Enclosure 3

MOL.20071220.0210

QA: NA
DG 12/20/07

Report No. SAIC-00/2641

An Employee-Owned Company

Umatilla Chemical Agent Disposal Facility Quantitative Risk Assessment

Prepared by:

Science Applications International Corporation
Abingdon, MD 21009
Under Contract DAAM01-96-D-0009

Prepared for:

Program Manager
for Chemical Demilitarization
Aberdeen Proving Ground, MD 21010

Volume I
Main Report, Appendices A & B
References and Acronyms

Report No. SAIC-00/2641

An Employee-Owned Company

Umatilla Chemical Agent Disposal Facility Quantitative Risk Assessment

Prepared by:

Science Applications International Corporation
Abingdon, MD 21009
Under Contract DAAM01-96-D-0009

Prepared for:

Program Manager
for Chemical Demilitarization
Aberdeen Proving Ground, MD 21010

December 2002

Volume I
Main Report, Appendices A & B
References and Acronyms

ACKNOWLEDGMENTS

The study documented in this report incorporates the work of many individuals within and outside of Science Applications International Corporation (SAIC). The SAIC Program and Integration Support (PAIS) Quantitative Risk Assessment (QRA) project team was comprised of:

Principal Investigator:	David M. Birk	
Task Manager:	Cindy A. Williams	
Safety Department Manager:	N. Douglas Woody	
PMCD RM&QA Chief:	Gregory W. St. Pierre	
PMCD Safety Team Lead:	Steven R. Blunk	
PMCD Safety Team—UMCDF:	Scott J. Wright	
SAIC Team/Authors:	Paul J. Amico	Susan E. Bayley
	David M. Birk	Gary J. Boyd
	Dr. David R. Bradley	Cindy R. Ching
	Daniel R. Christman	Erin P. Collins
	James G. Funk	David C. Gellner
	Paul R. Grimes	Jean N. Hillstrom
	Suzanne M. Loyd	Carleen M. Phillips
	Lane B. Robbins	Arthur F. Tucker
	Cindy A. Williams	Charles E. Winfrey
Science and Technology Corp Author:	Maryann Clark	
SAIC Technical Editor:	Christina R. Frank	
Other Contributors:		
Stevenson & Associates	Walter Djordjevic	Ming Tsong Li
	Tsiming Tseng	
Jack R. Benjamin & Associates, Inc.	Martin W. McCann, Jr.	John W. Reed
	Hemant H. Shah	
Geomatrix Consultants, Inc.	Katheryn L. Hanson	Robert R. Youngs
Sigma Science, Inc.	James Holderness	Lisa P. Stringfield
University of Tennessee, Chattanooga	Dr. Robert T. Bailey	
Safety & Reliability Optimization Services	Stuart R. Lewis	
ARDEC--U.S. Army Armament Research, Development & Engineering Center	Elizabeth Forest	Henry H. Lee
	Philip J. Magnotti	Jacob K. Struck
Sandia National Laboratories	Parris Holmes, Jr.	Kimball O. Merewether
	Larry K. Warne	

Other personnel made significant contributions to the QRA through analyses, review, and project support. Also, some individuals supported the Tooele Chemical Agent Disposal Facility (TOCDF) Phase 2 QRA (December 1996) and their work on that project has been used in part or whole for this QRA.

SAIC:

Bruce A. Byrne	Cedric J. Ching	Jacqueline T. Croat	G. Robert Donenges
Howard K. Graham	Juli Hans	John Herron	Roxanne Lynch
Jim Quigg	David C. Smith		

Others:

Dr. Mark D. Brandyberry (now with University of Illinois)	Jon D. Imboden
Tom J. McComas (now with General Physics)	Ali B. Mohamed
David V. Smith (now with U.S. Coast Guard)	Ram W. Tuli (now with Natural Solutions, Inc.)

Much of the information supporting this report could not have been obtained without assistance and the cooperation of government and personnel at Edgewood.

CT Anderson (RM&QA)	Beth Feinberg (PMATA)	Lynn Holt (TVA)
Mike Myirski (CSEPP)	Mike Robinson (PMCD)	

The QRA team received great cooperation during a very busy time at the site. The assistance of personnel at Umatilla Chemical Depot (UMCD) and Umatilla Chemical Agent Disposal Facility (UMCDF) is greatly appreciated.

PMCSD:	Gary Anderson	Hawkins Conrad
	Rick Taft	Wendell Wrzesinki
Washington Demilitarization Company:	Bob Abbott	Gus Aljure
	Allan Bean	Murel Benson
	Michael Cloninger	Chris Dana
	Clark de Nevers	Joe Gonzales
	Jack Leary	Livingston Parkhill
	Richard Romero	Jeff Simundson
	James Snyder	Michael Strehlow
	Dave Webb	Doug Wisehart
	John Zoulek	
UMCD:	Danny Aiken	Scott Barton
	Dick Edwards	Phillip Ferguson
	John McCluskey	George Newman
Others:	Brad Burns (Jacobs)	G. Robert Hall (JACADS)
	Darrel Johnston (SWRI)	Stephen Maurer (SWRI)
	Don Rogers (EG&G, TOCDF)	

Many other people at the site provided insight and information as to the planned and actual operation of the facility and stockpile. Their assistance is acknowledged.

The QRA has been improved by the review and comments of the QRA Expert Panel, consisting of subject matter experts from QRA and other fields, with Mitretek Systems serving as the group secretariat. The Expert Panel consists of:

Dr. Robert J. Budnitz (Future Resources Associates, Inc.)
Willard Gekler (Consultant, EQE/PLG, Inc.)
Stuart G. Harris (Confederated Tribes of the Umatilla Indian Reservation)
Dr. Kathryn Higley (Oregon State University)
Dr. Sam Mannan (Associate Professor, Texas A&M University)
Richard W. Prugh (Process Safety Engineering, Inc.)
Dr. Shivaji S. Seth (U.S. Department of Energy)

This report could not have been produced without significant effort on the part of the SAIC Technical Publications staff. Their contribution is greatly appreciated:

Belinda Baker	Tesha Casale	Raymond Cummings	Kathy Fuller
Barbara Heusler	BJ Jennings	Cecille Meadows	Beth Molnar
Mia Nance	Tonya Page	Jan Potochney	Erica Rinaldi
Nancy Simini	Dave Walsh	Sue Wolsfield	Barbara Yeager

(This page intentionally left blank.)

FOREWORD

The Phase 2 QRA for UMCDF is published following detailed technical review of the models and inputs. This final report includes resolution of all comments received on the preliminary draft version. In the future, the UMCDF risk models should be revised to reflect changes after operations begin as part of the risk management process.

This is obviously a large report containing a great deal of data. The report has been organized to meet the needs of the various parties involved in the risk management process. The following table summarizes the reporting strategy. Section 1 describes the layout of the report in more detail.

Output	Audience	Comments
20-page QRA Summary	Program management	To be provided at a later date to accompany this report
Approximately 400-page QRA Main Report	Reference for technical users	Provided in this report
Approximately 8,000-page QRA Appendices	Reference for risk professionals and reviewers	Provided in this report
Review Comments and Responses Including Expert Panel Comments	Reviewers and others	Provided as appendix S, and includes resolution of comments on the UMCDF June 2001 Preliminary Draft Report
Quantus Risk Management Workstation	Results viewer for UMCDF users and complete tool for risk professionals	The current plan is to provide Quantus to the site for use in follow-on task

(This page intentionally left blank.)

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

Section	Title	Page

TABLE OF CONTENTS (Continued)

Section	Title	Page

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Continued)

LIST OF ILLUSTRATIONS (Continued)

LIST OF ILLUSTRATIONS (Continued)

LIST OF ILLUSTRATIONS (Continued)

LIST OF ILLUSTRATIONS (Continued)

LIST OF TABLES

LIST OF TABLES (Continued)

LIST OF TABLES (Continued)

LIST OF TABLES (Continued)

LIST OF TABLES (Continued)

LIST OF TABLES (Continued)

LIST OF TABLES (Continued)

(This page intentionally left blank.)

SECTION 1
INTRODUCTION

Chemical weapons have played an important role as a United States military deterrent over the past 50 years. The changing global political climate, however, has led to an elimination of the need for the United States to stockpile these weapons and the chemical agents used in their manufacture. In 1985, Congress enacted Public Law (PL)[1] 99-145. This law directed the Department of the Army (DA) to establish a program to dispose of the United States stockpile of unitary chemical weapons and agents. In 1997, the United States ratified the Chemical Weapons Convention. This treaty commits the signatories to destroy all of their chemical warfare materiel in an environmentally safe manner by April 2007 (OPCW, 1993). The Chemical Stockpile Disposal Project (CSDP) was established to achieve these goals. The Program Manager for Chemical Demilitarization (PMCD) has responsibility for the disposal program. PMCD is committed to meeting the disposal objectives while protecting the environment and the safety and health of the workers and the people of the surrounding communities.

The disposal facility scheduled to eliminate the chemical stockpile at the Umatilla Chemical Depot (UMCD) near Umatilla and Hermiston, Oregon, is preparing for operations. This report describes the inputs, models, and results of the Umatilla Chemical Agent Disposal Facility (UMCDF) Phase 2 Quantitative Risk Assessment (QRA). It supersedes the UMCDF Phase 1 QRA published in 1996 that was completed before all the UMCDF-specific design and operational details were available (SAIC, 1996a). The Phase 2 QRA is an examination of the public and worker risks associated with potential accidental releases of chemical agent. The QRA is one element of the PMCD Risk Management Program (RMP). The QRA and its relation to other safety initiatives are summarized in the remainder of this section. A summary of the organization of this report is provided in section 1.11.

1.1 Program Manager for Chemical Demilitarization Risk Assessment Activities

PMCD has developed an RMP in keeping with U.S. Army regulations and other state and federal laws and to meet the goals of minimizing risks to the worker, environment, and communities. To accomplish this objective, the U.S. Army uses risk assessments to understand and control risks. Several different types of risk assessments are performed and, taken together, they form a complete picture of the risks of storage and disposal.

The following hazards are studied in risk assessments:

- Chemical agent

[1] A complete list of acronyms and abbreviations is provided in appendix B.

- Energetics, including explosives and propellant
- Stack emissions
- Industrial hazards involving other chemicals and materials, such as caustic chemicals, acids, natural gas, and hydrogen
- Occupational hazards, such as lifting injuries or hearing damage.

Identifying and understanding hazards through risk assessment is the first step in successfully reducing risks. Several risk assessments are done for each disposal facility, each with a different purpose and scope. Some hazards are examined in more than one assessment. There are three main types of risk assessments that provide a comprehensive analysis of storage and disposal risk:

- Hazard Evaluations – Identify and rank potential hazards resulting from disposal operations. Multiple evaluations are performed for each site and cover risks associated with chemical agent and explosives, as well as industrial and occupational hazards.
- Health Risk Assessments (HRAs) – Examine the risks to the surrounding communities and environment from incineration stack emissions. HRAs for each site include a Human Health Risk Assessment (HHRA) and an Ecological Risk Assessment (ERA).
- QRAs – Evaluate the likelihood and effects of an accidental release of chemical agent during storage and disposal. Risks to both the public and workers are studied.

As displayed in figure 1-1, these assessments cover the range of potential hazards. Additional assessments also are done to support informed risk management decision making. The assessments are summarized in the remainder of this section.

1.1.1 Hazard Evaluations. The U.S. Army performs hazard evaluations as a primary means of safety assurance. These assessments are performed to identify and rank risks to the community and workers. Most hazard evaluations are prescribed by U.S. Army system safety requirements.

<table>
<tr><th></th><th colspan="9">Risks</th></tr>
<tr><th></th><th>Environment</th><th colspan="2">Public</th><th colspan="4">Workers</th><th>Program</th></tr>
<tr><th></th><th>Pollutants & Emissions & Agent</th><th>Pollutants & Emissions</th><th>Chemical Agent</th><th>Chemical Agent</th><th>Energetics (Explosives)</th><th>Industrial/ Occupational Hazards</th><th>Pollutants & Emissions</th><th>Cost & Schedule</th></tr>
<tr><td rowspan="5">Assessments</td><td>Ecological Risk Assessment</td><td colspan="2">Human Health Risk Assessment</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td>Phase 1 & 2 QRA</td><td colspan="2">Phase 2 QRA, Quantitative Risk Assessment</td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td colspan="6">Hazard Evaluations</td><td></td></tr>
<tr><td></td><td></td><td>Emergency Planning Studies</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>Programmatic Risk Assessments</td></tr>
</table>

Figure 1-1. Summary of Chemical Stockpile Disposal Program Risk Assessment

Hazard evaluations are used throughout the disposal program. These hazard evaluations are used to study hazards at different levels of detail from the design stage through the entire facility operation and shutdown. The hazard evaluations performed for each disposal facility include:

- Preliminary hazards list and analysis, reviewing facility hazards during the first stages of design
- System hazard analysis, identifying hazards associated with the equipment to be used during disposal
- Job hazard analysis, examining hazards associated with workers' job activities, from routine through nonstandard operations. These analyses are updated to reflect changes in procedures and operations.
- Process hazard analysis, studying the hazards of the facility before startup and throughout the facility's operations. The site systems contractors complete process hazard analyses, as required, to maintain compliance with Occupational Safety and Health Administration (OSHA) process safety management requirements.

Hazard evaluations estimate the severity of the hazards and typically include some consideration of how likely they are to occur. While the evaluations are primarily qualitative, the hazard evaluation results are standardized through a set of risk assessment codes (RACs) that consider frequency and severity (PMCD, 1991). Severity is considered in terms of worker injury, release of hazardous materials, and the potential for property or equipment damage. The RMP calls for actions to mitigate risks above a certain RAC and to ensure that the appropriate management personnel understand the associated risks of operations. After hazards have been ranked, ways to improve safety are identified and put in place as needed.

Hazard evaluations are updated as needed. RACs are re-evaluated based on equipment changes, operational changes, or new hazard assessment results. To track hazards identified in the hazard evaluations, the U.S. Army has established a hazard tracking log.

1.1.2 Human Health and Ecological Risk Assessments. For facilities involving combustion processes, an HRA is performed to meet the requirements of the Resource Conservation and Recovery Act (RCRA). The HRA includes an HHRA and an ERA. [Nomenclature here can be confusing because the acronym HRA in common usage is sometimes used to mean the HHRA and sometimes the HHRA and ERA.] The HRA considers facility emissions due to normal and minor upset conditions and includes all potential pollutants, such as dioxins, furans, polychlorinated biphenyls (PCBs), and heavy metals. The HRA is based on protocol meeting U.S. Environmental Protection Agency (USEPA) guidance and approved by the state in which the facility is located. The results of the HRA are compared to pre-established criteria defined by the state. The facility must meet the criteria to proceed with operations.

The ERA examines the potential impact of the facility emissions on local ecology. Any deleterious effects on local water, habitats, or endangered species are considered.

1.1.3 Quantitative Risk Assessment. To help reduce the chance of an accidental release of chemical agent, PMCD completes QRAs. While the HRA looks at routine operations, the QRA examines the potential health risks to workers and the community from possible accidents during disposal operations or storage of the weapons and agents. The scope of the QRA is limited to the greatest hazards, the chemical agents and associated energetics.

The QRA studies the complete disposal process, as well as munition storage, and considers:

- Human errors, such as an accident driving a forklift
- Equipment failures, such as a drain line valve failure
- Explosion or combustion of energetics
- Loss of support utilities, such as electric power
- External influences, such as accidental aircraft crashes
- Acts of nature, such as storms and earthquakes.

Thousands of potential accidents, including very rare events, are studied using models of the facility processes. The result of the QRA is a list of events that would be most likely or cause the greatest harm to human health. The combination of likelihood and health consequence is called risk. PMCD reviews this list to identify and make changes to equipment or procedures to further increase safety.

1.1.4 Comparison of the Human Health Risk Assessment and the QRA. There is frequently some understandable confusion concerning the HHRA and QRA because they both produce numerical risk results. The QRA scope is limited to accidental releases of chemical agent (large enough to cause adverse public or worker health effects) associated with storage or any part of the disposal processes. Aspects of normal plant operation, such as normally allowed non-agent stack emissions, were excluded from the QRA reported here but are being addressed in the HHRA. Thus, a full range of risks is covered, but with different types of assessments.

The results of the HHRA are compared to the regulatory levels of acceptability (thresholds) of the state in which the facility is proposed. The HHRA thresholds are part of the state regulatory processes. These thresholds reflect one approach for assuring public safety. The regulatory communities have established these thresholds over time to provide reasonable assurance that emission levels pose no public health risk.

Interpreting the meaning of these estimated risk values requires both an understanding of their magnitude relative to decision-making thresholds and an appreciation of the level of protectiveness incorporated in the models used to produce the estimates. For risks that are well understood, it is generally possible to make fairly accurate estimations without substantially over- or underestimating the results relative to reality. Estimation of risks that are increasingly less understood requires increasingly complex models to quantify. When issues of human health, safety, or the environment are involved, one prudent approach is to calculate risk estimates that are protective of the community. The screening HHRA is developed using this type of protective approach. Assumptions are very conservative to ensure that the actual risk is below the results shown in the HHRA.

This protective approach produces results generally considered to be representative of high estimates or even overestimates of the actual risks. For the estimation of chronic human health risks in the HHRA, the screening methods used are of such a nature. There is an intentional effort to estimate on the high side for the sake of protectiveness. This allows decisions to be made that are not dependent on knowing what the actual risks are, but that whatever they might be is very likely to be below the estimated risk value produced by the protective model. How much the actual risks are below the estimated risks depends on how conservative or protective the model input values are and how many of these conservative inputs are entered into the model. The incorporation of these incremental "safety factors" increases the magnitude of the estimated risks above the actual risk value that would be calculated if the modeler knew an exact value for each input.

The QRA is not completed to meet a regulatory requirement, and different methods are used, even though the HHRA and QRA both produce quantitative results for human health effects. The QRA is intended to represent, to the maximum extent possible, a best estimate of the frequency of potential accidents and the magnitude of the consequences (number of people affected). In contrast to the protective methods of the HHRA, the QRA is intended to be more predictive (although it must be fully understood that it deals in uncertain probabilities of what could happen, not a true prediction of what will happen). The QRA models, therefore, do not include all of the conservative assumptions that are inherent to the HHRA screening methods.

The results of the QRA are not compared to a threshold, but are used to rank contributors to risk so that the most important elements of risk can be considered for possible mitigation. Risks also can be compared, such as the risk of storage to the risk of processing. Risks also can be compared to other risks in life, although that requires great care in understanding what is being compared.

In terms of risk management, the QRA results will be translated into the U.S. Army and PMCD's existing system of RACs (PMCD, 1991). This allows QRA risks to be considered within the existing and accepted decision framework, rather than having separate numerical decisions associated with QRAs and all of the other hazard analyses.

1.1.5 Emergency Planning Studies. The Chemical Stockpile Emergency Preparedness Program (CSEPP) also performs evaluations to help determine risk management strategies. CSEPP provides assistance to local communities for emergency planning activities. Studies are performed to understand the potential threats and develop the most effective emergency plans. The assessments also help determine appropriate drills.

1.1.6 Programmatic Risk Assessments. Other inputs to decision making are management issues related to cost and schedule. While not the overriding risk management concern, all decisions need to be considered in the light of impact on cost and schedule, and comparisons of different ways of accomplishing the same risk management objectives need to be made. Models have been developed to determine the cost and schedule risk associated with decisions made at various points through the project life.

1.1.7 Other Assessments. The specific activities being carried out in support of the CSDP may require additional assessments. U.S. Army safety programs require additional evaluations for specific types of activities involving explosives. State and local authorities might require, as part of the permitting process, supplemental evaluations, such as more comprehensive agricultural risk assessments. Another assessment that also is required at each location is an Environmental Impact Statement (EIS). An EIS that reviews the potential effects on the environment from a proposed activity is required by the National Environmental Policy Act. The EIS considers human health, air quality and noise concerns, future land use, local ecology, and waste management practices. It also considers the social and economic impact on the surrounding community.

1.2 Program Manager for Chemical Demilitarization Risk Management

The preceding assessments are the first step in risk management, the process by which risks are identified, controlled, and reduced. Risk management also includes:

- Establishing requirements, to minimize risks
- Monitoring, to continuously ensure that safety measures are effective
- Assessing and tracking changes, to maintain safety throughout the life of the plant
- Encouraging public participation, to ensure that members of the public are informed and involved.

By identifying and managing risks, the PMCD achieves its objective of providing maximum protection to the health and safety of the public, workers, and the environment. The PMCD RMP is summarized in *Guide to Risk Management Policy and Activities* (PMCD, 1997a) and *Chemical Agent Disposal Facility Risk Management Program Requirements* (PMCD, 1996).

1.3 National Research Council and the QRA

Ongoing review of the CSDP by a standing committee of the National Research Council (NRC) of the National Academy of Sciences (NAS) helps ensure that the program is technically sound and uses available technology. To this end, the committee makes recommendations with respect to the implementation of various technologies and takes other steps that have the potential for minimizing adverse impacts of the CSDP.

In a letter to the Assistant Secretary of the U.S. Army (Installations, Logistics, and Environment) [ASA (IL&E)], dated 8 January 1993, the NRC Committee for Review and Evaluation of the U.S. Army CSDP recommended that a comprehensive plan be developed to manage the risk associated with the disposal of chemical munitions and associated chemical agents. The recommendation indicated that site-specific QRAs be performed prior to development of a site RMP. In a 1994 report entitled *Recommendations for the Disposal of Chemical Agents and*

Munitions (NRC, 1994), NRC reiterated its recommendation to perform site-specific risk analyses using the most recent information and methods. NRC recommended that analyses be conducted to compare the relative risk of continued storage and disposal at each stockpile storage site. The principal objectives would be to identify major risk contributors and to use the QRA models in ongoing risk management. The QRA also updates conclusions drawn from the risk analysis developed in 1987 (PMCD, 1987a,b) to support the Final Programmatic Environmental Impact Statement (FPEIS) (PMCD, 1988). The FPEIS risk analysis compared several programmatic alternatives and concluded that maximum safety dictates prompt disposal.

In response to these recommendations, PMCD directed that a QRA and an RMP be developed for the first of eight planned continental United States (CONUS) facilities: the Tooele Chemical Agent Disposal Facility (TOCDF). The goal of these activities was to minimize the risk that could be posed to the public, site work force, and environment by potential agent-related accidents during chemical disposal operations. The TOCDF QRA was published in 1996 (SAIC, 1996b).

The NRC has continued to provide oversight of the program and has consistently reinforced its view of the importance of the QRA as part of the RMP. In 1996, *Review of Systemization of the Tooele Chemical Agent Disposal Facility* (NRC, 1996) was published. The review recognized and expressed general satisfaction with the ongoing risk management efforts including the QRA and recommended that the QRA be completed before the start of agent operations at TOCDF. This was followed by a more specific report, *Risk Assessment and Management at the Deseret Chemical Depot and the Tooele Chemical Agent Disposal Facility* (NRC, 1997a), which included a review of the QRA and other risk management efforts. The NRC committee found that the TOCDF QRA met the recommendations provided previously by NRC and offered the following with regard to the TOCDF QRA:

> The Stockpile Committee has followed the DCD/TOCDF QRA project closely since its inception and has maintained oversight of the Expert Panel independent peer review process. The QRA has achieved the goals set out in the committee's 1993 letter report and the *Recommendations* report (NRC, 1994). The success of the QRA was a direct result of a skilled SAIC technical team, firm support from the U.S. Army and TOCDF personnel, and frequent and positive interactions between the TOCDF field staff and the QRA team. The resulting QRA was significantly improved during the Expert Panel review. The findings of the QRA are consistent with the interim findings in the *Systemization* report (NRC, 1996).

NRC urged some additional work to promote integration of the QRA activities and other endeavors within a complete RMP. The NRC also reinforced its view that the QRAs should be maintained current and used to evaluate ongoing operations.

Finally, NRC has issued an update to the TOCDF report, *Tooele Chemical Agent Disposal Facility Update on National Research Council Recommendations* (NRC, 1999). With regard to the QRAs, that report urged that the Phase 2 QRAs for facilities under development be performed as soon as feasible to allow risk mitigation measures to be implemented into the design. NRC was concerned, however, that although aspects of the QRA and RMP were being successfully carried out, it was on a less formal basis than the committee would prefer to see. They recommended formalization of the RMPs. Activities are currently underway with UMCDF to ensure that risk management efforts meet PMCD's goals.

1.4 Objectives of the QRA

The QRA will be used to help efficiently manage and minimize the risk associated with facility operations, as part of PMCD's overall RMP. A principal goal of this assessment is to identify those systems, components, and activities that govern the risks associated with disposal of chemical munitions and agents. Insights derived from the QRA will be used to identify potential improvements in systems or operations that could further reduce the public and worker health risks during disposal operations. In addition, the QRA can be easily modified to allow evaluation of whether proposed modifications to the facility, operating procedures, or the schedule for disposal would be expected to avert a significant amount of risk relative to the complexity of the change. The QRA provides the plant-specific inputs for the UMCDF RMP as documented in the RMP requirements document (PMCD, 1996). For example, the QRA models can be used for evaluation of modifications, studies of incidents and near misses, and emergency preparedness activities. The evaluation of risk also will serve as the basis for communicating the risk insights to the operating staff and other interested parties.

Thus key objectives of the QRA include: 1) developing an analytical model that can be used as the basis for ongoing risk management and to evaluate proposed modifications, and can be updated as changes are made to the facility or as additional insights into accident behavior become available, 2) incorporating the model into a computer workstation, and 3) documenting the analyses in a manner that will both support the results and provide the necessary bases for external reviewers to determine that the work has been accomplished in a thorough and competent manner.

Another objective is to replace previous risk assessments that are now out of date. The Phase 2 QRA is a state-of-the-art QRA that will represent an update to the 1987 risk assessment that supported the FPEIS. The UMCDF QRA will be used to re-evaluate the findings of the FPEIS risk analysis and develop a more current understanding of the types of accidents that could be important based on: 1) actual design and planned operational practices of UMCDF, 2) relevant data collected since the FPEIS study was performed, and 3) improvements in QRA methodology. While the FPEIS risk assessment was based on a 35 percent design and the Phase 1 QRA was based on the TOCDF design, the UMCDF Phase 2 QRA reflects the site-specific design and proposed operations. The QRA was prepared during construction of UMCDF and later will be updated to reflect the changes to design and operation that occur between model development and initiation of operation.

The QRA will be used in several ways to help PMCD in risk management. These uses are described more specifically in section 1.10.

1.5 Scope of the QRA

As described in section 1.1.3, the scope of the Phase 2 QRA includes analyzing the risk to the public and site workers from accidental releases of chemical agent during chemical munition and agent storage and disposal activities at UMCDF and UMCD. The risks associated with the energetics that are included with some munitions also are evaluated. The QRA includes an estimate of the risks associated with the following aspects of disposal:

- Stockpile munition handling associated with moving munitions in preparation for transport to the facility

- Transportation of munitions from the stockpile storage area to UMCDF

- Disposal processes within UMCDF.

In addition, an estimate of the risk associated with storing munitions in the stockpile storage area is included.

The QRA considers the effects of postulated accidental releases of chemical agent on both the public (the population outside the UMCD boundary) and workers (within the UMCD boundary). Only accidental releases of agent large enough to cause adverse health effects to the public or workers are included.

Both public and worker risk were calculated in terms of acute fatality risk, which is the probability of fatality over a specified period of time due to a one-time exposure to postulated releases of chemical agent. The public risk of exposure-induced cancers also is considered for potential releases of mustard agent (nerve agents are not considered carcinogenic). Worker risk is limited to estimates of fatalities (this is discussed further in section 11.4). Because some agent-related accidents could also involve explosions, the explosion effects are assessed in terms of fatalities. The cause of a worker death due to an agent-related accident is not differentiated between explosion effects and agent exposure. Risk was not assessed for accidents involving workers where there is no potential for agent exposure (i.e., typical industrial accidents that do not involve handling munitions or agent).

For all operations and storage activities, a full range of potential events that could lead to an agent release was considered. Both releases that result from internal events (originating inside the plant or directly from the activity being performed) and those initiated by external events (such as earthquakes, tornadoes, and aircraft crashes) were modeled.

As with previous studies, intentional acts such as sabotage or terrorism are not included in this quantitative analysis. If they were studied using QRA methods, the report would need to be classified, because the QRA models would describe possible methods of sabotage. Sabotage and terrorism are taken very seriously by the U.S. Army for chemical and all other weapons systems. Many additional precautions have been taken in response to the events of 11 September 2001. A description of the studies and activities taken to assess and minimize the risks of sabotage and terrorism is provided in section 5.

Walkdowns (site visits by QRA analysts to see all the equipment) of systems and structures were performed to support the analyses. System walkdowns were performed to support development of the risk models. Seismic, lightning protection, tornado, and fire analysis walkdowns were conducted to support the external event analyses. The transportation analysis was based on actual road conditions and traffic patterns at UMCD. Discussions were held with numerous plant staff regarding munition handling and disposal operations. This approach is preferred over obtaining information only from design drawings and other reference documents.

This study takes advantage of current operational and equipment data. Most notably, the development of models and a quantitative database for equipment reliability includes information collected from actual disposal processing at TOCDF and the Johnston Atoll Chemical Agent Disposal System (JACADS). Detailed investigations of operating experience have been conducted and the UMCDF QRA reflects those insights.

Risks lie in a continuum between a definite outcome (for example, a 100 percent chance that a worker would be injured) down to very rare occurrences (for example, one chance in a billion that the person would be injured). The estimated risks are uncertain due to limitations of knowledge concerning both the likelihood and consequences of events. They also may be uncertain due to randomness involved in the risk phenomena (for example, lightning may strike someone at a golf course with a probability that may be fairly well known, but there is an element of randomness as to which golfer might get struck). These uncertainties also must be considered by the decision makers.

The Phase 2 QRA is comprehensive in that it includes an estimation of both public and worker risk, and also includes an evaluation of uncertainties. Uncertainties in the parameters and models used in the analysis were quantified in order to display the confidence in the results. In addition to the uncertainty analysis, selected sensitivity analyses were conducted. The sensitivity analyses determine how the risk results vary based on changes to key assumptions in the risk model.

1.6 Quality Assurance and Review

Management controls were established to ensure that the analysis was accomplished in accordance with the statement of work and Science Applications International Corporation (SAIC) Program and Integration Support procedures and policies. The SAIC Integrated Program Services (IPS) Quality Manual was implemented for this task. The Quality Manual and IPS Standard Procedures (SPs) describe a quality system that satisfies the requirements of the American National Standards Institute (ANSI)/American Society for Quality Control (ASQC) Q9001-1994, *American National Standard for a Quality System*. The Quality Manual and SPs must meet the supplemental requirements of the PMCD Quality Assurance Program Plan. The Quality Manual describes the SAIC organizational structure, responsibilities, authorities, and interfaces. The SPs provide technical, quality, and administrative guidance to IPS personnel and set standard practices to promote consistency and accountability in delivered products.

The analyses and documentation have been subjected to review throughout the development of the assessment. There are three principal review activities: 1) intra-project review, 2) PMCD and UMCDF staff review, and 3) expert review panel (discussed in section 1.7).

The SAIC intra-project reviews are the technical reviews that are part of the analysis itself. These reviews were designed to meet the needs of the QRA project, based on experience in performing previous large integrated assessments. These reviews took place every day and ranged from informal to formal, independent reviews. The formal intra-project reviews satisfy the more specific quality assurance requirements established by SAIC.

An additional review activity is PMCD and UMCDF review and input. These reviews started during the development of the models. Meetings were held to review specific analysis areas with PMCD personnel most appropriate for the specific subject area. This review activity continued up to the development of results and the publication of reports. The project review activities are discussed in detail in appendix S.

1.7 Expert Panel Review

Another review activity to confirm that the QRA is performed using appropriate methods and models is the independent expert review panel. This panel is composed of specialists in the QRA field, as well as professionals from the chemical industry and academia. The panel meets on a periodic basis with the QRA staff to review modeling methods and results, and to confirm the validity of the approach. The NRC letter specifying the need for site-specific risk assessments also included a statement about the need for independent oversight. The subsequent NRC reports expressed satisfaction with the independent review process and recommended that the process be continued. PMCD established an independent expert review panel through Mitretek Systems, a separate contractor independent of SAIC, to oversee the progress of the QRA. The local Citizens' Advisory Commission (CAC) was briefed on the QRA and asked to help identify a local member for the expert panel. The balance of the panel is made up of other nationally known experts in risk assessment and management. The expert review panel will produce an independent report under separate cover. All of the panel's comments and SAIC's resolution of the comments are provided in appendix S of this report.

1.8 Public Involvement

The risk management process also includes public involvement. Public involvement occurs through a number of avenues, some of which are mandated by federal and state law. The environmental permitting process includes provisions for notification of the public regarding endeavors that could affect their communities. The public has specific mechanisms for review and comment on permits and supporting analyses.

While the U.S. Army endorses and supports these public involvement activities, a more important effort is direct involvement of the public as an input to decision making. An extensive effort is focused on providing the public an opportunity to share the information concerning the projects. Recent public involvement efforts are summarized in the Public Outreach and Information Office's annual report (PMCD, 1999). In addition to these public outreach efforts, specific activities to involve the public in risk management decision making have been initiated.

With regard to the QRAs, the CACs have been briefed on the process and solicited for their input regarding appropriate public involvement. The general conclusion was that because the QRA is a highly technical endeavor, review by local experts would be most appropriate. Additional mechanisms for disseminating the QRA results and soliciting further risk management inputs by the communities are being studied.

1.9 Previous Risk Analyses Supporting the Final Programmatic Environmental Impact Statement

The U.S. Army performed a probabilistic risk assessment in 1987 (PMCD, 1987a,b) to support the CSDP FPEIS (PMCD, 1988). The study assessed accident sequences that could result in agent releases associated with activities involving three disposal alternatives under consideration for the CSDP, as well as the continued storage alternative. Disposal alternatives assessed included onsite disposal, transportation to a regional site for disposal, and transportation to a national site for disposal. The assessment only considered public risk. The objective of the

FPEIS was to examine accident scenarios, estimate their probabilities of occurrence, and evaluate attendant environmental impacts. The risk analysis included an evaluation of potential accidents and naturally occurring phenomena, such as earthquakes and tornadoes. Acts of war, sabotage, and terrorism were not included in the scope of the effort. Based on this analysis, the U.S. Army selected onsite disposal as the preferred alternative in the FPEIS.

At the time the FPEIS risk analysis was conducted, the design of the proposed disposal facility was approximately 35 percent complete. JACADS, which includes many of the same design elements as the planned CONUS chemical agent disposal facilities (CDFs), did not become operational until June 1990. Therefore, the operational experience from JACADS could not be incorporated in the original FPEIS risk analysis.

The results of the FPEIS included estimates of various public risk measures. To protect munition inventory information that was classified at the time, the results were presented in terms of ranges rather than specific values. The ranges were chosen to accommodate uncertainties in the results and to allow comparisons without disclosing specific values. The risk assessment included analyses showing the impact of various risk mitigation measures that had been proposed.

The FPEIS risk analyses were used in the development of the current QRAs. The QRAs completely replace the previous risk analyses with updated information about the facilities and processes, new QRA methods, and operational data.

1.10 Uses of the QRA in Risk Management

The way that the QRA is used in risk management will be a function of how the site systems contractors implement PMCD risk management requirements. The QRA uses are expected to evolve as this report and the associated models are reviewed and understood. It is the purpose of this report to describe the QRA methods, models, and results. Some uses of the models are described here, but the actual UMCDF uses and the methods employed to maintain the models current will be determined as the QRA and risk workstation are transitioned to the site. The PMCD guidance for site implementation is described in the *Guide to Risk Management Policy and Activities* (PMCD, 1997a) and *Chemical Agent Disposal Facility Risk Management Program Requirements* (PMCD, 1996).

The development of a risk management workstation was a goal coupled to the completion of the QRA reported here. To meet that goal, SAIC has developed the Quantus risk management software. Quantus is an easy-to-use, integrated suite of risk assessment and management tools. Quantus was developed for two audiences. First, it meets the exacting needs of the risk engineers for accurate development and solution of complex probabilistic models. The second audience is decision makers, who need access to the results in usable and understandable formats. Decision makers also have the power to do "what-if" analyses to investigate changes. Because all of the models are developed and stored in Quantus, the program and the QRA are completely integral. This report is provided to allow the user to understand the models that are maintained and manipulated in Quantus. Section 2.7 provides an overview of Quantus. Quantus is described in the *Quantus User's Manual* (SAIC, 2002a) and use of the code for specific problems will be described in separate documents such as the *Quantus Quick Start Guide* (SAIC, 2002b).

The QRA uses will evolve, but there are a number of demonstrated areas where the QRAs have proven their usefulness to decision makers. Some specific examples are provided on how the QRA has been used to address design, operations, storage risks, and management needs.

The QRA has been used to examine the design of the facilities. The TOCDF QRA resulted in a re-design of a portion of the Anniston and Umatilla disposal facility structures to reduce possible earthquake damage. The amount of stored liquefied petroleum gas (LPG) was reduced based on risk findings. As part of a formal Change Management Plan instituted by PMCD, sensitivity studies also have been performed on the amount of agent stored in tanks. The reliability models developed for the QRA have been used to study issues of the need for redundancy, such as in emergency power systems.

With regard to operations, the most frequent use of the QRA has been to assess the scheduling of disposal operations. Along with efficient plant operations, PMCD has a goal of eliminating the storage risk as quickly as possible. Therefore, a strategy is needed to limit storage risk while optimizing facility operations. Reducing equipment changeouts to accommodate different types of munitions and reducing the need to clean the plant to switch between different chemical agents are important considerations. Many studies have been completed and continue to be performed to support site decision making regarding scheduling.

Other operational changes were made after completion of the TOCDF QRA. Metal Parts Furnace (MPF) airlock residence times were minimized based on a QRA finding of a potential for an agent vapor buildup. Disposal of one type of munition (the weteye bomb) was delayed due to the potential for a munition-specific risk that required additional study prior to processing. The QRAs had even broader impact in that the U.S. Army-wide planning guidance for munitions handling (called maximum credible events) was redefined using the QRA models of accident frequencies.

The QRA was used to identify potential risk-reduction opportunities for storage of chemical weapons and agents. This included lowering the VX rocket pallet stacks to reduce earthquake damage potential at the Deseret Chemical Depot. All igloos housing M55 rockets have had additional electrical bonding installed to offer increased protection against lightning based on the Phase 1 QRA findings. The risk sensitivity to the use of the enhanced onsite containers in transportation has been studied. The UMCDF electric power models from the draft QRA have already been used to examine the potential need for additional backup power.

The QRAs also have played a role in other management activities. The QRAs provide information in support of regulatory and legal activities. The QRAs have provided a risk basis for the U.S. Army's positions in these arenas. This has included direct use in legal actions such as a TOCDF injunction hearing and use in helping to explain PMCD positions to state regulators. The QRA results also are used by the CSEPP to develop a planning base that considers the full range of possible releases identified in the QRA. The local emergency planners use the planning base to allow preparations for probabilistically significant accidents. It should be noted here that actual emergency response would be based on real-time information concerning the accident that occurred, the weather at the time of the accident, and other conditions at the time of the event. Thus while the QRA is useful for planning and exercises, actual responses are based on the very specific aspects of an event when it occurs, controlled by the local emergency operations center and the local emergency response organizations.

The QRA has proven useful in accident investigations and in pre-operational surveys. For example, key contributors to QRA sequences can be examined during surveys to determine if appropriate mitigations are in place and effective. Other related issues have been addressed. For example, onbase land reuse proposals at Pine Bluff, Arkansas, and Pueblo, Colorado, have been studied to determine if the land reuse would subject any occupants to increased risks. In summary, the QRA has found many useful applications in responding to day-to-day management needs, both internally and in response to Pentagon and other inquiries.

1.11 Organization of the QRA Report

This report, including the appendices, describes the analyses and results of the QRA performed for UMCDF in detail. The main report includes sections that present the methods and results in sufficient detail to describe the QRA. Supporting information and details of the analyses are included in the appendices. A short summary report is provided under separate cover.

Section 1 provides an overview of the QRA objectives and scope, section 2 describes the basic QRA methodology, and section 3 outlines the facility and disposal process. These overviews are followed by discussions of specific tasks of the risk analysis in sections 4 through 12. More information concerning the content of these task analysis sections is provided in section 2.

