National Nuclear Security Administration

U.S. Department of Energy
NNSA Production Office
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July 11, 2014

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DNF SAFETY BOARD

The Honorable Peter S. Winokur
Chairman
Defense Nuclear Facilities Safety Board
625 Indiana Avenue, NW, Suite 700
Washington, DC 20004

Dear Mr. Chairman:

This is in response to your letter of June 2, 2014, regarding concerns with the protection against falling man events for special tooling used in nuclear explosive operations at Pantex. The National Nuclear Security Administration (NNSA) and NNSA Production Office (NPO) understand the significance of the hazards involved in Pantex nuclear explosive operations and appreciate the Board's concerns with the safety analyses supporting these operations.

The NNSA, NPO, and Consolidated Nuclear Security, LLC (CNS) are confident in the safety of operations at Pantex. Nuclear explosive operations and associated special tooling have been analyzed for credible falling man scenarios through the Pantex Tripping Man Analysis Methodology (1335-ANL). While this methodology does not use bounding values for all individual assumptions, when considered as a whole the combination of conservative and realistic assumptions provides a reasonably conservative representation of the hazard. Based on review of the Board's concerns and existing safety analyses for Pantex nuclear explosive operations, no immediate compensatory measures are deemed necessary.

As a continuous learning organization, the Pantex contractor has been working to establish a more detailed analysis of falling man hazards. Tripping tests and dummy drop tests performed at Virginia Polytechnic Institute and State University (VT) have recently been completed. The current schedule is for VT to release an integrated report to define the falling man scenario in August 2014. Once this final report is published by VT, a technical review will be conducted to determine the adequacy and relevance of the data to Pantex operations. The results of this review will be entered into the Pantex "New Information" system and evaluated against the existing falling man analysis used in the Documented Safety Analysis.

The enclosed report addresses the specific examples identified in your letter; discusses the results of falling man experiments and Nuclear Explosive Safety evaluation concerns; and provides planned actions and a timeline for ongoing activities for improving the Pantex falling man analysis and reevaluating special tooling.

Your letter also requested a briefing. Based on discussions with your staff, we intend to provide the briefing and an opportunity to view tooling of interest during the Annual Board Visit to the Pantex Plant planned for August 2014.

Please contact me at (865) 576-0752 or Ken Ivey at (865) 574-0277 if you have questions or need additional information.

Steven C. Erhart
Manager
NNSA Production Office

Enclosure:
As Stated

cc w/enclosure:
F. Klotz, NA-1, FORS
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JUL 11 2014

Mr. Kenneth A. Hoar
Assistant Manager for
Nuclear Safety & Engineering
U.S. Department of Energy
NNSA Production Office
P.O. Box 2050
Oak Ridge, TN 37831

Subject: Falling Man Report in Response to DNFSB Letter

Re: DNFSB Letter, Winokur to Klotz, dated June 2, 2014

Dear Mr. Hoar:

Enclosed for your use is the Falling Man Report written to address the Defense Nuclear Facilities Safety Board Letter (DNFSB) from Peter S. Winokur Chairman to The Honorable Frank G. Klotz, Administrator, National Nuclear Security Administration, dated June 2, 2014.

If you have any questions, please contact me at (806) 477-7259 or Doug Kaczmarek at (806) 477-4905.

Respectfully,

Joseph S. Papp
Pantex Engineering Director

Enclosure: As stated

cc: S. Erhart, NPO Y-12
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Mission Engineering

Pantex

Falling Man Report

Prepared by Doug Kaczmarek

Falling Man Report

Executive Summary

This report has been written to address the Defense Nuclear Facilities Safety Board Letter (DNFSB) from Peter S. Winokur Chairman to The Honorable Frank G. Klotz, Administrator, National Nuclear Security Administration, dated June 2, 2014.

Pantex developed and implemented an analytical methodology for falling man in the Pantex Documented Safety Analysis (DSA) in the April 2002 timeframe. Prior to the development of Tripping Man Analysis, 13385-ANL, by the Pantex Special Tooling & Tester Design Department, no criteria were available to define the abnormal event loading associated with a falling man in standards, code requirements, industry or academia. The falling man as defined in the Documented Safety Analysis is considered a rare event.

