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INITIATING-EVENT FREQUENCIES FOR NUCLEAR WEAPON DISMANTLEMENT HAZARD ANALYSIS

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ABSTRACT

A quantitative data base for initiating events encountered during nuclear weapons handl is described. This data base was assembled from incident reports at the plant where th weapons are handled. The strengths and pitfalls of constructing such a data base are elaborated using examples encountered in the data. Insights gained into accident sequences, human error probabilities, and other areas of concern are discussed.

I. INTRODUCTION

With the end of the Cold War, the United States is preparing to disassemble a l number of nuclear warheads. This is scheduled to occur at the Department of Energy (DOE) Pantex facility near Amarillo, Texas. The DOE is working to reduce the likelih of accidents during dismantlement through an integrated program of tooling, procedura and training upgrades. An integral part of this program is a concurrent hazard analysis the dismantlement process. In a previous paper, we reported on a quantitative hazard analysis for dismantlement of a particular weapon.[1] As part of that effort, it was neces to estimate initiating-event frequencies associated with accident sequences leading to th energetic release of radioactive or toxic materials. In this paper, we describe the use of plant operational data to estimate event frequencies. Operations with nuclear weapons somewhat unusual, and the use of the actual plant data where available is preferable to using surrogate data from other industries.

Accident sequences leading to the production of a radioactive aerosol require th application of some energy source to the weapon pit—the fissionable material located i primary section of a thermonuclear weapon. During dismantlement, the system is in various configurations from full-up weapon to individual components, including hemispheres of high explosive (HE) and the pit. Specific accident sequences are assoc with these configurations. A primary energy source and one or more enabling events identified for each sequence. Energy sources are external (earthquake), facility (fire), process (HE) related. Enabling events allow a particular energy source to operate on a weapon configuration. We searched the database for energy sources and enabling conditions identified in the accident sequences. Major categories for which frequency were obtained included all incidents related to weapon HE, detonators, and pits. We considered various insults to these components, including drops (manual or during ho operations), strikes by other objects, fires, and various facility failures. External-even frequencies were not considered. For these categories, we provide occurrence frequen on a per-weapon basis.

[illegible]

The maximum likelihood estimators for frequency f or probability p of occurrence using operational data of $\hat{n}$ occurrences in T total time on test or N trials respectively are[2]

$$f = \hat{n}/\hat{T}$$

and

$$p = \hat{n}/\hat{N} \ .$$

In these point-value estimates, the number of occurrences is in the numerator, and some count of the number of trials or time on trial is in the denominator. In this paper, the source for the numerator will be called event data; that for the denominator will be called population data. In general, no attempt was made to define prior distributions for these occurrence frequencies. The rationale for this was that many of the operations associated with nuclear weapon disassembly are either unique or sufficiently rare that identifying suitable surrogate data is problematic. In only one case, the occurrence of fires in disassembly cells, did we use a Bayesian approach; this is discussed separately below.

One obvious source for event data for nuclear weapons processing at the Pantex Plant is the Unusual Occurrence Report (UOR) collection generated at the facility over the years. UORs are generated when certain types of events occur during nuclear weapons handling or storage. These types of events include as a subset the types of events of interest in weapons safety assessment. Thus, the UORs offered great promise as an event data source.

The Pantex UOR database includes approximately 1600 incident reports for the time period from November 1976 to June 1990. Many of these incidents are not directly related to nuclear weapons and are similar to those seen in other DOE facilities. Earlier investigators from the three weapons laboratories (Los Alamos, Livermore, and Sandia National Laboratories) had filtered the UOR database to eliminate nonnuclear incidents. The result was a much smaller set of 208 records referred to as the TriLab database. UORs in the TriLab database were judged to be of significance with respect to nuclear operations at Pantex. Incidents in the database are identified according to weapon type, components involved, and time of day. A short description of the incident is given as well. An attempt was made to determine whether human error played a role in the incident and, if so, whether a procedure violation had taken place. Supporting documentation for these judgments is no longer available.

