rigging failure). In NUREG-0612, the mean value was 5.0×10^{-5} per year and log-mean value was 6.3×10^{-6} per year, respectively.

Load Path

At this point the path of the lift, and the portion of the path interval over which significant damage is likely to occur given a cask drop, needs to be factored into an overall estimate of a rapid loss of inventory.

The load path assessment is plant specific. Based on NUREG-0612 it was estimated that the heavy load is near, or over, the spent fuel pool between 5% and 25% of the time. It is therefore assumed that 1-in-10 (or 10% of the load path) drops will be over the spent fuel pool at a height sufficient to damage the pool floor if dropped. Further if the drop occurs on the spent fuel pool wall, only 1-in-10 will likely result in damage to the wall. Therefore the likelihood of damage to the pool floor is estimated to have a mean value of 4.5×10^{-6} per year, with a log-mean value of 1.3×10^{-6} per year. Failure of the pool wall is estimated to be a factor of 10 lower.

Conclusion

This reassessment has determined that, based on available — although questionable as to its suitability to NSSS SFP handling systems — data, the drop per year values presented at the July 1999 SFP workshop are of the correct order of magnitude. Given uncertainties in load path characteristics, but assuming only 10% of the path to be critical to rapid pool draining, the likelihood of the rapid loss of inventory values presented in the workshop are also of the correct order of magnitude (absent a specific load drop evaluation to determine structural damage).

It is important to note that operator errors have been determined to be of secondary importance and component failures dominate the current risk estimates.

The drops per lift range is estimated to be on the order of 1.0×10^{-4} to 1.0×10^{-5} per lift. This range was used in the NUREG-0612 evaluation and is supported by the Savannah River report. There have been about 150 casks loaded for dry storage at commercial reactor sites in the past 14 years. Point estimates of failure rates may be calculated with the following equation for those events not observed (zero occurrence - no drops or any other reportable event) in C number of components (lifts) for T years:

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

For the current experience base, $\lambda_{95\%} = 7.0 \times 10^{-4}$ per year (assuming each cask load requires two lifts). At the 50% confidence limit, $\lambda_{50\%} = 1.6 \times 10^{-4}$ per year.

The dominate contributor is the "Failure due to random component failure," with a backup component, event CF2, combined with the conditional failure of the backup component given the

failure of a component with a backup in the range of 0.1 to 0.01. If the upper and lower bound estimate for this conditional failure are reduced by a factor of 10, and if the failure of a component without a secondary device (event CF4) is also reduced by a factor of 10, and if operator errors are not considered, the mean crane failure rate is reduced from about 4.0×10^{-5} to 4.0×10^{-6} per year, with a range of 8.6×10^{-6} to 7.6×10^{-8} per year. The overall mean drop rate (including rigging failure, with a mean value of 5.0×10^{-6} per year) would be reduced from 4.5×10^{-5} to about 1.0×10^{-5} per year.

Recommendation

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 the uncovering of spent fuel is on the order of 1.0×10^{-6} per year, given 100 lifts per year and 1-in-10 drops results in significant damage to the spent fuel pool. A heavy load (shipping cask) drop leading to the uncovering 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 guidelines for the control of heavy loads, Section 5 of NUREG-0612, should be followed for a decommissioning plant. Specifically, if a detailed evaluation of the specific plant heavy load handling system cannot be shown to be significantly better than the generic assessment described above, 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 uncovering of spent fuel should be considered, as appropriate, on a plant specific basis.

In the staff's evaluation of heavy loads presented in NUREG-0612, one of the underlying assumptions was that between 42 and 74 days was a safe decay time if a full core were damaged (Ref: NUREG-0612, page B-1) — negligible release of radioactivity. Therefore an 0.1 to 0.2 multiplier (38 to 72 days out of 365 days per year) was included in the assessment to estimate the per year frequency of a release exceeding the guidelines. This multiplier is no longer applicable with high density storage racks in a spent fuel pool. It is appropriate to reconsider the acceptance of a single-failure proof without a load drop analysis for a decommissioning plant since the NUREG-0612 evaluation would show a log-mean value of 2.0×10^{-6} per year of exceeding the release guidelines. The mean value would be 5.0×10^{-5} per year.

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Table 1 - Summary of Navy crane data (1996 through mid-1999)

Event	Percent of events	Cause	Percent of event by cause
Dropped load	9	Equipment	33
		Improper rigging	66
Overload	12	Improper operation	25
		Improper rigging	38
		Procedure	37
Crane collision	17	Improper operation	46
		Procedure	18
		Other	27
Damage crane	27	Improper operation	50
		Improper rigging	28
		Procedure	22
Damage load	5	Equipment	33
		Improper rigging	67
Load collision	14	Improper operation	56
		Improper rigging	22
		Procedure	11
		Other	11
Personnel injury	8	Improper operation	20
		Improper rigging	60
		Procedure	20
Two-blocking	5	Improper operation	67
		Procedure	33
Other	3	Improper operation	33
		Improper rigging	33

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		Procedure	33
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Table 2 - NUREG-0612 Failure of crane (from Figure B-3, sheet 2(a))