The results of the risk analysis are provided in section 13 for the disposal process. The analysis of stockpile storage risk is summarized in section 14, and the risk results for stockpile storage are provided in section 15.

A discussion of the risk results is provided in section 16. This section includes a comparison to the risk analysis performed in support of the FPEIS. Section 16 also describes sensitivities and limitations associated with the UMCDF QRA.

Appendix A is a complete list of references for the main report, and appendix B is a list of acronyms and abbreviations.

Appendix C includes all the process operations diagrams (PODs) that are introduced in section 4 of the main report, along with a discussion of the internal event initiators. All of the systems analyses, including system descriptions, are included in appendix D; fault trees and cutsets (the solutions to fault trees) are provided in the annexes to appendix D. Details of the data analysis and human reliability analyses are included in appendices E and F, respectively (backup for sections 7 and 8 in the main report).

The onsite transportation analysis is described in appendix G. Support for the external event analyses discussed in section 5 of the main report is included in appendices H through K. Details of the seismic analyses, including the seismic hazard, fragility, and quantification are described in appendix H. The aircraft analysis is described in appendix I and includes information on the aircraft hazard, crash effects, and aircraft sequences considered for UMCDF. Although the primary focus of appendix J is on tornadoes and lightning strikes, all of the weather-related external event analyses are included. Appendix K documents all other external events, such as fires, considered for UMCDF.

Appendix L provides details to support discussions in section 6 concerning the accident progression event trees (APETs) that were used to support quantification of the UMCDF QRA. Structural models, munition response models, filter models, furnace models, etc., are described in appendix M. A synopsis of the MELCOR intra-building agent transport model used to study building ventilation is included in appendix N. Section 9 of the main report summarizes the information in appendices M and N. The models that compose the Source Term Evaluation Program introduced in section 10 of the main report are included in appendix O.

Appendix P has been reserved for the data to support the uncertainty distributions used in the UMCDF QRA and includes Latin Hypercube Sampling matrix statistics, variable correlation information, etc., which are introduced in section 12 of the main report. The consequence analysis, including a description of the Chemical MELCOR Accident Consequence Code System (CHEMMACCS) and all inputs, is described in appendix Q. The direct effects of accidents on workers could not be appropriately modeled with CHEMMACCS and the models developed for workers are described separately in appendix Q. Lists of accident sequence results are provided in appendix R. Appendix S includes a summary of quality assurance activities. Appendix S also includes comments provided by the expert panel and other reviewers. Responses are documented for all comments.

Figure 1-2 shows the structure of the UMCDF QRA main report and the relationship of the supporting appendices to the sections of the main report.

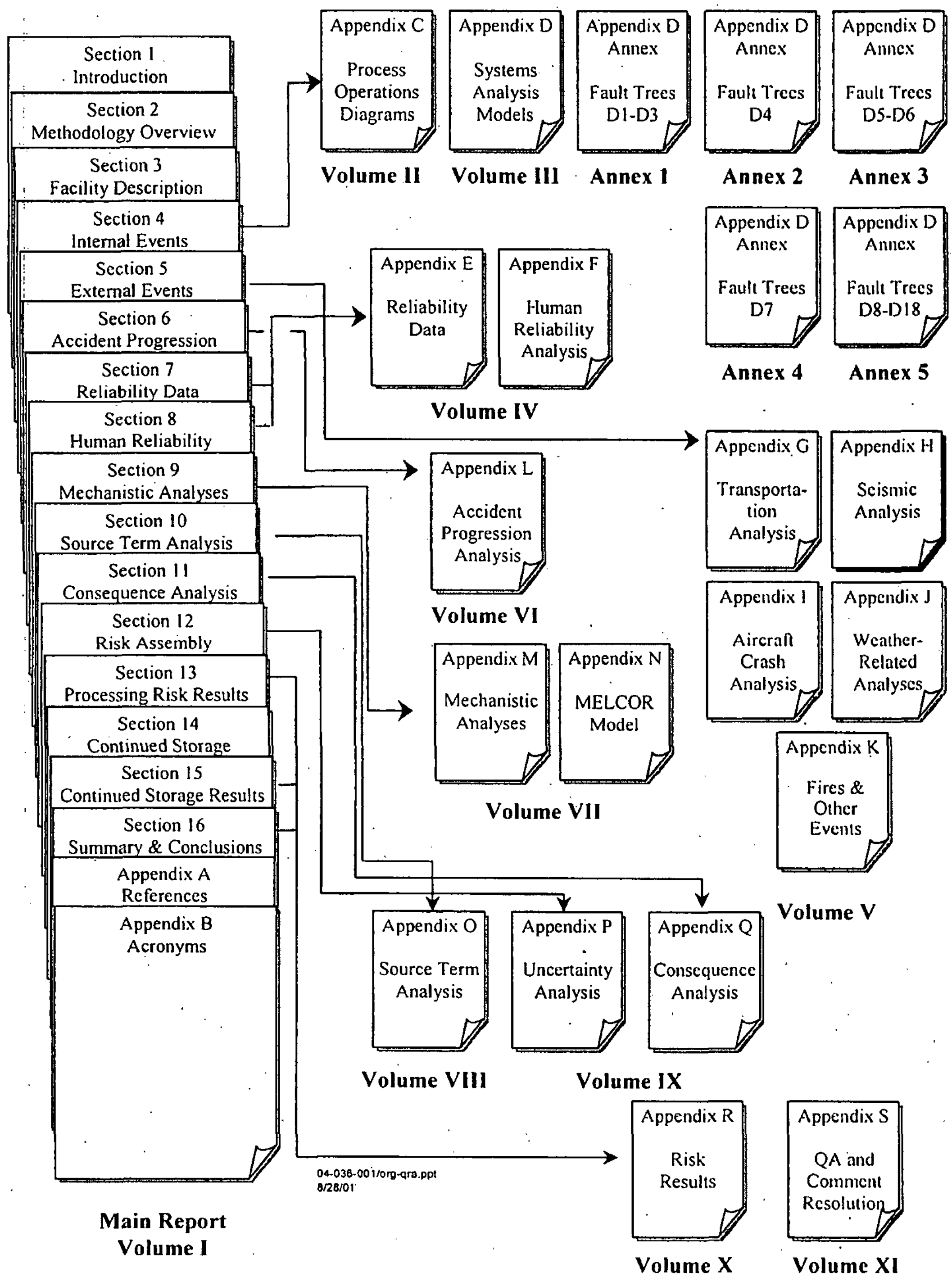


Figure 1-2. Organization of the QRA Report

(This page intentionally left blank.)

SECTION 2
QRA METHODOLOGY OVERVIEW

Like most modern industrial facilities and processes, UMCDF and demilitarization activities have been designed with careful consideration of safety. A QRA may be used to further enhance safety through development of models that enable an integrated assessment of equipment and operations. The quantification of these models provides insights concerning the frequencies of potential accidents and the relative safety importance of different equipment and activities. Thus, a QRA is a good adjunct to the engineering design and operation practices that ensure plant safety. The quantitative results are used to understand risks to the public and facility workers, allowing comparison to other risks for further perspective on the safety of the overall UMCDF process. As described in section 1, the QRA will be incorporated into a comprehensive RMP designed to minimize facility risks to workers and the public.

The methods used in this analysis were based on QRA approaches that have been demonstrated via application to other facilities and technologies. The methods have been customized and extended for the CDF process to reflect the specific nature of the activities and ensure maximum benefit in terms of insights and feedback that could be used to understand risks and improve the processes. The basic QRA methodology has been documented previously (SAIC, 1997). While the UMCDF QRA has been developed in keeping with the guidance provided in the methodology manual, there have been substantial improvements (these are summarized in section 2.8). Therefore, the methods are described in their entirety in this report and its appendices. Major steps in the QRA process are shown in figure 2-1. The following sections summarize the analysis activity in each step.

a. *Identify Initiators.* Deviations from normal process operations are systematically identified and organized in logic models. In the QRA model, these deviations are termed initiators because they are the starting point for a potential accident sequence. The search for potential initiators considers all activities associated with the facility, including stockpile handling and transport of the munitions to the facility. The initiators may result from equipment failure, human failure, or external events such as earthquakes or aircraft crashes that could pose a threat to UMCDF.

b. *Model Sequences.* The sequences of events stemming from each initiator that lead to agent release are identified and modeled. This involves an evaluation of systems, operations, and physical phenomena. The subsequent progression of the accident is evaluated to understand the effectiveness of mitigation systems [e.g., the heating, ventilation, and air conditioning (HVAC) carbon filters] and accident

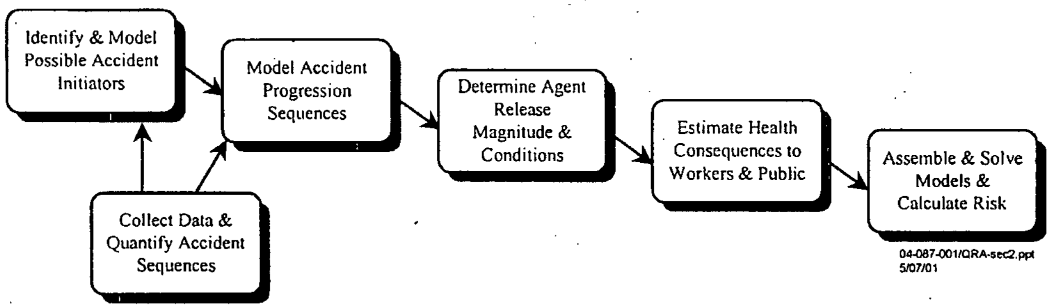


Figure 2-1. Steps in the Quantitative Risk Assessment Process

phenomenology (the potential for explosive propagation or the loss of building integrity). The possible agent releases that could result are modeled in terms of the differing combinations of events that could occur, thereby defining accident sequences for agent release.

c. *Collect Data and Quantify.* Data are collected to evaluate the likelihood of both initiators and subsequent events leading to accident sequences with the potential for agent release. This includes data on equipment or component failures, and assessments of human failure probabilities. In addition, other events in the accident sequences are quantified, such as the probability of a munition explosion given impact or the probability of a building failure given explosion. After assigning frequency or probability values to all of the events in an accident sequence model, the frequencies of accident sequences resulting in agent releases are calculated.

d. *Determine Agent Release.* For each quantified accident sequence, *source terms* (defined as the amount of agent release and the conditions associated with the release) are developed. These source terms provide the basis for predicting the health consequences of the accidents to the public and workers.

e. *Estimate Health Consequences.* Computer models are used to calculate the dispersion of any agent released from the facility through the air. These models evaluate the exposure and resultant health consequences to workers and the public surrounding UMCD.

f. *Calculate Risk.* The frequency of each accident sequence (F) is multiplied by the consequences of that sequence (C) to produce the risk (R) for each release:

$$\boxed{R = F \times C}$$

The consequences in this QRA are measured in terms of fatalities or cancers in the worker or public population. The summation of risk for all sequences produces the risk of the facility.

The analysis steps described in the previous sections require substantial model and data handling. As part of the QRA development process, SAIC has developed the Quantus Risk Management Workstation (hereafter referred to as Quantus) for PMCD. This workstation performs all the data storage and mathematical model solution associated with the UMCDF QRA. Quantus was developed with two main objectives. The first is that it meets the exacting technical requirements of the risk engineers for accurate model development and solution. The second is that Quantus provides comprehensive methods for examining and displaying risk results in formats suitable for use by project decision makers responsible for risk management. This includes the ability to do "what-if" analyses to assist in decision making among alternatives. Thus, the UMCDF QRA and Quantus are part of the same effort to provide risk management insights. This report describes and justifies all of the information contained in Quantus for UMCDF. This information is provided for use and review as part of the continuing process of verifying the models. Appendix S describes the quality assurance and review activities for the QRA development. The actual Quantus software is described under separate cover (SAIC, 2002a). Quantus was developed according to a set of standard procedures to control development and ensure completion of a verified product.

2.1 Identification of Initiators

Accidents can be systematically examined as a progression of events, called an accident sequence, which describes how a facility or operation moves from a normal, safe state to an accident condition in which the public or workers are exposed to potential health consequences. Given that risk is examined in terms of accident sequences, it is essential that the identification and modeling of these sequences be as complete as possible. The first step, therefore, is an exhaustive consideration of the potential events that could initiate an accident sequence.

Each accident sequence can be described as beginning with an initiating event, or initiator, that starts an offnormal progression of events that could result in agent release. For analytical convenience, events are usually categorized as either *internal* or *external* events. Internal events occur within the process system, such as an operational error or equipment failure. External events are initiated outside the process system and may have widespread effects. Thus, an operational error or a failure of a piece of equipment is an internal event, while earthquakes, fires, floods, or aircraft impacts are external events.

Identification of possible initiators was based on past analyses, especially the TOCDF Phase 2 QRA (SAIC, 1996b); operational experience at TOCDF and JACADS; and technical evaluations of UMCDF operations and equipment. In addition, QRAs of other facilities have developed lists of initiating events, which were used to ensure completeness in this study (USNRC, 1983, 1990, 1991, 1992).

The QRA Team was tasked with identifying accidents including those that are very unlikely, down to a 1 in 100 million chance per year (10^{-8}). This frequency was selected by PMCD to be assured of meeting the Congressional requirement for maximum protection of the public. This 10^{-8} frequency is lower (thus more protective) than frequencies typically considered in other industries such as nuclear power. This required an extensive search for possible initiators.

Figure 2-2 illustrates the initiator identification process. Internal initiators were identified through a systematic evaluation of the entire disposal process, from loading munitions at the storage yard to final disposal of the munitions and their agent. The evaluation was aided by the use of PODs, which delineate the steps of a process and the possible deviations from normal processing that might occur at each step. A more detailed discussion of the use of PODs is provided in section 4. The thorough consideration of the process and past evaluations resulted in a comprehensive assessment of potential initiating events.

After identification of the initiators, fault tree models were developed to quantify the various combinations of failures that could lead to the initiator. A fault tree is a logic structure that determines the possible combinations of events that can lead to a specific outcome. (Section 4 describes the development of fault trees in more detail.) In this case, the fault trees were used to model the basic causes of various types of initiators. For example, a POD might show that a munition could be dropped during handling in the unpack area (UPA). The fault tree then identifies the specific combinations of equipment and/or human failures that could result in a munition drop. It should be noted that some events identified on a POD did not require detailed fault tree models because they could be described in a single event. Other events, however, required detailed system modeling along with support system models, such as electric power, to fully identify all combinations of failures that could cause the event. Section 4 describes the identification and modeling of internal events. The initiators specifically considered are listed in section 4.5.

The external initiating event search began with an exhaustive list of potential events and an initial evaluation to determine if each event is possible at the facility or site. As noted previously, other sources provide extensive lists of possible external events. The initial

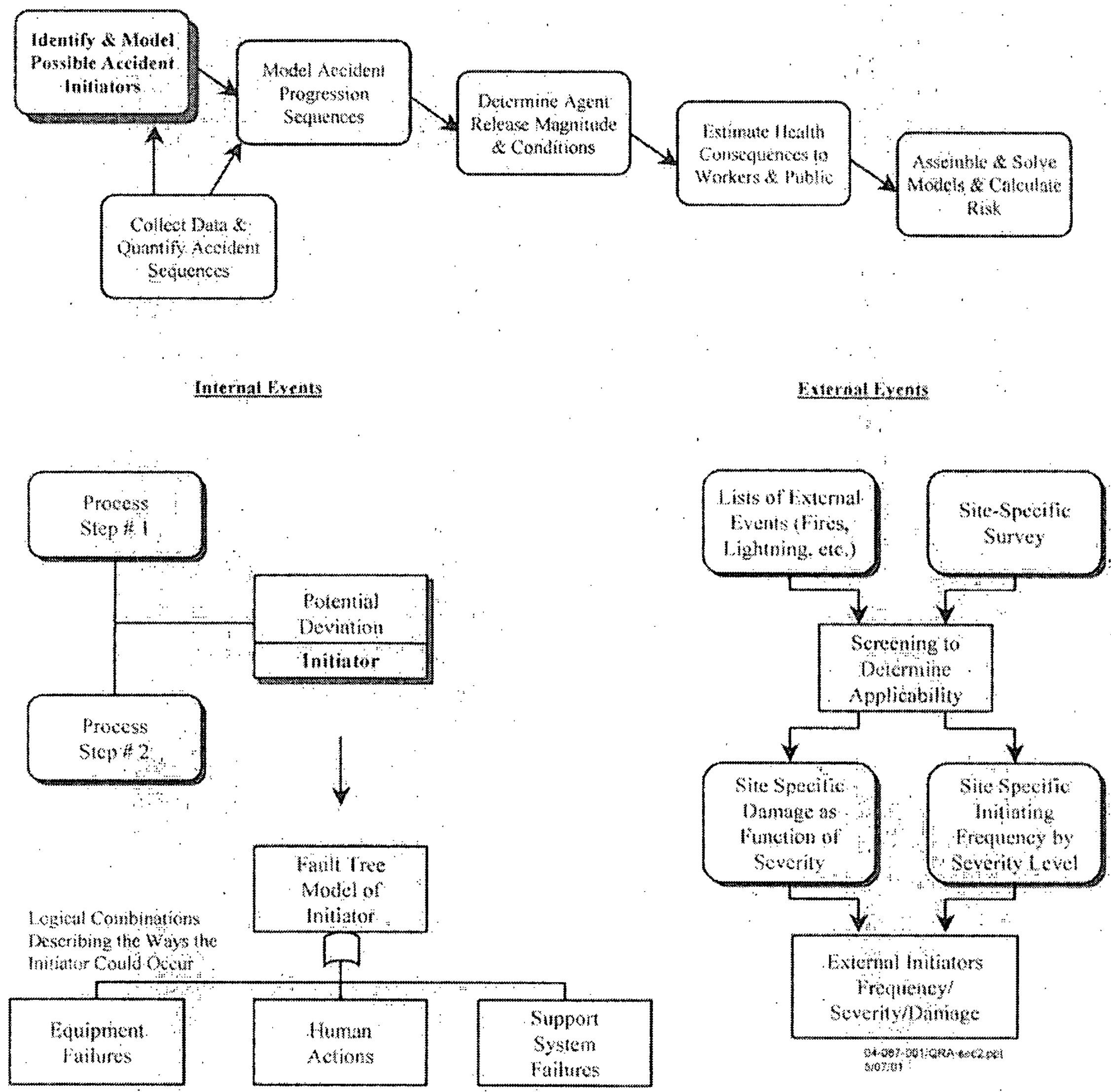


Figure 2-2. Identification of Initiators

evaluation of an event was based on applicability to the site (e.g., a tidal wave is not possible at Umatilla), frequency relative to the 1×10^{-8} per year accident sequence frequency cutoff criterion, and susceptibility of the site and facility to the postulated hazard.

For events not screened out, it was necessary to determine the frequency and magnitude of the hazard. In general, historical records were used to generate the data to support an estimate of the frequency and magnitude of the events of concern. The method for this part of the analysis depended on the specific external event, but the basic steps were similar. For example, weather records were used to generate the frequency of events (such as tornadoes) of different severities. Other events (such as earthquakes) required combinations of historical information and analytical techniques to estimate the hazard at the site. Some other external events relied primarily on analysis because there may not be data for the specific event of concern. External initiating event analyses are discussed in section 5.

Given that an external event can occur, it also is necessary to understand the level of damage that might be induced. For example, different structures and equipment will respond differently to the same earthquake. Similarly, the response of structures and equipment to strong winds also must be analyzed. This information, coupled with the frequency and magnitude information, allows the identification of specific external initiating events that could cause agent release.

2.2 Modeling of Accident Progression

After the initiators are identified, it is necessary to describe the potential accident sequences that could result in a release of agent and subsequent public or worker risk. The initial concern is whether an initiator could progress to the point where agent is released from its intended confinement. (Some initiators may be so severe that the initial confinement is breached directly.) It also is important to consider the conditions associated with the initial release (e.g., agent leak or spill, munition explosion, or fire with agent involvement). Thus, the initiator analysis may identify the drop of a rocket pallet from a forklift, and the accident progression analysis will identify the possible outcomes (e.g., no agent release, agent leakage or spill, or rocket explosion). The outcomes are most often probabilistic assessments of physical phenomena, such as a rocket leak probability after a drop.

In some scenarios, the initial release may be compounded by further failures. Two types of events are generally considered in modeling accident progression: mitigative and propagative events. *Mitigative* events are those actions or systems that operate to reduce or prevent an eventual release, such as the HVAC system and associated filters, blast gates, and human actions. *Propagative* events are those events that account for physical phenomena (e.g., explosive effects) that cause the accident to involve additional agent sources or to fail barriers. Additional agent sources are generally other munitions in the area.

The analysis of potential accident progression is accomplished through the use of an APET, shown schematically in figure 2-3. The goals of APET modeling are to delineate the full range of sequences that could result in agent release and to characterize each sequence in sufficient detail to permit analysis of the sequence frequency and the amount and characteristics of agent release. The APET is a probabilistic model for postulated accidents that lead to agent release.

The APET considers accident progression from initiation to agent release and includes potential propagation to other munitions. The APET also models the status of barriers to release (e.g., room confinement) and mitigation systems (e.g., the cascade HVAC and filter system). The APET provides a consistent framework for the accident progression analysis.

The APET consists of a series of questions and potential answers (or outcomes) that define how the accident might proceed. Frequencies are assigned to the initiating event in each sequence. Probabilities are assigned to all subsequent APET logic branch points based on their relative likelihoods. The probabilities used in the APET are determined by several different approaches, including: fault tree analysis, mechanistic analysis, past experience or experiment data, and engineering judgment. As indicated in figure 2-3, fault tree models are coupled to the APET to model the probability that mitigative systems will be available during the accident. The APET logic specifically includes any dependencies among events so that each accident sequence is appropriately quantified. For example, the potential occurrence of an explosion following an initiator would influence the availability of the HVAC and filter system as a potential mitigation of the accident. Each path through the tree (or accident sequence) has a frequency of occurrence equal to the product of the initiating event frequency and the probabilities of each event in the path.

2.3 Quantification of Accident Models

The goal of a QRA is to obtain a probabilistic estimate of risk by quantifying the events in the models described previously. This requires assigning probabilities or frequencies to each event in the accident sequences. The data collection and model development are closely coordinated because the extent to which a model can be developed is governed, to some degree, by the availability of relevant data. Similarly, the accident progression phenomena in the APET need to be modeled at the level of detail matching available mechanistic calculations. Figure 2-4 is a schematic of this analysis activity. An overview of the quantification bases is provided in this section; more detail is available in sections 7, 8, and 9.

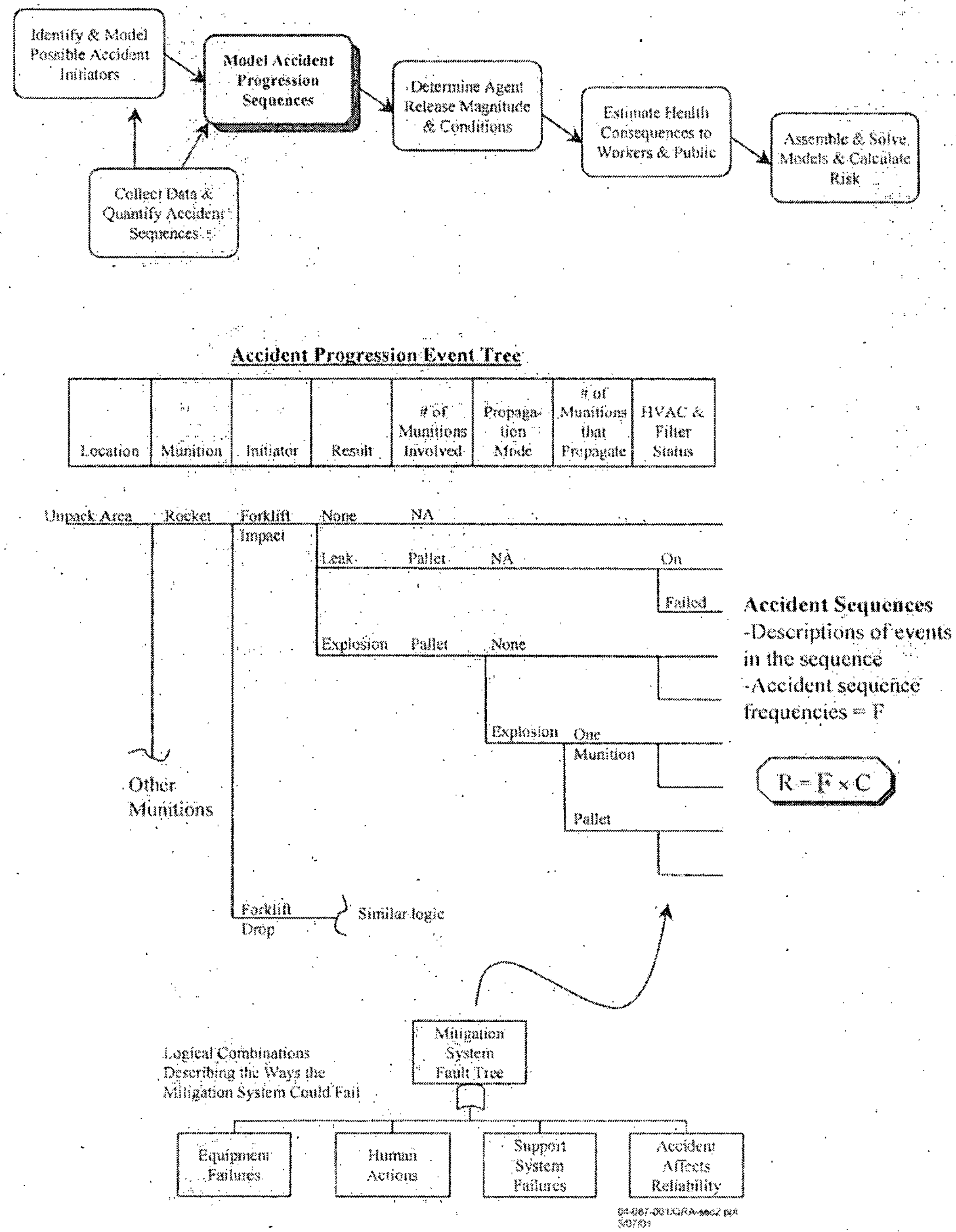


Figure 2-3. Modeling of Accident Progression

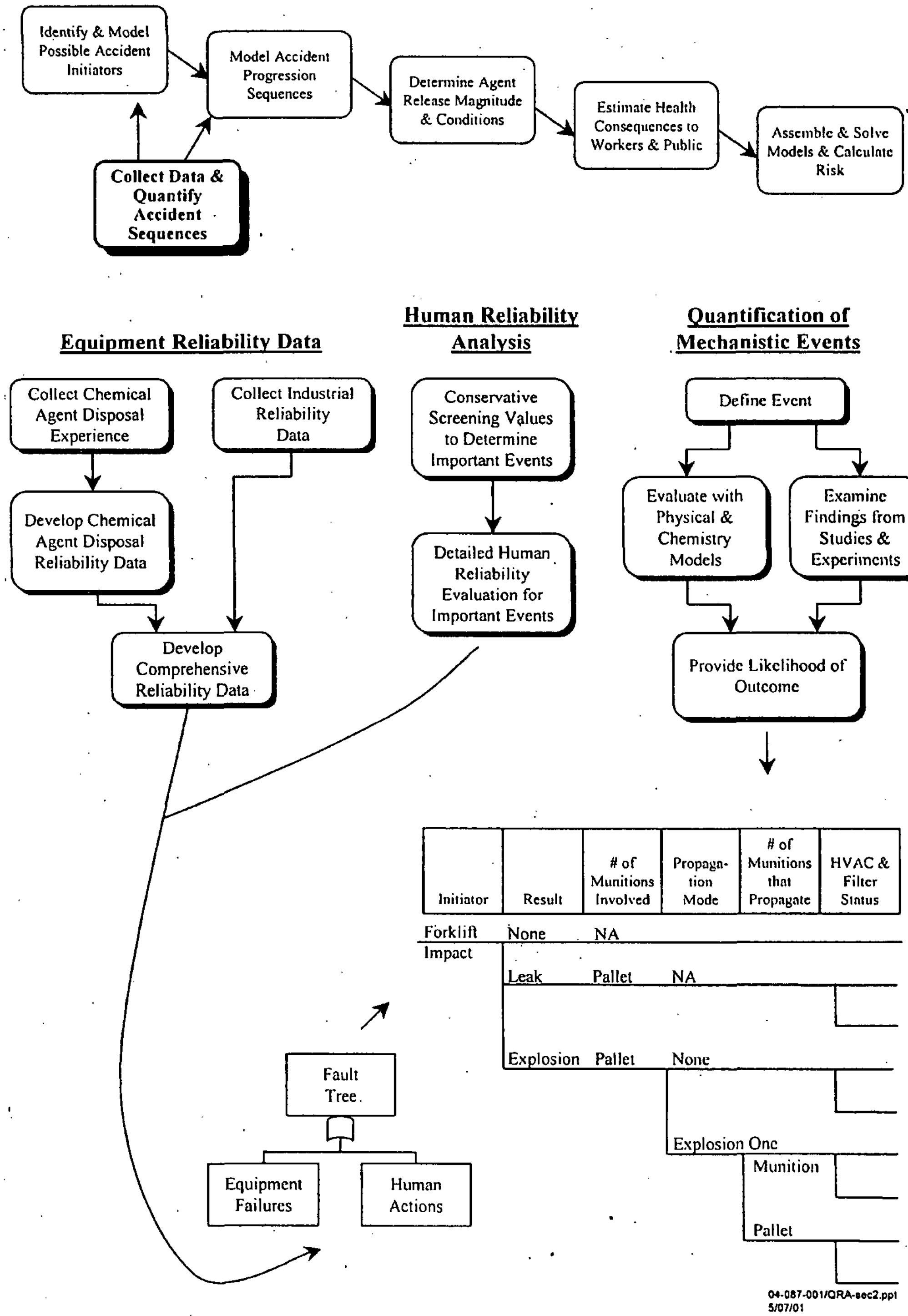


Figure 2-4. Quantification of Accident Sequence Models

The fault tree and event tree models require three types of quantitative input: equipment reliability, human reliability, and probabilities for mechanistic phenomena.

a. *Equipment Reliability.* The equipment (and the components making up the equipment) are modeled in fault trees for initiators, mitigation systems, and support systems. Quantification of the models requires assigning failure frequencies or probabilities to each event in those models. As part of the QRA, an extensive reliability data gathering and analysis task generated reliability data based on TOCDF operational experience.

   For some components, these were sufficient data, while for others industrial data had to be included also. Industrial reliability data were developed from a combination of generic data derived from process industries and nuclear facilities, Department of Defense (DoD), Department of Energy (DOE), and other sources. The equipment reliability database developed for the TOCDF QRA from the information collected during operations at JACADS also was used as a data source. UMCDF equipment reliability will be used after operational experience is gained. Further information on equipment data is provided in section 7.

b. *Human Reliability.* Human performance affects the potential for accidents. While some data for equipment performance might include human failures, there are unique events associated with process operations that require an assessment of human reliability. QRA techniques developed to assess human reliability were used in conjunction with consideration of the specific operations, procedures, and facilities. The human reliability events were initially assigned conservative screening values to determine if the events, in combination with the other events in the accident sequence, were important to public or worker risk. Only the significant events were analyzed in more detail. Human reliability is the topic of section 8.

c. *Probabilities for Mechanistic Phenomena.* The accident sequence models include many events whose quantification depends on mechanistic analyses. For example, the responses of furnaces to various perturbations are considered, as are explosive propagation phenomena involving structural damage. Some values are developed based on models drawing on basic chemical or physical principles. Other values may draw on existing experimental results or operational experience. The probabilities for these events were assigned after mechanistic analyses had been performed, and considered both available probabilistic data about the phenomena and engineering judgment. Consistent with the other data efforts and the goals of the program, the probability assignments frequently involved conservative assessments with refinements of the values that were found to be important to risk. Quantification of mechanistic events is discussed in section 9.

The external event tasks also require data, such as frequencies of the natural phenomena, that initiate the accident sequences. As described previously, the data are derived from historical information or from models reflecting historical and analytical data. Section 5 describes the sources of data for all external initiating events applicable to the UMCDF site.

2.4 Characterizing Agent Releases

The goals of APET modeling are to define the sequences that could result in agent release and characterize the sequences in sufficient detail to permit analysis of the agent release. Therefore, the APET logic is designed to explicitly reflect the factors that significantly affect the release for every sequence. This information then can be used to develop a source term that characterizes a release for evaluation of consequences. The expression source term refers to the following information characterizing a release of agent: 1) type(s) of agent released; 2) quantity of each type; 3) physical state of the released agents (liquid, vapor, or aerosol); 4) rate, timing, and duration of the release; 5) elevation of release; and 6) time of day at which the release is possible. (Because some operations are limited to daylight hours and weather patterns are different day to night, it was necessary to consider when the accident could have occurred to develop a reasonable estimate of health consequences.) Taken together, these characteristics define the source term for agent release.

Figure 2-5 illustrates the source term task. Based on the description of the accident, a source term is defined. A source term function uses the information defining an accident progression sequence to develop an estimate of a source term for the sequence. The source term function for this study was automated through development of a computer code function in Quantus. For purposes of development and for use as a stand-alone source term evaluator, the source term algorithm was developed in Microsoft® Excel spreadsheets. The source term algorithm defines a source term for each sequence by assembling the information needed to estimate each source term parameter listed previously. The source term algorithm includes modeling necessary to specify the actual release that would be expected from the accident sequences. For example, it includes an evaporation model that determines the amount of release based on evaporation rates for the agents and the conditions of the accident. An explosive release model that is used to determine the release associated with various types of explosions is included. The source term function also considers the effect of mitigation systems such as carbon filters. The release for an accident sequence is the sum of releases from all phenomena and all agent sources involved in the accident.

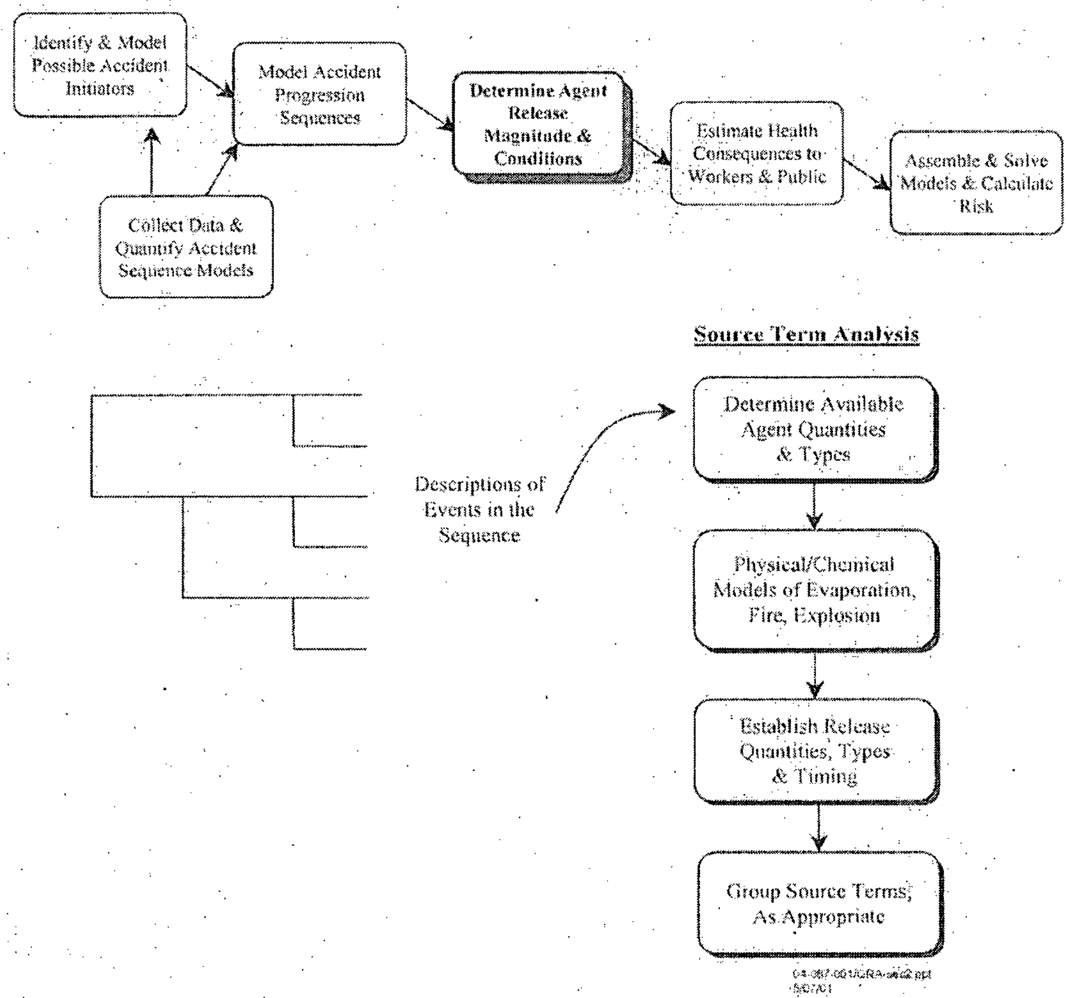


Figure 2-5. Characterizing Agent Releases

The source terms developed for each accident progression sequence form the basis for the next steps of the analysis, including atmospheric dispersion modeling. The atmospheric dispersion modeling can be computer resource intensive. Because many of the calculated source terms have nearly identical consequences, it is more efficient to calculate one set of consequences that applies to a group of similar source terms. A function is available to allow grouping of like source terms, if necessary. The source term conditions for each of these groups are the input required for the assessment of consequences, as summarized in the following sections. More details regarding source term analysis are provided in section 10.

2.5 Estimating Consequences

The final technical evaluation step in the QRA process is the assessment of potential public or worker health consequences. As indicated in figure 2-6, it is necessary to develop an estimate of the health consequences for each source term. The consequences of an accident are estimated by evaluating the atmospheric dispersion of agent in the environment, determining the population exposure to agent (doses), and estimating the probable number of persons who would experience the health consequence of interest. For this QRA, the consequences of interest are fatality due to agent exposure or increased likelihood of cancer due to exposure to mustard agent. In order to obtain a probabilistic evaluation of potential consequences, the evaluation considers the variability in weather.

The U.S. Army has developed a dispersion model contained within the U.S. Army's D2PC computer program (Whitacre et al., 1987). The model within this program has been incorporated in a consequence analysis code that was originally developed for QRA in the nuclear industry; the result is a code specifically applicable to chemical agent risk assessment. This code, CHEMMACCS, includes the appropriate D2PC models for chemical agent in a structure that is suited for QRA. The CHEMMACCS code permits input of the local population distribution and an hourly set of site-specific weather data over 1 year. (One year of weather data is the maximum allowed as input to CHEMMACCS and was the only verified data available at the time of quantification. Previous sensitivity studies have shown that risk results are not highly sensitive to year-to-year variations.) These weather data then are randomly sampled within the code as described in section 11. There are 1,460 weather samples run for every consequence calculation.

Using CHEMMACCS, public and worker health consequences for the source term groups are calculated. The consequences include estimates of acute fatality and excess cancers. This study also includes use of the models in sensitivity studies, such as the evaluation of the results under different health dose-response models.