Practical difficulties with using the database exist. Records for the years 1986 through 1988 are not contained in the database. Titles of the UORs for these years were preserved, but the reports themselves were destroyed accidentally before microfilming. The requirements for UOR reporting changed during the time period covered by the database, and the level of detail in the records is inconsistent. However, it is believed that all incidents directly related to nuclear weapon operations at Pantex were entered into the reporting system.

Figure 1 shows the number of UORs per year for the TriLab database. Most incidents were flagged in the database as involving human error. This is not surprising because weapon assembly and disassembly are labor-intensive. The database contains data on specific procedure violations as well as more generic human error; these judgments were made by the database compilers. The fraction of procedure violations was small.

The total number of nuclear-significant UORs per year varies by over a factor of 5 for the time period used. Occurrence frequencies should be related to the plant activity, and this is considered below. Two areas of interest are the small number of incidents in the human error category for 1979 and the fact that no procedure violations were reported in 1982. This is suggestive of changing reporting requirements and will be examined later.

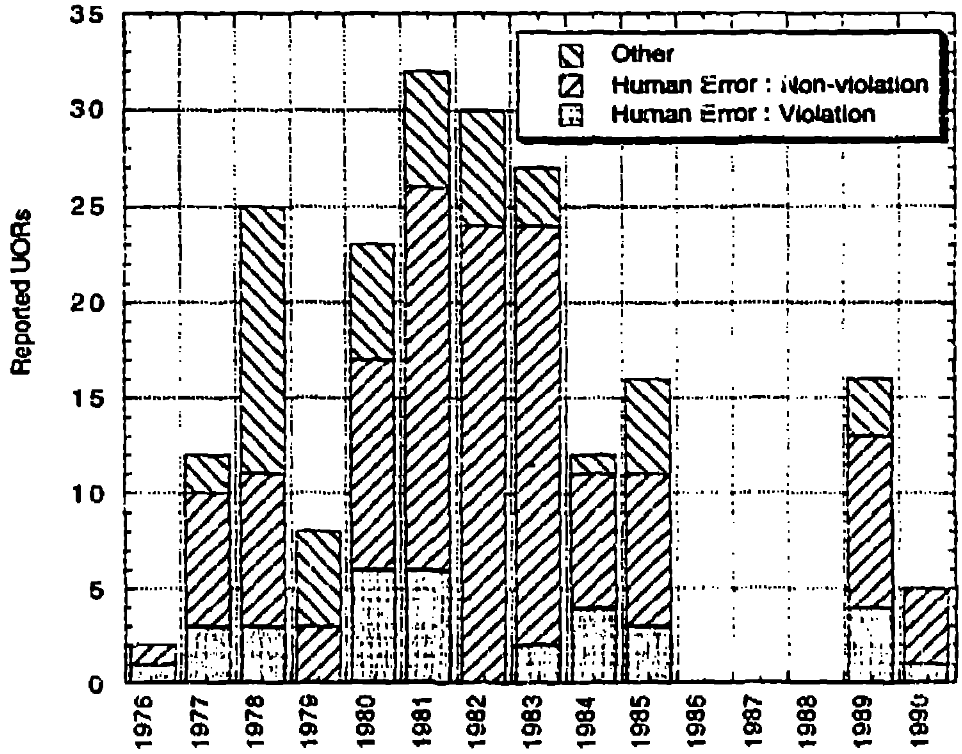

Figure 1. UORs in the TriLab database. Shown are the subcategories for human error, procedure violations, and others reported.

III. POPULATION DATA

Plant production data were used to convert UORs per unit time to UORs per weapon handled. Production data may be a time on test, a number of opportunities for error, or a number of cycles. Production data for the Pantex Plant were used to estimate the number of opportunities for certain types of production errors. The production data were divided into activities. Activities that involved assembly or disassembly usually were combined when opportunities for HE drops or strikes were calculated. Table 1 gives the annual frequencies for various initiating events of interest for the quantitative risk assessment. These are grouped first according to weapon-specific energy sources and then by process- and facility-related classes. A particular concern was dropping of weapon subassemblies or tooling, and this subcategory is shown at the end of the table.