The analytical methodology was created to establish and document a credible scenario for an abnormal event to characterize associated loading. The intent was not to establish bounding criteria independently for all associated variables (these variables are further described in Section 2.0 of this report), but rather to establish a credible and conservative integrated approach. Using independent bounding criteria for all associated variables would result in grossly oversized and more complex tooling that would require manipulation by hoist lift, be much less user friendly from a human factors perspective, and create other hazards to the unit such as increased impact energies in the event of dropped tooling. It should be noted that some of the key elements considered during Seamless Safety for the 21st Century (SS-21) tooling upgrade projects were the minimization of hoist lifts and enhancement of process ergonomics.

Although individual assumptions in the analysis may not be fully bounding, when considered as a whole, Pantex's position based on engineering judgment is that the combination of conservative and realistic assumptions provides a prudent consideration of this rare event.

Falling Man Report

1.0 Introduction

After identifying a falling man as a potential hazard to special tooling and weapon components, work began to characterize the postulated event in order to better understand the hazard and develop an appropriate control set. Of special note, the "falling man" is sometimes referred to as the "tripping man." In the analysis conducted to date and in this report, the two are synonymous. The term "falling man" is used except in cases where a previous published report is referenced.

The falling man scenario is one in which the production technician is presumed to trip while approaching the unit assembly and in an involuntary response puts his hands out to arrest his fall, resulting in an impact to the tooling or the unit. In 2002, a standard was created to provide consistent guidance for design, tooling analysis, and hazard analysis related to a tripping man event. This analytical methodology established and documented a credible scenario for an abnormal event to characterize associated loading. The intent was not to establish fully bounding criteria for each associated variable but rather, to understand loading requirements by starting with the simplest, most conservative approach, in the form of a static model to represent a dynamic event.

2.0 Present Falling Man Analysis Methodology

In developing the design input for this rare event, no standard or code requirements were available. Pantex's first attempt at defining a falling man standard was documented in the "Tripping Man Analysis", 13385-ANL. This analysis documents the methodology for understanding how a falling technician could potentially adversely interact with tooling and includes characterization of tipping, sliding, and a conservative approximation of the forces exerted. While this clearly is a dynamic event, there is very little understanding of the dynamic event parameters available in prior reference materials. As a result, our analysis to date has been based on representative static loading assumptions and a semi-rigid human body. Continuing studies addressed in following sections of this report have been undertaken to help Pantex better understand the dynamic nature of this event, and to help refine analytical assumptions accordingly.

To further simplify the model, actual distributed load conditions are replaced with point loads. In addition, the analyst applies the static loads in a worst case loading condition for structural analysis. Furthermore, Pantex's standards for "rare events" require a design basis factor of safety of 1.25 against the onset of yield. It is important to note that the onset of yield is not synonymous with catastrophic failure of Pantex special tooling. This is a significant additional level of conservatism in the analysis.

Summary of Key Elements of Conservatism

Assumption	Impact to Results
Yield-vs-Failure	Additional energy is required beyond the onset of yield for catastrophic failure
Safety Factors Against Yielding	Additional margin in analysis
Worst Case Point Loading Condition	Results in highest bending moments and worst case loading conditions
Semi-Rigid Body Model	Deformable body shown to absorb considerable energy and effectively reduces dynamic impulse loading

3.0 Results of All Falling Man Experiments to Date

There have been three reports published addressing the falling man rare event. Two reports published by Virginia Tech (VT), and a third report generated by Los Alamos National Laboratory (LANL), used the data from the VT reports. These reports are summarized below.

3.1 Task 3: Fall Experiment, Human Volunteer Testing Summary Report, dated 10/26/12

In order to characterize "Falling Man" scenarios, this research effort addressed a collaborative initiative between LANL and VT to identify the biomechanical parameters and force properties associated with a "falling man" scenario. The characterization is further necessary since the current methodology assumes that the falling man transfers 100% of the kinetic energy onto the item of interest without consideration of compliance of the soft tissues or energy dissipation via human being muscle motor control. To better understand the assumptions used in the "falling man" scenarios, a literature search on the subject and a series of human volunteer experiments were conducted, utilizing the motion analysis system in the laboratory setting. Studies included grip strength holding a screwdriver object, measurements of maximum strike force using a screwdriver, and measurements of human body segment reaction during a tethered drop.