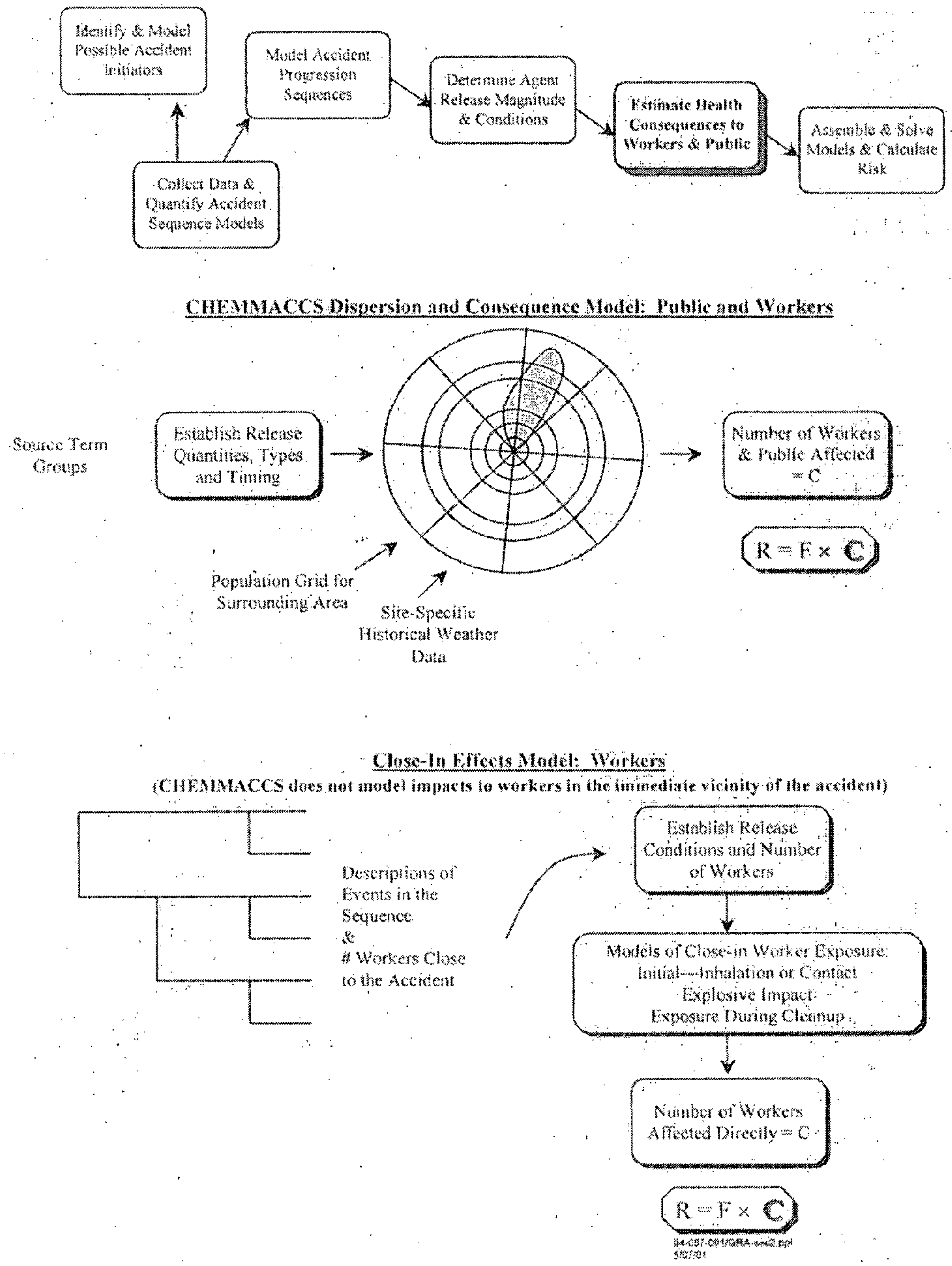


Figure 2-6. Estimating Public and Worker Health Consequences

As indicated in figure 2-6, there is another consequence evaluation associated with close-in effects. In order to have comprehensive coverage of worker risks, it is necessary to consider the effects of the accident on the workers close to the mishap.

An atmospheric dispersion model is not applicable for this evaluation because workers could be affected directly through such mechanisms as splashing or explosion. Thus another function is used, similar to the source term function, that enables an estimation of close-in effects. Included in the function are calculations of inhalation or skin contact, explosive effects, and possible exposures during cleanup of an accident. Consequences are calculated for these close-in risk effects and then added to the consequences calculated for other workers who might be exposed to agent as it is dispersed from the immediate area, as calculated in CHEMMACCS.

2.6 Assembling Risk Results

Figure 2-7 illustrates the overall risk assessment arranged as a process from initiator identification through risk assembly. The process of assembling the risk from thousands of individual accident sequences is complex, but is implemented in Quantus, which is designed to handle this complexity. This section provides an introductory overview of the risk assembly process. The details of risk assembly are discussed in section 12.

The risk assembly process combines inputs and outputs from the initiating event fault tree analysis, the APET model, the source term analysis, and the consequence analysis. The APET is the logic model used to assemble each accident sequence analysis. All sequences, regardless of their origin, are modeled as one or more questions in the APET. The result of the APET quantification is a set of accident progression sequences describing the events that occur and the characteristics needed to develop the agent release source term. Each accident sequence has a frequency (**F**) that is stored as one of the two elements of the risk equation, $R = \mathbf{F} \times C$.

A source term is estimated for each accident progression sequence using the agent release characteristics associated with the sequence. Source terms that are similar enough to produce similar consequences may be combined into source term groups. The relationship between the individual accident progression sequences and the source terms are tracked in a set of computer files used in the final risk assembly.

For each source term, an estimate of the consequences due to that source term is generated. This is done using the CHEMMACCS dispersion model and also using a separate function for close-in risks. The results of these calculations are the consequences (**C**), the estimates of the numbers of fatalities or cancers, that would be expected for each accident sequence. This is the second element of the risk equation, $R = F \times \mathbf{C}$.

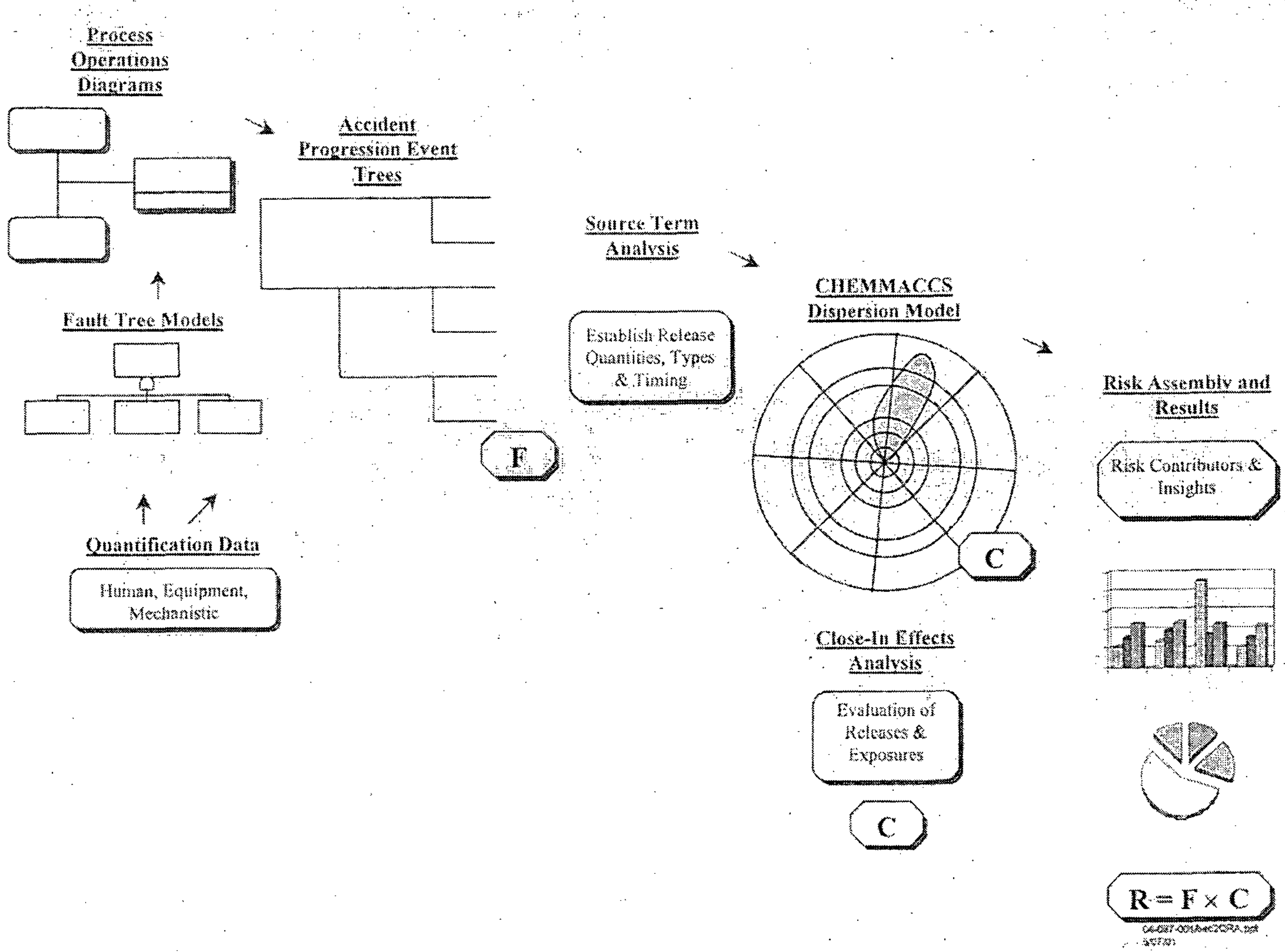


Figure 2-7. Risk Assembly Process

The frequency and consequences associated with each sequence are combined to estimate risk. The risks of sequences are summed to arrive at the total risk. For this assessment, it is necessary to consider the risks separately for each different disposal campaign; for example, the risks are different for disposal of rockets than for disposal operations involving ton containers. There are additional complexities associated with the calculation summation of risks that are discussed in section 12. Risk presentation also is discussed in section 12.

The process described here has not included a discussion of the uncertainty in the risk estimation. The consequence values described in the previous sections are actually produced as curves of probability and consequence, and the frequencies of the accident progression have probability distributions that reflect uncertainty. The same process described in this section applies when evaluating uncertainty in the risk estimation, but there also are a number of technical complexities introduced. The entire risk model is solved hundreds of times, each time sampling key parameters from uncertainty distributions. Each sample also includes the 1,460 random weather samples. Section 12 is a discussion of risk assembly when considering uncertainty.

Once the risk is assembled, the relationships of the model inputs are carefully evaluated for insights. Insights are derived from the quantitative assessment of the importance of various plant features, operations, or individual failures. The release characterization process yields insights concerning mitigation features. The consequence assessment also will help to identify the accidents with the most significant potential for public or worker health consequences. The risks of different activities also may be compared. For example, the risk of the disposal processes can be compared to the risk of continued storage. Sensitivity analyses are used to investigate the most important aspects of the facility and its operations and highlight important uncertainties.

The QRA process often yields engineering insights that are not based on quantitative assessments, but instead result from the assembly of an integrated model of the entire process and its operations. For example, the POD development process can generate insights concerning operational steps and uncertainties in the exact nature of the activities. The integrated assessment of support systems can suggest means to reduce common dependencies. The investigation of the systems and operations often identifies procedures or support information that could be refined or improved.

2.7 Quantus Risk Management Workstation Overview

The risk assembly process described in the previous sections is carried out using Quantus. SAIC has developed Quantus to allow the risk assessment process to be carried out on a personal computer. Figure 2-8 illustrates how Quantus relates to the assembly process. Quantus includes the data and models and enables assembly and solution of those models to calculate risk. The

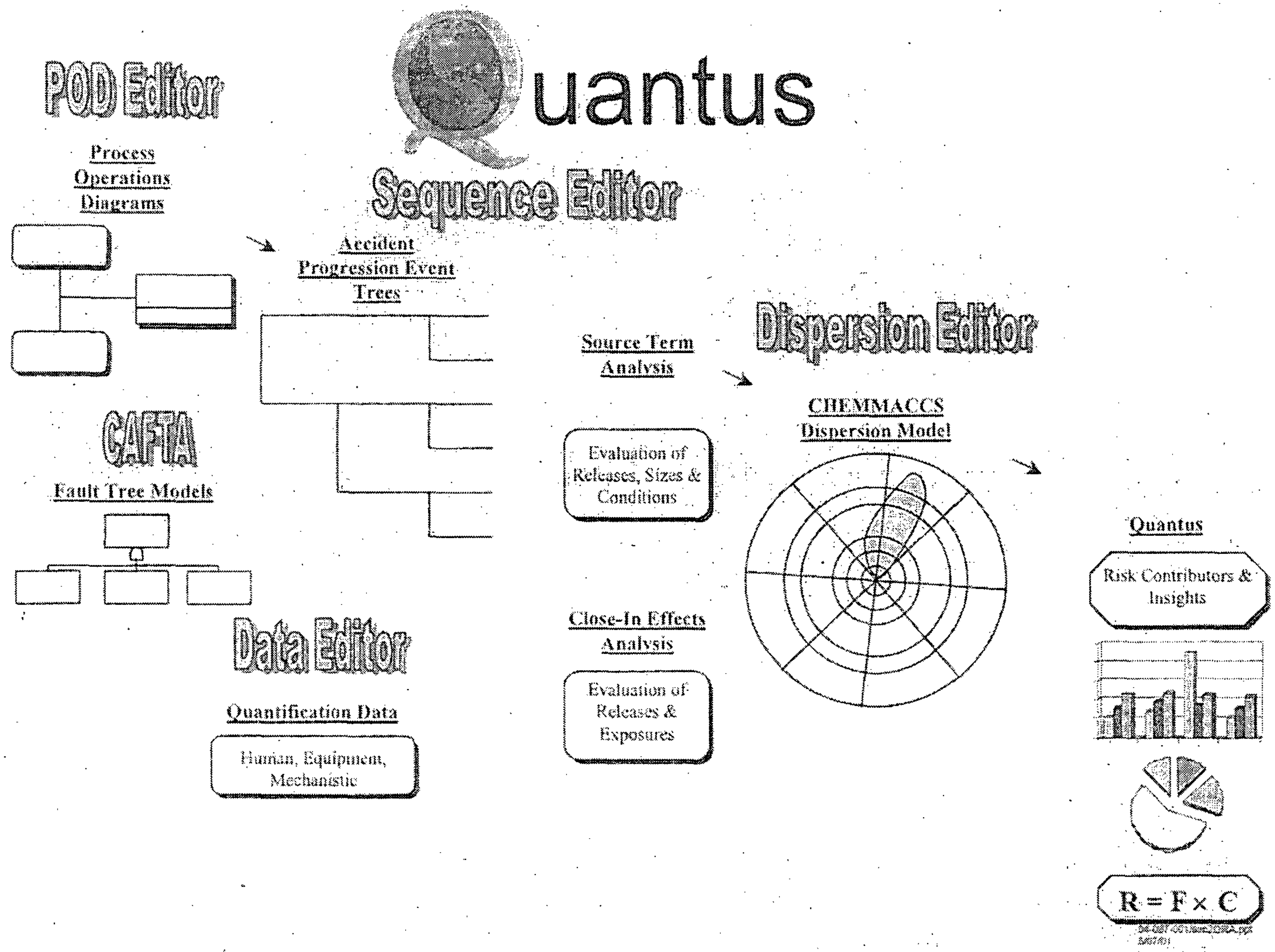


Figure 2-8. Use of Quantus for the Risk Integration Process

Quantus user interface is organized by a series of editors that allow users access to the various parts of the model and data.

The first element of Quantus is the POD editor. The PODs are the origin of all process-based initiating events. Thus, the POD editor stores all the PODs and associated notes and lists all the deviations considered as potential initiators. The POD editor allows users to update or modify the PODs as required. The PODs could require changes if any portion of the disposal process procedures or practices were changed or if equipment were altered, removed, or added.

The POD initiating events are modeled using fault trees. The fault trees are developed and maintained in SAIC's fault tree software, the Computer-Aided Fault Tree Analysis (CAFTA) code (Data Systems & Solutions, 2000). All of the fault trees are developed, maintained, and solved within CAFTA and the models are distributed with Quantus. An interface that enables the POD initiating event frequencies to be captured from the CAFTA models is in development.

The models of accident sequence are accessed through the Quantus sequence editor. This editor includes all aspects of the sequence definition. The APET is the central logic model of the QRA and can be viewed and modified in the Quantus sequence editor.

The structure and probabilities associated with the APET are accessed through the sequence editor. The accident sequences are further defined through the application of associated functions. The source terms and close-in health effects for each accident sequence are generated through the use of functions that are part of the sequence editor. Thus, the overall purpose of the sequence editor is to 1) allow access to all the models and.data used to identify the specific accident sequences that are possible, 2) generate the frequencies for sequences, 3) group sequences in terms of similarities of agent release or potential worker risk, 4) call functions that estimate the agent release or worker consequences for each type of accident sequence, and 5) group the source terms if necessary.

The dispersion analysis continues the characterization of the accident sequence consequences. Because this involves the application of an entirely new model, CHEMMACCS, it is accessed as a separate dispersion editor in Quantus, rather than as a sequence function. The user can change the aspects of the dispersion model, such as selection of weather, protective actions, and other key elements directly in the dispersion editor.

The data editor is used to control viewing and access to the data used in quantification and all other values that are essential to the model solution. Although shown as independent on figure 2-8, the Quantus data editor actually overlaps with the other editors in that an experienced user can make changes affecting all other editors within the data editor. Quantus was developed with a single data repository to ensure data quality during the model building and solution effort.

The data editor also is used to modify any parameters associated with the source term function. The source term function does not require an editor because it is primarily a collection of models, but the inputs to those models may require modification, and this is accomplished through the data editor.

The last editor is the Quantus results viewer. This enables the user access to all of the risk results. The results viewer permits the user to parse the results in many different ways, allowing the user to focus in on risk results of specific interest. This report includes summaries of frequently used results, but the results editor allows access to a myriad of ways to customize the risk results to meet individual needs.

Quantus is the mechanism through which the analyses described in this report are assembled, controlled, solved, and examined for insights. This report describes the technology and science of QRA. Quantus is described in the *Quantus User's Manual* (SAIC, 2002a) and use of the workstation for specific problems will be described in separate documents such as the *Quantus Quick Start Guide* (SAIC, 2002b).

2.8 Summary of Improvements Since Publication of Methodology Manual

It is the objective of this report to describe the methods used in every part of the risk analysis, either directly in text or through appropriate reference. PMCD published a methodology manual (SAIC, 1997) describing the methods used in the previously published TOCDF QRA. While the basic approach has not changed, many areas of the analysis have been enhanced or refined. The discussion of techniques in this report supercedes that provided in the previous methodology manual.

For those involved in the program since the earlier risk assessment activities in 1996 and 1997, it is useful to understand where the analysis has changed. Table 2-1 provides a summary of changes by analysis area.

Table 2-1. Improvements in Methods Since the 1997 Methodology Manual

Analysis Topic	Discussion of Changes in Methods
Initiators and PODs	The process is the same, but PODs are easier to use and more detailed. • A POD editor has been added to Quantus to automate the process and allow easy editing • PODs have been expanded to ensure greater coverage of worker risk • PODs reflect detailed consideration of JACADS and TOCDF experience • Some additional PODs added for clarity (e.g., secondary waste).
Systems Analyses and Fault Trees	The methods are the same. There are a few differences in implementation. • A new version of CAFTA for Microsoft® Windows® was used • The fault tree naming scheme has been tied to component numbers • Extensive consideration of TOCDF and JACADS experience.
Accident Progression Analysis	The basic method is the same but the implementation is entirely different, allowing much greater control, error checking, and flexibility. • Entirely new Quantus interface that greatly eases data entry and user understanding • Graphical displays • Diagnostic tools added to ease review of large logic models • New methods of solution to solve for unique categories of sequences.
Reliability Data	The same method was used. An entirely new source of data from TOCDF maintenance records was available and was used with the previous data.
Human Reliability	New methods were employed based on improvements in the technology primarily from the nuclear industry. Thus, this area was refined to reflect methods improvements and to make the analysis more reproducible. A new method called Human Error Assessment and Reduction Technique (HEART) was added to the Technique for Human Error Rate Prediction (THERP) method that also is used.
Mechanistic Analyses	The same approaches were used—using combinations of physical principles, modeling, and experimental evidence. Many new analyses were conducted and previous analyses were refined using these methods. Many of the specific analyses reported in section 7 of the methodology manual have been updated. Carbon filter loading has been entirely reassessed.
Source Term	This part of the analysis was entirely revamped. A new method was used for developing source terms and the process is both more detailed and more transparent for review. • Significant updates to technical calculations, such as agent release from fires • More detail added to the sequence descriptor (the *binner* in the methodology manual) • New spreadsheet-based methodology that allows all parts of the calculation to be traced • Algorithms hard-coded into Quantus but also maintained in spreadsheets to allow offline checking and verification • A new method of grouping source terms has been developed that is more accurate and allows user flexibility.
Consequence Analysis: Public	The method is the same and CHEMMACCS is used. There have been some modifications to allow better treatment of explosive releases, maintaining the close tie back to the U.S. Army's D2PC code.
Consequence Analysis: Close-In Worker	This is entirely new and the methodology manual no longer applies. • Method parallels worker risk spreadsheet analysis • Each accident considered for explosive, vapor, and cleanup worker risk • Much greater discrimination of types of accidents.

Table 2-1. Improvements in Methods Since the 1997 Methodology Manual (Continued)

Analysis Topic	Discussion of Changes in Methods
External Events: Lightning	Entirely new treatment of lightning based on inputs from a 4-year test program involving response of igloos and M55 rockets to lightning.
External Events: Fire	Entirely new fire methodology based on National Fire Protection Association statistics. This replaces the nuclear power plant methods used in the methodology manual. A new process has been developed to comprehensively assess fire and all previous discussions of methods no longer apply.
Other External Events	Essentially the same methods used as described in the methodology manual.
Risk Assembly	The same process is used, although its implementation in Quantus is significantly upgraded.
Quantus	Many changes have been made to better allow the solution of the risk models. • A new scheduler to allow easy manipulation of disposal schedule changes • New POD interface • APET interface completely redone, easing input and reviewability and allowing greater flexibility and solution power • Source term interface entirely new, allowing use of source term spreadsheets for hard-coded algorithms • New solution engine and ability to view accident sequence frequency and consequences and how they contribute to risk.

SECTION 3
FACILITY AND DISPOSAL PROCESS DESCRIPTION

This section provides an overview of disposal processes for the munitions and chemical agents to be disposed of at UMCDF. (Some of the agent is stored in bulk containers, bombs, and spray tanks. For convenience, all containers may at times be referred to as munitions in this QRA.) This section includes a description of the munitions in storage and their storage configurations. Then the entire disposal process is outlined, starting with removal of the munitions from storage and transport to the disposal facility, followed by the entire demilitarization and disposal process. The plant systems are detailed, including demilitarization, furnace, control, safety, and support systems. Finally, some critical assumptions used during the risk assessment are discussed at the conclusion of the section.

This section is provided only as an overview to familiarize the reader with the facilities and processes being studied in the risk assessment. Details concerning all aspects of the disposal process are provided as appropriate throughout this report as they relate to the specific portions of the analysis. The processes and equipment are also detailed in appendices C and D.

3.1 Description of Chemical Agents and Munitions

Three chemical agents are stored in several munition types at UMCD. Each agent has unique properties that affect the risk associated with processing. Each munition type requires specific demilitarization operations.

3.1.1 Chemical Agents. Three chemical agents are stored at UMCD: two (GB and VX) are nerve agents, and one (HD) is a blister agent. Each agent has unique properties, as shown in table 3-1. GB and VX are organophosphorus esters that directly affect the nervous system. Usually odorless, colorless, and tasteless, nerve agents are highly toxic in both liquid and vapor forms. VX is more toxic than GB, but GB is considerably more volatile (evaporates more quickly) and generally poses the larger inhalation threat in an accidental release. Details concerning the toxicity of these nerve agents are discussed in appendix B of the FPEIS (PMCD, 1988). Neither nerve agent has shown any potential for long-term latent effects such as cancers.

The vesicant (or blister) agent is the mustard-derived agent HD, typically termed *mustard.* Like all vesicants, mustard is a persistent agent that damages any tissue upon contact. It affects the eyes and lungs and blisters the skin, damages the respiratory tract when inhaled, and causes vomiting and diarrhea when absorbed. Mustard can be fatal, but skin damage is the main effect. The effects of mustard are usually delayed for 4 to 6 hours, but latent periods have been observed for up to 24 hours. Mustard acts first as a cell irritant and finally as a cell poison to all tissue

Table 3-1. Characteristics of Nerve Agents

Agent	CAS No.[a]	Vapor Pressure (at 25°C)	Inhalation LCt_{50}[b,c] (mg-min/m^3)	Liquid Skin Contact LD_{50}[b] (mg/70 kg person)	IDLH[d] (mg/m^3)
GB[e]	107-44-8	2.9 mm Hg	42	1,700	0.2
VX[f]	50782-69-9	0.00063 mm Hg	18	10	0.02
HD[g]	505-60-2	0.11 mm Hg	600	7,000	N/A

Notes:

a Chemical Abstract Service Number
b Estimated dose expected to be lethal to 50 percent of exposed humans
c Based on a 25-liter per minute breathing rate
d Estimated air concentration Immediately Dangerous to Life and Health (IDLH) used for determining need for protective equipment (from AR 385-61, U.S. Army, 1997) (30-minute exposure)
e Chemical formula $C_4H_{10}FO_2P$
f Chemical formula $C_{11}H_{26}NO_2PS$
g Chemical formula $C_4H_8Cl_2S$

surfaces contacted. Symptoms include inflammation of the eyes, nose, throat, trachea, and lung tissue. Redness of the skin, blistering, and ulceration also may occur. The eyes are very sensitive to low concentrations; wet skin absorbs mustard faster than dry skin. Biological evidence indicates that mustard exposure can result in carcinogenesis.

3.1.2 Munitions.

Section 3.1.2 has been deleted due to operational secutrity review.

3.2 Overview of the Umatilla Chemical Depot and UMCDF

Section 3.2 has been deleted due to operaational security review.

3.3 Munition Storage

Section 3.3 has been deleted due to operational security review.

3.4 Removal of Munitions from Storage and Transportation

The process of removing munitions from storage and transporting them to UMCDF is similar for most munitions. All munitions except spray tanks are taken from the storage igloo and inserted into enhanced onsite containers (EONCs) on tractor-trailers.

The EONC is an upgrade to the onsite container used at TOCDF and Deseret Chemical Depot. It is a large steel cylindrical container specifically designed for transport of munitions from storage to disposal. The EONC offers additional protection in case of an accident. It is made of an outer 0.5-inch stainless steel shell that provides the basic protection, an inner 0.1875-inch stainless steel shell that allows for decontamination in case of a leak, and a foam/ceramic barrier between the shells that absorbs thermal and impact energy. The enhancements include a closing and locking mechanism that is less labor-intensive than the original onsite container, which was closed with 17 bolts. The EONC has an integral locking ring for the door, and the ring and door opening are performed hydraulically rather than through direct manual actions. The munitions are loaded into the EONC on a tray specifically designed to fit into guides on the inner shell. The tractor-trailer transports the EONC to the CHB. The EONC is shown in figure 3-10.

Because spray tanks are stored in individual steel aircraft engine shipping containers and are too long to fit into an EONC, they are loaded directly onto a diesel-engine truck for transport to the facility. Two spray tanks fit on a truck.

3.4.1 Removal from Storage. Although there are minor differences in storage yard handling operations, the majority of handling operations for different munitions are similar. The first step in all storage yard handling involves sampling the igloo atmosphere for potential agent contamination. This first-entry monitoring is always performed before workers enter a storage location.

Forklifts are used to remove the pallets and ton containers from the igloo one at a time. Two forklifts, each with a different capacity, are used for munition movement: a 4,000-pound electric forklift and a 16,000-pound diesel forklift. The electric forklift will remove the pallets individually from the igloo and place them on an EONC tray on the igloo apron. Once the EONC tray is loaded, the pallets are banded to the EONC tray. The 16,000-pound forklift then picks up the tray and slides it into the EONC. The EONC door is closed and secured.

Ton containers will be removed individually from the igloos with a 6,000-pound forklift equipped with a M1 lifting beam designed for lifting the ton containers. The ton containers are transported to the EONC tray outside the igloo. Then, a 16,000-pound forklift loads the tray into the EONC and the door is secured.

Spray tanks are stored in igloos in their own containers. A 6,000-pound forklift drags the container from the igloo using a chain, and then the 16,000-pound forklift loads the container onto a truck, two per truck.

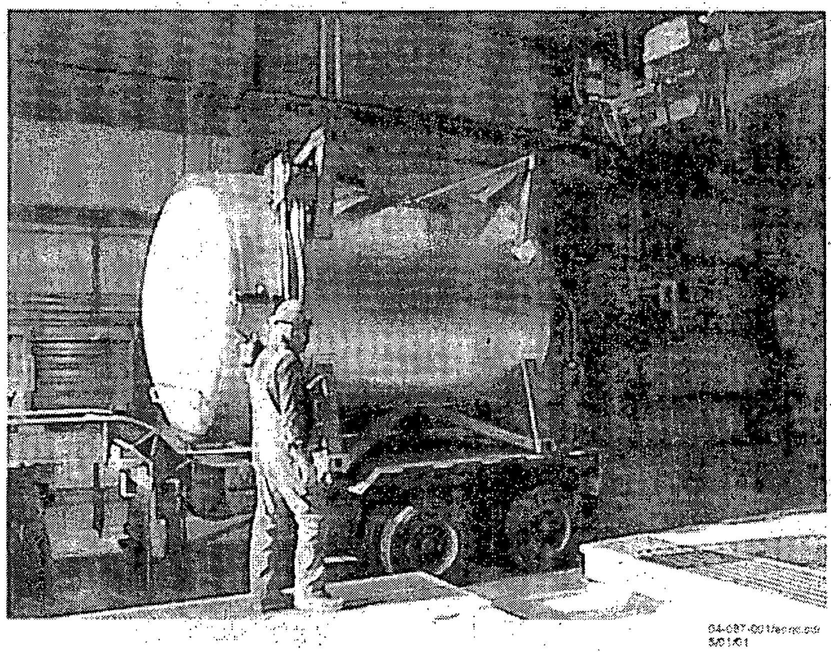


Figure 3-10. Enhanced Onsite Container

3.4.2 Transportation to UMCDF. Once the munitions are loaded into the EONC, the truck proceeds at a maximum of 10 miles per hour (mph) along roads through the gate between the stockpile area and UMCDF to one of the CHB unloading docks, a maximum distance of approximately 1.5 miles.

In addition to the precautions taken to avoid accidents, EONCs provide considerable protection. The double-walled EONC weighs approximately 8 tons when empty, and is designed to resist impact, puncture, and fire. The initial testing included a 10-foot free drop onto a flat surface, a 40-inch drop onto an unyielding probe, a 15-minute fire, and a 50,000 pound crush test. All of these tests include a no-leakage criterion in addition to the criterion that the munitions inside will be unaffected by the challenge. The fire rating of the EONC will not be exceeded even if the entire truck fuel tank is consumed in a fire.

The EONCs are taken to the UMCDF site through one of the munition transportation gates. The tractor-trailer pulls into one of the covered CHB unloading docks, a full EONC is unloaded from the transport truck to a tray, and then an empty EONC is loaded onto the transport truck for use in the storage yard. The tractor-trailer leaves the UMCDF site through the other munition transportation gate and returns to the storage area.

3.5 Munition Handling in Container Handling Building and Unpack Area

EONCs are unloaded from the trucks at one of the CHB unloading docks using an overhead crane and spreader bar with International Organization for Standardization (ISO) connectors at the four corners to lift the EONCs from the trucks. The four ISO connectors are connected through linkage rods and a pull chain, so all four must engage before lifting by the overhead crane. The EONCs are fastened to trays by ISO connectors on a floor-level conveyor system. An EONC door seal test then is performed to check for potential leaks that occurred during transportation. The trays are conveyed into a container storage area where they are stored until needed. When the UPA is ready, an EONC is conveyed through the CHB to an elevator, which lifts it to the CHB/UPA on the second floor. Munitions then are removed and placed on the conveyor system for the demilitarization process. The spray tank containers are handled similarly; they are removed from the truck and put onto CHB trays to await conveyance to the UPA. However, because of their length, spacer trays are inserted between each CHB tray holding a spray tank.

The two munition storage areas in the CHB can hold up to 48 EONCs. The storage areas provide a buffer that allows processing to continue at UMCDF when transportation activities have been halted (due to darkness or weather). When the processing systems in the MDB are ready for munitions, an EONC is removed from the storage area and conveyed to the east CHB lift. The lift door opens and the EONC is transferred into the lift. The door closes and the EONC proceeds to the second floor. On the second floor, the lift door opens and the EONC is transferred to the CHB/UPA.

The CHB/UPA could be described as an annex to the UPA. The CHB/UPA is open to the UPA, but is considered to be separate since it is technically located in a different building. In the CHB/UPA, the atmosphere in the EONCs coming out of the lift is monitored for agent with an Automatic Continuous Air Monitoring System (ACAMS) through a port to ensure that no leakage has occurred during transport. If no agent is detected, the EONCs are opened and the munition tray pulled out onto a raised scissor lift. A forklift then is used to take the munition pallets and bulk items (once in their cradle) to the UPA. If a positive ACAMS reading is obtained during EONC sampling, the EONC remains closed and is processed through the Toxic Maintenance Area (TMA). If an EONC is sent to the TMA, it first is lifted from the UPA east conveyor to the west conveyor and sent down to the CHB level via the west lift. Empty EONCs are moved by crane to the west CHB lift and returned to the CHB loading docks. In the UPA, munition pallets are placed near the conveyor for the respective demilitarization processing system. Bulk items in their cradle are placed on a tray pre-positioned on the conveyor. Operators disassemble the pallets and place rockets onto the RHS feed table and other munitions onto the input conveyors. The UPA is the last area where operators directly contact the munitions during normal processing. During non-normal processing, operators may contact munitions during TMA handling, processing of overpacked munitions, and deactivation furnace system (DFS) chute jam clearing.

3.6 Demilitarization Processing Systems

Four systems are used to process munitions: the rocket handling system (RHS), bulk handling system (BHS), projectile handling system (PHS), and mine handling system (MHS). These systems transfer munitions from the UPA to equipment located in the explosion containment room (ECR) or the munitions processing bay (MPB), where they are demilitarized.

3.6.1 Rocket Handling System. The RHS begins in the UPA where rockets are removed from pallets and placed on a feed table by two operators. The feed table is slanted to keep the rockets rolling to the drum load position. At the drum load position, the machine checks the collar on the shipping and firing tube to ensure proper orientation of the rocket. If the rocket is oriented correctly (warhead forward), a rotating drum airlock places it onto a conveyor in the explosive containment vestibule (ECV). If the collar on the shipping and firing tube is not in the correct position, the drum airlock places the rocket on a reject table located beneath the feed table.

In the ECV, the conveyor moves the rocket toward the ECR. A pneumatic stop holds the rocket on the input conveyor until the rocket drain station in the ECR is ready to process. When the drain station is ready, the blast gate into the ECR opens, the pneumatic stop lowers, and the rocket enters the ECR. When the rocket reaches the drain station, the blast gate closes and the system brings the next rocket from the UPA into the ECV.

Once the blast gate is closed, the drain station clamps the rocket from above and below. Two separate hydraulic punches (rear drain punch and front drain punch) extend through the bottom clamp, through the shipping and firing tube, and into the agent cavity. A third punch extends from above to allow air into the agent cavity. A pump pulls the agent through a strainer and into a small tank for measurement before it is pumped to the agent holding tank to await incineration in the Liquid Incinerator (LIC). When the agent drain has been verified by the tank measurement, the drain station unclamps the rocket and rotates it 90 degrees to minimize dripping. The rocket then moves to the rocket shear station (RSS) and the rocket in the ECV moves to the drain station.

At the RSS, two clamps extend from the sides to catch the shipping and firing tube collar. A pusher arm shoves the collar tight against the clamps. A hydraulic shear blade extends to cut off the fuze of the rocket (the first of eight sections to be fed to the DFS). Decontamination solution/cooling water is sprayed onto the shear blade as it extends and retracts. The sheared fuze falls into a hopper before being cycled through blast gates into the DFS. Once the fuze has been fed to the DFS, the clamps retract and the pusher arm shoves the rocket forward to complete the remaining cuts. The next four pieces, sections 2 through 5, are fed together, followed by feed of sections 6 and 7. The final section, the tail, is dropped onto the discharge gate and held there until the fuze from the next rocket is cut and dropped onto the gate.

Not all rockets at UMCDF can be processed as previously described. A certain subset of the UMCD rocket inventory is believed to contain gelled GB. These rockets are intentionally left undrained during processing because the agent abnormalities complicate the agent draining process. These rockets are sheared without punching and draining, and then processed in the DFS undrained.

The RHS has two identical rocket handling lines. Under normal operating conditions, rockets are processed on both lines. The rocket from the first line ready for feed to the DFS is completely processed before the rocket from the other line is processed.

Figure 3-11 depicts the rocket processing system and its relationships to the furnaces.

3.6.2 Bulk Handling System. The bulk item demilitarization process begins in the UPA. The overhead crane is used to take bulk items and place them in steel cradles, and then a forklift moves the bulk item and cradle onto a tray on a bypass conveyor. Ton containers and spray tanks are loaded into individual cradles. The 750- and 500-pound bombs are loaded end-to-end in one cradle (the 750-pound MC-1 bombs are loaded nose to center of cradles, whereas the MK-94 500-pound bombs are loaded with rear portions to center). The trays then are conveyed through an airlock into the ECV. Since the bulk items do not contain any explosives, the trays bypass the ECR and continue through a process gate from the ECV to the Upper Munitions Corridor (UMC). On the discharge conveyor in the UMC, the tray stops. A charge car (a conveyor cart that runs on rails in the UMC) then loads the tray and takes it to a buffer storage conveyor to wait until the bulk drain station (BDS) is ready to process the next bulk item. When the BDS is ready, the charge car loads the tray that has been in storage the longest.

The MPB is entered by passing through a process gate onto the BDS indexing conveyor. When the tray is in the correct position at the BDS, the conveyor stops. The tray is raised on load cells and the weight of the tray is recorded. The hydraulic punch extends and retracts. The drain probe is inserted and the agent is pumped to the 1,300-gallon (1,020-gallon working volume) agent holding tank, located in the toxic cubicle (TOX) room, to await processing in the LIC. During the draining of the bulk item, a drain verification system monitors the amount of agent remaining. When the agent is drained, the tube retracts and the tray is weighed again. A bulk

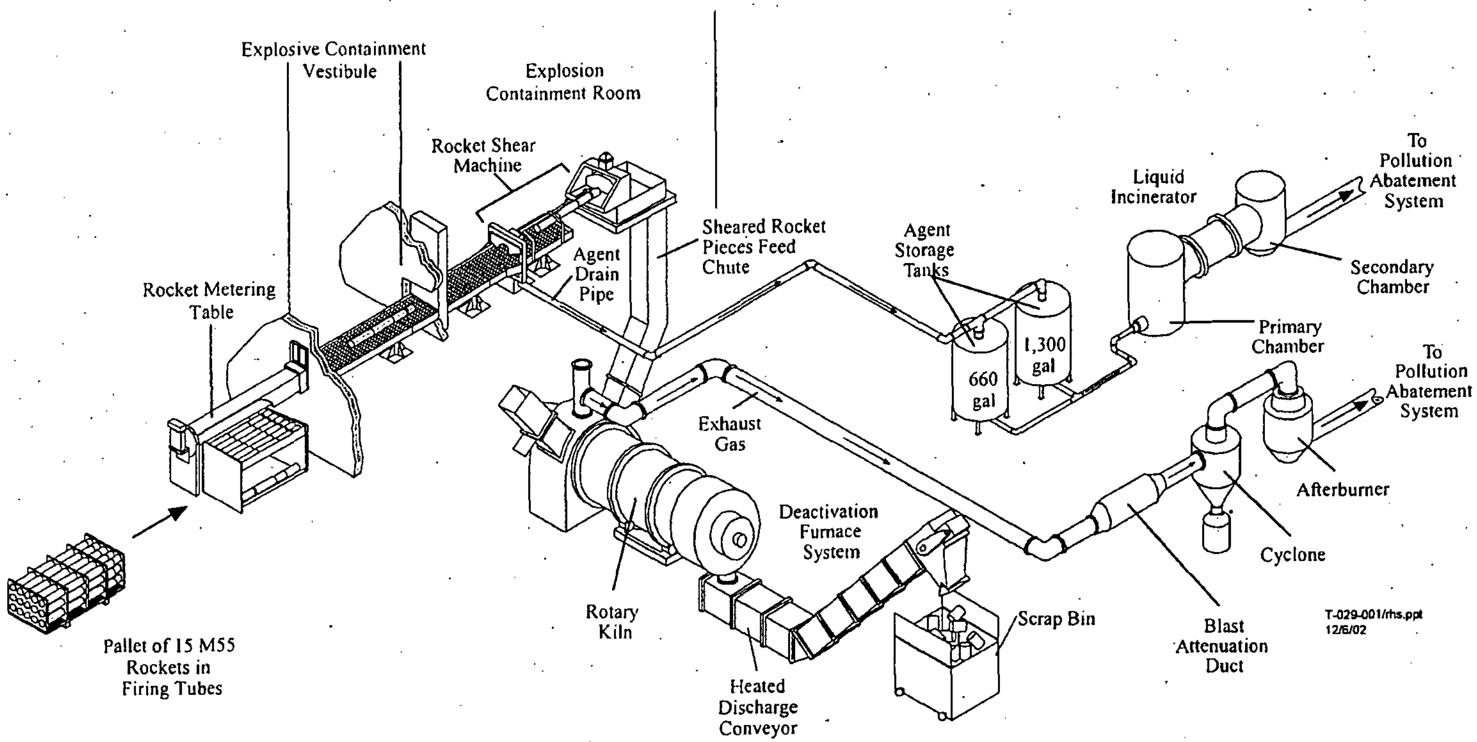


Figure 3-11. Rocket Handling System

item is not considered drained unless a minimum of 95 percent of the agent content has been drained. If the measurements show that the proper amount of agent has been drained, the tray is conveyed through the MPB to a lift. The spray tanks have an additional step involving drilling of the nose closure. Bulk items that cannot be properly drained will be processed on a tray-by-tray basis, and the temperature and residence time in the MPF will be adjusted to ensure adequate agent destruction without excessive agent volatilization rates.