Event	Description	Units	High	Low	Mean ⁽¹⁾	LogMean ⁽²⁾
CF11	Operator error leading to load hangup	/Year	7.0e-05	2.0e-06	3.6e-05	1.2e-05
CF12	Failure of the overload device	/demand	1.0e-02	1.0e-03		
CF1	Load hangup event (CF11 and CF12)	/Year	7.0e-07	2.0e-09	3.5e-07	3.7e-08
CF21	Failure of single component with a backup	/Year	8.0e-04	2.0e-05	4.1e-04	1.3e-04
CF22	Failure of backup component given CF21	/demand	1.0e-01	1.0e-02		
CF2	Failure due to random component failure (CF21 and CF22)	/Year	8.0e-05	2.0e-07	4.0e-05	4.0e-06
CF31	Operator error leading to Two-blocking	/Year	5.0e-04	1.0e-05	2.6e-04	7.1e-05
CF32	Failure of lower limit switch	/demand	1.0e-02	1.0e-03		
CF33	Failure of upper limit switch	/demand	1.0e-01	1.0e-02		
CF3	Two-blocking event (CF31 and CF32 and CF33)	/Year	5.0e-07	1.0e-10	2.5e-07	7.1e-09
CF4	Failure of component that doesn't have backup	/Year	3.0e-06	9.0e-08	1.5e-06	5.2e-07
CF	Failure of crane (CF1 or CF2 or CF3 or CF4)	/Year	8.4e-05	2.9e-07	4.2e-05	5.0e-06

(1) - (High + Low)/2

(2) - $\exp^{(\ln(\text{high}) + \ln(\text{low})) / 2}$

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Table 3 - WIPP Failure of crane (from WIPP/WID-96-2196, Appendix A5)

Event	Description	Units	High	Low	Mean ⁽¹⁾	LogMean ⁽²⁾
CF11	Operator error leading to load hangup	/lift	7.0e-06	4.7e-07	3.7e-06	1.8e-06
CF12	Failure of the overload device	/demand	1.0e-02	1.0e-03		
CF1	Load hangup event (CF11 and CF12)	/lift	7.0e-08	4.7e-10	3.5e-08	5.7e-09
CF21 ⁽³⁾	Failure of single component with a backup	/lift	8.0e-05	5.3e-06	4.3e-05	2.1e-05
CF22	Failure of backup component given CF21	/demand	1.0e-01	1.0e-02		
CF2	Failure due to random component failure (CF21 and CF22)	/lift	8.0e-06	5.3e-08	4.0e-06	6.5e-07
CF31	Operator error leading to Two-blocking	/lift	5.2e-05	3.5e-06	2.8e-05	1.3e-05
CF32	Failure of lower limit switch	/demand	1.0e-02	1.0e-03		
CF33	Failure of upper limit switch	/demand	1.0e-01	1.0e-02		
CF3	Two-blocking event (CF31 and CF32 and CF33)	/lift	5.2e-08	3.5e-11	2.6e-08	1.3e-09
CF4 ⁽⁴⁾	Failure of component that doesn't have backup	/lift	3.4e-07	2.3e-08	1.8e-07	8.8e-08
CF	Failure of crane (CF1 or CF2 or CF3 or CF4)	/lift	8.5e-06	7.7e-08	4.3e-06	8.0e-07

(1) - $(High + Low)/2$

(2) - $\exp((\ln(high) + \ln(low)) / 2)$

(3) - Based on 1970s Navy data, about 50% of incidents resulted from random material failure, personnel errors, design deficiencies, improper maintenance or inadequate inspection. The 1990s Navy data indicates about the same percentage.

(4) - After conformance with NUREG-0554 (Ref: NUREG-612, page B-11)

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Table 4 - Failure of crane based on 100 lift per year (with Navy drop data 1-in-10 drops)

Event	Description	Units	High	Low	Mean ⁽¹⁾	LogMean ⁽²⁾
CF11	Operator error leading to load hangup	/Year	7.0e-05	4.7e-06	3.7e-05	1.8e-05
CF12	Failure of the overload device	/demand	1.0e-02	1.0e-03		
CF1	Load hangup event (CF11 and CF12)	/Year	7.0e-07	4.7e-09	3.5e-07	5.7e-08
CF21	Failure of single component with a backup	/Year	8.0e-04	5.3e-05	4.3e-04	2.1e-04
CF22	Failure of backup component given CF21	/demand	1.0e-01	1.0e-02		
CF2	Failure due to random component failure (CF21 and CF22)	/Year	8.0e-05	5.3e-07	4.0e-05	6.5e-06
CF31	Operator error leading to Two-blocking	/Year	5.2e-04	3.5e-05	2.8e-04	1.3e-04
CF32	Failure of lower limit switch	/demand	1.0e-02	1.0e-03		
CF33	Failure of upper limit switch	/demand	1.0e-01	1.0e-02		
CF3	Two-blocking event (CF31 and CF32 and CF33)	/Year	5.2e-07	3.5e-10	2.6e-07	1.3e-08
CF4	Failure of component that doesn't have backup	/Year	3.4e-06	2.3e-07	1.8e-06	8.8e-07
CF	Failure of crane (CF1 or CF2 or CF3 or CF4)	/Year	8.5e-05	7.7e-07	4.3e-05	8.0e-06

(1) - (High + Low)/2

(2) - $\exp^{(\ln(\text{high}) + \ln(\text{low})) / 2}$

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Table 5 - 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	F ₁ + F ₂

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(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.