In summary, while the experiments began to help us characterize the human interactions associated with the potential rare event, results were largely inconclusive and did not reveal any significant information in refining the Pantex falling man analytical methods. However, this report did provide information to determine further desired areas of study.

3.2 CIB Report Number 2012-012, Simulation of the "Falling Man" Scenario: Crash Test Dummy Fall Experiments, dated 10/18/2012

The scope of this work was primarily to gather data and answer questions related to weapon component impact and object penetration. The VT work also provided the force-time profile used in the LANL experiments (LA-UR-13-23325, Falling Man Impact Experiments: The Response of Materials to Low Velocity Penetrating Impacts with Simulated Human Impact Dynamics). Two types of test series were performed. A forward fall test where the test dummy was permitted to fall on to an impact target under solely gravitational acceleration and a pull test in which the test dummy was accelerated to an initial velocity at the vertical position equal to that of walking speed in Pantex production facilities.

The objective of the crash test dummy fall experiment was to quantify the acceleration, chest deflection, and reaction forces for forward, unmitigated falls onto three impactor types (6" diameter plate, 3" diameter plate, and a screwdriver) and two initial velocities (0.00 m/s, and 1.07 m/s). All impact data was collected on a force gauge located 9" above floor level. The fall was performed with a standard 50th percentile male anthropomorphic test device (ATD). Measured results were then scaled to represent the current assumption for the Pantex worker models. According to subject matter experts at VT, the practice of scaling the results is considered a standard academic approach for these types of tests.

The results of the pull test showed that the impact velocities were not considerably different between those of the static fall tests, or between impactor types. The resultant reaction forces and chest deflections were significant and similar in magnitude, duration, and shape between static fall tests and pull tests for each impacting surface. These findings demonstrate the human body compliance under representative conditions and further substantiate a level of conservatism in the current falling man analytical assumptions of the falling technician. Additionally, for small impactor types it was demonstrated that much greater body deformity and increased contact time were observed thereby reducing the effective dynamic loading.

In summary, this study provided some useful insights validating the conservative nature of our relevant assumptions however; it did not adequately answer all of Pantex's questions. As a result, additional studies at VT to further develop the falling man scenario and associated loading profiles were initiated. The follow on study will further develop the falling man scenario in the form of three vignettes to include loading condition imposed by an incapacitated individual, load conditions imposed by an unencumbered individual, and those imposed by an individual carrying a representative tool.

3.3 LA-UR-13-23325, Falling Man Impact Experiments: The Response of Materials to Low Velocity Penetrating Impacts with Simulated Human Impact Dynamics, dated 5/7/2013

Experiments were performed to examine the response of high explosives (HE) and cased HE to low velocity, penetrating impacts with pointed hand tools. The energy for these impacts arises from the mass and velocity of the representative Pantex worker. As noted in this LANL report, early attempts to estimate force and energy from "Falling Man" scenarios were made with unrealistic rigid body assumptions. The rigid body assumptions assume that there is no deflection of the body when it strikes a weapon component resulting in very short impulse durations. LANL further states these early results estimated energy levels that were excessively high. The methodology for generating these estimates was deemed by LANL to be overly conservative and, as an alternative, an experimental program was initiated to measure accurate impact dynamics and then test representative targets with simulated human impact dynamics.

Collaboration was established with biomechanics experts from VT to determine the worst-case fall scenario. This was determined to be a forward fall from an unresponsive subject (no attempt to arrest one's fall) where the tool becomes pinned against the sternum. This would provide the worst case loading for tool penetration into the weapon component. A vehicle crash test dummy was used to measure the force, energy and duration for this type of collision. These measurements were used to develop and calibrate a pendulum-mounted impact device designed at LANL. This device permitted the authors to test a variety of representative target assemblies (cased or bare) impacted by either a "1/4 inch screwdriver or 3/16 ball driver" with simulated (and realistic) human impact response.