Once the tray is processed in the MPB, a lift takes the tray to the buffer storage area (BSA) on the first floor. In the BSA, the tray awaits processing by the MPF. Upon leaving the BSA, the tray is conveyed through a process gate and loaded onto a charge car. If room in the BSA is needed, the charge car can take the tray to a third conveyor line in the BSA for temporary storage. When the MPF is ready for the next tray, the charge car takes the tray to the MPF for thermal decontamination.

The BHS processes bulk items on two nearly identical processing lines (the larger spray tanks only fit on line B). Both processing lines use the same charge car. If a failure occurs on one operating line, processing will be switched to the other line to continue processing. Figure 3-12 depicts one of the BHS processing lines and its relationship to the furnaces.

3.6.3 Projectile Handling System. In the UPA, projectiles are removed from the pallets and placed on a table. Operators then slide the projectiles onto a conveyor. The projectile is oriented with the tail-end forward. Once the control system verifies the orientation of the projectile, the conveyor carries the projectile through an airlock into the ECV. In the ECV, a pneumatic stop holds the projectile until the ECR is ready to process the next projectile. When the load station in the ECR is ready, the blast gate opens, the stop lowers, and the projectile enters the ECR. When the projectile reaches the load station, the blast gate closes and the next projectile is brought into the ECV from the UPA.

In the ECR, the projectile is pushed into one of eight cradles on a circular table. The table is a part of the projectile/mortar disassembly machine (PMD). The PMD is interlocked to prevent operation while any blast doors or gates are open. The PMD table rotates clockwise until the nose of the projectile is at the nose closure removal station (NCRS). The rotation positions another cradle at the load station and the next projectile is brought from the ECV. The lifting lug is removed at the NCRS. The removed pieces are placed on a conveyor to be sent to the DFS. The PMD table rotates again. This brings the initial projectile to the miscellaneous parts removal station (MPRS). Another projectile is loaded from the ECV to the load station and the projectile at the NCRS is processed. At the MPRS, supplementary charges are removed. These pieces also are sent to the DFS. When all the stations are ready, the table rotates again, bringing the initial

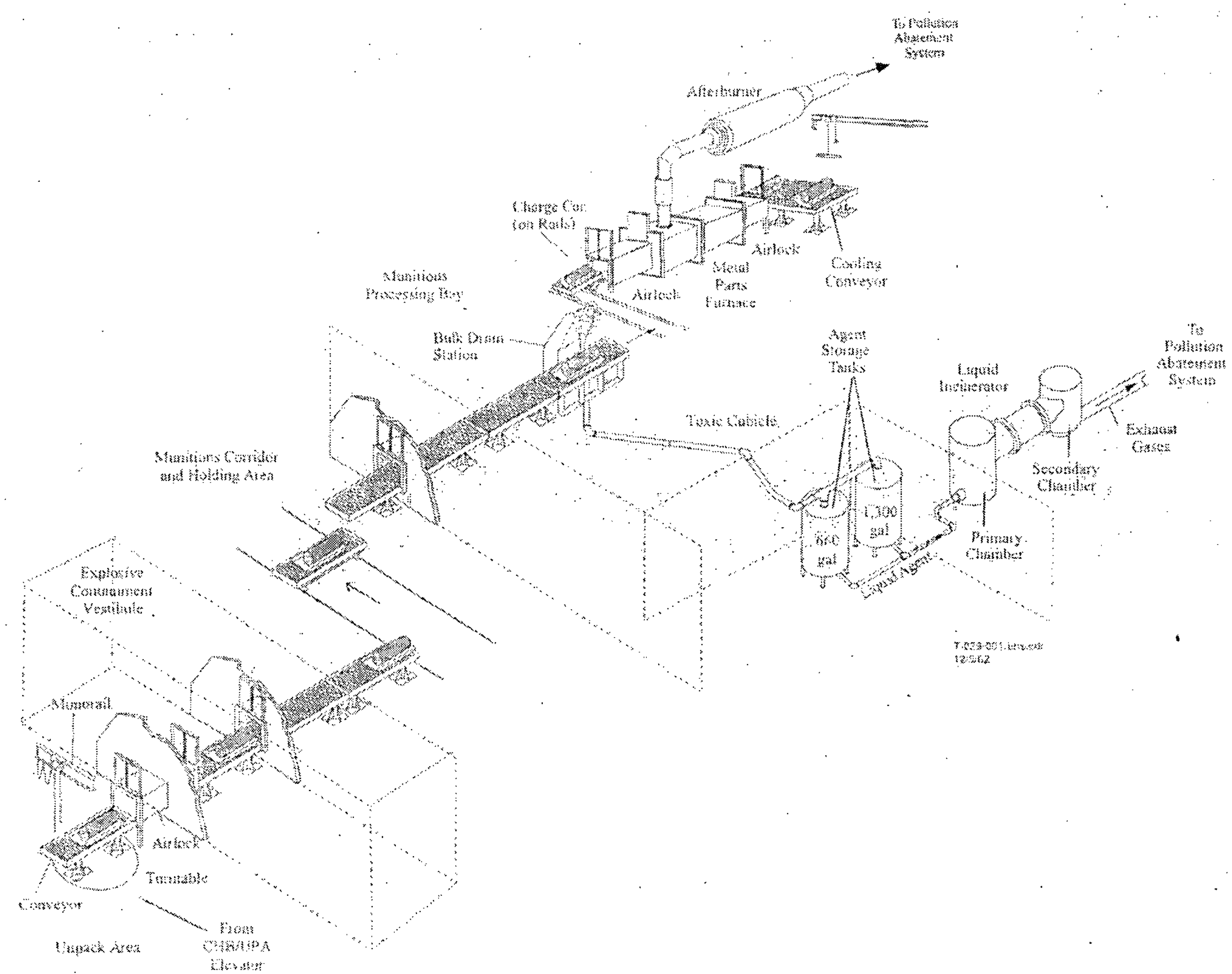


Figure 3-12. Bulk Handling System

projectile to the burster removal station (BRS). Another projectile is loaded from the ECV and the projectiles at the NCRS and MPRS are processed. At the BRS, the explosive burster is removed from the projectile and taken to the burster size reduction (BSR) machine. The BSR machine shears the bursters (a water spray is provided during shearing) and sends the pieces to the DFS. The PMD table then rotates the initial projectile to the unload station, which is opposite the table from the load station. The projectile is pushed out of the cradle onto a conveyor concurrent with another projectile being loaded from the ECV, and processing continues at the other stations. The conveyor carries the initial projectile through a blast gate into the UMC.

In the UMC, the projectile is probed to ensure the burster has been removed. The projectile then is removed from the conveyor by the tilting conveyor. The tilting conveyor carries the projectile to the tilting mechanism. The tilting mechanism clamps the projectile and tilts it onto its tail-end on a pedestal. From the pedestal, a robot picks up the projectile by its end and places it on a steel egg-crate tray located on the bypass conveyor line.

While projectiles are being sent to the ECV from the UPA, empty trays are placed on the bypass line. Each tray is conveyed through the ECV to the UMC, where a robot loads the projectiles coming out of the ECR. When the tray is full, it is conveyed to the end of the bypass line. The UMC charge car then loads the tray and takes it to a buffer storage conveyor, where it will remain until the MPB is ready to process the next tray. When the MPB is ready, the charge car will load the tray that has been in storage the longest. The tray will be sent through a process gate into the MPB.

In the MPB, there are three multipurpose demilitarization machines (MDMs). Each MDM has a six-position, rotating table with four active and two empty stations. Each position on the table has a well to hold a projectile sitting on its end. A projectile is usually present at all six positions, and operations occur at all active stations simultaneously. Each MDM has a robot to load and unload projectiles from trays on an indexing conveyor.

When the tray of projectiles enters the MPB, it passes the BDS and proceeds to an MDM indexing conveyor. The indexing conveyor carefully positions the tray, allowing a robot to grab the projectiles by the end. Each projectile is carried to the MDM load/unload station. The MDM table then rotates one position. The next active station the projectile reaches is the bore station. Meanwhile, a projectile that has already been processed is lifted out of the load/unload station and set back in the tray. At the bore station, any projectiles that have the burster well welded to the projectile body are milled to remove the weld. (Data cards for the projectile lots at UMCD do not indicate the presence of welded burster wells among the projectiles there, as discussed in appendix E12.) The MDM table then rotates the projectile to the pull and drain station (PDS). At the PDS, the burster well is removed by an expandable collet. The drain probe is inserted and the agent is pumped to the agent holding tank to await processing in the LIC. The burster well is reinserted and the table rotates the projectile to the crimp station. At the crimp station, the burster well is pulled again. A set of jaws deforms the burster well before it is returned to the projectile. This allows gases to escape the projectile body during thermal decontamination. When the table rotates again, the projectile is returned to the load/unload station. The robot then places the projectile back on the tray.

When all of the projectiles on the tray have been drained, the tray is conveyed to the end of the MPB. A lift takes the tray to the BSA on the first floor. In the BSA, the tray awaits processing in the MPF. When leaving the BSA, the tray is conveyed through a process gate and loaded onto a charge car. If room in the BSA is needed, the charge car can take the tray to another conveyor line in the BSA. If the MPF is ready for the next tray, the charge car takes the tray to the MPF for thermal decontamination.

Projectiles that cannot be properly drained will be processed on a tray-by-tray basis, and the temperature and residence times in the MPF will be adjusted to ensure adequate agent destruction without excessive agent volatilization rates.

The PHS processes projectiles on two nearly identical processing lines. Both processing lines use the same charge car, and all three MDMs can be accessed from either line. If a failure occurs on one operating line, processing will be switched to the other line. Figure 3-13 depicts one of the PHS processing lines and its relationship to the furnaces.

3.6.4 Mine Handling System. In the UPA, operators remove the mine drum lids and monitor mine drums within the pallet. Drums with lids that cannot be removed and drums in which the atmosphere tests 0.7 time-weighted average (TWA) or greater are sent to the ECV for unpacking. The operators then transfer the pallet to a staging area using a forklift. At the staging area, the drums are unpacked. The fuzes and activators are loaded into a cardboard mine, and the mines are placed upside down on the gravity conveyor. The cardboard mine also is placed on the gravity conveyor. The conveyor takes the mines to the ECV, where they are metered to enter the ECR one at a time.

In the ECR, the metal and cardboard mines are transported to the mine machine. A two-point sensor at the verification station is used to differentiate between the metal and cardboard mines. The orientation station rotates the metal mines to prevent punching through the burster located in

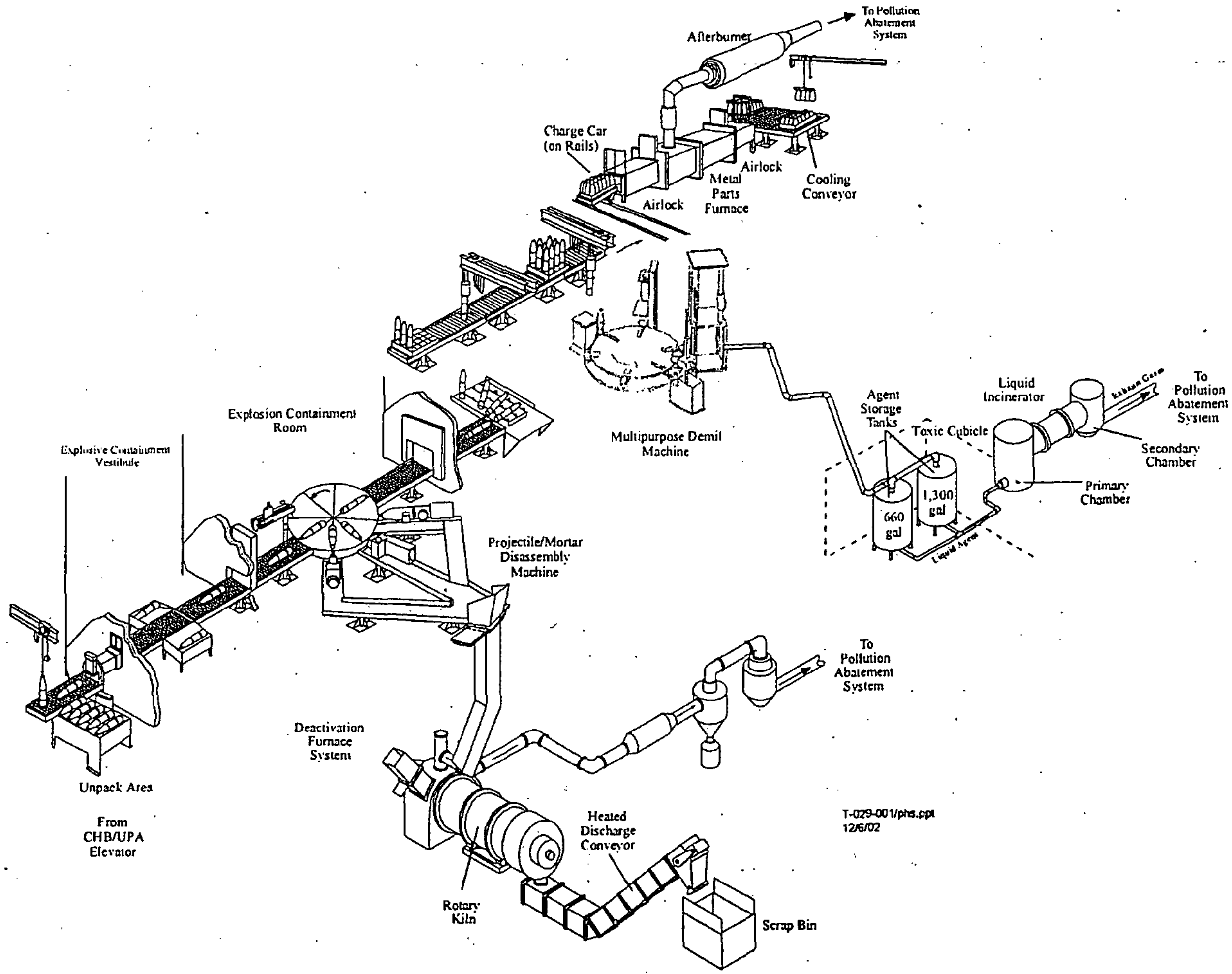


Figure 3-13. Projectile Handling System

the side well. A yoke assembly then turns the metal mine onto its side (90-degree rotation). When the metal mine is vertical, a punch is extended through its side. The agent is drained through the hollow punch to a small quantification tank. When the quantification tank verifies that at least 95 percent of the agent has been drained, the agent is pumped to the agent holding tank to await processing in the LIC. Next, the metal mine is turned upside down (another 90-degree rotation) and placed on a trolley. When a cardboard mine enters the ECR, the same basic sequence of events occurs except that it is not punched; rather, a complete 180-degree rotation of the yoke assembly occurs, thus placing the cardboard mine on the trolley. The trolley transports the metal and cardboard mines to the Fuzewell Assembly Removal Station (FARS). The fuzewell assembly is unscrewed at the FARS and left inside the metal mine, and the cardboard mines are processed through the FARS but remain unchanged. The mine is conveyed off the conveyor directly onto the DFS gate. Figure 3-14 depicts the MHS and its relationship to the furnaces.

3.7 Furnaces and Incinerators

The demilitarization process needs to destroy chemical agent, including any agent remaining on metal parts or dunnage, and the energetic materials, including bursters and propellant. To detoxify the chemical agents, the molecular bonds must be broken and the components reacted to produce much less hazardous materials. Complete oxidation of the agent molecules through combustion achieves the detoxification goals. All agent, agent-contaminated munition components, and drained bulk containers are processed in furnaces or incinerators to ensure complete combustion of the agents. Energetic materials are burned, and all waste material is maintained at high temperatures long enough to ensure destruction of any remaining agent.

Three types of furnaces are used in the demilitarization process. The DFS is used to destroy (deactivate) explosive components, the MPF is used to decontaminate metal components, and the LIC is used to destroy liquid agent removed from munitions. Each furnace has a PAS that removes combustion byproducts from the exhaust gases. A PFS also is included for each furnace to provide additional safety measures in the event of an upset condition. The DFS, MPF, and LIC discharge through a common stack.

3.7.1 Deactivation Furnace System. The DFS is used to decontaminate and destroy explosives and propellant. Rocket energetics include the fuze, burster, and propellant. After the agent is drained, the rockets are sheared and all the pieces sent to the DFS. Mine energetics include the central booster, burster, fuzes, and activators. The fuzes and activators for all three mines in a drum are sent to the DFS in a single cardboard mine. The drained mine body is sent to the DFS with the central booster and the burster. Projectile energetics include the burster and supplementary charges. Projectile supplementary charges removed by the PMD are fed to the DFS with the burster pieces from the BSR.

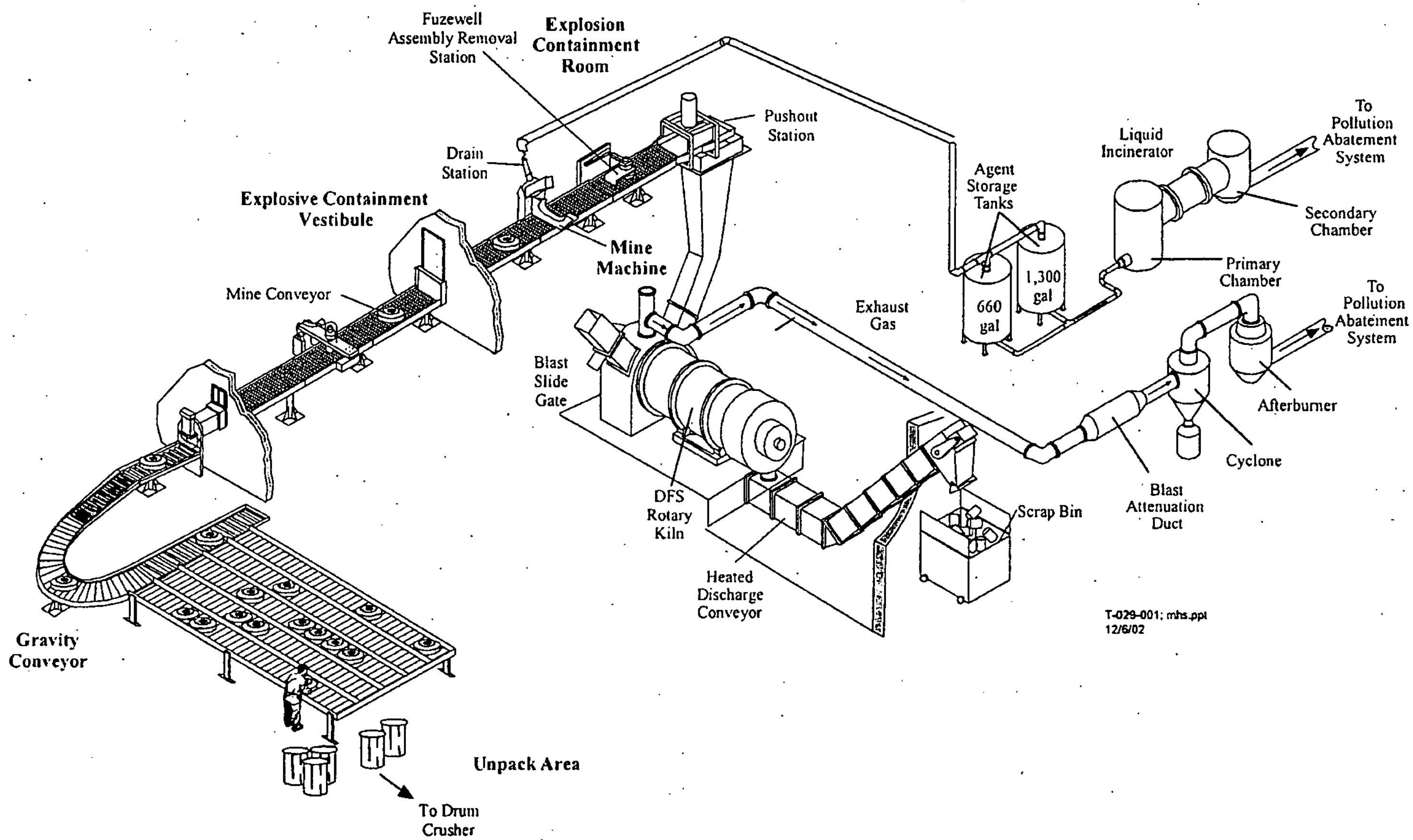


Figure 3-14. Mine Handling System

Figure 3-15 illustrates the layout of the DFS. The DFS has a rotary kiln design that is fed munition pieces via a chute from each ECR. Each chute has two gates to prevent the propagation of explosions between rooms. The first gate is referred to as the slide gate. A slide gate is located in each ECR. When the furnace is ready, the slide gate opens and the munition pieces fall into the chute onto the second gate. The second gate is referred to as the tipping valve. After the slide gate is confirmed closed, the tipping valve opens. The munition pieces fall into the charge end of the rotary kiln.

Once munition pieces are in the kiln, a spiral baffle keeps them separated. As the kiln rotates, the baffle moves the pieces down the kiln. The furnace temperature (1,100°F for rocket campaigns, 1,050°F for other campaigns) ignites the burster and propellant. A burner management system (BMS) oversees the operation of the burner and is hardwired to provide all safety interlocks required by the National Fire Protection Association (NFPA). Interlocks on the DFS are also in place for environmental compliance with RCRA requirements for treatment of hazardous wastes. The explosive components fed to the DFS have been sheared or punched to create a large surface area (except for gelled GB rockets). The explosives' increased surface area and lack of confinement allow them to burn rapidly without a detonation. In the event of a detonation, the kiln is constructed of 2-inch thick steel at the charge end. A blast attenuation duct prevents explosive overpressures from reaching equipment in the PAS. Additionally, the

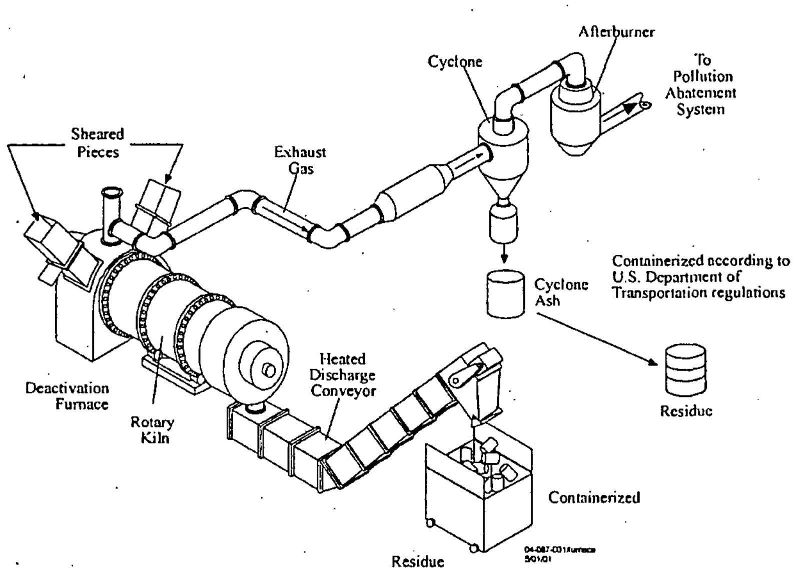


Figure 3-15. Deactivation Furnace System

DFS room is designed as a blast enclosure with reinforced concrete walls, blast doors, and blast dampers. When munition pieces reach the discharge end of the kiln, they are dropped onto the heated discharge conveyor.

The heated discharge conveyor passes under 24 electric heater banks. Energetic materials are burned by the time they reach the heated discharge conveyor. Residual agent has evaporated and been destroyed. The heaters ensure the 5X level of decontamination (defined as exposure to at least 1,000°F for a minimum of 15 minutes) is reached. Decontaminated scrap then drops into a discharge bin enclosed in its own explosive containment compartment outside the DFS room.

The exhaust gases from the furnace are pulled out of the furnace at the charge end of the kiln. The gases pass through a blast attenuation duct to suppress the pressure wave in the event of an explosion. A cyclone separator removes ash from the exhaust stream. An afterburner is used to further ensure complete combustion of agent and other combustion products. The exhaust then flows through the DFS PAS/PFS.

3.7.2 Metal Parts Furnace. The MPF is used to thermally decontaminate bulk containers and munition bodies after removal of their explosives. Projectile shells, drained ton containers, bombs, spray tanks, mine arming plugs, and munition overpacks are processed through the furnace on trays. Three furnace zones are used to allow semicontinuous feed of the furnace. The primary chamber is maintained at 1,450°F for bulk containers and 1,600°F for projectiles. The metal parts are monitored for agent in an exit airlock, and then cooled on an open conveyor (located outside the MDB) before being containerized for disposal. A BMS oversees the operation of the burners and is hardwired to provide all safety interlocks required by the NFPA. Interlocks on the MPF are also in place for environmental compliance with RCRA requirements for treatment of hazardous wastes. Figure 3-16 illustrates the MPF.

The trays enter the furnace through a charge airlock. The airlock doors are interlocked against opening at the same time. The inner airlock door also is interlocked from opening when the inner door of the discharge airlock is open. When zone 1 of the furnace is empty, the inner airlock door is opened and the tray enters the furnace.

In zone 1, the load is heated until the agent reaches its boiling temperature and starts to volatilize at a substantial rate. The tray then is moved to zone 2, where the majority of the agent is vaporized and destroyed and the metal is heated to the 5X decontamination level (defined as exposure to at least 1,000°F for a minimum of 15 minutes). Then, the tray is moved to zone 3, where it remains until the 5X criterion is met.

Once the metal has met the 5X criterion, the tray exits the furnace to the discharge airlock. The airlock is vented to the afterburner to maintain negative pressure. In the airlock, the tray is

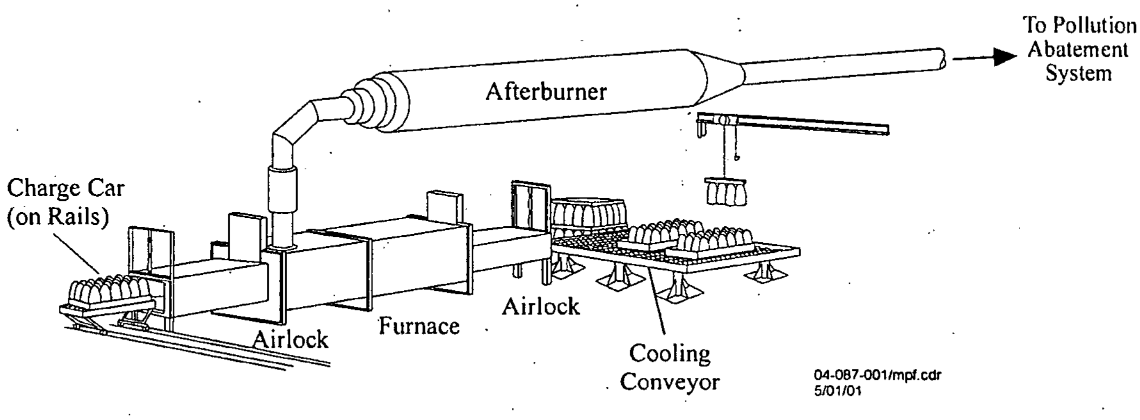


Figure 3-16. Metal Parts Furnace System

partially allowed to cool until it can be monitored with an ACAMS device for any remaining agent contamination. If no contamination is detected, the tray exits the discharge airlock and is conveyed to a cooling conveyor outside the MDB where the metal parts cool before being containerized for disposal. If agent vapors are detected, the tray is moved from the airlock back into zone 3 of the furnace for further processing. Space must be maintained between zones to ensure that a tray can be moved backward (for additional treatment to meet ACAMS criteria) without forcing a zone 1 tray out of the front end of the MPF.

The exhaust gases from the MPF are pulled out of the furnace through a duct at zone 1. The gases pass through an afterburner to ensure all agent has been destroyed before entering the MPF PAS/PFS.

3.7.3 Liquid Incinerator. As agent is drained from munitions, it is collected in the agent holding tank. When the system is at operating conditions, the control room operator (CRO) will start the agent feed from the agent holding tanks to the furnace. The agent is oxidized in the primary chamber, and the exhaust gases pass through a secondary afterburner chamber. Spent decontamination solution (spent decon) or process water can be injected into the secondary chamber for thermal destruction or cooling, respectively. The exhaust gases then enter the LIC PAS/PFS. Figure 3-17 illustrates the LIC system.

As agent is drained from munitions, it is collected in the 1,300-gallon (1,020-gallon working capacity) agent holding tank located in the TOX room. A 660-gallon agent tank with a 500-gallon working capacity also is available as a surge volume, but is not used during normal operations.

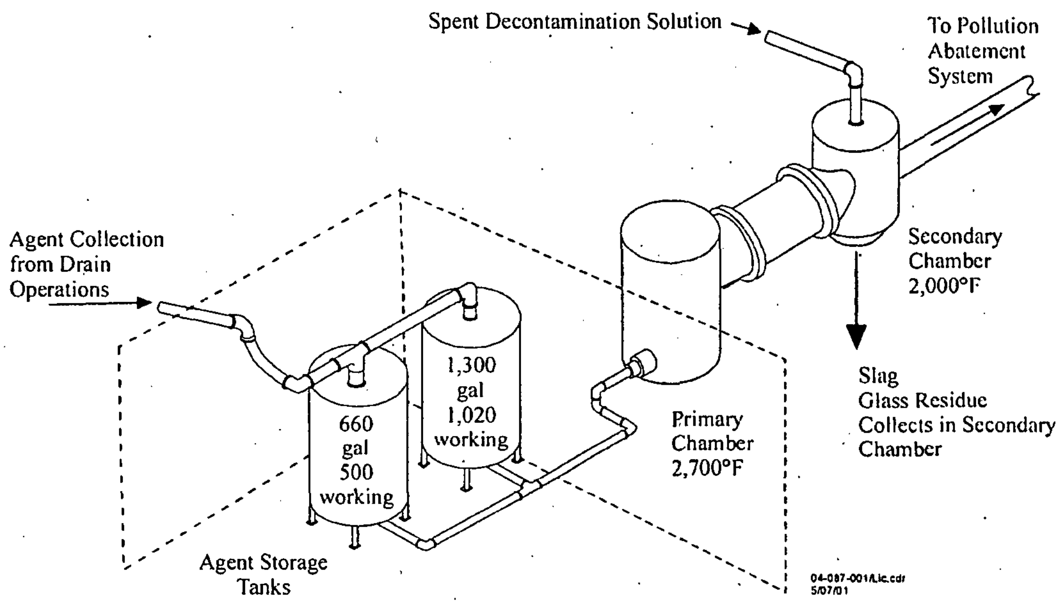


Figure 3-17. Liquid Incinerator System

A high alarm indicator on the 1,300-gallon tank denotes that the tank is full and will not allow further addition of agent into the tank. The agent passes through a duplex strainer before being pumped to the LIC primary chamber.

The LIC primary chamber is a vertical, refractory-lined cylinder with a natural gas burner located on the sidewall near the bottom. Natural gas or propane gas, combustion air, and agent enter the furnace through the burner to maintain 2,700°F. A blower drawing air from the primary chamber room supplies combustion air. The plant air system provides atomization of the agent as it is injected into the chamber. Once agent feed is started, the heat of agent combustion allows the natural gas feed to be reduced until the agent is the primary fuel source for the chamber. Thermocouples in the primary chamber exhaust duct monitor the temperature, and the control system modulates the natural gas flow to maintain the temperature at its setpoint. The exhaust gases are pulled from the primary chamber to the secondary chamber to ensure the agent is destroyed with a destruction and removal efficiency of at least 99.9999 percent.

The LIC secondary chamber, like the primary chamber, is a vertical, refractory-lined cylinder. However, the side-mounted burner is located near the top instead of the bottom. Natural gas and combustion air enter the chamber through the burner to maintain 2,000°F. A blower drawing air from the secondary chamber room supplies combustion air. Process water or spent decon is injected through a top-mounted nozzle. Plant air is used to atomize the injected fluid. The fluid is injected to provide a means of exhaust temperature control. Under normal operations, agent and spent decon are not processed simultaneously. A BMS oversees the operation of the secondary chamber burner and is hardwired to provide all safety interlocks required by the NFPA. Interlocks on the LIC are also in place for environmental compliance with RCRA requirements for treatment of hazardous wastes. Exhaust from the secondary chamber is pulled into the LIC PAS/PFS.

When spent decon is incinerated in the secondary chamber, a layer of salt is deposited in the chamber. These molten salts flow to the bottom of the chamber where they collect and solidify. The slag removal system uses a series of electric heater elements to re-melt these salts and remove them via a gate near the bottom of the chamber. The molten slag pours into a drum waiting on a conveyor below. When the drum is full, the gate is closed and another drum is moved into place. When the slag removal has been completed, the drums of slag are allowed to cool. Once cooled, the drums are covered and conveyed outside the building where they are packaged for disposal.

3.8 Operations Control Room

The operations control room (CON) provides direction for all aspects of facility operations. The CON is maintained at a positive relative pressure to prevent migration of any substances into the room. The air intake passes through a series of filters to ensure that the CROs are able to safely direct facility operations at all times. An automatic fire suppression system provides fire protection.

The CON uses several operator consoles and a large status display panel to direct the facility operations. Each console includes two advisor screen monitors, two closed-circuit television (CCTV) monitors, a keyboard, and a trackball pointer device. The advisor screens display color diagrams of plant systems and are used to monitor and control the plant. The CCTV monitors display real-time images of facility equipment and their surrounding areas. The keyboard is used to enter commands to access information requested by the operator and the trackball is used to select icons on the advisor screens for further action. The status display panel consists of several large monitors that provide additional information to operators.

3.9 Safety Systems

The facility also has several systems designed to mitigate potential accidents and ensure safety. The ECRs protect against the effects of potential detonations in areas that process energetic material. The filtered cascading HVAC system constantly draws air from uncontaminated areas through contaminated areas and to the filters, preventing agent migration to areas of lesser contamination. The fire protection system monitors all plant areas (including incinerator rooms) for signs of a fire and has automatic fire suppression systems to extinguish any such fire in the CHB, UPA, CON, TOX, and ECRs. The agent monitoring system continuously monitors for agent to alert workers of agent migration. The door monitoring system controls the opening of doors to prevent agent migration through airlocks. These systems provide an extra level of protection to workers and the public.

3.9.1 Explosive Containment. During the disposal process, several steps require the direct handling of energetic materials such as propellant, fuzes, and bursters. Whenever such handling of energetics occurs, there is always the remote possibility of an explosion. In anticipation of such an event, the disposal steps involving direct removal of energetics from munitions are performed by remote control in ECRs. These rooms prevent the explosion from damaging the structure of the building and prevent agent migration due to a pressure wave.

Rockets, mines, and projectile bursters are processed in the ECRs. These rooms are designed to contain a blast equivalent to the detonation of 15 pounds of TNT. Access to these rooms is through one of three blast gates or two blast doors. Operations in the rooms are prevented from occurring when any of these doors or gates is open. The airflow through the rooms is through blast dampers, which will automatically close if an explosion occurs.

The DFS also is located in an explosion containment room. It is designed to contain a blast equivalent to the detonation of 28.2 pounds of TNT. Access to the room is through two blast doors, which are interlocked with the furnace feed gates. The furnace is fed from the ECRs located directly above. Two blast gates form an airlock, preventing propagation of an explosion between these rooms. The airflow through the DFS room is through blast dampers, which will automatically close if an explosion occurs. The scrap from the furnace exits the heated discharge conveyor into a blast enclosure. When that area is opened for emptying, two gates on the heated discharge conveyor chute close. The exhaust gases from the furnace pass through a blast attenuation duct that prevents explosive overpressures from reaching the cyclone separator.

3.9.2 Cascade Ventilation and Filtering. During the disposal process, several areas of the facility can reasonably be expected to reach some level of agent contamination. This agent contamination cannot be allowed to migrate out of the building or to areas where unprotected workers could be present. To prevent this migration from occurring, the MDB cascade ventilation system decreases the air pressure in proportion to the potential contamination of the room. This ensures that migration only occurs towards areas that have a higher contamination level.

The expected level of agent contamination categorizes the MDB rooms. The ventilation ducts are arranged such that air cascades from the areas of no agent contamination to areas of expected liquid or vapor contamination. These areas are categorized as types 'A' through 'E,' where 'A' could be most contaminated (liquid agent expected) and 'E' is least contaminated (no liquid or agent vapor allowed). The floor plans provided in section 3.11 show the ventilation classifications for facility rooms.

Outside air is supplied to the HVAC system by two of three air handling units, with the third unit in standby. The header ducts distribute the supply air through 13 different paths. The amount of air supplied to each room is regulated by means of a manual fixed-volume balancing damper that has been pre-adjusted to maintain the desired pressure and flow rate through each room. The air is moved through the MDB by several cascaded flow routes, which are ultimately tied together through a common duct leading to the exhaust air filtration units. Seven of nine air handling units (one is in standby and one in maintenance) pull air from the MDB, through the filters to the 120-foot stack. Air flowing through the air filtration units to the atmosphere passes through a series of nine filters.

Each exhaust air filtration unit contains a large particle prefilter, a high-efficiency particulate air (HEPA) filter, a series of six activated carbon filters, and a second HEPA filter to remove carbon particles (refer to figure 3-18). The air stream is monitored after the first, second, third, fourth, and fifth carbon filters in each unit. If agent above the TWA is detected past the first carbon filter bank, the first two filter banks of that unit are replaced within 3 months of detection. If agent above the TWA is detected past the second carbon filter bank, the first three filter banks of that unit are replaced within 3 months of detection. If agent is detected past the third bank, the unit is shut down immediately and all but the fifth banks are replaced. If agent is detected past the fourth or fifth carbon filter bank, the unit is shut down and all the carbon filters are replaced. The standby unit will be started to replace the shutdown unit.

3.9.3 Fire Protection. The possibility of a fire at UMCDF is a serious concern due to the possible presence of agent and/or explosives. Automatic fire detectors are located throughout the facility in each room. These include photoelectric, ultraviolet/infrared, and thermal detectors. The detectors alarm in the CON and also on panels located outside of the main entrances to the central protected areas.

Automatic pre-action sprinkler systems protect the CHB and UPA. The thermal detectors in each system automatically open a deluge valve, admitting water to the sprinkler system. The sprinkler heads open only if exposed to heat from a fire.