Table 1. Average Initiating-Event Frequencies for UORs of Interest

Incident Type	Avg. Incidents per weapon	Incident Type	Avg. Incidents per weapon
High Explosives			
Total HE UORs	1.6E-3	*Hoisting Incidents*	
Drops		Total Hoisting UORs	1.6E-3
By Hand—Hemis	6.0E-5	Strikes/Drops/Tips—(w/c)	3.6E-4
By Hand—Fragments/Tiles		Hoist Component Failures	4.8E-4
By Vacuum Fixture	3.0E-4	Rotocage Hoisting Failures	5.4E-4
Strikes on HE	6.6E-4	Hoist Procedure Fail.	7.8E-4
Pressing Incidents	1.2E-4	Weapon Snags/Tube Bends	1.2E-4
Pits		*Forklift Incidents*	
Total Pit UORs	2.7E-3	Total Transport UORs	1.2E-3
Drops		General Operations	6.0E-4
By hand	6.0E-5	Strikes/Drops	2.4E-4
With vacuum fixture	3.0E-4		
Defective Pits	1.8E-4	*Facility Failures*	
Broken/Bent Tubes	1.8E-3	Loss of Power	1.2E-3
		Loss of Vacuum—cell	1.2E-4
Detonator /Cable UORs	1.2E-3	Loss of Vacuum—fixture	6.0E-5
		Electrical—grounding/shorting	5.4E-4
Tips of Assemblies/Parts	1.2E-4	Deluge/Sprinkler Trips	2.4E-4
Sticking Parts	3.6E-4	*Fires*	6.0E-5
Tooling: Incorrect; defects	7.2E-4		
Operator Clothing Incidents	2.4E-4	*Firearm incidents*	2.4E-4
Drops—Total	2.0E-3	*Total TriLab Database*	9.7E-3
HE (all forms)	3.0E-4		
Pits	2.4E-4		
Detonators	1.2E-4		
Fixtures/Tooling	4.2E-4		
Components/Assemblies	6.6E-4		
Weapons	2.4E-4		

Yearly variation in frequency for accidents was reduced considerably when yearly variations in the production were considered. Figure 2 shows the number of UORs per weapon as a function of time. An apparent reduction in the frequency of UORs per weapon over the time span covered by the data is seen. This reduction, especially coupled with an increasing emphasis on compliance with UOR reporting over the years, gives some evidence that incident rates may be decreasing with improved procedures and more strict administrative controls.

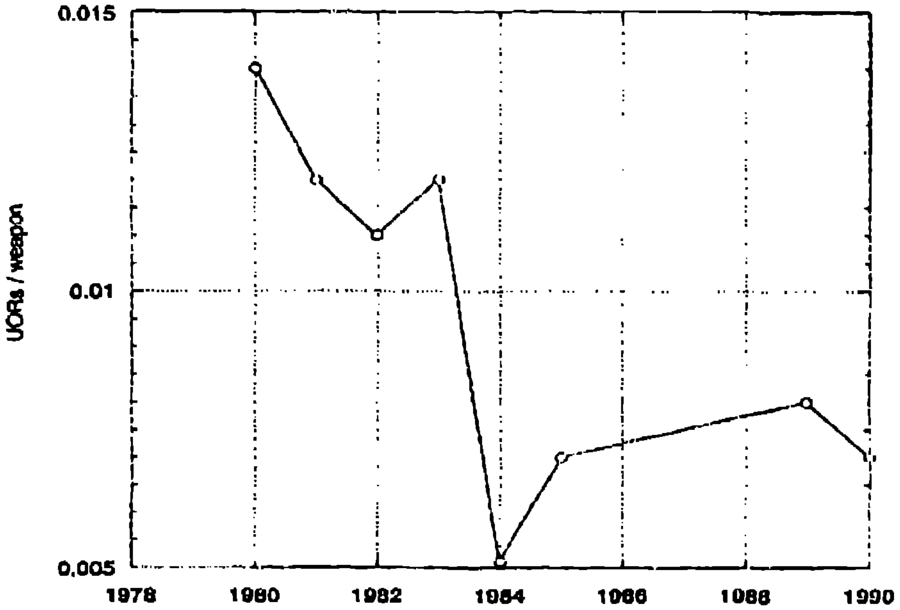

Figure 2. UORs per weapon as a function of time.