Results showed that during "Falling Man" impacts with hand tools pinned against the person's sternum, a major fraction of the kinetic energy was directed into the "person". This is a consequence of the relatively high compliance of the torso (note results and conclusions from Section 4.2) compared to the stiffness of the targets. The deformation of the torso, experiencing stress from the tool handle, also determines the duration and, consequently, the peak force attained during the impact event. These forces appear to be insufficient to cause perforation of the tested casing material. However, the force generated was high enough to perforate bare mock HE. In all cases where force was higher than the respective material failure threshold, the potential energy was sufficient to cause full depth perforation. Finally, the shape of the tool tip was shown to be an important factor in penetration.

While this report provides important information to Pantex about how the duration of the impact and load distribution is relevant to the falling man analysis, it is also directly applicable to the design agencies in developing weapon response.

3.4 Summary Conclusions: Application to Pantex Rare Event Analysis

Based on the three reports, parallels may be drawn between body deflection and the Pantex analytical model utilizing arm deflection. The results of the experiments in the reports show that the body compliance and the use of arm deflection is an appropriate approximation of human body compliance and the associated force profile from a falling man rare event. Although individual assumptions in the Pantex analysis do not comprehensively address all spectrums of variance, Pantex considers the combination of conservative and realistic assumptions provides a rational representation of the hazard.

4.0 Factor of 5 and 10 referenced by the DNFSB

Pantex believes the two loading error comments referenced in the DNFSB letter are inaccurate and these conclusions may have been reached from a misinterpretation of the reported data. It is our understanding from prior discussions with our DNFSB liaison that these conclusions were reached from calculations using a dynamic load versus a static load which would account for the significant discrepancies.

4.1 "Factor of 5"

Regarding the "factor of 5" comment, this error results from a comparison of two very dissimilar sets of test results. For the test series at 9 inches off the floor (see Table 18 of report LA-UR-13-23325) and impacting a screwdriver, the mean dynamic force measured for the 50% dummy was 4372 N (982 lbs.). From this value, it is our understanding that the DNFSB extrapolated the mean dynamic impact force for the representative Pantex worker to be 6055 N (1361 lbs.). In comparison to the actual 280 lbs. body weight of the modeled Pantex worker this would result in an erroneous error of approximately 5x (1361 lbs. / 280 lbs. = 4.86).

4.2 "Factor of 10"

Regarding the "factor of 10" comment, it is our understanding that the DNFSB again compared two vastly different test results comparing a dynamic event to a static peak load event. Table 5 from the LANL impact experiments presents the calibration summary for the pendulum test apparatus used to simulate the falling man loads for impact and puncture studies on weapon components. The DNFSB staff references a value of 539 J (398 ft.-lbs.) as the mean peak energy for the falling man impact. This number actually represents the measured value of the pendulum test apparatus and not the energy from 50% dummy drop peak measured value or the projected energy from the representative Pantex worker. The proper number to reference from this table would have been 465 J (343 ft.-lbs.). It is our understanding, that the DNFSB staff then evaluated the relationship between the energy match calibration data (398 ft.-lbs.) with the 58 ft.-lbs. horizontal load from the falling man analysis methodology. This resulted in an erroneous error of approximately 7x (398 ft.-lbs. / 58 ft.-lbs. = 6.9). Based on multiple conversations with the DNFSB representative it is not apparent how the factor of 10 was derived from the information provided.

5.0 Summary of Nuclear Explosive Safety (NES) Assessments

Since 2006, there have been twelve NES evaluations in which the falling man hazard was a topic of discussion. These discussions resulted in four Pre-start (or Category A) Findings, three Post-start (or Category B) Findings, eleven Deliberation Topics and one Senior Technical Advisor (STA) comment. However, not all of the NES evaluations have been directly related to the Pantex Special Tooling falling man calculation methodology.

Ten of the nineteen write-ups are related to the calculation methodology while the remaining nine write-ups mention the falling man hazard as an initiating event or a secondary consequence or some precursor initiating event. Of the ten issues related to the calculation methodology, four were Findings, five were Deliberation Topics, and one was an STA comment. All approved NES Pre-start Findings related to the falling man scenario have been resolved in a manner that allowed NNSA to approve operations.

