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An Evaluation of the Effectiveness of the US Department of Energy Integrated Safety Process (SS-21) for Nuclear Explosive Operations Using Quantitative Hazard Analysis

by

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Abstract

This paper evaluates the effectiveness of the US Department of Energy Integrated Safety Process or "Seamless Safety (SS-21)" program for reducing risk associated with nuclear explosive operations. A key element in the Integrated Safety Process is the use of hazard assessment techniques to evaluate process design changes in parallel or concurrently with process design and development. This concurrent hazard assessment method recently was employed for the B61-0, 2 & 5 and W69 nuclear explosive dismantlement activities. This paper reviews the SS-21 hazard assessment process and summarizes the results of the concurrent hazard assessments performed for the B61 and W69 dismantlement programs. Comparisons of quantitative hazard assessment results before and after implementation of the SS-21 design process shed light on the effectiveness of the SS-21 program for achieving risk reduction.

1 Introduction

In response to criticism from the Defense Nuclear Facilities Safety Board (DNFSB) regarding its Nuclear Explosive Safety Study process and concern over the continuing practice of "auditing" safety into nuclear explosive processes and in recognition of the large uncertainty in the response of high explosives (HE) to various insults, the US Department of Energy (DOE)/Albuquerque initiated the Seamless Safety "SS-21" program to design safety into a nuclear explosive process. In December 1993, the DOE formally initiated the SS-21 program, and a demonstration project was started based on the B61-0 Center Case Disassembly, to demonstrate, in part, the viability of conducting hazard assessments concurrent with process design and development to facilitate risk reduction. The goal of the SS-21 program or

Integrated Safety Process is to "integrate established, recognized, verifiable safety criteria into the process at the design stage rather than continuing the reliance on reviews, evaluations and audits." The entire SS-21 design process is verified by a hazard assessment (HA) that is conducted concurrently with the Seamless Safety process development and implementation activities.

For the B61 and W69 HAs, the "final" or SS-21 process was compared with the HA performed on the initial or baseline process to provide an indication of overall risk reduction. A comparison of the risks associated with the initial dismantlement process and the SS-21 process provides a qualitative estimate of the effectiveness of the SS-21 process to achieve risk reduction.

2 Purpose and Scope of the Hazard Assessment

The scope of the HA is defined in DOE/AL Order 5610.11A and draft DOE-STD-XXXX-95, "Preparation Guide for the U.S. Department of Energy Hazard Analysis Reports for Nuclear Explosive Operations," and specifies that the HA must address all aspects of worker and public safety and environmental protection. The HA, which is based on traditional HA techniques,^{1,2} must address all nuclear explosive operations and associated activities and must identify all hazards using a step-by-step review of the entire operation. Human reliability and human factors analyses are performed and are used to help determine accident-sequence likelihoods. For accident sequences resulting in high consequence (i.e., HE detonation, HE deflagration, nuclear detonation, and fire), a thorough and detailed analysis of accident sequences is performed. For these high-consequence accident sequences, sufficient analytic detail, including uncertainty analyses, is included in the HA. The HA also identifies and categorizes safety-significant or safety-class systems, structures, and components as well as identifies operational safety controls.

The HA provides the basis for the Hazard Analysis Report (HAR) and the Nuclear Explosive Hazard Assessment (NEHA). The NEHA focuses on the high-consequence accident sequences and is provided to the Nuclear Explosive Safety Study Group during their review and scrutiny of the proposed process. The HAR identifies the dominant accident sequences for a wide range of accident types. The identified accident sequences can be ranked in terms of importance and reviewed by design teams to identify opportunities for risk reduction. The HAR establishes the bases for administrative controls and for the identification of positive measures. The HA focuses risk-reduction efforts on the higher risk operations. The HAR, of which the NEHA is a subset, provides a thoroughly documented safety basis for the specific nuclear explosive operation that can be maintained as a "living document" to support future change control and risk-reduction measures.

3 Conduct of the B61 and W69 Hazard Assessments

A comprehensive discussion of the HA process used to conduct hazard assessments for nuclear explosive operations was provided in Refs. 3 and 4. During the preparation phase of the HA, an extensive data gathering effort was undertaken to evaluate

weapon response in the disassembly accident environments and to obtain information on past operating incidents. Both the baseline and SS-21 process HAs were performed using a multi-step process involving observations of disassembly activities using a trainer, hands-on experimenting with the trainer, and extensive reviews of process videos. This accident-sequence identification phase was iterative in that interim HAs were conducted identifying high-risk candidate activities for which process redesign efforts were undertaken. During reviews of procedures and videos, accident sequences were developed by the HA Team using guide words, historical events, member experience and training, and "What If?" questions.

The developed accident scenarios and the scenario consequences were reviewed in detail by the HA team, which then developed an estimate of the likelihood or probability of the accident sequence as well as the conditional probability or likelihood of the consequence given that the accident sequence occurred. The overall likelihood of the accident occurring with the stated consequence was the product of the accident sequence and consequence likelihood probabilities. This product was used to determine the overall likelihood bin for the risk-ranking process as summarized in Table 1.