The agent collection system (ACS) located in the TOX room is protected by dry-chemical systems. In the event of a fire, the dry-chemical system smothers the fire. An alarm will sound before the system initiates to allow personnel to evacuate the area. A fire extinguishing medium system protects the CON by displacing the oxygen when activated. A limited area deluge

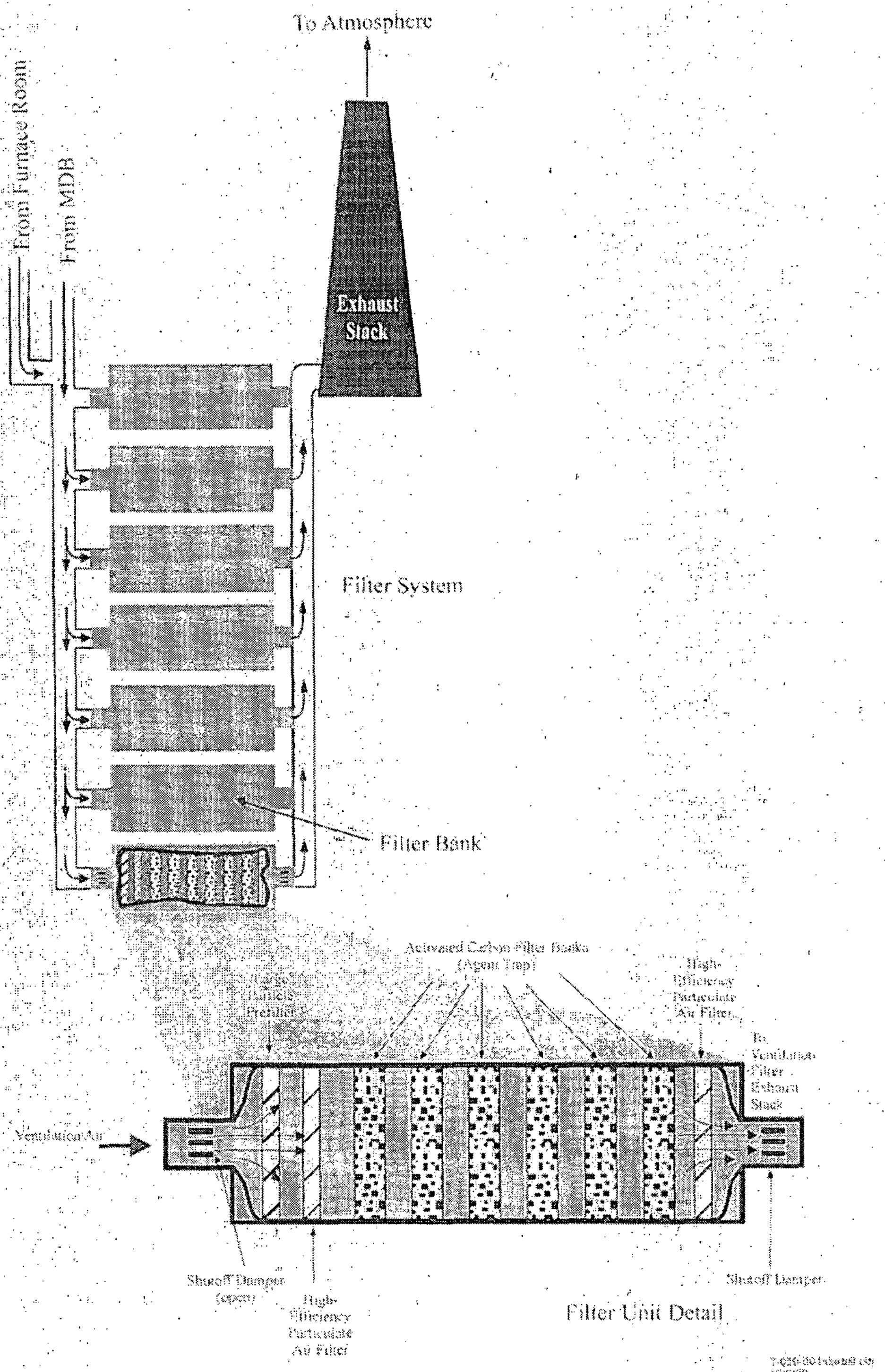


Figure 3-18. Carbon Filter Units

sprinkler system protects areas in the ECR that may collect combustible residues and be vulnerable to fire.

3.9.4 Agent Monitoring. Agent monitoring is provided throughout the facility by a series of ACAMS. Each ACAMS samples air from a given area during a preset period. Any agent present in the sample air stream is collected on a solid sorbent for gas chromatographic analysis. The results of the analysis are displayed and also recorded on a strip-chart recorder. An audible and visible alarm is triggered when the agent level is above the preset hazard level. All ACAMS data are permanently collected by the process data acquisition and reporting (PDAR) system.

3.9.5 Door Monitoring. The door monitoring system allows access to the facility without upsetting the MDB cascade ventilation system. In addition to ventilation control, the system also allows operators to observe the status of doors and provides pneumatic assistance in opening doors against large pressure differentials.

During normal operations, the cascade ventilation system provides pressure differentials to prevent agent migration to lower level contamination areas. Open doors upset the pressure balance in adjacent rooms and can allow agent migration. The door monitoring system interlocks airlock doors to ensure air changes occur in the airlock before opening to the lower level contamination area. The system also interlocks multiple doors entering the same room to prevent access when the pressure differential has been lowered by another open door. All door interlocks are provided with a local override switch for emergency egress.

In addition to the door interlocks, the door monitoring system also provides an interface for operators. CROs are able to view the status of the MDB doors via a status screen. Local operators are presented the door interlock status via red and green indicators. Local operators also are given pneumatic assistance in opening doors that require greater than 30 pounds of force to open. This is often the case due to the pressure differentials created by the cascade ventilation system.

3.10 Support Systems

The facility has a variety of other systems that play roles in supporting the main systems, mitigating potential accidents, or ensuring safety. Support systems include the main electrical power; plant, instrument, and life support air; hydraulics; fuel gas; process water; cooling systems; and pollution abatement systems, along with their accompanying filter systems.

3.10.1 Electric Power. Electric power is required to operate nearly every component at the facility. The distribution system is divided into the primary and secondary systems. The primary system consists of two 4,160-V substations, switchgear, and diesel generator. The secondary system consists of 480-V switchgear, motor control centers, distribution transformers, panelboards, and two uninterruptible power supply (UPS) systems. The loads in the facility are divided into three categories: critical, essential, and utility.

The primary power system takes power from the Umatilla Power Cooperative 115-KV distribution grid and steps it down to 4,160 V for use at the facility. Two independent feeders supply power to the site. Boardman and McNary substations provide power to the 4,160-V switchgear (PPS-SWGR-101 and PPS-SWGR-102, both rated 1,200 A). A third switchgear (PPS-SWGR-103) for emergency power connects a diesel generator to either (or both) switchgear on a loss of power.

The secondary power system consists of four 480-V switchgear, SPS-SWGR-101 through -104. Each switchgear is fed by a separate 4,160-/480-V dry-type transformer. Normally, each transformer feeds one 480-V switchgear; however, by closing the appropriate tie breakers, the system can be configured so that SPS-101 and SPS-102 can be fed by either of two transformers. SPS-103 and SPS-104 can be cross-connected similarly. Each 480-V switchgear provides power to several loads including motor control centers, which distribute power to the smaller loads. Power to the two UPS modules is provided by SPS-101 and SPS-102. Each UPS includes a battery, rectifier, inverter, and static transfer switch. The UPS modules will provide battery power to critical loads if there is an interruption in normal utility power. In addition, if the UPS is taken offline for maintenance, the UPS can be completely bypassed by feeding the UPS distribution panel via the maintenance bypass switch from the bypass source. The UPS distribution panel also can be fed via the static transfer switch, which is powered from a different source than the bypass source. Power is distributed to critical loads from 208-/120-V panel UPS-PANB-101. Either UPS module can supply power to the panel. One UPS module is designated as the primary, with the other unit coming online should the primary unit fail.

The facility loads are categorized by the requirements of service. Critical loads are loads that cannot experience any interruption in power, such as programmable logic controllers (PLCs). These loads are all powered by the UPS panelboard. Essential loads are loads that are required for safe plant shutdown, but can withstand an interruption in power for a few seconds, such as life support air compressors. The diesel generator powers these loads during a loss of offsite power. Utility loads are those loads that may result in a loss of production, but would not present a threat to health or safety, such as process water pumps. These loads are not powered during a loss of offsite power.

3.10.2 Compressed Air. Compressed air is required by many components throughout the facility for a variety of reasons. Three different systems provide compressed air based on the requirements of the load. Equipment throughout the plant, such as furnaces, air-operated pumps, pneumatic cylinders, and utility stations, uses plant air. Pneumatic valves and instrumentation use the instrument air system. Personnel in demilitarization protective ensemble (DPE) use the life support system. These three systems provide for the compressed air requirements at the facility.

Plant air is drawn from the mechanical equipment room (20-133) through an inlet air filter by one of two redundant air compressors. The air is compressed to 125 pounds per square inch gauge (psig) before entering an oil separator, aftercooler, and moisture separator. From the moisture separator, the air flows through a common header, then through a coalescing prefilter to the air dryer units. From the air dryer units, the air passes through a particulate removal afterfilter to the plant air receiver. From the plant air receiver, plant air is distributed to the various loads via a plant air header.

The instrument air system is very similar to the plant air system. Air is drawn through an inlet air filter by one of two redundant air compressors. The air is compressed to 125 psig before entering an intercooler and aftercooler along with their respective moisture separators. From the moisture separator, the air flows through a common header, then through a coalescing prefilter to the air dryer units. From the air dryer units, the air passes through a particulate removal afterfilter to the instrument air receiver. From the instrument air receiver, instrument air is distributed to the various loads via an instrument air header.

The life support system also draws air from the mechanical equipment room (20-133), but the inlet filter includes HEPA and chemical, biological, and radiological (CBR) filters. One of two redundant oil-less air compressors compresses the air to 125 psig. Air from the compressor enters an intercooler and aftercooler along with their respective moisture separators. From the moisture separator, the air flows through an air receiver into a common header, then through a coalescing prefilter to one of two redundant air dryer units. From the air dryer units, the air passes through catalytic and charcoal filters to the life support air receiver. From the life support air receiver, air is distributed to the various loads via an air header. Air entering the receiver is checked for moisture and carbon monoxide content.

3.10.3 Hydraulics. The hydraulic system provides high pressure hydraulic fluid to the hydraulic cylinders and motors throughout the facility. Hydraulic pressure powers conveyors, blast doors and gates, and the majority of the demilitarization machines. This pressure is provided by the hydraulic power unit and distribution system. Three independent loops supply hydraulic power. Each loop has two equipment hydraulic modules and several valve manifolds to distribute the fluid. Accumulators maintain a nearly constant pressure and allow for fluctuations in loading. Heat exchangers maintain the fluid temperature at an acceptable level.

The hydraulic power and distribution system contains six hydraulic power units (HYPUs), 18 valve manifolds, interconnecting lines, and associated piping and electrical equipment. Each

HYPU consists of a hydraulic pump, fluid reservoir, accumulators, monitoring instrumentation, and associated piping and valves. The HYPUs are paired to provide limited redundancy.

Each pump is electrically driven, has variable displacement, and pressurizes the fluid to 2,200 pounds per square inch (psi). The pump discharge is protected against overpressure by a relief valve. All pumps are standard for commonality of spares. Each HYPU is equipped with accumulators. The accumulators satisfy peak flow demands and provide pulse dampening. The hydraulic fluid used in the system is a glycol-based, nonflammable fluid.

3.10.4 Fuel Gas. The fuel gas system provides a continuous source of regulated gas to the facility. The gas is used by furnaces and hot water boilers. The system consists of a primary and backup supply.

The primary supply of fuel gas is commercial natural gas supplied by the local utility main supply line. The gas is supplied at a nominal pressure of 50 psig. The gas pressure is reduced as it is distributed to the various loads throughout the facility.

A limited backup supply of LPG is available from a 10,000-gallon onsite tank. The gas can be used to maintain some loads, but is not considered a backup for furnace operations.

3.10.5 Cooling Systems. The primary and secondary cooling systems provide the heat removal required by components at the facility. The primary cooling system cools the plant air, instrument air, and life support air compressors and the MPF secondary cooling system. There are two secondary cooling systems: one cools the equipment hydraulic modules and the DFS lube oil, and the other cools the MPF discharge airlock door.

The primary cooling system is a closed-loop system that uses an outdoor, air-cooled heat exchanger and a 50 percent glycol-water cooling medium. The system consists of a primary cooling-medium air cooler, an expansion tank, a pair of redundant circulating pumps, an air separator, and associated instruments and piping.

The MPF secondary cooling system is a closed-loop system used to cool the MPF discharge airlock door. The water is cooled by a heat exchanger with the primary cooling system. The MPF secondary cooling system consists of the heat exchanger, two redundant pumps, an air separator, an expansion tank, and associated instruments and piping.

The DFS lube oil and hydraulic module systems are cooled separately from the other cooling systems. The hydraulic module secondary cooling system is a closed-loop system used by the six equipment hydraulic modules and the DFS lube oil. The water is cooled by a separate chiller.

The system consists of a heat exchanger, two redundant pumps, an air separator, an expansion tank, and associated instruments and piping.

3.10.6 Process Water. The process water system is used for numerous plant operations, including shear blade cooling for the rocket shear machines; cooling water spray to the DFS feed chute; and water supply to the decon and utility stations, the secondary LIC chambers during startup and shutdown, and the individual PASs for each of the furnaces, among other uses.

Process water is softened water supplied from the water treatment system. The process water system consists of a storage tank, three supply pumps, and associated controls and indicators.

3.10.7 Pollution Abatement Systems and PAS Filter Systems. All the furnace systems have a PAS/PFS to chemically treat exhaust gases. The PAS/PFS systems for the DFS, MPF, and LIC are nearly identical and share a common exhaust stack. Each PAS has a quench tower, venturi scrubber, scrubber tower, mist eliminator vessel (in some texts, this may be referred to as the demister vessel), filter system, and two-stage induced draft fan. Figure 3-19 illustrates a PAS. Additionally, there are two backup mist eliminator vessels that can be brought online when the primary mist eliminator vessel of the LIC, MPF, or DFS is shut down for maintenance.

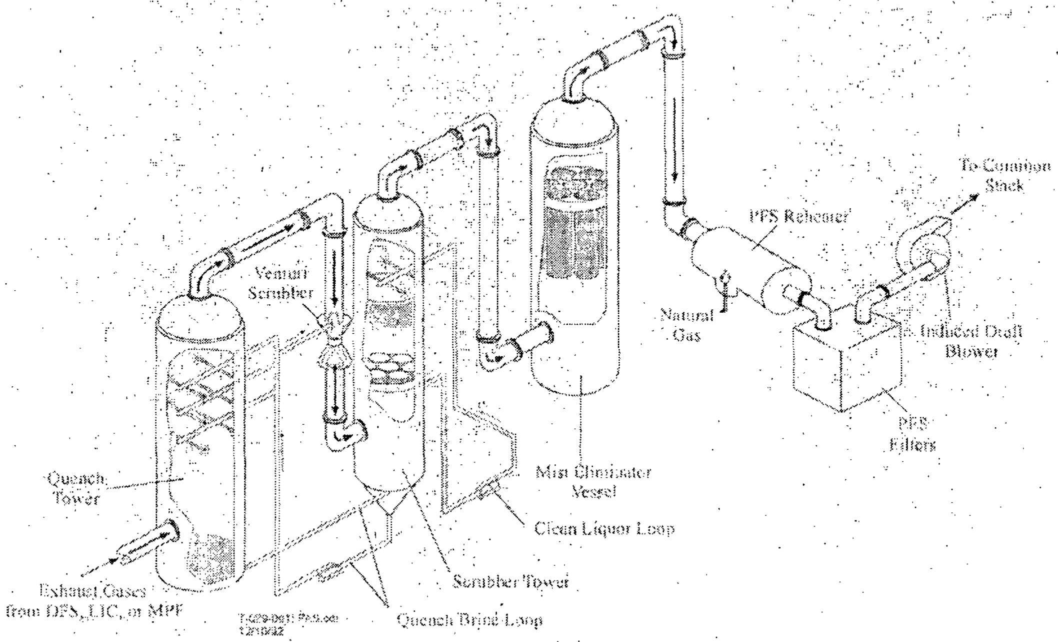


Figure 3-19. Pollution Abatement System

The quench tower is a vertical vessel designed to cool the exhaust gases from the furnaces. As gases enter the bottom of the tower through a refractory-lined duct, a brine solution is sprayed from the top. As the mist evaporates, the gases are cooled to near the saturation temperature. The spray collects in the bottom of the tower and drains by gravity to the scrubber tower sump. The cooled gases exit the top of the tower and flow to the venturi scrubber.

The venturi scrubber is a variable-throat venturi with multiple caustic brine nozzles. As gases from the quench tower enter the venturi, the brine reacts with the acidic gases and entraps fine particulates. The gases and spray are accelerated through the venturi throat and then make a 90-degree turn to enter the bottom of the scrubber tower. The spray and particulates are removed from the gas stream by the turn and collect in the scrubber tower sump. Brine from the quench tower and venturi scrubber collects in the scrubber tower sump. The brine is recycled back to the quench tower and venturi scrubber.

The scrubber tower neutralizes the acidic gases in the airstream. Gases enter at the bottom and flow upward through a packed bed with a caustic clean liquor flow. A chimney tray collects the clean liquor, which is cooled by the PFS clean liquor air coolers and recycled at the top of the packed bed. The neutralized gases exit at the top of the tower.

The gases exit the scrubber tower and enter the bottom of the mist eliminator vessel. The gases flow up through the vessel past vertical candle elements. The candles remove metal oxides and other entrained particulates. The mist condenses on the candles and flows down to the sump, where the liquid is recirculated to the scrubber tower. Non-soluble particulates eventually necessitate replacement of the candles. The clean gases exit the top of the fiberglass vessel.

The gases flow from the mist eliminator to the PFS gas reheater. This gas-fired burner decreases the relative humidity of the exhaust gases to less than 55 percent by increasing the temperature of the exhaust gas. A blower supplies combustion air from the outside to the reheater burner. A BMS oversees the burner and provides all safety interlocks required by the NFPA.

The exhaust gas then flows to the PFS filter unit to remove any trace agent or organic vapors present in the unlikely event of a furnace upset. The PFS filter unit consists of a prefilter, HEPA filter, series of two carbon filter banks, and final HEPA filter. The LIC and MPF PFSs each have one filter unit. The DFS PFS has two filter units. A PFS carbon filter unit is available as a common spare for any of the PFS carbon filter units. The LIC or MPF PFS carbon filter unit also can be used as a backup unit for the DFS if those PFS carbon filter units are not in operation. The exhaust gases exit the PFS filter and are pulled into the induced draft fan.

The induced draft fan maintains the negative pressure in each furnace. The fan is actually two separate single-stage fans operating in series. Adjustable speed drives allow the flow through the fans to be controlled. If utility power is lost to the facility, an emergency diesel generator comes online, and a single stage of the DFS or MPF fans will be operated at reduced speeds.

3.11 UMCDF Munitions Demilitarization Building Floor Plans

In a few portions of the QRA (notably the fire analysis), the building layout and location of equipment are important to the analysis. Often, discussions refer to rooms by number. Figures 3-20 through 3-23 provide floor plans of the four basic levels of the MDB, with room numbers, symbols where necessary (such as UPA for Unpack Area), and in a few cases, important equipment noted. The MDB has two basic floors, but each of these floors is approximately two floors high. Thus, in some areas of the building, there are first-floor and second-floor platform areas that effectively form two subfloors in addition to the main floors. Layouts for all four of the floors are provided in the four drawings. Also indicated on the drawings are ventilation categories A through E, as discussed in section 3.9.2.

3.12 Processing Campaigns

The munitions at UMCD will be processed over a series of eight campaigns at UMCDF. Each campaign will process all the munitions of a single type and agent, except the first two campaigns at UMCDF, which include co-processing where bulk items are processed in conjunction with M55 rockets. Following each campaign, a changeover period will occur when the facility will be converted to process the next munition or agent type. The specific campaign durations are critical to the evaluation of risk. In Quantus, the scheduler function is used to establish the disposal schedule and campaign duration. Table 3-3 lists the campaign durations associated with each campaign modeled in this QRA. Based on input from the site, the Defense Acquisition Board schedule for UMCDF from September 2001 was used in this analysis, and can be updated throughout the life of the facility to reflect the most accurate understanding of the disposal schedule. The Quantus scheduler interface can be used to update the analysis based on user inputs of actual or proposed schedule changes. The first two campaigns have been broken into multiple sections so that risk associated with co-processing can be displayed separately in the risk results.

Table 3-3 also lists the calendar time associated with each campaign. It identifies an average throughput rate as a function of calendar time. These values are used in the Quantus risk models to ensure accounting for all processing hours and disposal of all munitions. These throughputs are for calculation purposes only—they do not represent reliability-based throughputs of disposal machinery capability or experience. The calculated accident sequence frequency and risk values are averages over the entire campaign duration. Further refinement of the models can be done to focus on evaluating the time variation in risk within a campaign, but that is not a part of the initial QRA model development scope.

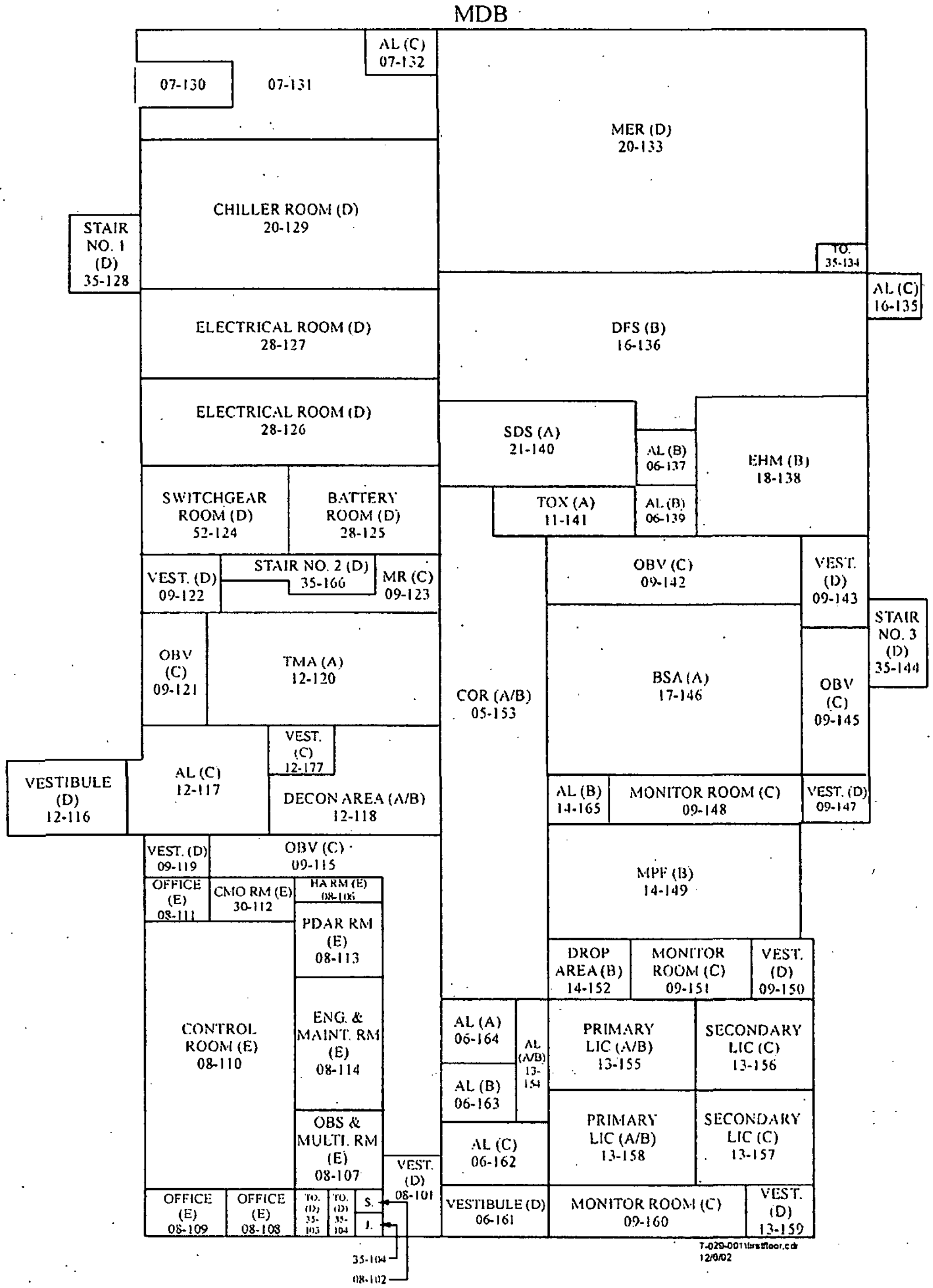


Figure 3-20. First Floor Plan

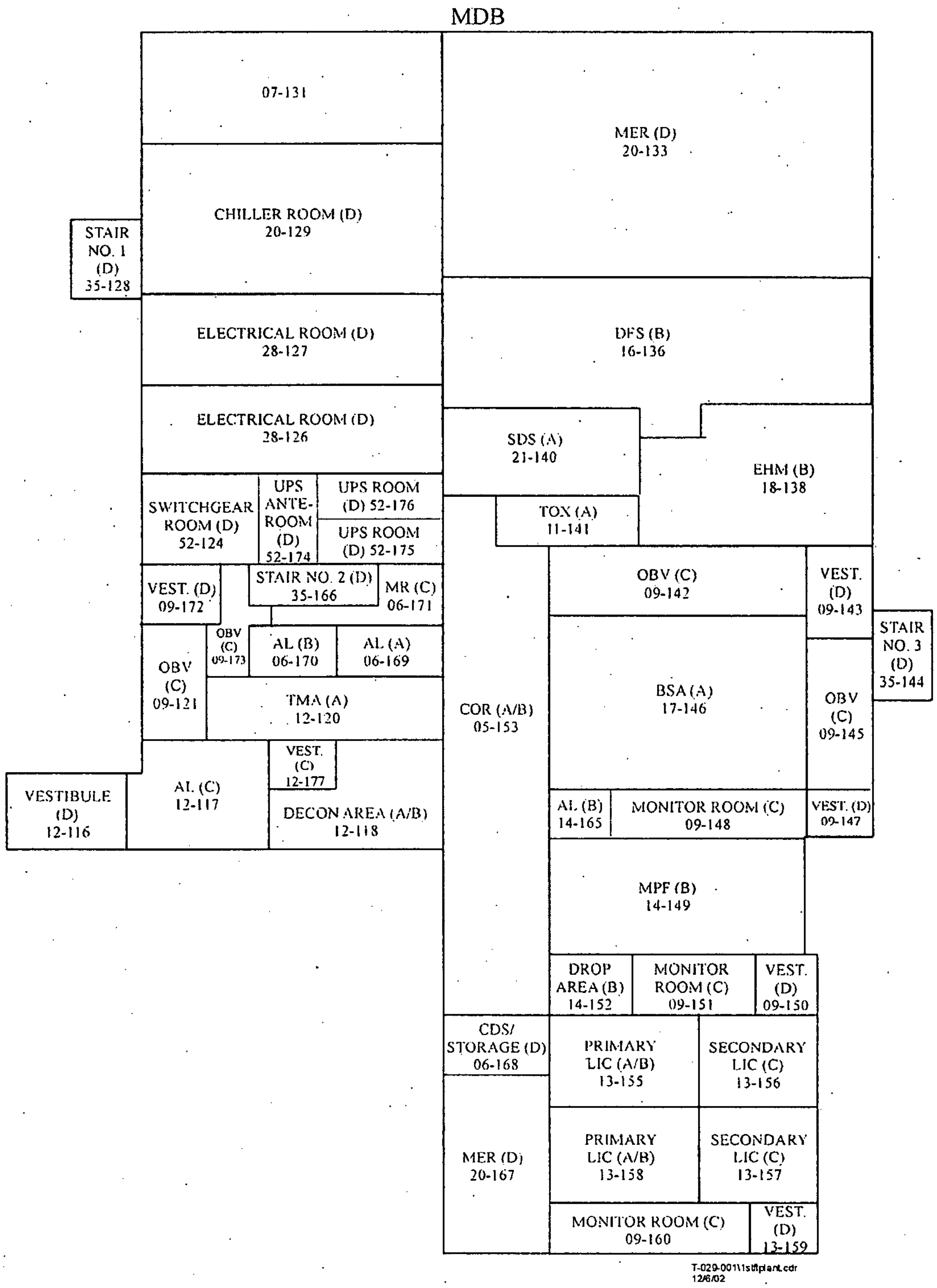


Figure 3-21. First-Floor Platform Plan

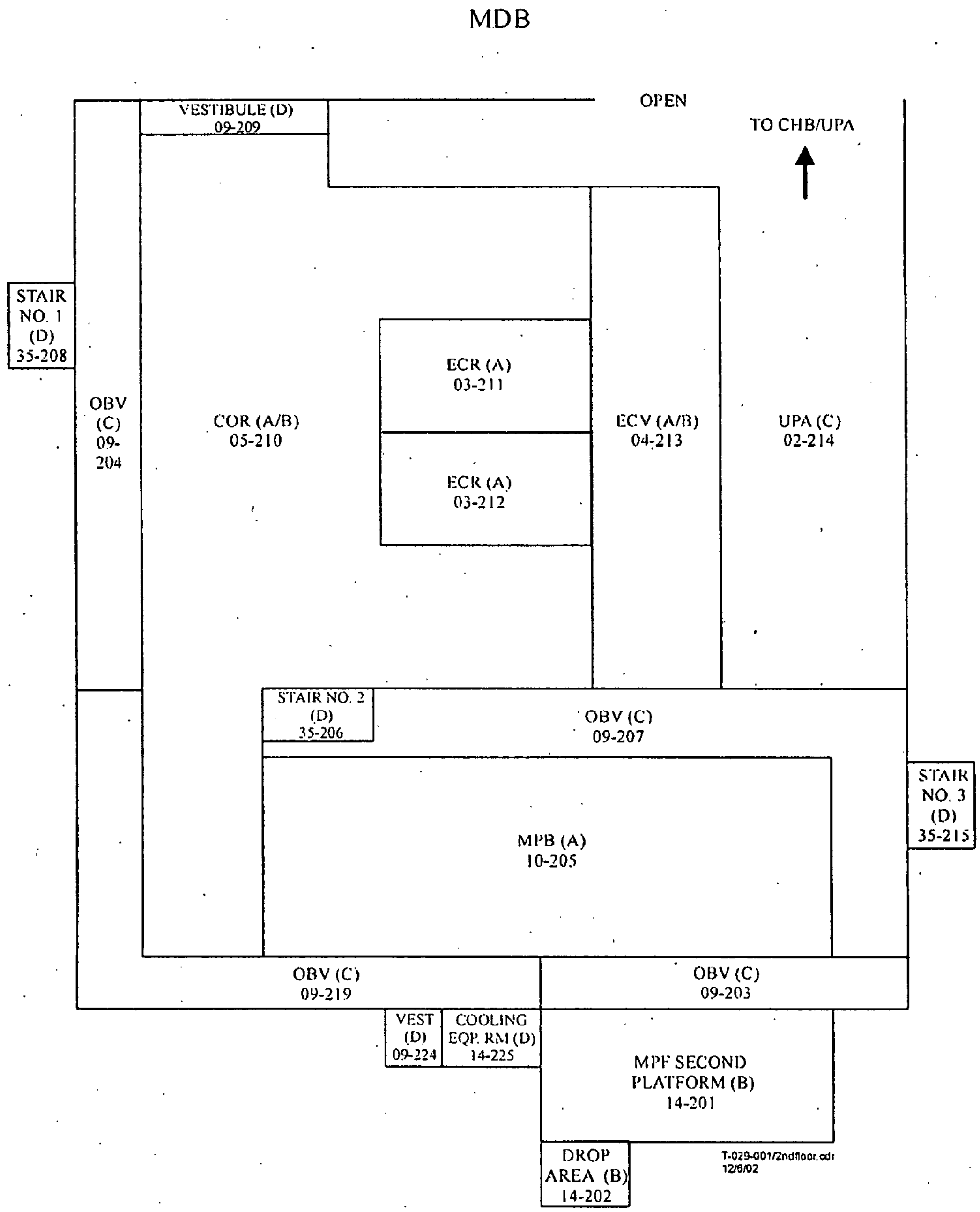


Figure 3-22. Second Floor Plan

MDB

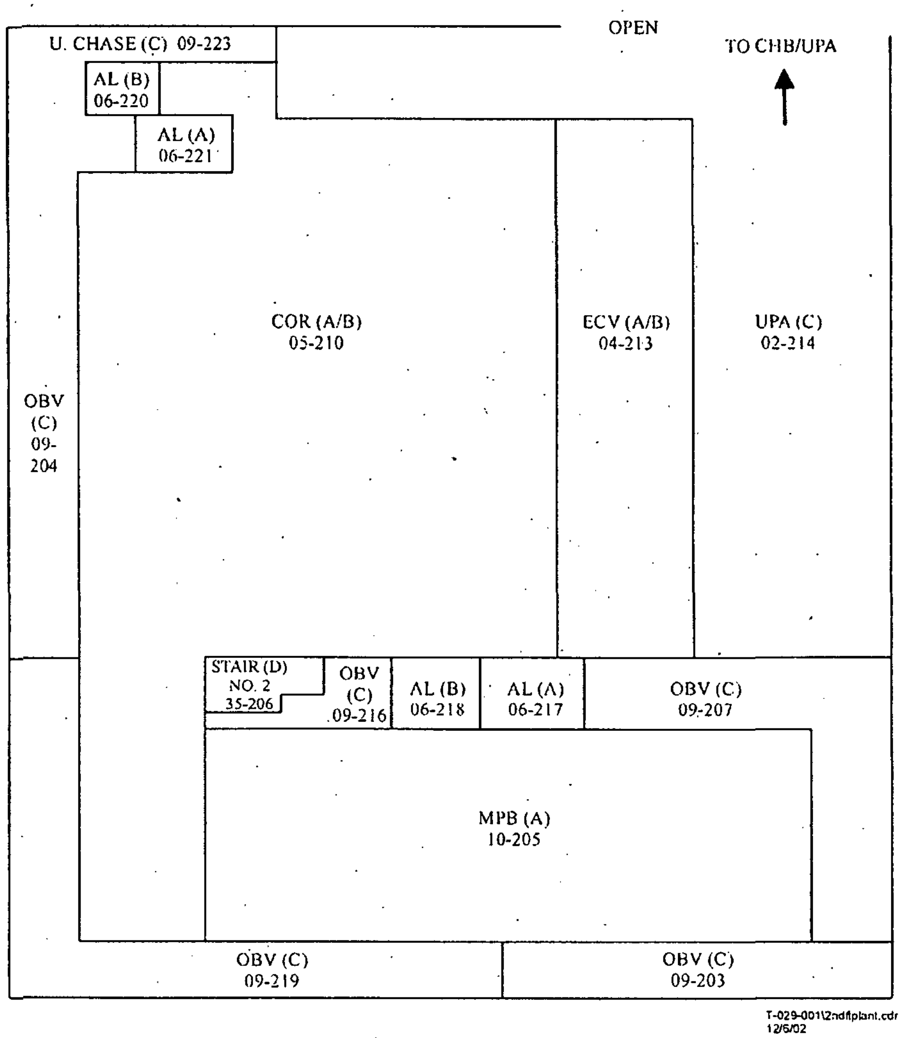


Figure 3-23. Second-Floor Platform Plan

Table 3-3. Disposal Schedule Used in UMCDF QRA

Munition		Start Date	Finish Date	Days[a]	Weeks	Total Hours	Number of Munitions	Average Rate[b] (munition/hr)
1a	GB M55 Rockets (1)	02/28/03	07/03/03	126	18.0	3,024	19,299	6.38
1b	GB M55 Rockets with MC-1 Bombs	07/04/03	03/05/04	246	35.1	5,904	37,680/2,418	6.38/0.41
1c	GB M55 Rockets with MK-94 Bombs	03/06/04	03/06/04	1	0.1	24	153/27	6.38/1.13
1d	GB M55 Rockets (2)	03/07/04	10/16/04	224	32.0	5,376	34,310	6.38
	Changeover	10/17/04	04/24/05	190	27.1	4,560		
2a	VX M55 Rockets (1)	04/25/05	06/22/05	59	8.4	1,416	6,253	4.42
2b	VX M55 Rockets with Spray Tanks	06/23/05	08/02/05	41	5.9	984	4,345/156	4.42/0.16
2c	VX M55 Rockets (2)	08/03/05	09/08/05	37	5.3	888	3,921	4.42
	Changeover	09/09/05	11/11/05	64	9.1	1,536		
3	VX 8-inch Projectile	11/12/05	12/14/05	33	4.7	792	3,752	4.74
	Changeover	12/15/05	01/25/06	42	6.0	1,008		
4	VX 155mm Projectile	01/26/06	03/30/06	64	9.1	1,536	32,313	21.04
	Changeover	03/31/06	05/18/06	49	7.0	1,176		
5	VX Land Mines	05/19/06	07/18/06	61	8.7	1,464	11,685	7.98
	Changeover	07/19/06	01/24/07	190	27.1	4,560		
6	GB 155mm Projectile	01/25/07	04/21/07	87	12.4	2,088	47,406	22.70
	Changeover	04/22/07	06/02/07	42	6.0	1,008		
7	GB 8-inch Projectile	06/03/07	07/27/07	55	7.9	1,320	14,246	10.79
	Changeover	07/28/07	02/02/08	190	27.1	4,560		
8	HD Ton Containers	02/03/08	11/22/08	294	42.0	7,056	2,635	0.37
	Closure	11/23/08	11/22/09	365	52.1	8760		
	Totals			2,460		59,040	220,599	
	Total operating days (no closure)			2,095				
	Total operating years			5.7				

Notes:

[a] The schedule provided here is the calendar time associated with operations. This includes fully operational periods as well as downtime for maintenance, etc.

[b] This is an average rate across the calendar time. It is used in the risk calculations to ensure that the entire calendar time of a campaign is considered. It is not the typically cited "throughput" of the equipment itself, because it also includes downtime.

The models in the QRA have built-in assumptions on throughput rates for the campaigns, based on the number of munitions in the stockpile at UMCD. No attempt has been made to characterize risk at reduced throughput rates, such as during any initial trial burns or the first few months of processing.

3.13 QRA Assumptions Concerning Processing

Assumptions concerning facility design and operation are listed in the relevant sections throughout this report. Some of the critical assumptions are described in this section. These key assumptions could impact the risk results if actual operations were substantially different from those assumed. In most cases, the assumptions are based on preliminary documentation that has not yet been finalized. In some cases, the assumptions reflect planned features that have not yet been fully implemented.

a. *Manual Processing.* Based on observations and discussions with TOCDF operators, it is currently assumed portions of the demilitarization process will be performed in remote manual mode a significant fraction of the time. (For the current model, a very conservative 50 percent remote manual has been used for a number of operations to judge the importance of this aspect.) The PMCD *Chemical Demilitarization Operations Manual* contains a requirement to minimize time in manual mode (PMCD, 1998); however, experience at TOCDF indicates that attempts to do so have not been fully successful. Some operations, such as first-floor charge car movements are typically done in manual, while other operations with furnaces are more likely in automatic. The QRA models for operations account for the actual control systems involved in operations. The hard-wired interlocks are credited appropriately in either mode of operation. Software interlocks providing safety shutdowns are always engaged, even in remote manual mode. Disposal operations are not done locally. The PODs have been used to hypothesize cases where some local operations might be required before remote operations could continue.

b. *Nonstandard Operations.* Many different process stops may be postulated that would result in the need for operations staff intervention. For example, a crane failure with a suspended load or a conveyor failure might call for a non-routine operation. Nonstandard operations were included in the PODs and risk models only when unique actions were identified to be necessary. Past experience in the chemical process and other industries indicates that ad hoc actions attempting to recover from process events can be significant relative to personnel safety. It is assumed that the appropriate disciplines will review any nonstandard recovery operations before implementation.

c. *MPF Feed Airlock Vent.* The MPF feed airlock vent system was assumed to be disconnected.

d. *Radio/Cellular Phone Usage.* Restricted use of radios is assumed during rocket processing. The use of two-way radios, but not cellular phones, is addressed in the PMCD *Chemical Demilitarization Operations Manual* (PMCD, 1998). It is assumed cellular phones are prohibited by a specific policy and procedures (final procedures are not yet available to verify this assumption). Less restricted use of radios and cellular phones could impact risk. DPE radios are low power and do not impact risk.

e. *Handling at the Storage Area.* Forklift handling, particularly of the rockets at the igloos, presents the opportunity for a significant accident since accidents could propagate to other rockets. The current models are based on handling operational steps provided by UMCD personnel cognizant of the activity. Leaker handling activities are known since this is an ongoing practice, but all the details of igloo unloading for disposal processing are not yet finalized for all munitions. The results of this QRA are sensitive to the handling operations, and significant changes in operational steps could change the assessment of these accidents. As necessary, the QRA can be updated as part of risk management activities to reflect changes in planned operations.

f. *Munitions Tracking System.* The models for the munition processing systems include consideration of a munitions tracking system still under development. Assumptions regarding this system are provided in the bulk and projectile handling analyses in appendix D. These assumptions can be updated when final plans are available.

g. *Transportation.* The models assume that the transportation of munitions will be in accordance with current policies limiting transportation activities in threatening weather conditions. In addition, the models limit transportation to the hours of 7 a.m. through 5 p.m. as a conservative average.

h. *Leak in Transit.* Munitions (except spray tanks) detected as leaking in the UPA are assumed to be transported to the TMA, decontaminated, and sent through the facility opposite to normal process flow.

i. *Agent Storage in Tanks.* It is assumed for this analysis that the 1,300-gallon (1,020-gallon working volume) agent tank (currently noted as a surge tank on other documentation) will be the primary storage tank. It is assumed that the

660-gallon tank (500-gallon working volume) will be maintained empty as a possible surge tank. If used during processing, the surge volume will be emptied as soon as possible.

j. *Dunnage Incinerator (DUN).* The DUN will not be used at UMCDF. Instead, the current plan is that dunnage will be placed into a drum and transported to an igloo for storage. At a later time, contaminated waste and DPE suits will be returned to the facility from storage and processed in the MPF.

k. *Storage of Spent Carbon.* Spent carbon is assumed to be packed in standard Department of Transportation containers and transferred to an igloo for storage prior to disposal. Spent carbon will be processed in the DFS; however, this process remains undefined and has not been studied in this analysis.

l. *UMCDF Worker Population.* The number of Disposal-Related Workers at the UMCDF site was estimated based on numbers from TOCDF. As UMCDF operations staffing plans develop, the number of workers will be verified with the numbers currently being used and can be updated as necessary. Population data for other workers at UMCDF were collected from the site and are specific to UMCD.

m. *Mine Drum Crushing.* Mine drums are assumed to be crushed in the UPA; however, space limitations in the UPA may necessitate moving the mine drum crushing operation to another location.