6.0 Special Tooling in Question

The DNFSB staff evaluated two pieces of tooling where failure could result in an impact to uncased conventional HE. The tools in question are 076-2-0394, Installation FXTR, and 076-2-0526, Pit Transfer Plate. The DNFSB staff changed the input parameters (technician weight, location of applied load, height of configuration, and damping distance) to come up with their concerns.

For 076-2-0394, Installation FXTR, the DNFSB staff performed a sensitivity study on arm length (damping distance) for a horizontal impact load, application of the 100% technician weight, and an unrealistic location on the tool to apply the falling man load. Their conclusion was a yield factor of safety less than 1.0. This tool was analyzed and determined to be adequate for falling man loads in all configurations per the approved Pantex falling man methodology. The factor of safety against the falling man rare event loading was determined by applying a combined loading condition at the threaded portion (1/4-20UNC) of the rod (Piece-2). A falling man was considered to have struck the lower edge of the Aft Case Bowl (076-2-0367) tool assembly thereby producing the worst case moment arm length. The resultant moment and vertical load component of the falling man were then applied at the noted section to arrive at a factor of safety of 1.4 against bending.

For 076-2-0526, Pit Transfer Plate, the DNFSB staff analyzed it in a configuration position 3 where the pit and vacuum fixture are supported above the uncased CHE and imparted the 100% falling man on one arm of the tool to determine a yield factor of safety less than 1.0. This tool was analyzed and determined to be adequate for falling man loads in all configurations per the approved Pantex falling man methodology. Under a falling man load condition the tool was analyzed in a configuration that produced the worst case moment arm length, considered to be the vertical position during transfer operation at position (analysis position 2). The falling man horizontal load component was applied in a manner acting perpendicular to rotational plane and at the top of the pivot arm (Piece-6). One beam was assumed to carry the entire load by ignoring the structural reinforcement provided by the gussets. The resultant factor of safety under this bending condition was 1.29 against yield.

Overall, special tooling has been evaluated, and Pantex is confident that the current methodology provides the appropriate conservatism. All special tooling used in Nuclear Explosive operating areas has been evaluated for falling man and sufficient control strategies have been implemented to mitigate this rare event.

7.0 Any Immediate Compensatory Measures Deemed Necessary Based on These Results

Based on testing thus far, engineering judgment tells us that our current analysis is conservative and no immediate compensatory measures have been identified or deemed necessary. This decision will be reexamined when the results from the new VT testing report is completed and evaluated by Pantex and the Nuclear Weapons Complex.

8.0 Actions and Timeline Associated with Revising the Falling Man Analysis and, as needed, Re-evaluating Special Tooling Based on These Results

VT identified delays caused by added work necessary to characterize the impact measurement technique for a carried tool, has delayed the testing, analysis of results and integration in a final report. Once the final report is published by VT, it will be entered into the "New Information System" and evaluated by Pantex against the currently approved DSA for impacts on the current falling man scenario and analysis. An independent (outside NNSA and DOE) review group of the Pantex current methodology is scheduled to begin around August 1, 2014. Once Pantex receives the November 2014 VT report and their methodology, the same independent review group will evaluate the new VT methodology.

Activities related to review of the current analysis methodology, the contract with VT to investigate the falling man accident scenario, and incorporation of any relevant changes are shown in the table below.

Activity	Expected Due Date
Initiate Independent Review of Current Pantex Methodology	August 2014
Perform Dummy Drop Tests on Representative Tooling by VT	October 2014
Receive VT Report/Methodology	November 2014
Begin Design Agencies Review of VT Report/Methodology	November 2014
Receive Design Agencies Comments on VT Report/Methodology	January 2015
Incorporate Design Agency Comments in VT Report/Methodology	February 2015
Initiate Independent Review of VT Report/Methodology	February 2015
Submit New Information if necessary based on the VT Report/Methodology	February 2015
Perform initial evaluation/screen of current DSA scenarios with new VT Methodology	March 2015
Perform initial evaluation/screen of current Falling Man credited tools with new VT Methodology	March 2015
Provide results of DSA/Tooling using new VT Methodology evaluation and proposed path forward to NNSA	May 2015