Likelihoods were assigned to the discrete events in the accident sequences through review of occurrence reports and data relating to equipment failure probabilities and human reliability. Accident consequences were estimated based on a review of historical and experimental data and models related to accident phenomena, such as evaluation of HE tests conducted at Pantex and at Los Alamos National Laboratory to determine the probability of detonation if an HE component were dropped. Table 2 summarizes the consequence severity categories used for the HA. Using likelihood and consequence categories determined from Tables 1 and 2, respectively, risk severity levels were assigned to each accident sequence in accordance with the

Table 1. Probability or Frequency Categories

Category	Definition
I—Normal	Events that are planned or expected to occur with a frequency between once per weapon dismantled to once in every 1000 weapons dismantled. These events would be expected to occur one or more times per dismantlement campaign (nominally 1000 weapons). ($1 > \text{Probability per dismantlement} \geq 10^{-3}$)
II—Anticipated	Incidents or events of moderate frequency that may occur once or more during the dismantlement campaign (nominally 1000 weapons). ($10^{-3} > \text{Probability per dismantlement} \geq 10^{-5}$)
III—Unlikely	Incidents or events not expected, but that may occur during the dismantlement campaign (nominally 1000 weapons). ($10^{-5} > \text{Probability per dismantlement} \geq 10^{-7}$)
IV—Very Unlikely	Incidents or events that are credible but not expected to occur during the dismantlement campaign (nominally 1000 weapons). ($10^{-7} > \text{Probability per dismantlement} \geq 10^{-9}$)
V—Improbable	Exceedingly low probability incidents or events that cannot be judged incredible over the life of the facility but are extremely unlikely to occur during the dismantlement campaign (nominally 1000 weapons). ($10^{-9} > \text{Probability per dismantlement}$)

Table 2. Consequence Severity Categories

Category	Definition (Bounding Consequences)	
	Worker	Facility
A Catastrophic	Loss of Life as a result of chemical, physical (e.g., explosion), or nuclear-related hazard. • Lethal chemical >> ERPG-3	Significant Facility Damage or contamination resulting in loss of facility for future use.
B High	Severe Injury/Permanent Disability • Exceed lifetime occupational radiation limits • Physical injury resulting in permanent disability • Chemical exposure > ERPG-3	Moderate to Significant Facility Contamination and Damage • Repair and cleanup possible but quite expensive
C Moderate	Lost Time Accident but No Disability • Chemical exposure < ERPG-3 • Exceed annual/quarterly worker radiation dose limits • OSHA reportable injury	Facility Contamination Minor Facility Damage • Repair and cleanup possible at moderate expense
D Low	No Significant Impact: Minor or No Injury • Minor recordable injury • Chemical exposure < ERPG-1	Minor or No Facility Contamination • Minor facility damage

matrix in Table 3. These risk severity levels then were used to identify those postulated accidents that represented unacceptable risk and to rank recommendations for risk reduction.

4 Comparison of the Baseline and SS-21 Disassembly Process Risk for the B61 and W69

Table 4 presents a comparison of the Baseline and SS-21 disassembly processes for the B61 from the overall risk rank perspective. A reduction in the overall number of accident sequences for the SS-21 process was achieved primarily through tooling and procedure modifications. When viewed from the overall risk rank standpoint, the SS-21 process achieved a 67% reduction in risk rank 2 sequences. Risk rank 3 scenarios are about the same for both processes. The SS-21 process resulted in about a 50% reduction in risk rank 4 scenarios.

In Table 5, HE detonation (HED) event likelihoods are summarized for both the W69 and B61 Baseline and SS-21 processes. As presented in Table 5, the SS-21 process resulted in a significant reduction in the likelihood of HEDs when compared

Table 3. Risk Matrix

Severity of Consequence	Likelihood of Postulated Accident				
	I	II	III	IV	V
A	1	1	2	3	3
B	1	2	3	3	4
C	2	3	3	4	4
D	3	4	4	4	4
E	NH	NH	NH	NH	NH

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E - No Hazard	No Impact to Worker	No Facility Damage

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D	3	4	4	4	4
E	NH	NH	NH	NH	NH

Table 4. Overall Risk Rank Comparison—B61

Risk Rank	Baseline Process	SS-21 Process
1	0	0
2	18	7
3	54	50
4	33	17
NH	2	1

Table 5. Comparison of HED Event Likelihoods

Event Likelihood	B61 Baseline Process	B61 SS-21 Process	W69 Baseline Process	W69 SS-21 Process
I	0	0	0	0
II	0	0	0	0
III	15	1	5	0
IV	12	12	32	15
V	14	26	14	23

with the Baseline process for both the W69 and B61. Similarly, Table 6 presents a comparison of worker injury and radiation dose events (excluding HEDs) for the Baseline and SS-21 processes for the W69 and B61. Again, both the B61 and W69 SS-21 processes achieved a significant reduction in worker risk.

5 Conclusions

In summary, from a qualitative perspective, both the SS-21 designed B61-0 and W69 disassembly processes resulted in a significant reduction of HED, worker injury, accidental worker radiation exposure, and facility contamination risk as compared with the Baseline process. This significant reduction in risk for both the B61 and W69 dismantlement programs is the result of major tooling and procedural enhancements made as part of the SS-21 Integrated Safety Process.

The qualitative results show that using the SS-21 design process can result in a significant reduction in risk for nuclear explosive operations. Note that there are inherent risks associated with work on nuclear explosives that cannot be eliminated entirely with any process design. However, the SS-21, or Integrated Safety Process, can be used to effect an overall reduction in risk and an overall improvement in safety for nuclear explosive activities.

Table 6. Comparison of Industrial Accident/Worker Injury/Radiation Dose Events

Risk Rank	B61—Baseline Process	B61—SS-21 Process	W69—Baseline Process	W69—SS-21
1	0	0	0	0
2	3	3	0	0
3	21	10	30	4
4	31	17	53	39

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