(This page intentionally left blank.)

SECTION 4
INTERNAL EVENTS AND SYSTEMS ANALYSIS

Risk is assessed by first identifying possible accidents that could lead to health consequences to the public or facility workers. Then, the occurrence frequencies of such accidents are estimated. Accidents can be systematically examined as a series or progression of events that follow an initiating event, or initiator.

As described in section 2, initiating events can be categorized as either internal or external events. Internal events are those originating within the process such as equipment or human failures. External events are associated with challenges outside the process, such as earthquakes, aircraft crashes, and tornadoes. This section only deals with internal events (external events are discussed in section 5).

The first step in the sequence analysis is the search for initiators. Then, logic models are developed to determine the combinations of specific events that could result in the initiators. Two different logic structures, summarized as follows, were used in the internal initiating events analysis:

- *PODs.* PODs were used to identify possible deviations from normal, safe facility operations that could potentially initiate an agent release or cause an agent exposure to a worker (an initiator).

- *Fault Trees.* Fault trees were used to model facility systems and operations to determine ways that combinations of events and subsequent failures could cause the initiators described in the PODs.

4.1 Process Operations Diagrams

Accidents can be systematically examined as a progression of events, called an *accident sequence*, which describes how a facility or operation moves from a normal, safe state to an accident condition in which the public or workers are exposed to potential health consequences. Given that risk is examined in terms of accident sequences, it is essential that the identification and modeling of these sequences be as complete as possible. The first step, therefore, is an exhaustive consideration of the potential events that could initiate an accident sequence.

Each accident sequence can be described as beginning with an initiating event, or initiator, that starts an offnormal progression of events that could result in agent release. For analytical convenience, events are usually categorized as either *internal* or *external* events. Internal events occur within the process system, such as an operational error or equipment failure. External events occur outside the process system or have widespread effects. Thus, an operational error or a failure of a piece of equipment is an internal event while earthquakes, fires, or aircraft impacts are external events.

Internal initiators are identified through a systematic evaluation of the entire disposal process, from loading munitions at the storage yard to final disposal of the munitions and their agent. The evaluation is aided by the use of PODs that delineate the steps of a process and the possible deviations from normal processing that might occur at each step.

The POD is a step-by-step flow diagram of process operations that enables a systematic review of each process step. The PODs were developed by listing the steps of normal operations based on system documentation. The focus in the PODs for the QRA is on identifying process steps in sufficient detail to identify deviations that could lead to agent-related risk to the public or the site and disposal workers. If used for other purposes such as industrial hazards, a different level of detail might be considered, but the analysis process would be similar.

The POD development process is subjective, particularly in determining what level of detail to consider, i.e., what process steps and deviations to identify. However, the level of detail necessary becomes apparent throughout each of three principal review activities. These activities are highlighted in the following text and described in further detail in section 1.6.

Intra-Project Reviews. These are the technical reviews completed throughout the analysis to meet the needs of the QRA project and satisfy specific quality assurance requirements established by SAIC.

PMCD and UMCDF Staff Reviews. These reviews begin during model development and continue as draft versions of the PODs are distributed and comments are solicited from PCMD and the site staff.

Expert Panel Review. The expert panel meets periodically throughout the QRA process to review models and results. This panel provides a review that is independent of all reviews done by SAIC, PMCD, or UMCDF staff.

It is important to note that, as a result of these reviews, the PODs have undergone numerous changes since first published in draft form (SAIC, 1999a). These changes include adding new initiators, changing the developed status of initiators, and modifying the process steps as more information is gained.

Given each normal processing step, it was necessary to consider the deviations that could occur during that step or if that step did not happen properly. There are three principal types of deviations: 1) those that can be described as initiators, directly leading to the potential for agent release; 2) those that create a different process pathway because different operational steps must ensue as a result of the initiator; and 3) those that do not cause an immediate problem but may cause one at some later step in the process (e.g., a munition loaded backward would not be a problem until later in the demilitarization process).

By asking a set of "what-if" questions after each successive operational step, a thorough assessment of potential initiators was generated. Figure 4-1 illustrates the POD development process and the efforts to achieve completeness. Although the identification of initiators is a subjective process, each POD was reviewed by several analysts and revised accordingly. During this process, events that have occurred at TOCDF or JACADS were incorporated as initiators. To identify events that have already occurred, the Programmatic Lessons Learned (PLL) database was searched exhaustively and information was gathered from TOCDF walkdowns, discussions with plant personnel, unusual occurrence reports, TOCDF weekly reports, JACADS end of campaign reports, and other sources. In addition, existing analyses were reviewed to ensure that previously identified events were covered. This included previous analyses of the facility and various safety studies produced in support of the overall CSDP, such as the:

- 1987 Risk Analysis (PMCD, 1987a)
- TOCDF Systems Hazard Analysis (Parsons, 1991)
- TOCDF Hazard Tracking Log (Price et al., 1989)
- Safety Assessment Report for the TOCDF with its source documents
- Hazard and operability analyses (HAZOPs) performed for JACADS and TOCDF as part of the initiator identification task
- TOCDF QRA (SAIC, 1996b).

As part of its RMP, the U.S. Army and its systems contractors perform and update several types of hazard evaluations, including job and systems hazards analyses. These are also sources that are examined, to the extent available, to identify potential initiators. One objective of the continuing RMP is to cross-reference the hazards analyses and the QRA to ensure full coverage.

A POD traces the major activities in each disposal process, with each activity indicated by a rounded rectangle. Figure 4-2 shows a part of the RHS process flow. The intended process flow

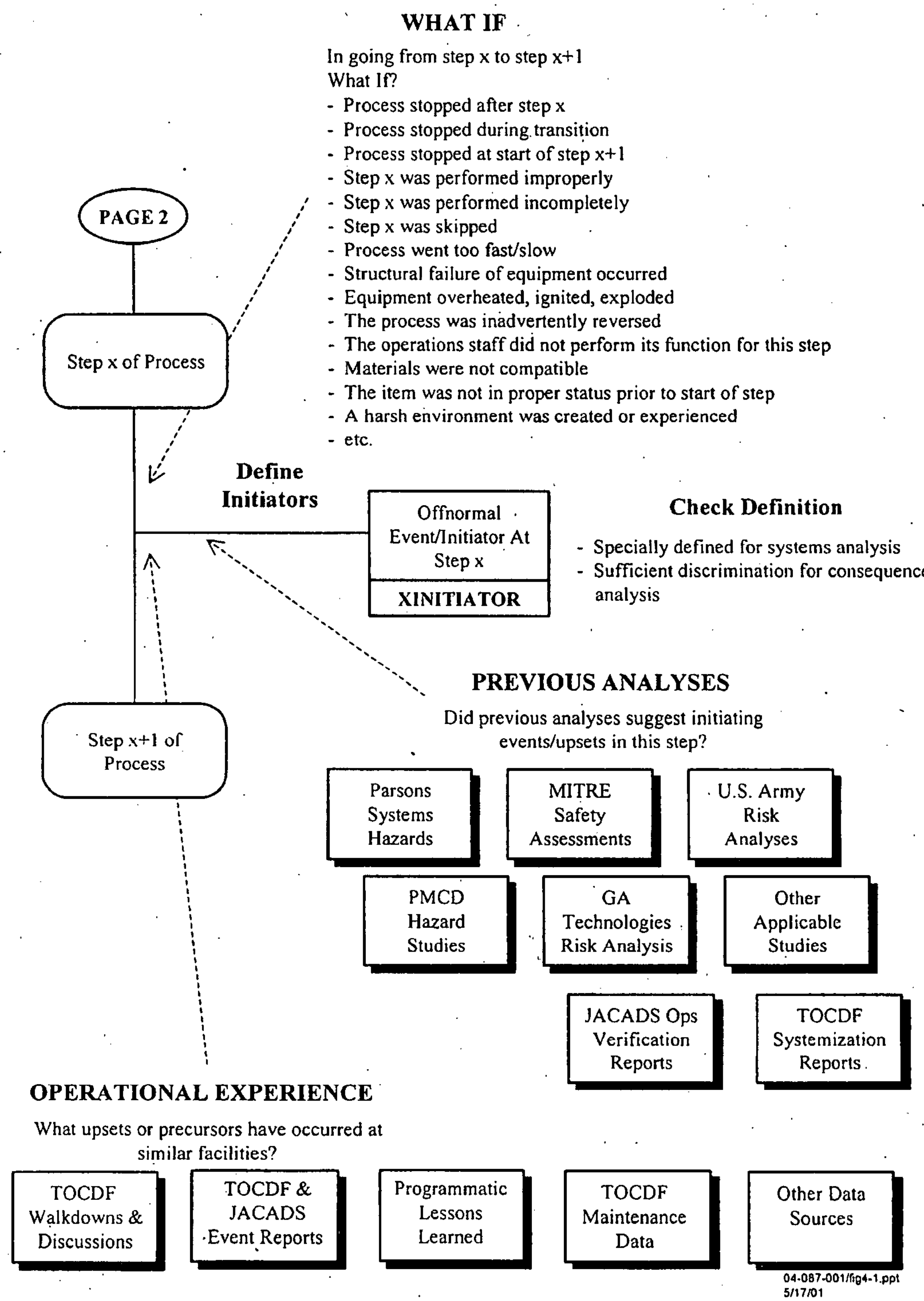


Figure 4-1. Process Operations Diagram Development Process

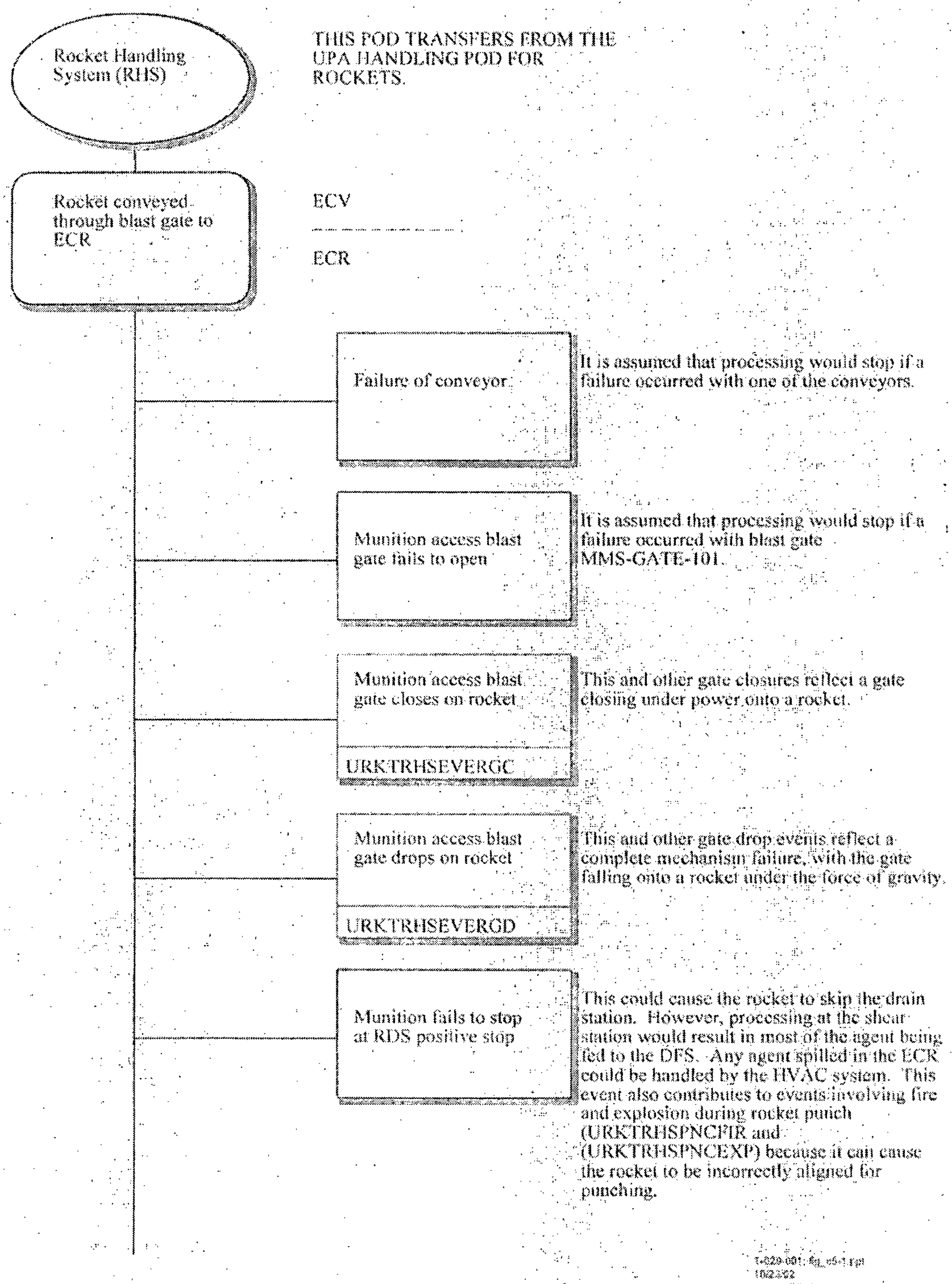


Figure 4-2. Rocket Handling System Process Operations Diagram (Example Page)

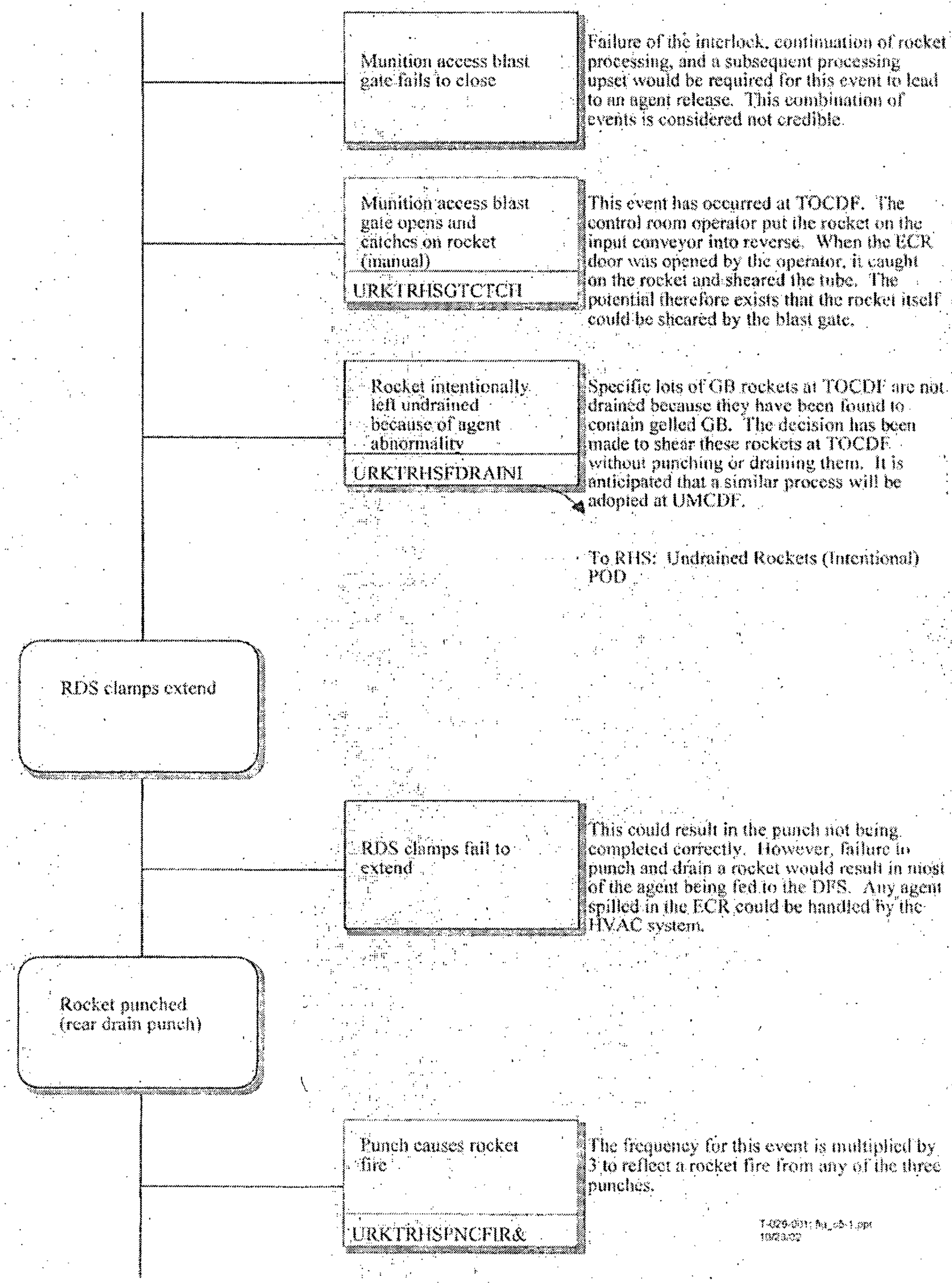


Figure 4-2. Rocket Handling System Process Operations Diagram (Example Page) (Continued)

is a vertical cascade of such rectangles, where the leftmost column represents the normal operational flow. As shown in figure 4-2, the normal flow path for rockets is conveyance into the ECR, clamping at the drain station, followed by additional steps on the remainder of the PODs that are not illustrated in figure 4-2. Assumptions regarding the operational steps are listed directly on the POD.

The deviations from normal operations (identified to the right in rectangles, just below a process step) represent possible events that could occur at a step. Initiators judged to be potentially significant to the risk model are provided a name in a rectangle below the description, separated by a line. The name is used to track the event through the QRA solution process. The naming scheme is discussed in appendix C.

Deviation events not judged to initiate significant accidents leading to potential agent release are not further developed in the analysis. Therefore, they are not assigned initiator names. Events may remain undeveloped for a variety of reasons:

a. The deviation does not initiate a sequence that could lead to agent release. The scope of the QRA is limited to agent-related risk.

b. The deviation interrupts processing but does not lead to facility conditions that would impact the likelihood of agent release or worker exposure. The failure of the conveyor in figure 4-2 is an example of this type of event.

c. The deviation is less severe and significantly less frequent than a similar developed initiator, so the impact of the undeveloped event is subsumed in the analysis of the developed event.

d. The upset described by the deviation has been studied and found to pose a negligible probability of release. For example, an EONC could inadvertently be conveyed into a closed rollup door. Examination of the rollup door and the conveyor speeds has been considered and found to pose a negligible risk given the protection afforded by the EONC. Similarly, gate closures on items are studied to determine if there is any possibility for damage.

e. The deviation does not lead to an agent release potential immediately but may influence the likelihood of agent release at a later time. These deviations are listed and not given initiator names, but are considered in the development of a later initiator. For example, an incorrect attachment of an item to a crane will manifest itself when the item is lifted. The incorrect attachment may be included as an undeveloped event in the POD but as an explicit event in the fault tree development for crane drop. In the example in figure 4-2, failure of the rocket to stop at the rocket drain station (RDS) positive stop does not lead to an immediate upset but could contribute to other initiators later in the POD.

f. The deviation includes the potential for worker risk, but the risk is not unique enough to be modeled separately and will be included as a standard maintenance risk.

g. The deviation has been examined and found to be probabilistically negligible (for this study this is less than 10^{-8} per year).

The development of risk models includes substantial subjective judgment. While the criteria above provide guidance, the adequacy and completeness of the models are determined by review and iteration. The reasons for not developing deviations are summarized directly on the POD. In examining the PODs, reviewers may question reasoning or the level of analysis supporting a judgment not to develop a potential deviation. Additional analyses will be performed until resolution is reached on the reasoning for an event being undeveloped, or undeveloped events may be changed to developed initiators. This process of critical review and challenge ultimately determines the acceptability of the models.

In some cases, a deviation starts an alternative pathway that is represented in another POD. Alternate pathways include an initiator that starts a new path, with an arrow indicating the POD that continues the development of the logic for that path. In the example in figure 4-2, a different POD is used to describe the disposal process for rockets with agent abnormalities that prevent proper draining, i.e., GB rockets containing gelled agent.

To keep each POD to a manageable size, the process was broken into functional stages and a POD was developed for each stage. This allows the use of a single POD to model portions of the process, e.g., toxic agent collection and liquid incineration, that are common to all munition types. The PODs transfer from one to another so that the entire disposal process is considered.

There was one other factor that drove the development of the PODs and the definition of initiators. A close interaction with the accident progression and consequence evaluation was required to ensure that sufficient discrimination was made in the specification of the initiator to allow its consequences to be modeled. In other words, events with vastly different characteristics could not be grouped together in a single initiator because it would not be possible to separately discriminate the possible consequences of the events. Interaction with the analysts responsible for the study of accident progression, phenomenology, agent source term, and consequences enabled the establishment of a set of characteristics that would clearly define each accident sequence. One example is the possibility of accidents involving forklifts. The potential consequences of impacting a pallet of munitions with the forklift tines are different from dropping a forklift load, so those accidents must have separate initiators, rather than being combined into a single forklift accident initiator.

The POD is the primary tool for documentation of the CDF process and the internal initiating events. It identifies those initiators that were quantified as well as those screened from further analysis. PODs were developed for each step in the disposal process starting with handling at the storage location through incineration.

4.2 Overview of Process Operations Diagrams

The PODs cover the entire process, starting with the removal of items from the storage area. Because there are a large number of steps in the disposal process, the PODs were developed to represent distinct disposal activities. The disposal of a munition is therefore described by a series of about ten different PODs. The PODs have been divided up by system, area of the facility, and type of equipment and procedures involved. Although intended to be straightforward, the breakdown of PODs may not always be intuitive depending on the reader's background and familiarity with the processes. A guide to the PODs for each munition is provided in appendix C to allow the reader to reference the appropriate PODs. Each POD identified in the overview figures is discussed in detail later in appendix C.

Figure 4-3 illustrates the PODs used to study the risks involved with the disposal of M55 rockets. The process starts with a POD describing removal of rockets from the storage area and follows the munitions through the entire process to 5X DFS residue and fully treated furnace exhaust gases. After munitions are removed from the storage yard, transported to the facility, and handled in the CHB, they are sampled for agent leakage within their containers in the UPA. EONCs with positive ACAMS readings during ACAMS testing are sent to the TMA. All other munitions are sent through the UPA. The POD development continues for the RHS followed by the DFS for the rocket pieces, agent collection and storage in the Agent Collection System (ACS), and destruction of agent in the LIC. There is also a POD that branches off from the RHS POD that covers the cases where rockets are not drained, such as for "gelled" GB rockets.

The HVAC POD covers the entire MDB cascade ventilation system and carbon filtration. This POD is not a series step in the disposal process, but parallels activities in the MDB and examines the potential for HVAC-related upsets.

The PODs developed for the UMCDF are provided in appendix C. The initiators identified through this process and their frequencies are summarized in section 4.5.

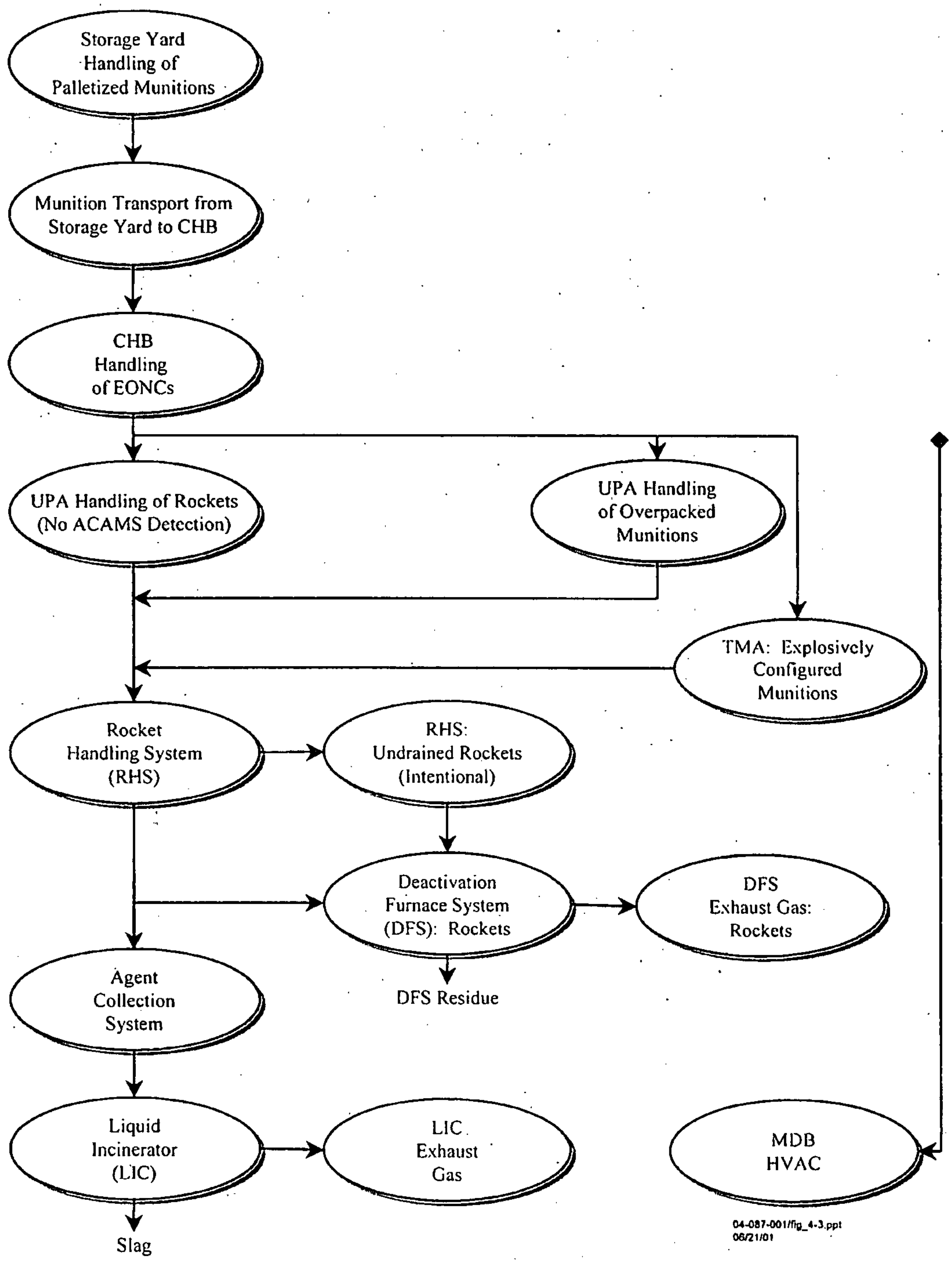


Figure 4-3. Overview of Process Operations Diagrams for Rockets

4.3 Modeling of Processing Initiators

The initiators identified on the PODs may arise from complex combinations of events, including mitigation failures and phenomenological events. In QRAs, fault trees are generally used to logically model these combinations of events. The fault trees required to represent and quantify these events may range from the simple to the very detailed. At the simple end of the spectrum are single events; detailed fault tree modeling is not needed because data are available to estimate the probability or frequency of the initiator without further development, or there are no modeling techniques that will allow quantification and a subject matter judgment will be made.

For example, forklift operational data may be directly appropriate for determining the probability that the load being picked up will sustain a significant impact in the process, and the entire model for this scenario may be captured by this single event. On the other hand, furnace upsets that could result in an explosion may include many different detailed scenarios that could lead to the same type of initiator, each of which is a combination of an initiating event and subsequent system faults.

The following sections describe the fault tree models and the methods used to develop them. These sections provide an overview of the methods and models; copies of the fault trees and system cutsets are provided as an annex to appendix D.

4.3.1 System Modeling Methods and Assumptions. Development of the system fault tree models was based on the guidelines outlined in the Probabilistic Risk Assessment (PRA) Procedures Guide (USNRC, 1983). Emphasis was placed on choosing appropriate system boundaries, consistently treating component failures in the models, developing and applying a basic event naming scheme, and providing consistent documentation. For each system, applicable design drawings, system descriptions, one-line drawings, and operating and maintenance procedures were collected and reviewed. System walkdowns also were used to aid in understanding integrated system operation.

Based on knowledge of the system and its role in the accident sequence, fault tree models were developed for the initiators as they appeared on the PODs. The following general rules were followed in the development of the system fault tree models:

- System success criteria were based on vendor information, supporting scoping calculations and engineering judgment. In some instances, conservative assumptions were made to bound those cases for which limited information existed. Such assumptions were re-evaluated, as necessary, if they had a dominant effect on the results of the analysis.

- Fault trees were developed only to the level of detail at which appropriate data existed or to the level at which common cause failure (CCF) events could be identified. For example, in reviewing data for crane failures, information to determine the specific failure mechanism (e.g., wiring fault, control logic fault) was not always available. Consequently, a single basic event was modeled for crane drops that included all such failures.

- Appropriate references to support systems were made through the use of transfer gate logic linking to the same support system model for several front-line systems. This ensured that the same support system logic was applied to all applicable fault trees. A set of system boundary conditions was employed to ensure that this linking was done correctly.

- CCFs were modeled for redundant equipment likely to fail as the result of being exposed to similar stresses. These failures were modeled by multiplying the failure of a single such component by a beta factor of 0.1. This value is conservative and commonly used in systems analysis.

- Human error contributions to system unavailability were considered for each event in the fault trees. Human errors made prior to the initiating event were modeled at the component level.

- Maintenance and testing that could be performed while the facility was operating were included in the fault tree and modeled at the component level. It should be noted, however, that testing was only included if it put the system in a configuration that would make it unavailable.

Fault trees form the basis for the systems analysis. Several sources of information were used in developing the system fault tree models. It was essential for this information to be recorded in a consistent format such that it could be easily reviewed and understood. As such, each set of system fault trees is documented in a section of appendix D. Copies of the fault trees and systems cutsets are provided as an annex to appendix D.

The following sections provide an overview of the fault tree models developed for the processing systems at UMCDF. It should be noted, however, that the accident sequences arising from internal initiating events have been shown to play less of a role in the public risk profile than external events due to: 1) the relatively small amounts of agent involved in most internal events, 2) effectiveness of the mitigation systems, and 3) low frequencies for many internal event sequences. Consequently, a detailed discussion of each event and each fault tree model is not included here. The fault tree models are described in detail in appendix D.

4.3.2 Fault Tree Models for Handling Systems. A set of fault tree models was developed for munition handling activities. Handling activities include those at the storage yard, CHB, and UPA. Models also were developed for overpacking leaking munitions, handling munitions in overpacks, and processing leaking munitions through the TMA.

There are several different types of handling equipment used for munition handling operations. Forklifts at the storage yard remove munitions from the storage igloo or warehouse and load them into EONCs or directly onto trucks (spray tanks). Cranes remove EONCs or containers from the transport vehicle at the CHB. Conveyors and lifts move EONCs and containers from the CHB to the UPA and convey munitions from the UPA to the ECV. Forklifts, cranes, and operators move munitions in the UPA to the appropriate disposal line. Additional steps are incorporated into the process for leaking munitions. EONCs are moved using lifts, cranes, trucks, and conveyors from the UPA to the TMA. Lifts, hoists, conveyors, and operators move leaking munitions throughout the TMA. Conveyors, charge cars, lifts, and cranes move leaking munitions from the TMA to the appropriate disposal line. Fault tree models were developed for each of these handling operations.

Fault tree models were developed for each forklift operation in the storage yard. For palletized munitions (rockets, projectiles, mines, and bombs), two separate forklift movements are required to unload the pallets from the igloo and load them into the EONC. A 4,000-pound forklift is used to unload the pallets from the igloo and place them onto the igloo apron. Then a 16,000-pound forklift is used to load the tray into the EONC. Both forklift drops and impacts are considered for the 4,000- and 16,000-pound forklift operations. Because the pallets will generally be loaded onto the EONC tray before the EONC truck arrives, the potential for the arriving truck to impact the pallets on the tray was considered.

For unloading ton containers, the forklift tines are removed and an M-1 lifting beam is used. The 6,000-pound forklift is used to unload the ton containers from the warehouse and load them onto an EONC tray. Forklift drops are considered for this operation. The 16,000-pound forklift then is used to lift the full EONC tray and slide it into the EONC. Forklift impacts and drops are considered for this operation. Because the ton containers will generally be loaded onto the EONC tray before the EONC truck arrives, the potential for the arriving truck to impact ton containers on the tray was considered.

For unloading spray tanks, one forklift movement is needed to remove them from the igloo with the 6,000-pound forklift by dragging it with a chain attached to the forklift. Another movement is used to lift the spray tank onto the truck with the 16,000-pound forklift. Impacts are considered during the 6,000-pound forklift movement, and drops are considered during the 16,000-pound forklift movement.

Fault tree models were developed for all CHB handling operations that had the potential to result in an agent release. Agent exposure during EONC or container seal testing was considered if a leak occurred during transportation and the seal fails. Crane accidents that resulted in an EONC or spray tank container drop were considered during unloading from the transport vehicle.

Because spray tank containers are longer than the CHB trays, a spacer tray is required between each spray tank to accommodate the oversize length of these containers. Therefore, an impact of a spray tank container with an empty CHB tray used as a spacer is considered.. Also, the potential exists for an impact between an empty spray tank container and full spray tank container when loading an empty container onto the truck. The CHB lift door closing and dropping on the spray tank container also was considered because the spray tank containers are not as robust as EONCs. An event that includes a gross failure of the lift and an EONC or container falling into the CHB lift shaft due to interlock failures or failures of the lift also was considered.

Several fault tree models were developed for UPA handling operations. Failure of the ACAMS to detect EONC or container internal leakage was considered for cases where munitions have developed leaks after they have left the storage area (this can be found in the APET). Drops from the scissor lift were considered during munition tray removal from the EONC. The possibility of an empty EONC impacting pallets on the scissor lift also was considered. Crane drops, forklift drops, and impacts were modeled for munitions and bulk items moved with cranes and forklifts in the UPA. Similarly, crane drops were considered for munitions moved with one of the UPA cranes (e.g., 155mm and 8-inch projectiles are loaded onto the conveyor with a jib crane). Manual drops were considered for rockets manually loaded onto their respective conveyors. Fault tree models also were developed for forklift drops and impacts during mine processing, along with drum lid drops and fuze drops.

In most cases, simple fault tree models consisting of only one or two basic events were developed for all handling operations because data or single human failures could be used to adequately model the events. For example, data were available for crane failures involving load impact, making it unnecessary to model crane subcomponents such as motors and cables.

4.3.3 Models for Transportation Initiating Events. Munition transport encompasses all truck transfer operations involving stored chemical munitions and their subsequent delivery to the demilitarization facility. Risk is associated with collision and/or overturn accidents with trucks carrying munitions configured in EONCs or trucks (spray tanks). These risks depend upon the typical travel distance, transport truck accident rates, munition processing rates, the number of munitions in the stockpile and on the truck, and the fragility of the munitions and their containers. Transportation of spent HVAC charcoal filters also is modeled.

Transport risk consists of truck accidents and their occurrence frequencies. Progression from truck accidents to a release of agent, factoring in the potential for fire as a critical element in the source term that results, is considered during the APET discussions in section 6. This section documents the first analysis element: transportation initiating events.

Tractor trailers are used to transport chemical munitions between storage sites and the process facility on specially constructed roads. All munitions are transported inside EONCs or on trucks. Trucks transporting munitions for each specific demilitarization campaign will carry only one EONC. Trucks transporting spray tanks will carry two spray tanks.

Traffic routes at UMCD have been established to ensure that all transport vehicles will leave and re-enter K-Block through a gate to be located on the east side. Traffic routes within K-Block do not ensure one-way traffic at their facility, because multiple igloos in the storage yard may be open at one time. Discussions with UMCD personnel indicate transport of munitions from K-Block to the CHB will only involve the transporting trailer (no additional security vehicles). UMCD K-Block personnel also indicated that the speed limit in K-Block is 30 miles per hour (mph), but vehicles inside the declared worksite will be limited to 10 mph.

The accident-initiating event frequency was developed based on accident data collected for large trucks during highway travel. The data collected by the National Highway Transportation Safety Administration (NHTSA) indicate that large trucks operating in a rural nonfreeway environment have an accident rate of 9.7×10^{-7} per mile. (Though conservative, this statistic is not considered to be representative of the onsite transportation of munitions over an environment more controlled than public highways.) However, a database that specifically logged miles traveled and accidents during transport in situations similar to the stockpile was not readily available.

This accident-initiating event frequency only accounts for the occurrence of an accident. The possible effects of the accident were examined and then modeled in the APET, as discussed briefly in section 2.3 and in more detail in section 6 and appendix L.

The accident frequency rate presented in the previous section was used to generate transportation accident-initiating event frequencies for each campaign. These frequencies depend upon the expected travel distance, munition processing rates, and the available number of munitions. The expected travel distance is assumed to be 2.5 miles for all munitions. Details and assumptions used in these calculations are found in appendix G.

Accidents involving transportation of spent charcoal filters back to the storage area were evaluated. In the case of filters, only accidents involving fires have the potential to result in agent release. The postulated accident frequencies (including the conditional probability of fire) are listed in table 4-11. Details of the filter transportation analysis are included in appendix G.

4.3.4 Fault Tree Models for Disposal Systems. Another set of fault tree models was developed for the disposal systems at UMCDF. These include the RHS, projectile handling system (PHS), BHS, and MHS. These fault tree models are more complex than those developed for handling because they involve a larger number of systems.

Rocket Handling System. The RHS is designed to prepare rockets for demilitarization. Rockets are demilitarized by first removing the agent stored in the rocket body cavity, shearing the rocket into eight pieces, and finally destroying the rocket body through incineration in the DFS.

After a rocket is loaded onto the rocket metering table in the UPA, it is conveyed on the rocket input conveyor into the ECV. From the ECV, the ECV/ECR blast gate opens and the rockets are conveyed into the ECR. Fault tree models were developed for inadvertent blast gate closures on a rocket.

Rockets are processed in the ECR by the rocket shear machine (RSM). The RSM is comprised of two major work stations: the RDS and the RSS. The rocket is stopped at the RDS where it is clamped and punched. Fault tree models were developed for fires and explosions during the punch and drain operations. Agent is drained into the agent quantification system (AQS) tank for the duration of the drain timer. After the rocket has been drained, and the amount collected has been verified, the clamps are retracted and the rocket is rotated 90 degrees to minimize dripping of any residual agent from the rocket while it is being transferred to the shear station. The RSS receives drained rockets and cuts them into eight sections. The first cut separates the fuze from the rest of the body. Fault tree models based on data (discussed in further detail in appendix D2) were developed for fires or explosions during rocket shearing.

Projectile Handling System. The PHS is designed to demilitarize projectiles. Two types of projectiles will be demilitarized at UMCDF: 155mm projectiles and 8-inch projectiles. Projectiles are demilitarized by removing the explosive components and the agent contained within the munition body. The munition bodies are thermally processed in the MPF while the explosives are destroyed in the DFS. Removal of the explosive components and agent draining are done in two stages. The first consists of disassembling the munitions on the PMD. The second consists of draining the munitions on the MDM.