Each weapon assembly/disassembly presents a certain number of opportunities (on average) for error. This number of opportunities was estimated based on discussions with senior Pantex production technicians and engineering personnel. Some examples of opportunity estimates are shown in Table 2.

Table 2. Examples of Estimated Number of Opportunities

Activity	Opportunities per Weapon Assembly/Disassembly
HE Hand Carries	6
Pit Hand Carries	3
Hoists	6

These opportunity multipliers are the number of opportunities per weapon. For example, based on Pantex interviews, we determined that the average number of HE carries per weapon disassembly or assembly for all weapons is about six. Thus, the approximate probability of a hand-carried HE drop per opportunity is the average number of drops per weapon divided by the average number of opportunities per weapon; from Table 2, this is six.

IV. INSIGHTS FROM DATA ANALYSIS

Apart from the quantitative estimates of accident initiating-event frequencies calculated from the event and population data discussed earlier, a number of insights into potential weapons processing accident sequences was gained from the UOR data. Some of these insights are discussed below.

A. Accident-Sequence Identification

Great effort was expended in the safety analysis to identify potential accident sequences as exhaustively as possible. Fault-tree analysis was used to identify accident sequences that were developed further by constructing event trees. What-if and hazard analysis methods were used to generate accident sequences through a step-by-step evaluation of weapons handling procedures by a team of weapons processing experts. An extensive study of safety literature for weapons processing was undertaken as well. In spite of these efforts, some accident sequences were identified only through a careful study of the UORs.

An example of such an accident sequence involves overhead crane maintenance. An accident sequence that had been identified by fault-tree analysis was the fall of an overhead bridge crane from its track; one primary cause was failure to restore after maintenance. This accident sequence was assigned a very low probability based on industrial data. However, a study of the UOR data revealed that there had been actual instances of, not the entire crane, but parts of the crane falling when the crane was used to hoist loads. These parts ranged in mass from small bolts to quite massive chain covers. Thus, the UOR data revealed accident initiating events that had lower energy but were much more likely than the accident sequences identified through the standard systematic analysis procedures.

B. Human Error Rates

Predicting human error rates is a notoriously inexact art in safety analysis. The depth of this problem was illustrated by the UOR data base. Estimates of the probability of dropping HE during manual handling had been predicted in past studies using the Accident Sequence Evaluation Program (ASEP) technique.[3] This method gave a relatively high probability of such an occurrence. However, a search of the UOR data base indicated that dropping HE is a rare occurrence. The ASEP estimate for this operation was on the order of 10^{-2} per handling, whereas the UOR record indicated a frequency of less than 10^{-4} per handling. The lower value is supported by interviews with operational experts, even the most experienced of whom could not recall any occurrences. Based on the reporting requirements, the use of the two-person rule, and the candid observations of experienced technicians, the UOR data on dropping HE was felt to be representative of the actual experience.

The observed low error probabilities are consistent with theoretical models of human performance.[4] Standard human reliability techniques usually deal with rule-based behavior rather than skill-based behavior, such as manually handling HE. Human error probabilities for skill-based behavior are thought to be lower than for rule-based behavior.