After a projectile is loaded onto the PHS conveyor in the UPA, it is conveyed through the UPA/ECV airlock into the ECV and through the ECV/ECR gate into the ECR. Once inside the ECR, the projectile is conveyed to the PMD where the explosive components (boosters, bursters, fuzes, other energetic components) or lifting plugs are removed. Fault tree models were developed for rejected projectiles that have to be reloaded onto the PHS conveyor in the ECV. A model also was developed for failure to remove the burster at the PMD because this will result in a failure to drain the projectile at the MDM or the possibility of an explosion at the MDM. The burster is cut into pieces at the BSR machine and the pieces are transferred to the DFS while the projectile is conveyed out of the ECR into the UMC. Fault tree models also were developed for failures of a burster probe in the UMC to check for successful burster removal. The projectiles are conveyed to the tilting conveyor and then loaded onto a tray.

Once the tray is full, it is conveyed onto the UMC charge car and directly to the MPB for processing or to a storage conveyor for buffering. Fault tree models were developed for potential drops during transfer to the charge car or a storage conveyor. The tray is conveyed into the MPB to the MDM for processing. Fault tree models were developed for trays bypassing the MDM and rows of projectiles skipping MDM operation due to mis-indexing faults. The MDM operation consists of removing the burster well, draining the agent and crimping the burster well. Fault tree models were developed for explosions at the pull station for projectiles that have not had their bursters removed. Fault tree models also were developed for failing to pull the burster wells. Models were developed for failing to drain the projectile, spills during draining, and undetected drain verification system faults that would result in failing to drain a projectile.

After draining, the tray of projectiles is conveyed to the MPB lift and lowered to the BSA for storage. Lift failures that result in dropping a tray of projectiles were modeled. Trays of projectiles also may be transferred to conveyor line C in the BSA for storage. Drops during charge car loading and transfer to conveyor line C were modeled. From the BSA, the projectile trays are transferred to the MPF for thermal decontamination.

Bulk Handling System. The BHS is designed to prepare bulk munitions for demilitarization. Four types of bulk items will be processed at UMCDF: ton containers, spray tanks, MC-1 bombs (also referred to as 750-pound), and MK-94 bombs (also referred to as 500-pound). Bulk items are demilitarized by draining the agent and then thermally processing the bulk container in the MPF.

The BHS includes transfer of the munitions from the UPA to the UMC (through the ECV on the bypass conveyor), to the MPB and BSA. Bulk items are conveyed onto the UMC charge car where they are transferred to a storage conveyor for buffering or sent directly to the MPB for draining. Fault tree models were developed to consider drops during transfer to the charge car or storage conveyor. At the bulk drain station, the bulk item is punched and the agent is drained and pumped to the ACS tank. Fault tree models were developed for spills during the punch and drain operation. Models also were developed for a failure to drain the munition. After the munition is punched and drained, it is conveyed to the MPB lift and lowered to the BSA for storage. Fault trees were developed to model spills during lift operation. Munitions also may be transferred to conveyor line C in the BSA for storage. Drops during charge car loading and transfer to conveyor line C were modeled. From the BSA, the bulk items are transferred to the MPF for thermal decontamination. One additional fault tree was developed for inadvertently transferring an unpunched and undrained bulk container to the MPF, potentially resulting in a boiling-liquid expanding-vapor explosion (BLEVE).

Mine Handling System. The MHS is designed to demilitarize mines. The MHS includes handling in the UPA and draining operations in the ECR. Operators remove mines from the mine drum in the UPA and load them onto the mine conveyor. The empty drums are transferred to the drum crusher area and crushed. From the ECV, the mine is conveyed to the mine punch and drain station (which will have replaced the RSM) and then to the DFS. Initiators modeled for MHS operations were similar to those identified for rockets. In addition, dropping the drum lid and fuzes during drum unloading was considered.

4.3.5 Fault Tree Models for the Agent Collection System and Incinerators. Fault tree models were developed for the ACS and the incinerators at UMCDF. Incinerators include the LIC, DFS, and MPF. These fault tree models are more complex than those developed for handling because they involve a larger number of support systems.

The ACS collects agent that has been drained from munitions in the ECR and MPB. The agent is pumped to a 1,300-gallon (1,020-gallon working capacity) tank located in the TOX room and then pumped to the LIC for incineration. Initiators considered for the ACS were spills of agent in various MDB locations. Spills were considered in the MPB, UMC, TOX room, and LMC. The fault tree models for the agent spills include pipe breaks, tank ruptures, and other events such as maintenance errors that would result in agent spills.

The LIC incinerates liquid agent supplied by the ACS. Liquid agent is pumped from the ACS to the primary chamber where it is incinerated (with the addition of fuel gas and excess combustion air at a temperature of 2,700°F). Exhaust gases flow directly from the primary chamber to the secondary chamber. Initiator fault trees for LIC operation include agent releases through the PAS and agent releases into the room. Spilled agent collected in the SDS tanks and sent to the secondary LIC also are modeled. In addition, natural gas explosions within the LIC and in the LIC room were modeled.

The function of the DFS is to thermally decontaminate drained rockets and mines and to destroy energetics removed from rockets, mines, and projectiles. The DFS is fed from the two ECRs and is controlled by the DFS PLC. Each ECR feed chute is provided with a set of blast gates to meter the munition pieces that are fed to the kiln. Munitions are gravity-fed to the chute and into the rotary kiln. DFS fault tree initiators include both DFS feed chute blast gates being open, failure of the lower blast gate to close, and a natural gas explosion in the DFS room. The frequency of a feed chute jam during rocket processing was determined based on processing experience at TOCDF and JACADS. Failures of the blast gates were considered because of the potential for explosions or fires in the ECR.

The function of the MPF is to thermally treat agent-contaminated metal parts including drained bulk items, projectiles, mine drums, and munition overpacks. Metal parts are loaded onto trays and fed to the MPF by a system of roller conveyors. Munitions are processed through the furnace in three zones. Metal parts are sampled for agent in the discharge airlock and conveyed outside. Exhaust gases from the furnace flow to the afterburner and then to the PAS where they are quenched and scrubbed. The following fault trees were developed for MPF operation: agent vapor explosions in the airlock, agent vapor accumulation in the furnace, release through the PAS, release into the MPF room, MPF natural gas explosions, MPF room natural gas explosions, and improper residence time. It should be noted that fault tree models were developed for munitions with normal agent heels (5 percent or less) as well as munitions that were not sufficiently drained (either intentionally or inadvertently).

4.3.6 Fault Tree Model for the Heating, Ventilation, and Air Conditioning System. Fault tree models also were developed for the HVAC system. The cascade HVAC system provides the MDB with a constant source of air in quantities sufficient to dilute any concentrations of agent vapor that may be present, to maintain the flow of air from areas of low contamination to areas of higher contamination, and to eliminate by filtration the possibility of releasing contaminants to the atmosphere.

Several models were developed for the HVAC system to include all upsets in which HVAC could contribute to an agent release in either Category C areas within the facility, or an agent release outside the building.

4.4 System Dependencies and Support System Models

Several support system models were developed to support the processing system fault trees. The support systems modeled in the QRA and the appendices documenting these models are:

- Fuel gas supply and distribution: appendix D9
- HVAC: appendix D10
- Electric power: appendix D11
- Instrument air system: appendix D12
- Plant air system: appendix D13
- Life support system: appendix D14
- Primary cooling system: appendix D15
- Process water system: appendix D16
- Hydraulic power unit and distribution system: appendix D17
- Secondary waste handling system: appendix D18.

Because support systems are used by several of the processing systems, individual fault tree models were developed. These fault tree models were then linked, as necessary, with the processing system models for quantification. The support system models depend on each other as well (e.g., HVAC depends upon electric power), and are solved as linked fault trees.

The fuel gas system primarily supports the furnace fault trees. The HVAC models include models in which the HVAC failure is either an initiator or a mitigator after some other accident. Electric power supports much of the plant operation, and has three separate sources: offsite power, emergency diesel generator power, and UPS power. Different combinations of these sources are necessary depending on the failure being modeled; not all components use emergency or UPS power. The instrument air system controls many of the dampers, valves, and other actuators throughout the plant. Failure of instrument air may have widespread effects in the plant, including effects on HVAC, the PAS, and other individual components. Plant air has similar, but not as widespread, effects on plant operation. Primary cooling carries heat loads from components such as the instrument air system, and process water supplies water to systems such as the PAS. The hydraulic system is important to the operation of many of the demilitarization machines, as well as portions of the conveyor system.

Much more detail on the operation of these systems is included in the appropriate sections of appendix D. In the main fault trees, links to support systems are shown as transfers to appropriate support system top events. Furthermore, each main fault tree in appendix D has a section listing support model connections for that fault tree.

4.5 Summary of Internal Initiators

The following sections include tables that list all of the internal initiators modeled in the UMCDF QRA. These tables are grouped together at the end of the section. The frequencies of the initiators are provided also. The frequencies were determined from solution of the fault tree models using the data described in section 7 of this document, for components and human failure events, respectively. Some tables list initiators for specific munition types, and other tables list initiators that are not applicable to any specific munition. For example, the table for rockets includes all the events associated with rocket handling and RHS operation, which are only applicable to rockets. Similarly, another table lists initiators for the furnaces, the ACS, and the HVAC system. Since the ACS is used to collect agent, most of the initiators in this system are not associated with a munition type. Munition handling events and processing events were quantified on a per-operation or per-munition basis; support systems were quantified on an hourly basis.

This section is provided to illustrate a step in the risk assessment process, not as a conclusion regarding acceptability. In some cases, the frequencies are conservative screening values that are left unrefined because they contribute to scenarios of negligible risk.

The models could be used in the future to evaluate other risks. This would be an appropriate use of the QRA models. For example, the scenarios in this section can be studied from a perspective of equipment damage or schedule risk. That has not been done at this point given the scope limitations of the QRA. When examining these other risk measures, the models may need to be refined to remove conservatism that was OK for human health risk but too conservative for meaningful evaluation of other risk measures.

Some events were quantified for multiple drain status or agent types; this is designated in the "Agent/Drain Status" column. An asterisk (*) is inserted as the last character of the event name for these events. Events for which this column is blank are events that were quantified for no specific drain status or agent type. A key to the letter designators is shown in table 4-1.

Table 4-1. Agent Type/Munition Configuration Codes

Agent Type[a]	Abbreviation
GB	G
HD	H
VX	V
Munition Configuration[b]	
Drained Munition	D
Unpunched (Burster Well Intact for Projectiles), Undrained	U
Punched (Burster Well Removed for Projectiles), >5 Percent Heel (Intentional)	I
Punched (Burster Well Removed for Projectiles), >5 Percent Heel (Inadvertent)	A

Notes:

[a] The agent type designator is only used if the event has different frequencies based on agent type. It is used in some events in the Storage Yard Handling (appendix C1) and Container Handling Building Operations (appendix C3) PODs.

[b] The munition configuration character is only used if it is necessary to distinguish unique events based on agent draining; therefore, it is not used until after a munition is normally drained. It is used in some events in the Demilitarization Line Processing (appendix C5) and Agent Collection System and Furnace Processing (appendix C6) PODs.

Initiating events and frequencies for rockets are listed in table 4-2. This table includes all the internal initiating events associated with rocket handling at the storage yard, CHB, and during RHS operations. Other events applicable to rocket processing include those associated with the ACS, LIC, and DFS.

Initiating events and frequencies for projectiles are listed in tables 4-3 and 4-4. Note that models were developed for both types of projectiles. The table includes all the internal initiating events associated with projectile handling at the storage yard, CHB, and during PHS and MPF operations. MPF events were considered for projectiles with normal agent heels as well as projectiles that had more than normal agent heels (referred to as undrained projectiles). Other events applicable to projectile processing include those associated with the ACS, LIC, and DFS.

Initiating events and frequencies for mines are listed in table 4-5. The table includes all the internal initiating events associated with mine handling at the storage yard, CHB, UPA, and during MHS operations. Other events applicable to mine processing include those associated with the ACS, LIC, and DFS.

Initiating events and frequencies for bulk items are listed in tables 4-6 through 4-9. Note that models were developed for four types of bulk items. The table includes all the internal initiating events associated with bulk item handling at the storage yard, CHB, and during BHS and MPF operations. MPF events were considered for bulk items with normal agent heels as well as those that had more than normal agent heels (referred to as undrained ton containers). Other events applicable to bulk item processing include those associated with the ACS and LIC.

Initiating events and frequencies for the ACS, LIC, DFS, and HVAC are listed in table 4-10. The LIC events and many of the ACS events were not calculated for any particular munition.

The initiating event frequency for transportation accidents was discussed in section 4.4. Table 4-11 lists the transportation accident initiating event frequencies by campaign. The values in the table account for the travel distance and the number of munitions carried per EONC or truck load. All values are provided on a per hour basis.

Table 4-2. Initiators and Frequencies for Rockets

Event	Description	Agent/ Drain Status	Frequency (per munition)
Storage Yard Handling PODs are included in appendix C1; systems analysis is included in appendix D1			
RKTSTYFRKIM1	Impact during 4,000-lb forklift operation		8.0×10^{-7}
RKTSTYFRKDP1	Drop during 4,000-lb forklift operation		8.0×10^{-7}
RKTSTYTRUKIM	Arriving EONC truck impacts munitions on tray		2.2×10^{-8}
RKTSTYFRKIM2	Impact during 16,000-lb forklift operation		8.0×10^{-7}
RKTSTYFRKDP2	Drop during 16,000-lb forklift operation		8.0×10^{-7}
RKTSTYAGTWKR&	Worker enters igloo with undetected leaker	G	8.0×10^{-11}
		V	6.5×10^{-13}
CHB Handling of Rockets PODs are included in appendix C3; systems analysis is included in appendix D1			
RKTCHBSEALLK&	Leak during transport and EONC seal fails	G	2.7×10^{-11}
		V	2.1×10^{-13}
RKTCHBCRNDRP	EONC dropped during movement from truck to CHB container tray		2.4×10^{-7}
RKTCHBLFTDRP	CHB lift operation results in EONC drop		3.1×10^{-7}
UPA Handling of Rockets PODs are included in appendix C4; systems analysis is included in appendix D1			
RKTUPASCISDP	EONC tray with pallets dropped during scissor lift operation		4.2×10^{-6}
RKTUPAEMTONC	Empty EONC impacts pallets on scissor lift		6.6×10^{-6}
RKTUPACRNDRP	Pallet dropped during crane operation		5.2×10^{-8}
RKTUPAFRKDRP	Rocket pallet dropped during forklift operation		8.0×10^{-7}
RKTUPAFRKIMP	Rocket pallet impact during forklift operation		8.0×10^{-7}
RKTUPAMANDRP	Rocket dropped while loading onto rocket metering table		1.0×10^{-5}
RKTOVPCRNDRP	Pallet dropped during ECV hoist operation		1.7×10^{-7}
RKTOVPMANDRP	Rocket dropped in ECV during removal from overpack		7.1×10^{-3}
RKTOVPMUNMPF	Rocket inadvertently sent to MPF		1.5×10^{-5}
Rocket Handling System PODs are included in appendix C5; systems analysis is included in appendix D2			
RKTRHSEVERGC	Munition access blast gate closes on rocket		3.6×10^{-7}
RKTRHSEVERGD	Munition access blast gate drops on rocket		1.2×10^{-8}

Table 4-2. Initiators and Frequencies for Rockets (Continued)

Event	Description	Agent/ Drain Status	Frequency (per munition)
RKTRHSGTCTCH	Munition access blast gate opens and catches on rocket (manual)		2.0×10^{-5}
RKTRHSPNCFIR&	Punch causes rocket fire	G	6.6×10^{-9}
		V	9.5×10^{-9}
RKTRHSPNCEXP&	Punch causes rocket explosion	G	2.0×10^{-8}
		V	2.1×10^{-8}
RKTRHSPNCFRT&	Punch does not retract from rocket	G	2.3×10^{-6}
		V	2.7×10^{-6}
RKTRHSRDSSTK&	Rocket is stuck at RDS	G	8.7×10^{-6}
		V	1.2×10^{-5}
RKTRHSMMSGFO&(*)	Munition access blast gate fails to open	G	4.1×10^{-6}
		V	4.2×10^{-6}
		I	1.3×10^{-7}
RKTRHSSHRFIR&(*)	Rocket fire occurs at RSS	G	9.9×10^{-6}
		V	1.0×10^{-5}
		I	3.2×10^{-7}
RKTRHSSHREXP&(*)	Shearing causes rocket explosion	G	9.9×10^{-6}
		V	1.0×10^{-5}
		I	3.2×10^{-7}
ACS PODs are included in appendix C5; systems analysis is included in appendix D8			
RKTTOXUMCSPL	Agent spill in UMC from ACS piping		9.1×10^{-9} [a]
DFS Processing of Rockets PODs are included in appendix C6; systems analysis is included in appendix D6			
RKTDFSFDCHJM	DFS feed chute jams		3.5×10^{-4}
RKTDFSGBTVCL	DFS chute gate (tipping valve) fails closed		3.2×10^{-4}
RKTDFSRNGEXP	Natural gas explosion in the DFS room		1.2×10^{-9}
RKTDFSPASREL	Agent release to the DFS PAS		1.2×10^{-5}
RKTDFSHDCENC	Worker exposure during heated discharge conveyor enclosure operations		1.9×10^{-7}
RKTDFSCYCENC	Worker exposure during cyclone bin changeout		1.7×10^{-7}

Table 4-2. Initiators and Frequencies for Rockets (Continued)

Event	Description	Agent/ Drain Status	Frequency (per munition)
TMA Handling of Rockets PODs are included in appendix C7; systems analysis is included in appendix D1			
RKTTMALFTDRP	EONC dropped during lift operation		3.1×10^{-13}
RKTTMASCISDP	Munition tray dropped during EONC tray removal		3.0×10^{-6}
RKTTMACRNDRP	Munitions dropped during pallet hoisting to TMA floor and tray		6.3×10^{-6}
RKTTMATMLMGC	TMA/LMC gate closes on tray of rockets		6.7×10^{-6}
RKTTMALMCCDP	Tray of rockets dropped during LMC charge car loading		4.5×10^{-5}
RKTTMAMUNMPF	Tray of rockets inadvertently sent to MPF		1.8×10^{-6}
RKTTMALMBSGC	LMC/BSA gate closes on tray of rockets		9.4×10^{-6}
RKTTMABSALFT	BSA/MPB lift operation results in munitions drop		8.2×10^{-9}
RKTTMAMPUMGC	MPB/UMC gate closes on tray of rockets		6.7×10^{-6}
RKTTMAUMCCDP	Tray of rockets dropped during UMC charge car loading		4.4×10^{-5}
RKTTMAUMEVGC	UMC/ECV gate drops on tray of rockets		6.7×10^{-6}
Overpacking Leaking Rockets PODs are included in appendix C10; systems analysis is included in appendix D1			
RKTLKRFRKIM1	Pallet impact during forklift operation		1.1×10^{-4}
RKTLKRFRKDP1	Pallet dropped during forklift operation		1.1×10^{-4}
RKTLKRMANDP1	Munition dropped during pallet disassembly and reassembly		1.4×10^{-3}
RKTLKRMANDP2	Leaking munition dropped during decontamination and overpacking		7.1×10^{-3}
RKTLKRFRKIM2	Pallet impact during restacking		1.1×10^{-4}
RKTLKRFRKDP2	Pallet dropped during restacking		1.1×10^{-4}

Note:

[a] The frequency for this event is calculated on a per-hour basis.

Table 4-3. Initiators and Frequencies for 155mm Projectiles

Event	Description	Agent/ Drain Status	Frequency (per munition)
Storage Yard Handling PODs are included in appendix C1; systems analysis is included in appendix D1			
55ASTYFRKIM1	Impact during 4,000-lb forklift operation		1.5×10^{-9}
55ASTYFRKDP1	Drop during 4,000-lb forklift operation		1.5×10^{-6}
55ASTYTRUKIM	Arriving EONC truck impacts munitions on tray		9.3×10^{-9}
55ASTYFRKIM2	Impact during 16,000-lb forklift operation		1.5×10^{-6}
55ASTYFRKDP2	Drop during 16,000-lb forklift operation		1.5×10^{-6}
55ASTYAGTWKR&	Worker enters igloo with undetected leaker	G	5.2×10^{-11}
		V	1.8×10^{-12}
CHB Handling of 155mm Projectiles PODs are included in appendix C3; systems analysis is included in appendix D1			
55ACHBSEALLK&	Leak during transport and EONC seal fails	G	7.3×10^{-12}
		V	2.5×10^{-10}
55ACHBCRNDRP	EONC dropped during movement from truck to CHB container tray		1.0×10^{-7}
55ACHBLFTDRP	CHB lift operation results in EONC drop		1.3×10^{-7}
UPA Handling of 155mm Projectiles PODs are included in appendix C4; systems analysis is included in appendix D1			
55AUPASCISDP	EONC tray with pallets dropped during scissor lift operation		1.8×10^{-6}
55AUPAEMTONC	Empty EONC impacts pallets on scissor lift		2.8×10^{-6}
55AUPACRNDRP	Pallet dropped during crane operation		9.8×10^{-8}
55AUPAFRKDRP	Projectile pallet dropped during forklift operation		1.5×10^{-6}
55AUPAFRKIMP	Projectile pallet impact during forklift operation		1.5×10^{-6}
55AUPAJIBDRP	Projectile dropped by crane by lifting and loading onto conveyor		1.6×10^{-6}
55AUPAUPALGC	UPA/airlock gate closes on projectile		9.4×10^{-8}
55AUPAUPALGD	UPA/airlock gate drops on projectile		7.0×10^{-9}
55AUPAALEVGC	Airlock/ECV gate closes on projectile		5.0×10^{-5}
55AUPAALEVGD	Airlock/ECV gate drops on projectile		6.7×10^{-9}
55AOVPMUNMPF	Munition inadvertently sent to MPF		1.5×10^{-5}

Table 4-3. Initiators and Frequencies for 155mm Projectiles (Continued)

Event	Description	Agent/ Drain Status	Frequency (per munition)
Projectile Handling System PODs are included in appendix C5; systems analysis is included in appendix D3			
55APHSEVERGC	ECV/ECR blast gate closes on projectile		5.0×10^{-5}
55APHSEVERGD	ECV/ECR blast gate drops on projectile		6.9×10^{-9}
55APHSEVERSW	ECV/ECR swing roller fails to move into position causing projectile to fall		2.8×10^{-7}
55APHSECRFIR	Miscellaneous parts deposit energetic residue onto conveyor		3.6×10^{-5}
55APHSBRFREM	Projectile fails to have burster removed		1.3×10^{-7}
55APHSBSREXP	Burster explodes during shearing		9.5×10^{-10}
55APHSMMSGFO	Munition access blast gate fails to open		4.2×10^{-6}
55APHSERUMGC	ECR/UMC blast gate closes on projectile		5.0×10^{-5}
55APHSERUMGD	ECR/UMC blast gate drops on projectile		6.9×10^{-9}
55APHSERUMSW	ECR/UMC swing roller fails to move into position causing projectile to fall		2.8×10^{-7}
55APHSUMCCDP	Tray of undrained projectiles dropped during UMC charge car operations		1.4×10^{-5}
55APHSROWSKPU	Row of projectiles on tray skips MDM		1.3×10^{-9}
55APHSTRYSKPU	Projectile tray skips MDM		3.5×10^{-8}
55APHSBWFREMU	Projectile with intact burster well is sent to MPF		4.4×10^{-9}
55APHSLFTDRP*	Lift drops to first floor	D	1.0×10^{-8}
		I	3.2×10^{-13}
		A	$< 10^{-13}$
55APHSLMCCXR	Tray stuck during LMC charge car loading		4.2×10^{-4}
55APHSLMCCDP*	Tray dropped during LMC charge car loading	D	1.4×10^{-5}
		I	4.4×10^{-10}
		A	1.3×10^{-11}
DFS Processing of 155mm Projectiles PODs are included in appendix C6; systems analysis is included in appendix D6			
55ADFSFDCHJM	DFS feed chute jams		9.6×10^{-6}
55ADFSGBTVCL	DFS chute gate (tipping valve) fails closed		3.4×10^{-5}
55ADFSRNGEXP	Natural gas explosion in the DFS room		1.2×10^{-9} [a]

Table 4-3. Initiators and Frequencies for 155mm Projectiles (Continued)

Event	Description	Agent/ Drain Status	Frequency (per munition)
MPF Processing of 155mm Projectiles PODs are included in appendix C7; systems analysis is included in appendix D7			
55AMPFARLEXP*&	Charge airlock agent vapor explosion	DG	2.2×10^{-11}
		DV	2.0×10^{-11}
		IG	$<10^{-13}$
		IV	$<10^{-13}$
		AG	1.5×10^{-12}
		AV	1.3×10^{-13}
55AMPFRMAGHI*	Agent release to the MPF room	D	2.1×10^{-6} [a]
		I	7.7×10^{-11} [a]
		A	9.4×10^{-10} [a]
55AMPFFNGEXP*	Natural gas explosion in MPF	D	3.9×10^{-10} [a]
		I	$<10^{-13}$ [a]
		A	$<10^{-13}$ [a]
55AMPFRNGEXP*	Natural gas explosion in MPF room	D	$<10^{-13}$ [a]
		I	$<10^{-13}$ [a]
		A	$<10^{-13}$ [a]
55AMPFPASREL*	Agent release through MPF PAS	D	9.0×10^{-9} [a]
		I	5.5×10^{-13} [a]
		A	6.1×10^{-11} [a]
55AMPF2NGEXP*	Natural gas explosion in afterburner	D	3.5×10^{-10} [a]
		I	$<10^{-13}$ [a]
		A	$<10^{-13}$ [a]
TMA Handling of 155mm Projectiles PODs are included in appendix C7; systems analysis is included in appendix D1			
55ATMALFTDRP	EONC dropped during lift operation		1.3×10^{-13}
55ATMASCISDP	Munition tray dropped during EONC tray removal		1.3×10^{-6}
55ATMACRNDRP	Munitions dropped during pallet hoisting to TMA floor and tray		1.2×10^{-5}
55ATMATMLMGC	TMA/LMC gate closes on tray of projectiles		1.3×10^{-5}
55ATMALMCCDP	Tray of projectiles dropped during LMC charge car loading		8.4×10^{-5}
55ATMAMUNMPF	Tray of projectiles inadvertently sent to MPF		3.4×10^{-6}

Table 4-3. Initiators and Frequencies for 155mm Projectiles (Continued)

Event	Description	Agent/ Drain Status	Frequency (per munition)
55ATMALMBSGC	LMC/BSA gate closes on tray of projectiles		1.8×10^{-5}
55ATMABSALFT	BSA/MPB lift operation results in munitions drop		1.5×10^{-8}
55ATMAMPUMGC	MPB/UMC gate closes on tray of projectiles		1.3×10^{-5}
55ATMAUMCCDP	Tray of projectiles dropped during UMC charge car loading		8.2×10^{-5}
55ATMAUMEVGC	UMC/ECV gate closes on tray of projectiles		1.3×10^{-5}
Overpacking Leaking 155mm Projectiles PODs are included in appendix C10; systems analysis is included in appendix D1			
55ALKRFRKIM1	Pallet impact during forklift operation		2.0×10^{-4}
55ALKRFRKDP1	Pallet dropped during forklift operation		2.0×10^{-4}
55ALKRFRKIM2	Pallet impact during restacking		2.0×10^{-4}
55ALKRFRKDP2	Pallet dropped during restacking		2.0×10[illegible]

Table 4-4. Initiators and Frequencies for 8-inch Projectiles

Event	Description	Agent/ Drain Status	Frequency (per munition)
Storage Yard Handling PODs are included in appendix C1; systems analysis is included in appendix D1			
8IASTYFRKIM1	Impact during 4,000-lb forklift operation		2.0×10^{-6}
8IASTYFRKDP1	Drop during 4,000-lb forklift operation		2.0×10^{-6}
8IASTYTRUKIM	Arriving EONC truck impacts munitions on tray		1.9×10^{-8}
8IASTYFRKIM2	Impact during 16,000-lb forklift operation		2.0×10^{-6}
8IASTYFRKDP2	Drop during 16,000-lb forklift operation		2.0×10^{-6}
8IASTYAGTWKR&	Worker enters igloo with undetected leaker	G	6.0×10^{-12}
		V	7.6×10^{-12}
CHB Handling of 8-inch Projectiles PODs are included in appendix C1; systems analysis is included in appendix D1			
8IACHBSEALLK&	Leak during transport and EONC seal fails	G	1.7×10^{-12}
		V	2.1×10^{-12}
8IACHBCRNDRP	EONC dropped during movement from truck to CHB container tray		2.0×10^{-7}
8IACHBLFTDRP	CHB lift operation results in EONC drop		2.6×10^{-7}
UPA Handling of 8-inch Projectiles PODs are included in appendix C4; systems analysis is included in appendix D1			
8IAUPASCISDP	EONC tray with pallets dropped during scissor lift operation		3.5×10^{-6}
8IAUPAEMTONC	Empty EONC impacts pallets on scissor lift		5.6×10^{-6}
8IAUPACRNDRP	Pallet dropped during crane operation		1.3×10^{-7}
8IAUPAFRKIMP	Pallet impact during forklift operation		2.0×10^{-6}
8IAUPAFRKDRP	Pallet dropped during forklift operation		2.0×10^{-6}
8IAUPAJIBDRP	Projectile dropped by crane while lifting and loading onto conveyor		1.6×10^{-6}
8IAUPAUPALGC	UPA/airlock gate closes on projectile		9.4×10^{-8}
8IAUPAUPALGD	UPA/airlock gate drops on projectile		7.0×10^{-9}
8IAUPAALEVGC	Airlock/ECV gate closes on projectile		5.0×10^{-8}
8IAUPAALEVGD	Airlock/ECV gate drops on projectile		6.7×10^{-9}
8IAOVPMUNMPF	Munition inadvertently sent to MPF		1.5×10^{-5}

Table 4-4. Initiators and Frequencies for 8-inch Projectiles (Continued)

Event	Description	Agent/ Drain Status	Frequency (per munition)
Projectile Handling System PODs are included in appendix C5; systems analysis is included in appendix D3			
8IAPHSEVERGC	ECV/ECR blast gate closes on projectile		5.0×10^{-5}
8IAPHSEVERGD	ECV/ECR blast gate drops on projectile		6.9×10^{-9}
8IAPHSEVERSW	ECV/ECR swing roller fails to move into position causing projectile to fall		2.8×10^{-7}
8IAPHSECRFIR	Miscellaneous parts deposit energetic residue onto conveyor		3.6×10^{-5}
8IAPHSBRFREM	Projectile fails to have burster removed		1.3×10^{-7}
8IAPHSBSREXP	Burster explodes during shearing		9.5×10^{-10}
8IAPHSMMSGFO	Munition access blast gate fails to open		4.2×10^{-6}
8IAPHSERUMGC	ECR/UMC blast gate closes on projectile		5.0×10^{-5}
8IAPHSERUMGD	ECR/UMC blast gate drops on projectile		6.9×10^{-9}
8IAPHSERUMSW	ECR/UMC swing roller fails to move into position causing projectile to fall		2.8×10^{-7}
8IAPHSUMCCDP	Tray of undrained projectiles dropped during UMC charge car operations		2.4×10^{-5}
8IAPHSROWSKPU	Row of projectiles on tray skips MDM		1.7×10^{-9}
8IAPHSTRYSKPU	Projectile tray skips MDM		6.2×10^{-8}
8IAPHSBWFREMU	Projectile with intact burster well is sent to MPF		4.4×10^{-9}
8IAPHSLFTDRP*	Lift drops to first floor	D	1.9×10^{-8}
		I	5.8×10^{-13}
		A	$<10^{-13}$
8IAPHSLMCCXR	Tray stuck during LMC charge car loading		7.4×10^{-4}
8IAPHSLMCCDP*	Tray dropped during LMC charge car loading	D	2.4×10^{-5}
		I	7.8×10^{-10}
		A	2.3×10^{-11}
DFS Processing of 8-inch Projectiles PODs are included in appendix C6; systems analysis is included in appendix D6			
8IADFSFDCHJM	DFS feed chute jams		9.6×10^{-6}
8IADFSGBTVCL	DFS chute gate (tipping valve) fails closed		8.1×10^{-5}
8IADFSRNGEXP	Natural gas explosion in the DFS room		1.2×10^{-9}[a]

Table 4-4. Initiators and Frequencies for 8-inch Projectiles (Continued)

Event	Description	Agent/ Drain Status	Frequency (per munition)
MPF Processing of 8-inch Projectiles PODs are included in appendix C7; systems analysis is included in appendix D7			
8IAMPFARLEXP*&	Charge airlock agent vapor explosion	DG	4.0×10^{-11}
		DV	3.6×10^{-11}
		IG	$<10^{-13}$
		IV	$<10^{-13}$
		AG	2.8×10^{-12}
		AV	2.6×10^{-12}
8IAMPFRMAGHI*	Agent release to the MPF room	D	3.8×10^{-6} [a]
		I	1.4×10^{-10} [a]
		A	1.7×10^{-9} [a]
8IAMPFFNGEXP*	Natural gas explosion in MPF	D	6.9×10^{-10}
		I	$<10^{-13}$ [a]
		A	$<10^{-13}$ [a]
8IAMPFRNGEXP*	Natural gas explosion in MPF room	D	$<10^{-13}$ [a]
		I	$<10^{-13}$ [a]
		A	$<10^{-13}$
8IAMPFPASREL*	Agent release through MPF PAS	D	1.6×10^{-8} [a]
		I	1.2×10^{-12} [a]
		A	1.1×10^{-10} [a]
8IAMPF2NGEXP*	Natural gas explosion in the afterburner	D	6.1×10^{-10} [a]
		I	$<10^{-13}$ [a]
		A	$<10^{-13}$ [a]
TMA Handling of 8-inch Projectiles PODs are included in appendix C7; systems analysis is included in appendix D1			
8IATMALFTDRP	EONC dropped during lift operation		2.6×10^{-13}
8IATMASCISDP	Munition tray dropped during EONC tray removal		2.5×10^{-6}
8IATMACRNDRP	Munitions dropped during pallet hoisting to TMA floor and tray		1.6×10^{-5}
8IATMATMLMGC	TMA/LMC gate closes on tray of projectiles		1.7×10^{-5}
8IATMALMCCDP	Tray of undrained projectiles dropped during LMC charge car loading		1.1×10^{-4}
8IATMAMUNMPF	Tray of projectiles inadvertently sent to MPF		4.5×10^{-6}

Table 4-4. Initiators and Frequencies for 8-inch Projectiles (Continued)

Event	Description	Agent/ Drain Status	Frequency (per munition)
8IATMALMBSGC	LMC/BSA gate closes on tray of projectiles		2.4×10^{-5}
8IATMABSALFT	BSA/MPB lift operation results in munitions drop		2.1×10^{-8}
8IATMAMPUMGC	MPB/UMC gate closes on tray of projectiles		1.7×10^{-5}
8IATMAUMCCDP	Tray of projectiles dropped during UMC charge car loading		1.1×10^{-4}
8IATMAUMEVGC	UMC/ECV gate closes on tray of projectiles		1.7×10^{-5}
Overpacking Leaking 8-inch Projectiles PODs are included in appendix C10; systems analysis is included in appendix D1			
8IALKRFRKIM1	Pallet impact during forklift operation		2.7×10^{-4}
8IALKRFRKDP1	Pallet dropped during forklift operation		2.7×10^{-4}
8IALKRFRKIM2	Pallet impact during restacking		2.7×10^{-4}
8IALKRFRKDP2	Pallet dropped during restacking		2.7×10^{-4}

Note:

[a] The frequency for this event is calculated on a per-hour basis.

Table 4-5. Initiators and Frequencies for Mines

Event	Description	Agent/ Drain Status	Frequency (per munition)
Storage Yard Handling of Mines PODs are included in appendix C1; systems analysis is included in appendix D1			
MINSTYFRKIM1	Impact during 4,000-lb forklift operation		3.3×10^{-7}
MINSTYFRKDP1	Drop during 4,000-lb forklift operation		3.3×10^{-7}
MINSTYTRUKIM	Arriving EONC truck impacts munitions on tray		1.9×10^{-8}
MINSTYFRKIM2	Impact during 16,000-lb forklift operation		3.3×10^{-7}
MINSTYFRKDP2	Drop during 16,000-lb forklift operation		3.3×10^{-7}
MINSTYAGTWKRV	Worker enters igloo with undetected leaker		8.8×10^{-11}
CHB Handling of Mines PODs are included in appendix C3; systems analysis is included in appendix D1			
MINCHBSEALLKV	Leak during transport and EONC seal fails		2.5×10^{-11}
MINCHBCRNDRP	EONC dropped during movement from truck to CHB container tray		2.0×10^{-7}
MINCHBLFTDRP	CHB lift operation results in EONC drop		2.6×10^{-7}
UPA Handling of Mines PODs are included in appendix C4; systems analysis is included in appendix D1			
MINUPASCSDP1	EONC tray with pallet dropped during scissor lift operation		3.5×10^{-6}
MINUPAEMTONC	Empty EONC impacts pallet on scissor lift		5.5×10^{-6}
MINUPAFRKIM1	Pallet impact during forklift operation		3.3×10^{-7}
MINUPAFRKDP1	Pallet dropped during forklift operation		3.3×10^{-7}
MINUPALIDDP1	Drum lid dropped on drum		3.1×10^{-3}
MINUPAFRKIM2	Mine drum impact during forklift operation		4.0×10^{-6}
MINUPAFRKDP2	Mine drum dropped during forklift operation		4.0×10^{-5}
MINUPALIDDP2	Drum lid dropped on drum		3.1×10^{-3}
MINUPAFUZDP1	Fuze dropped during cardboard mine loading		5.2×10^{-3}
MINUPACRNDRP	Metal mine dropped during transfer		1.1×10^{-5}
MINUPAFUZDP2	Cardboard mine dropped		1.7×10^{-5}
MINUPAUPALGC	UPA/airlock gate closes on mine		1.7×10^{-8}
MINUPAUPALGD	UPA/airlock gate drops on mine		1.3×10^{-9}
MINUPAALEVGC	Airlock/ECV gate closes on mine		1.8×10^{-8}
MINUPAALEVGD	Airlock/ECV gate drops on mine		1.4×10^{-9}
MINUPAMNCRSH	Mine inadvertently crushed		6.4×10^{-7}

Table 4-5. Initiators and Frequencies for Mines (Continued)

Event	Description	Agent/ Drain Status	Frequency (per munition)
Damaged Mine Drum Processing in the ECV PODs are included in appendix C5; system analysis is included in appendix D5			
MINECVDRMDP1	Mine drum dropped during transfer to cart		1.5×10^{-10}
MINECVDRMDP2	Mine drum dropped during hoist		1.4×10^{-8}
MINECVUPALGC	UPA/Airlock gate closes on mine drum		1.7×10^{-7}
MINECVUPALGD	UPA/Airlock gate drops on mine drum		1.1×10^{-11}
MINECVALEVGC	Airlock/ECV gate closes on mine drum		1.7×10^{-7}
MINECVALEVGD	Airlock/ECV gate drops on mine drum		1.2×10^{-11}
MINECVDRMDP3	Mine drum dropped during hoist		1.4×10^{-8}
MINECVMINIMP	Operator impacts mine during lid removal		2.0×10^{-5}
MINECVLIDDRP	Drum lid dropped on drum		3.1×10^{-5}
MINECVFUZDP1	Fuze dropped during cardboard mine loading		6.8×10^{-5}
MINECVMINDRP	Mine dropped during transfer		3.4×10^{-5}
MINECVFUZDP2	Cardboard mine dropped		1.1×10^{-5}
MINECVMINMPF	Mine inadvertently sent to the MPF		1.0×10^{-6}
Mine Handling System PODs are included in appendix C5; systems analysis is included in appendix D5			
MINMHSEVERGC	ECV/ECR blast gate closes on mine		5.0×10^{-5}
MINMHSEVERGD	ECV/ECR blast gate drops on mine		1.4×10^{-9}
MINMHSMMSGFO	Slide gate fails to open		5.6×10^{-6}
MINMHSPNCBST	Burster inadvertently punched		6.0×10^{-4}
ACS PODs are included in appendix C6; system analysis is included in appendix D8			
MINTOXUMCSPL	Agent spill in UMC from ACS piping		9.1×10^{-9}
DFS Processing of Mines PODs are included in appendix C6; systems analysis is included in appendix D6			
MINDFSFDCHJM	DFS feed chute jams		9.6×10^{-6}
MINDFSGBTVCL	DFS chute gate (tipping valve) fails closed		8.7×10^{-5}
MINDFSRNGEXP	Natural gas explosion in the DFS room		1.2×10^{-9}
MINDFSPASREL	Agent release from DFS through PAS/PFS		9.5×10^{-6}
MINDFSHDCENC	Worker exposure during heated discharge conveyor enclosure operations		1.9×10^{-7}
MINDFSCYCENC	Worker exposure during cyclone bin changeout		1.7×10^{-7}

Table 4-5. Initiators and Frequencies for Mines (Continued)

Event	Description	Agent/ Drain Status	Frequency (per munition)
TMA Handling of Mines PODs are included in appendix C7; systems analysis is included in appendix D1			
MINTMALFTDRP	EONC dropped during lift operation		2.6×10^{-13}
MINTMASCISDP	Munition tray dropped during EONC tray removal		2.5×10^{-6}
MINTMACRNDRP	Munitions dropped during pallet hoisting to TMA floor and tray		2.6×10^{-6}
MINTMATMLMGC	TMA/LMC gate closes on tray of mine		2.8×10^{-6}
MINTMALMCCDP	Tray of undrained mine dropped during LMC charge car loading		1.9×10^{-5}
MINTMALMBSGC	LMC/BSA gate closes on tray of mines		3.9×10^{-6}
MINTMABSALFT	BSA/MPB lift operation results in munitions drop		3.4×10^{-9}
MINTMAMPUMGC	MPB/UMC gate closes on tray of mines		2.8×10^{-6}
MINTMAUMCCDP	Tray of mines dropped during UMC charge car loading		1.8×10^{-5}
MINTMAUMEVGC	UMC/ECV gate closes on tray of mines		2.8×10^{-6} [a]

Note:

[a] The frequency for this event is calculated on a per-hour basis.