The perceived hazards attendant on dropping HE are likely to produce a facilitative stress in the handler that increases vigilance and care, thus reducing error probabilities. Another observation in the data supports this contention. Other objects with sizes and shapes similar to HE, such as pits, are handled manually by the same technicians during the process. The UOR data indicate that the probability of dropping a pit per opportunity is significantly higher than that for HE. Dropping these objects would create administrative consequences, but it does not present the immediate fatal hazards of dropping HE. Thus, the UOR data provide qualitative corroboration of some common assumptions used in human reliability.

C. Time-of-Day Dependence of Frequencies

The incident times for all incidents indicate a strong peak in the data in the 1000–1100 and 1300–1400 time intervals. These intervals correspond to the morning break and the return from lunch. This result is in accordance with models of rule-based behavior. According to these models, the technicians are more likely to commit errors of omission by skipping steps after an interruption. Models also would predict that vigilance is reduced, especially after lunch, making both omissions and slips more likely. No corresponding increase for return from the afternoon break was noted. This discrepancy may arise because the technicians are more likely to stop weapon-handling activities following the afternoon break; observations at Pantex indicate that the late afternoon is the most common time to perform nonprocessing tasks such as cleanup, paperwork, or training.

D. Event Distribution Characteristics

The time distribution of events was as expected for most types of incidents, but some quirks were noted. One such aberration is the unnatural clumping of what should be randomly occurring events. For example, UORs generated by facility problems are relatively infrequent and do not appear to occur uniformly either in time or as a function of plant activity. This would indicate that reporting standards for this type of incident were probably not consistent. No specific cause and effect could be identified, but the general reasons for this clumping are discernible.

Inconsistency in reporting can arise from changes in the guidelines for UOR reporting in this case or from evolving viewpoints among the technicians who report the incidents. Depending on which cadre of technical personnel is assigned the reporting, coverage may vary. Discussions with technicians indicated that facility events are not considered in the same light as process faults by this group of experts but were considered very important by facilities personnel. This example highlights one of the pitfalls of compiling operational data over long periods. Reporting requirements and standards will change with time and with changes in management or oversight regulation. The "report of the week syndrome" has been observed in other operational data bases using UORs, and the analyst must be on guard for such a bias.[5]

As an example of the opposite to clumping problem, the number of total transportation UORs is distributed approximately uniformly over time and does not even appear to be a strong function of the production rate. One would expect the occurrence rate of transportation events to be strongly correlated to the production rate because the rate of transport of weapons should be a nearly linear function of production. The explanation of this anomaly is found by a close examination of the UORs. The UORs involve not only transportation incidents in which weapons actually are involved but other transportation incidents as well. The amount of transportation occurring in the plant is nearly independent of whether weapons are being transported because most of the transport is for reasons other than weapons handling. Some of the incidents have nothing to do with events that could pose a risk to weapons, but most of them involve vehicles and locations that could potentially have an effect on weapon safety. For example, any incidence of hot-rodding with forklifts in the plant is relevant to weapon safety because it is an indication of disregard for safety rules. It is important to remember that any plant transport can affect weapon safety because it generates opportunities for collisions. The effect of such a safety violation is mitigated by a special precaution taken during transport of a weapon. During weapon transport, a walker in front of the forklift verifies that the path is clear and that personnel in the area are aware that a weapon is in transport. Such administrative controls also would be expected to reduce the rate of forklift UORs actually involving a nuclear weapon to well below the rate for all in plant transportation accidents.

Another potential anomaly in operational data is intentional underreporting because of fear of reprisal or punishment. The operations at Pantex are closely supervised, and the technicians expressed a true fear of the consequences of failing to report a reportable incident. They uniformly felt that the risk of reporting was much less than the risk of trying to cover up because they felt the probability of discovery was high and the consequences of failing to report were far worse than those of reporting an error. The use of a two-man rule, constant indoctrination in the importance of compliance with orders, and the observed survival of personnel who report errors all make underreporting a secondary concern in our opinion.

E. Bayesian Updating

For fires, the UOR data were used in a Bayesian update of surrogate industrial data rather than directly. This was done because few fires of significant duration and intensity at Pantex were reported during the period covered by the UORs. Nuclear reactor containments.[6] were judged to be similar in usage and flammable content to assembly cells at Pantex, and therefore, data collected for these rooms were used to generate a prior distribution. This distribution was updated using Pantex data, where two fires were experienced in approximately 200 cell-years. Figure 3 shows the prior and posterior distributions for fire occurrence frequency. The mean value is 1.4×10^{-2} per year. The result is believed to be conservative for the Pantex Plant.

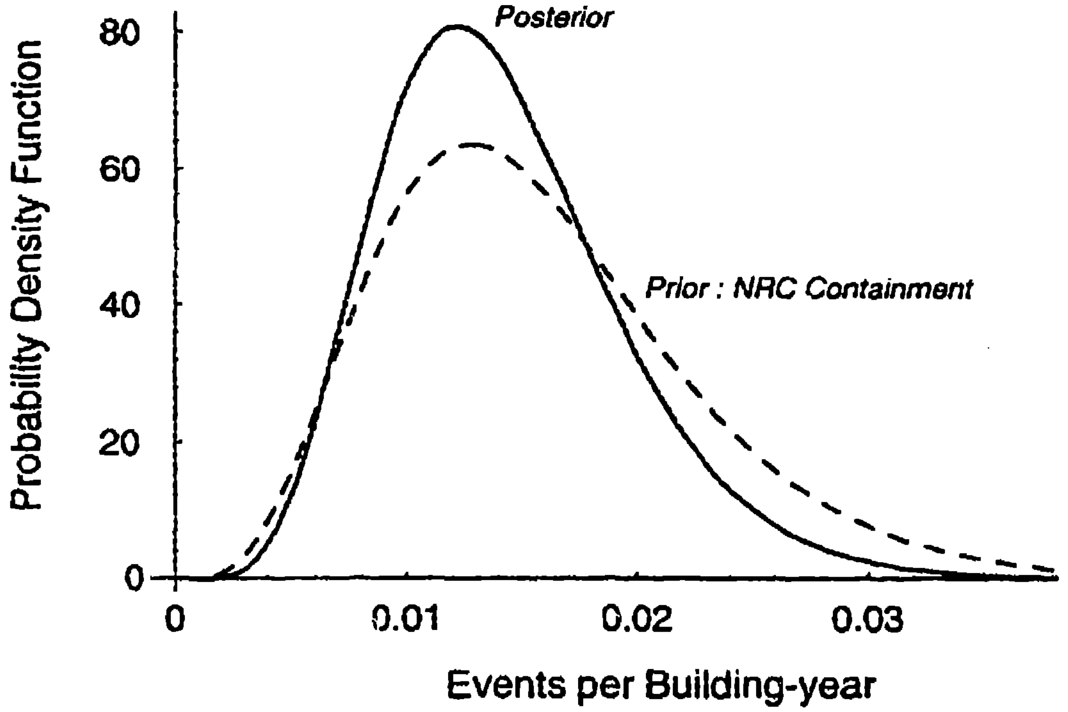

Figure 3. Probability density function for Pantex cells using NRC containment posterior as the Pantex prior distribution.

V. CONCLUSIONS

A quantitative database of initiating-event frequencies was constructed from incident reports involving nuclear weapons handling and processing. These data were used either directly or through aggregation with surrogate data through Bayesian updating in a quantitative safety analysis of nuclear weapons dismantlement. Many of the data generated are applicable to follow-on programs planned at the Pantex Plant and will serve as a basis for future quantitative analysis.

In addition to providing a quantitative basis for frequency or probability estimates, the study of the UOR database helped to identify accident sequences that were not recognized through any of the systematic analytical techniques traditionally used to identify potential accidents. Some of the human error probabilities based on the data were very different from predictions made using commonly used analytical methods for predicting human error rates. This was especially true for skill-based behavior under moderate stress.

Examples of situations that complicate the application of operationally based data were encountered during the analysis. These include changes in reporting requirements, shortcomings in the classification and search methods for the database, and changes in operating parameters.

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