Table 4-6. Initiators and Frequencies for Ton Containers

Event	Description	Agent/ Drain Status	Frequency (per munition)
Storage Yard Handling of Ton Containers PODs are included in appendix C1; systems analysis is included in appendix D1			
TONSTYFRKDP1	Drop during 6,000-pound forklift operation		1.2×10^{-5}
TONSTYTRUKIM	Arriving EONC truck impacts ton containers on tray		3.4×10^{-7}
TONSTYFRKIMP	Impact during 16,000-pound forklift operation		6.0×10^{-6}
TONSTYFRKDP2	Drop during 16,000-pound forklift operation		1.2×10^{-5}
TONSTYAGTWKRH	Worker enters igloo with undetected leaker		4.4×10^{-10}
CHB Handling of Ton Containers PODs are included in appendix C3; systems analysis is included in appendix D1			
TONCHBSEALLKH	Leak during transport and EONC seal fails		2.2×10^{-9}
TONCHBCRNDRP	EONC dropped during movement from truck to CHB container tray		3.6×10^{-6}
TONCHBLFTDRP	CHB lift operation results in EONC drop		4.7×10^{-6}
UPA Handling of Ton Containers PODs are included in appendix C4; systems analysis is included in appendix D1			
TONUPASCISDP	EONC tray with pallets dropped during scissor lift operation		6.3×10^{-5}
TONUPAEMTONC	Empty EONC impacts pallets on scissor lift		1.0×10^{-4}
TONUPACRNDRP	Bulk item dropped during crane operation		3.1×10^{-6}
TONUPAFRKIMP	Bulk item impact during forklift operation		1.2×10^{-5}
TONUPAFRKDRP	Bulk item dropped during forklift operation		1.2×10^{-5}
Bulk Handling System PODs are included in appendix C5; systems analysis is included in appendix D4			
TONBHSUPALGC	UPA/airlock gate closes on ton container		4.6×10^{-7}
TONBHSUPALGD	UPA/airlock gate drops on ton container		3.6×10^{-8}
TONBHSALEVGC	Airlock/ECV gate closes on ton container		4.6×10^{-7}
TONBHSALEVGD	Airlock/ECV gate drops on ton container		3.6×10^{-8}
TONBHSEVUMGC	ECV/UMC gate closes on ton container		5.9×10^{-7}
TONBHSEVUMGD	ECV/UMC gate drops on ton container		3.6×10^{-8}
TOMBHSUMCCDP	Ton container falls during transfer from conveyor to UMC charge car		9.2×10^{-4}
TONBHSUMMPGC	UMC/MPB gate closes on ton container		5.5×10^{-7}
TONBHSUMMPGD	UMC/MPB gate drops on ton container		3.9×10^{-8}
TONBHSMUNMPF	Ton container is not punched and is sent to MPF		4.8×10^{-7}

Table 4-6. Initiators and Frequencies for Ton Containers (Continued)

Event	Description	Agent/ Drain Status	Frequency (per munition)
TONBHSBDSSPL	Agent spill occurs at BDS		8.1×10^{-4}
TONBHSULFTGC*	Upper MPB/BSA lift gate closes on ton container	D	4.6×10^{-7}
		I	5.8×10^{-9}
		A	1.5×10^{-10}
TONBHSULFTGD*	Upper MPB/BSA lift gate drops on ton container	D	3.6×10^{-8}
		I	4.2×10^{-10}
		A	8.1×10^{-12}
TONBHSLFTDRP*	Lift drops to first floor	D	5.0×10^{-7}
		I	5.6×10^{-9}
		A	7.5×10^{-11}
TONBHSLLFTGC*	Lower MPB/BSA lift gate closes on ton container	D	4.6×10^{-7}
		I	5.2×10^{-9}
		A	8.1×10^{-11}
TONBHSLLFTGD*	Lower MPB/BSA lift gate drops on ton container	D	3.6×10^{-8}
		I	4.0×10^{-10}
		A	5.5×10^{-12}
TONBHSLMCCDP*	Ton container falls during charge car transfers in LMC, BSA, and MPF	D	9.2×10^{-4}
		I	1.0×10^{-5}
		A	1.4×10^{-7}
TONBHSLMCCXR	Ton container stuck during charge car transfers in LMC, BSA, and MPF		2.0×10^{-2}
TONBHSBSLMGC*	BSA/LMC gate closes on ton container	D	9.2×10^{-7}
		I	1.1×10^{-8}
		A	1.6×10^{-10}
TONBHSBSLMGD*	BSA/LMC gate drops on ton container	D	7.1×10^{-8}
		I	8.0×10^{-10}
		A	1.1×10^{-11}
TONBHSLMBSGC*	LMC/BSA gate closes on ton container	D	4.6×10^{-7}
		I	5.2×10^{-9}
		A	8.1×10^{-11}

Table 4-6. Initiators and Frequencies for Ton Containers (Continued)

Event	Description	Agent/ Drain Status	Frequency (per munition)
TONBHSLMBSGD*	LMC/BSA gate drops on ton container	D	3.6×10^{-8}
		I	4.0×10^{-10}
		A	5.5×10^{-12}
MPF Processing of Ton Containers PODs are included in appendix C6; systems analysis is included in appendix D7			
TONMPFARLEXP*	Charge airlock agent vapor explosion	D	5.5×10^{-10}
		I	3.9×10^{-11}
		A	4.2×10^{-12}
TONMPFRMAGHI*	Agent release to the MPF room	D	1.0×10^{-4} [a]
		I	1.2×10^{-6} [a]
		A	2.0×10^{-8} [a]
TONMPFFNGEXP*	Natural gas explosion in MPF	D	1.9×10^{-8} [a]
		I	2.1×10^{-10} [a]
		A	2.5×10^{-12} [a]
TONMPFRNGEXP*	Natural gas explosion in MPF room	D	$<10^{-13}$ [a]
		I	$<10^{-13}$ [a]
		A	$<10^{-13}$ [a]
TONMPFPASREL*	Agent release through MPF PAS	D	4.3×10^{-7} [a]
		I	7.3×10^{-9} [a]
		A	4.3×10^{-7} [a]
TONMPF2NGEXP*	Natural gas explosion in afterburner	D	1.7×10^{-8} [a]
		I	1.8×10^{-10} [a]
		A	2.2×10^{-12} [a]
TMA Handling of Ton Containers PODs are included in appendix C7; systems analysis is included in appendix D1			
TONTMALFTDRP	EONC dropped during lift operation		4.8×10^{-12}
TONTMASCISDP	Munition tray dropped during EONC tray removal		4.5×10^{-5}
TONTMACRNDRP	Munition dropped during hoisting to TMA floor and tray		9.4×10^{-5}

Table 4-6. Initiators and Frequencies for Ton Containers (Continued)

Event	Description	Agent/ Drain Status	Frequency (per munition)
TONTMAMUNMPF	Tray of munitions inadvertently sent to MPF		2.7×10^{-5}
TONTMABSALFT	BSA/MPB lift operation results in munitions drop		1.2×10^{-7}

Note:

[a] The frequency for this event is calculated on a per-hour basis.

Table 4-7. Initiators and Frequencies for Spray Tanks

Event	Description	Agent/ Drain Status	Frequency (per munition)
Storage Yard Handling of Spray Tanks PODs are included in appendix C1; systems analysis is included in appendix D1			
STKSTYFRKIMP	Impact during 6,000-pound forklift operation		6.0×10^{-6}
STKSTYFRKDRP	Drop during 16,000-pound forklift operation		6.0×10^{-6}
STKSTYAGTWKRV	Worker enters igloo with undetected leaker		6.1×10^{-11}
CHB Handling of Spray Tanks PODs are included in appendix C3; systems analysis is included in appendix D1			
STKCHBSEALLKV	Leak during transport and container seal fails		3.1×10^{-10}
STKCHBCRNDRP	Container dropped during movement from truck to CHB container tray		7.2×10^{-6}
STKCHBTRAYIM	Container impact with CHB tray		1.3×10^{-4}
STKCHBEMTCTR	Spay tank container on truck hit with empty container		2.5×10^{-3}
STKCHBLIFTCL	CHB lift door closes on container		5.0×10^{-5}
STKCHBLIFTDP	CHB lift door drops on container		4.2×10^{-8}
STKCHBLFTDRP	CHB lift operation results in spray tank container drop		9.4×10^{-6}
UPA Handling of Spray Tanks PODs are included in appendix C4; systems analysis is included in appendix D1			
STKUPACRNDP1	Container dropped during crane movement		3.1×10^{-6}
STKUPALIDIMP	Spray tank impact with container lid		5.0×10^{-4}
STKUPACRNDP2	Spray tank dropped during crane movement		3.1×10^{-6}
Bulk Handling System PODs are included in appendix C5; systems analysis is included in appendix D4			
STKBHSUPALGC	UPA/airlock gate closes on spray tank		4.6×10^{-7}
STKBHSUPALGD	UPA/airlock gate drops on spray tank		3.6×10^{-8}
STKBHSALEVGC	Airlock/ECV gate closes on spray tank		4.6×10^{-7}
STKBHSALEVGD	Airlock/ECV gate drops on spray tank		3.6×10^{-8}
STKBHSEVUMGC	ECV/UMC gate closes on spray tank		5.9×10^{-7}
STKBHSEVUMGD	ECV/UMC gate drops on spray tank		3.6×10^{-8}
STKBHSUMCCDP	Spray tank falls during transfer from conveyor to UMC charge car		9.2×10^{-4}
STKBHSUMMPGC	UMC/MPB gate closes on spray tank		5.5×10^{-7}
STKBHSUMMPGD	UMC/MPB gate drops on spray tank		3.9×10^{-8}
STKBHSMUNMPF	Spray tank is not punched and is sent to MPF		4.8×10^{-7}
STKBHSBDSSPL	Agent spill occurs at BDS		8.1×10^{-4}

Table 4-7. Initiators and Frequencies for Spray Tanks (Continued)

Event	Description	Agent/ Drain Status	Frequency (per munition)
STKBHSULFTGC*	Upper MPB/BSA lift gate closes on spray tank	D	4.6×10^{-7}
		I	1.2×10^{-9}
		A	1.5×10^{-10}
STKBHSULFTGD*	Upper MPB/BSA lift gate drops on spray tank	D	3.6×10^{-8}
		I	6.4×10^{-11}
		A	8.1×10^{-12}
STKBHSLFTDRP*	Lift drops to first floor	D	5.0×10^{-7}
		I	5.7×10^{-10}
		A	7.5×10^{-11}
STKBHSLLFTGC*	Lower MPB/BSA lift gate closes on spray tank	D	4.6×10^{-7}
		I	6.2×10^{-10}
		A	8.1×10^{-11}
STKBHSLLFTGD*	Lower MPB/BSA lift gate drops on spray tank	D	3.6×10^{-8}
		I	4.4×10^{-11}
		A	5.5×10^{-12}
STKBHSLMCCDP*	Spray tank falls during charge car transfers in LMC, BSA, and MPF	D	9.2×10^{-4}
		I	1.0×10^{-6}
		A	1.4×10^{-7}
STKBHSLMCCXR	Spray tank stuck during charge car transfers in LMC, BSA, and MPF	D	2.0×10^{-2}
STKBHSBSLMGC*	BSA/LMC gate closes on spray tank	D	9.2×10^{-7}
		I	1.3×10^{-9}
		A	1.6×10^{-10}
STKBHSBSLMGD*	BSA/LMC gate drops on spray tank	D	7.1×10^{-8}
		I	8.8×10^{-11}
		A	1.1×10^{-11}
STKBHSLMBSGC*	LMC/BSA gate closes on spray tank	D	4.6×10^{-7}
		I	6.2×10^{-10}
		A	8.1×10^{-11}

Table 4-7. Initiators and Frequencies for Spray Tanks (Continued)

Event	Description	Agent/ Drain Status	Frequency (per munition)
STKBHSLMBSGD*	LMC/BSA gate drops on spray tank	D	3.6×10^{-8}
		I	4.4×10^{-11}
		A	5.5×10^{-12}
MPF Processing of Spray Tanks PODs are included in appendix C6; systems analysis is included in appendix D7			
STKMPFARLEXP*	Charge airlock agent vapor explosion	D	9.8×10^{-10}
		I	6.1×10^{-11}
		A	7.7×10^{-12}
STKMPFRMAGHI*	Agent release to the MPF room	D	1.0×10^{-6} [a]
		I	1.5×10^{-7} [a]
		A	2.0×10^{-8} [a]
STKMPFFNGEXP*	Natural gas explosion in MPF	D	1.9×10^{-8} [a]
		I	2.1×10^{-11} [a]
		A	2.5×10^{-12} [a]
STKMPFRNGEXP*	Natural gas explosion in MPF room	D	$<10^{-13}$ [a]
		I	$<10^{-13}$ [a]
		A	$<10^{-13}$ [a]
STKMPFPASREL*	Agent release through MPF PAS	D	4.3×10^{-7} [a]
		I	3.0×10^{-9} [a]
		A	3.8×10^{-10} [a]
STKMPF2NGEXP*	Natural gas explosion in the afterburner	D	1.7×10^{-8} [a]
		I	1.8×10^{-11} [a]
		A	2.2×10^{-12} [a]

Note:

[a] The frequency for this event is calculated on a per-hour basis.

Table 4-8. Initiators and Frequencies for MK-94 Bombs

Event	Description	Agent/ Drain Status	Frequency (per munition)
Storage Yard Handling of MK-94 bombs PODs are included in appendix C1; systems analysis is included in appendix D1			
500STYFRKIM1	Impact during 4,000-pound forklift operation		6.0×10^{-6}
500STYFRKDP1	Drop during 4,000-pound forklift operation		6.0×10^{-6}
500STYTRUKIM	Arriving EONC truck impacts MK-94 bombs on tray		3.4×10^{-7}
500STYFRKIM2	Impact during 16,000-pound forklift operation		6.0×10^{-6}
500STYFRKDP2	Drop during 16,000-pound forklift operation		6.0×10^{-6}
500STYAGTWKRG	Worker enters igloo with undetected leaker		3.2×10^{-9}
CHB Handling of MK-94 bombs PODs are included in appendix C3; systems analysis is included in appendix D1			
500CHBSEALLKG	Leak during transport and EONC seal fails		1.6×10^{-8}
500CHBCRNDRP	EONC dropped during movement from truck to CHB container tray		3.6×10^{-6}
500CHBLFTDRP	CHB lift operation results in EONC drop		4.7×10^{-6}
UPA Handling of MK-94 bombs PODs are included in appendix C4; systems analysis is included in appendix D1			
500UPASCISDP	EONC tray with pallets dropped during scissor lift operation		6.3×10^{-5}
500UPAEMTONC	Empty EONC impacts pallets on scissor lift		1.0×10^{-4}
500UPACRNDRP	Pallet dropped during crane operation		3.1×10^{-6}
500UPAFRKIMP	Bulk item impact during forklift operation		1.2×10^{-5}
500UPAFRKDRP	Bulk item dropped during forklift operation		1.2×10^{-5}
500OVPMUNMPF	Munition inadvertently sent to MPF		1.5×10^{-5}
Bulk Handling System PODs are included in appendix C5; systems analysis is included in appendix D4			
500BHSUPALGC	UPA/airlock gate closes on MK-94 bomb		4.6×10^{-7}
500BHSUPALGD	UPA/airlock gate drops on MK-94 bomb		3.6×10^{-8}
500BHSALEVGC	Airlock/ECV gate closes on MK-94 bomb		4.6×10^{-7}
500BHSALEVGD	Airlock/ECV gate drops on MK-94 bomb		3.6×10^{-8}
500BHSEVUMGC	ECV/UMC gate closes on MK-94 bomb		5.9×10^{-7}
500BHSEVUMGD	ECV/UMC gate drops on MK-94 bomb		3.6×10^{-8}
500BHSUMCCDP	MK-94 bomb falls during transfer from conveyor to UMC charge car		4.6×10^{-4}
500BHSUMMPGC	UMC/MPB gate closes on MK-94 bomb		5.5×10^{-7}

Table 4-8. Initiators and Frequencies for MK-94 Bombs (Continued)

Event	Description	Agent/ Drain Status	Frequency (per munition)
500BHSUMMPGD	UMC/MPB gate drops on MK-94 bomb		3.9×10^{-8}
500BHS1TOMPF	Bomb tray with one unpunched bomb is sent to the MPF		4.8×10^{-7}
500BHS2TOMPF	Bomb tray with two unpunched bombs is sent to MPF		4.8×10^{-7}
500BHSBDSSPL	Agent spill occurs at BDS		8.1×10^{-4}
500BHSULFTGC*	Upper MPB/BSA lift gate closes on MK-94 bomb	D	4.6×10^{-7}
		I	5.8×10^{-9}
		A	1.5×10^{-10}
500BHSULFTGD*	Upper MPB/BSA lift gate drops on MK-94 bomb	D	3.6×10^{-8}
		I	4.2×10^{-10}
		A	8.1×10^{-12}
500BHSLFTDRP*	Lift drops to first floor	D	2.5×10^{-7}
		I	2.8×10^{-9}
		A	3.7×10^{-11}
500BHSLLFTGC*	Lower MPB/BSA lift gate closes on MK-94 bomb	D	4.6×10^{-7}
		I	5.2×10^{-9}
		A	8.1×10^{-11}
500BHSLLFTGD*	Lower MPB/BSA lift gate drops on MK-94 bomb	D	3.6×10^{-8}
		I	4.0×10^{-10}
		A	5.5×10^{-12}
500BHSLMCCDP*	MK-94 bomb falls during charge car transfers in LMC, BSA, and MPF	D	4.6×10^{-4}
		I	5.1×10^{-6}
		A	6.9×10^{-8}
500BHSLMCCXR	MK-94 bomb stuck during charge car transfers in LMC, BSA, and MPF		2.0×10^{-2}
500BHSBSLMGC*	BSA/LMC gate closes on MK-94 bomb	D	9.2×10^{-7}
		I	1.1×10^{-8}
		A	1.6×10^{-10}
500BHSBSLMGD*	BSA/LMC gate drops on MK-94 bomb	D	7.1×10^{-8}
		I	8.0×10^{-10}
		A	1.1×10^{-11}

Table 4-8. Initiators and Frequencies for MK-94 Bombs (Continued)

Event	Description	Agent/ Drain Status	Frequency (per munition)
500BHSLMBSGC*	LMC/BSA gate closes on MK-94 bomb	D	4.6×10^{-7}
		I	5.2×10^{-9}
		A	8.1×10^{-11}
500BHSLMBSGD*	LMC/BSA gate drops on MK-94 bomb	D	3.6×10^{-8}
		I	4.0×10^{-10}
		A	5.5×10^{-12}
MPF Processing of MK-94 bombs PODs are included in appendix C6; systems analysis is included in appendix D7			
500MPFARLEXP*	Charge airlock agent vapor explosion	D	5.5×10^{-10}
		I	3.9×10^{-11}
		A	4.2×10^{-13}
500MPFRMAGHI*	Agent release to the MPF room	D	5.1×10^{-5} [a]
		I	5.9×10^{-7} [a]
		A	1.0×10^{-8} [a]
500MPFFNGEXP*	Natural gas explosion in MPF	D	9.4×10^{-9} [a]
		I	1.0×10^{-10} [a]
		A	1.2×10^{-12} [a]
500MPFRNGEXP*	Natural gas explosion in MPF room	D	$<10^{-13}$ [a]
		I	$<10^{-13}$ [a]
		A	$<10^{-13}$ [a]
500MPFPASREL*	Agent release through MPF PAS	D	2.2×10^{-7} [a]
		I	3.6×10^{-9} [a]
		A	1.9×10^{-10} [a]
500MPF2NGEXP*	Natural gas explosion in afterburner	D	8.3×10^{-9} [a]
		I	9.2×10^{-11} [a]
		A	1.1×10^{-12} [a]
TMA Handling of MK-94 bombs PODs are included in appendix C7; systems analysis is included in appendix D1			
500TMALFTDRP	EONC dropped during lift operation		4.8×10^{-12}
500TMASCISDP	Munition tray dropped during EONC tray removal		4.5×10^{-5}
500TMACRNDRP	Munition dropped during hoisting to TMA floor and tray		4.7×10^{-5}

Table 4-8. Initiators and Frequencies for MK-94 Bombs (Continued)

Event	Description	Agent/ Drain Status	Frequency (per munition)
500TMAMUNMPF	Tray of munitions inadvertently sent to MPF		1.4×10^{-5}
500TMABSALFT	BSA/MPB lift operation results in munitions drop		6.2×10^{-8}
Overpacking Leaking MK-94 bombs PODs are included in appendix C10; systems analysis is included in appendix D1			
500LKRFRKIM1	Pallet impact during forklift operation		8.0×10^{-4}
500LKRFRKDP1	Pallet dropped during forklift operation		8.0×10^{-4}
500LKRFRKIM2	Pallet impact during restacking		8.0×10^{-4}
500LKRFRKDP2	Pallet dropped during restacking		8.0×10^{-4}

Note:

[a] The frequency for this event is calculated on a per-hour basis.

Table 4-9. Initiators and Frequencies for MC-1 Bombs

Event	Description	Agent/ Drain Status	Frequency (per munition)
Storage Yard Handling of MC-1 bombs PODs are included in appendix C1; systems analysis is included in appendix D1			
750STYFRKIM1	Impact during 4,000-pound forklift operation		6.0×10^{-6}
750STYFRKDP1	Drop during 4,000-pound forklift operation		6.0×10^{-6}
750STYTRUKIM	Arriving EONC truck impacts MC-1 bombs on tray		1.7×10^{-7}
750STYFRKIM2	Impact during 16,000-pound forklift operation		6.0×10^{-6}
750STYFRKDP2	Drop during 16,000-pound forklift operation		6.0×10^{-6}
750STYAGTWKRH	Worker enters igloo with undetected leaker		2.5×10^{-10}
CHB Handling of MC-1 bombs PODs are included in appendix C3; systems analysis is included in appendix D1			
750CHBSEALLKG	Leak during transport and EONC seal fails		6.3×10^{-10}
750CHBCRNDRP	EONC dropped during movement from truck to CHB container tray		1.8×10^{-6}
750CHBLFTDRP	CHB lift operation results in EONC drop		2.4×10^{-6}
UPA Handling of MC-1 bombs PODs are included in appendix C4; systems analysis is included in appendix D1			
750UPASCISDP	EONC tray with pallets dropped during scissor lift operation		3.2×10^{-5}
750UPAEMTONC	Empty EONC impacts pallets on scissor lift		5.0×10^{-5}
750UPACRNDRP	Pallet dropped during crane operation		3.1×10^{-6}
750UPAFRKIMP	Bulk item impact during forklift operation		1.2×10^{-5}
750UPAFRKDRP	Bulk item dropped during forklift operation		1.2×10^{-5}
750OVPMUNMPF	Munition inadvertently sent to MPF		1.5×10^{-5}
Bulk Handling System PODs are included in appendix C5; systems analysis is included in appendix D4			
750BHSUPALGC	UPA/airlock gate closes on MC-1 bomb		4.6×10^{-7}
750BHSUPALGD	UPA/airlock gate drops on MC-1 bomb		3.6×10^{-8}
750BHSALEVGC	Airlock/ECV gate closes on MC-1 bomb		4.6×10^{-7}
750BHSALEVGD	Airlock/ECV gate drops on MC-1 bomb		3.6×10^{-8}
750BHSEVUMGC	ECV/UMC gate closes on MC-1 bomb		5.9×10^{-7}
750BHSEVUMGD	ECV/UMC gate drops on MC-1 bomb		3.6×10^{-8}
750BHSUMCCDP	MC-1 bomb falls during transfer from conveyor to UMC charge car		4.6×10^{-4}
750BHSUMMPGC	UMC/MPB gate closes on MC-1 bomb		5.5×10^{-7}

Table 4-9. Initiators and Frequencies for MC-1 Bombs (Continued)

Event	Description	Agent/ Drain Status	Frequency (per munition)
750BHSUMMPGD	UMC/MPB gate drops on MC-1 bomb		3.9×10^{-8}
750BHS1TOMPF	Bomb tray with one unpunched bomb is sent to the MPF		4.8×10^{-7}
750BHS2TOMPF	Bomb tray with two unpunched bomb is sent to MPF		4.8×10^{-7}
750BHSBDSSPL	Agent spill occurs at BDS		8.1×10^{-4}
750BHSULFTGC*	Upper MPB/BSA lift gate closes on MC-1 bomb	D	4.6×10^{-7}
		I	5.8×10^{-9}
		A	1.5×10^{-10}
750BHSULFTGD*	Upper MPB/BSA lift gate drops on MC-1 bomb	D	3.6×10^{-8}
		I	4.2×10^{-10}
		A	8.1×10^{-12}
750BHSLFTDRP*	Lift drops to first floor	D	2.5×10^{-7}
		I	2.8×10^{-9}
		A	3.7×10^{-11}
750BHSLLFTGC*	Lower MPB/BSA lift gate closes on MC-1 bomb	D	4.6×10^{-7}
		I	5.2×10^{-9}
		A	8.1×10^{-11}
750BHSLLFTGD*	Lower MPB/BSA lift gate drops on MC-1 bomb	D	3.6×10^{-8}
		I	4.0×10^{-10}
		A	5.5×10^{-12}
750BHSLMCCDP*	MC-1 bomb falls during charge car transfers in LMC, BSA, and MPF	D	4.6×10^{-4}
		I	5.1×10^{-6}
		A	6.9×10^{-8}
750BHSLMCCXR	MC-1 bomb stuck during charge car transfers in LMC, BSA, and MPF		2.0×10^{-2}
750BHSBSLMGC*	BSA/LMC gate closes on MC-1 bomb	D	9.2×10^{-7}
		I	1.1×10^{-8}
		A	1.6×10^{-10}
750BHSBSLMGD*	BSA/LMC gate drops on MC-1 bomb	D	7.1×10^{-8}
		I	8.0×10^{-10}
		A	1.1×10^{-11}

Table 4-9. Initiators and Frequencies for MC-1 Bombs (Continued)

Event	Description	Agent/ Drain Status	Frequency (per munition)
750BHSLMBSGC*	LMC/BSA gate closes on MC-1 bomb	D	4.6×10^{-7}
		I	5.2×10^{-9}
		A	8.1×10^{-11}
750BHSLMBSGD*	LMC/BSA gate drops on MC-1 bomb	D	3.6×10^{-8}
		I	4.0×10^{-10}
		A	5.5×10^{-12}
MPF Processing of MC-1 bombs PODs are included in appendix C6; systems analysis is included in appendix D7			
750MPFARLEXP*	Charge airlock agent vapor explosion	D	5.5×10^{-10}
		I	3.9×10^{-11}
		A	4.2×10^{-12}
750MPFRMAGHI*	Agent release to the MPF room	D	5.1×10^{-5} [a]
		I	5.9×10^{-7} [a]
		A	1.0×10^{-8} [a]
750MPFFNGEXP*	Natural gas explosion in MPF	D	9.4×10^{-9} [a]
		I	1.0×10^{-10} [a]
		A	1.2×10^{-12} [a]
750MPFRNGEXP*	Natural gas explosion in MPF room	D	$<10^{-13}$ [a]
		I	$<10^{-13}$ [a]
		A	$<10^{-13}$ [a]
750MPFPASREL*	Agent release through MPF PAS[j]	D	2.2×10^{-7} [a]
		I	3.6×10^{-9} [a]
		A	1.9×10^{-10} [a]
750MPF2NGEXP*	Natural gas explosion in the afterburner	D	8.3×10^{-9} [a]
		I	9.2×10^{-11} [a]
		A	1.1×10^{-12} [a]
TMA Handling of MC-1 bombs PODs are included in appendix C7; systems analysis is included in appendix D1			
750TMALFTDRP	EONC dropped during lift operation		2.4×10^{-12}
750TMASCISDP	Munition tray dropped during EONC tray removal		2.3×10^{-5}
750TMACRNDRP	Munition dropped during hoisting to TMA floor and tray		4.7×10^{-5}

Table 4-9. Initiators and Frequencies for MC-1 Bombs (Continued)

Event	Description	Agent/ Drain Status	Frequency (per munition)
750TMAMUNMPF	Tray of munitions inadvertently sent to MPF		1.4×10^{-5}
750TMABSALFT	BSA/MPB lift operation results in munitions drop		6.2×10^{-8}
Overpacking Leaking MC-1 bombs PODs are included in appendix C10; systems analysis is included in appendix D1			
750LKRFRKIM1	Pallet impact during forklift operation		8.0×10^{-4}
750LKRFRKDP1	Pallet dropped during forklift operation		8.0×10^{-4}
750LKRFRKIM2	Pallet impact during restacking		8.0×10^{-4}
750LKRFRKDP2	Pallet dropped during restacking		8.0×10^{-4}

Note:

[a] The frequency for this event is calculated on a per-hour basis.

Table 4-10. Initiators and Frequencies for the Agent Collection System, Incinerators, HVAC, and Secondary Waste

Event	Description	Frequency (per hour)
ACS PODs are included in appendix C6; systems analysis is included in appendix D8.		
TOXMPBSPL	Agent spill in MPB from ACS piping	6.4×10^{-8}
TOXLRGSPL	Large agent leak in TOX room from pipe break	2.6×10^{-7}
TOXSMLSPL	Small agent leak in TOX room due to agent feed pump seal failure	1.5×10^{-4}
TOXCUBSPL	Agent spill in TOX room	1.2×10^{-5}
TOXLMCSPL	Agent spill from ACS piping in LMC	6.4×10^{-8}
LIC PODs are included in appendix C6; systems analysis is included in appendix D8		
LICVAPREL	Agent release in LIC room	1.8×10^{-5}
LICFNGEXP	Natural gas explosion in the LIC furnace	5.5×10^{-7}
LICRNGEXP	Natural gas explosion in the LIC room	3.8×10^{-8}
LICPASREL	Release through the LIC PAS	3.5×10^{-8}
HVAC PODs are included in appendix C8; systems analysis is included in appendix D10		
HVCAGNMIG	HVAC upset in processing area leads to agent migration	3.2×10^{-4}
HVCENGCTL	Loss of all MDB HVAC as engineering control	1.0×10^{-5}
HVCOFFFLT	Agent release from offline filter units	3.6×10^{-8}
HVCFLTFIR	Filter fire results in agent release	5.1×10^{-12}
Secondary Waste PODs are included in appendix C9; systems analysis is included in appendix D18		
WASFLTMTN	Routine maintenance of offline filter units	1.0×10^{-3}
WASFLTSTO	Charcoal filter storage results in agent release	6.1×10^{-10}
WASTRKCRB	Transportation accident	5.4×10^{-8}

Table 4-11. Transportation Accident Initiating Event Frequencies at UMCDF

Event	Description	Frequency (per hour)
URKTSTYTRKACC	Accident occurs during transport of rockets to CHB	1.2×10^{-8}
UMINSTYTRKACC	Accident occurs during transport of mines to CHB	1.0×10^{-8}
U55ASTYTRKACC	Accident occurs during transport of 155mm projectiles to CHB	5.0×10^{-9}
U8IASTYTRKACC	Accident occurs during transport of 8-inch projectiles to CHB	1.0×10^{-8}
UTONSTYTRKACC	Accident occurs during transport of ton containers to CHB	1.8×10^{-7}
USTKSTYTRKACC	Accident occurs during transport of spray tanks to CHB	1.8×10^{-7}
U500STYTRKACC	Accident occurs during transport of MK-94 bombs to CHB	1.8×10^{-7}
U750STYTRKACC	Accident occurs during transport of MC-1 bombs to CHB	9.0×10^{-7}

(This page intentionally left blank.)

SECTION 5
EXTERNAL INITIATING EVENTS ANALYSIS

Analysis of external events requires the use of specialized methods to address important factors not usually encountered in the analysis of internal events. These factors include the assessment of frequency of occurrence versus magnitude of external events, and the modeling of failure of components and structures in terms of variables that describe physical interactions. Substantial effort has been expended in identifying comprehensive lists of potential external events. The nuclear risk assessment industry efforts in this area (USNRC, 1990; ONRR, 1991; USNRC, 1983) are recognized as useful audit lists for QRAs of other facilities (CCPS, 1989a). These lists include weather-related phenomena (storms, tornadoes, lightning, etc.), other natural hazards (earthquakes, landslides, etc.), and manmade hazards (aircraft crashes, industrial accidents, dam failures, etc.). These standard lists were examined for applicability to UMCD (see table 5-1).

The criteria in USNRC (1982) were used to determine if an external event should be further evaluated. Based on these criteria, an external event was screened from further evaluation if: 1) the event was of equal or lesser damage potential than the events for which the plant has been designed (this required an evaluation of plant design bases in order to estimate the resistance of plant structures and systems to a particular external event), 2) the event had a significantly lower mean frequency of occurrence than other events with similar uncertainties and could not result in worse consequences than those events, 3) the event could not occur close enough to the plant to affect it (this is also a function of the magnitude of the event), 4) the event was included in the definition of another event, 5) the event was slow in developing and there is sufficient time to eliminate the source of the threat or provide an adequate response, or 6) the event was below 1×10^{-8} per year (or in other words, wasn't expected to occur more than once every 100 million years).

Although fires occur within the facility as a result of equipment and disposal processes (such that they could easily be described as an "internal event," they are analytically better described in this section as an external event. This is because fires are not studied with step-by-step evaluation of the processes using PODs like the other internal events. Fires must be studied by examining the hazard and postulating the possible impact to the entire facility. This distinction is not critical, and only the methods of analysis makes this considered an external event. However, the risk results presented in section 13 do not make this distinction because overall facility risk is discussed in terms of individual contributors only.

For each external event that was not screened, the following subtasks were performed:
1) characterization of the hazard in terms of frequency of occurrence and intensity level;
2) identification of vulnerabilities of systems, structures, and components to the external hazard;

Table 5-1. External Events Considered for UMCDF and UMCD

Event	Treatment
Aircraft Impact	Developed in detail
Avalanche	Screened from further analysis
Barometric Pressure	Not applicable to this site
Coastal Erosion	Included in the evaluation of External Flooding
Drought	Screened from further analysis
Explosive Gas (Hydrogen)	Developed in detail
External Flooding	Examined in EIS, not refined
Extreme Winds/Tornadoes	Developed in detail
Facility Fire	Developed in detail
Fog	Screened from further analysis
Forest Fire/Wildfire	Screened from further analysis
Frost	Not applicable to this site
Hail	Screened from further analysis
Hightide/High River or Lake Level	Included in the evaluation of External Flooding
High Summer Temperature	Screened from further analysis
Hurricane	Included in the evaluation of External Flooding and Extreme Winds/Tornadoes
Ice Cover	Screened from further analysis
Industrial/Military Facility Accident	Screened from further analysis
Internal Flooding	Screened from further analysis
Landslide	Screened from further analysis
Lightning	Developed in detail
Low Tide	Not applicable to this site
Low Winter Temperature	Screened from further analysis
Meteorite Impact	Screened from further analysis
Pipeline Accident	Screened from further analysis
Intense Precipitation	Included in the evaluation of External and Internal Flooding
River Diversion	Included in the evaluation of External and Internal Flooding
Sinkholes	Screened from further analysis
Sandstorm	Screened from further analysis
Seiche	Included in the evaluation of External Flooding
Seismic	Developed in detail
Toxic Gas	Screened from further analysis
Offsite Transportation Accident	Screened from further analysis
Tsunami	Screened from further analysis
Volcanic	Screened from further analysis
Waves	Included in the evaluation of External Flooding
Wildfire	Screened from further analysis

3) development of models to identify and assess various accident sequences that may result from the external event; and 4) quantification of the models to determine risk due to the external event. It should be noted that the external event hazards and the estimates of their frequencies are discussed at a very high level in this section. Actual hazard analyses, raw data, fragility curves, and detailed calculations used to derive event frequencies and outcomes for events that were fully analyzed are covered in more detail in the applicable external event appendices (see table 5-2).

Table 5-2. Summary of External Events Appendices

External Event Analysis	UMCDF QRA Appendix
Seismic Initiators	Appendix H
Aircraft Crash Initiators	Appendix I
Weather-Related Initiators	Appendix J
Fires and Hydrogen Explosions	Appendix K

5.1 Seismic Initiators

This section describes at a very high level the seismic analysis that was performed for UMCDF and UMCD. Although seismic initiators do not pose a significant threat to operations at UMCDF, they are the dominant risk concern for munitions stored in I-Block and K-Block.

5.1.1 Seismic Hazard at UMCD.[2] This section presents the results of a probabilistic seismic hazard assessment (PSHA) that was performed for the UMCDF QRA. The purpose of the seismic hazard assessment is to estimate the frequency of exceedance of specified earthquake ground motion levels at UMCD.

The PSHA conducted for the UMCDF (JBA, 1995) was based on an update of the seismic source characteristics developed as part of a comprehensive seismic hazard study conducted for the State of Oregon. This was the state-wide PSHA for the Oregon Department of Transportation and the assessment performed for the Department of Energy site at Hanford, Washington. The update for UMCD entailed the addition of local seismic sources near the site and an update of recurrence rates.

[2] On February 28, 2001, a 6.8 moment magnitude earthquake occurred near Nisqually, Washington. Nisqually is approximately 11 miles northeast of Olympia, Washington, and approximately 181 miles (292 km) northwest of UMCD (Nisqually, 2001). This earthquake was not included in the historic data supporting the UMCD QRA seismic analysis. Based on analysis and Expert Panel comments, it was determined that there is no significant impact from excluding the Nisqually earthquake on results of the seismic analysis (Mitretek, 2002).

UMCD is located in northeastern Oregon, near the town of Umatilla, approximately 4 miles south of the Columbia River. The northeastern region of Oregon is located in the Dalles-Umatilla Basin in the southern part of the Columbia Plateau physiographic province. In this part of the country, the geologic and physiographic provinces are coincident, and therefore no distinction between the two is made.

Figure 5-1 shows an updated map of historic seismicity in the regional vicinity of UMCD. The figure identifies events of magnitude 1 and greater. From the figure it is apparent that the seismicity in the immediate vicinity of the site (approximately 100 kilometers) is relatively low, both in terms of the number and size of past events. As shown in figure 5-1, an event of approximately magnitude 5 and Modified Mercalli Intensity (MMI) VII occurred about 10 kilometers from UMCD. This event occurred in 1893 and is estimated to have caused a peak ground acceleration (PGA) of 0.10 ground acceleration (g) at UMCD. Review of figure 5-1 indicates areas of concentrated seismicity are located to the west and northwest in the Cascades and Okanogan physiographic provinces and to the southwest at the juncture of the Pacific, Juan

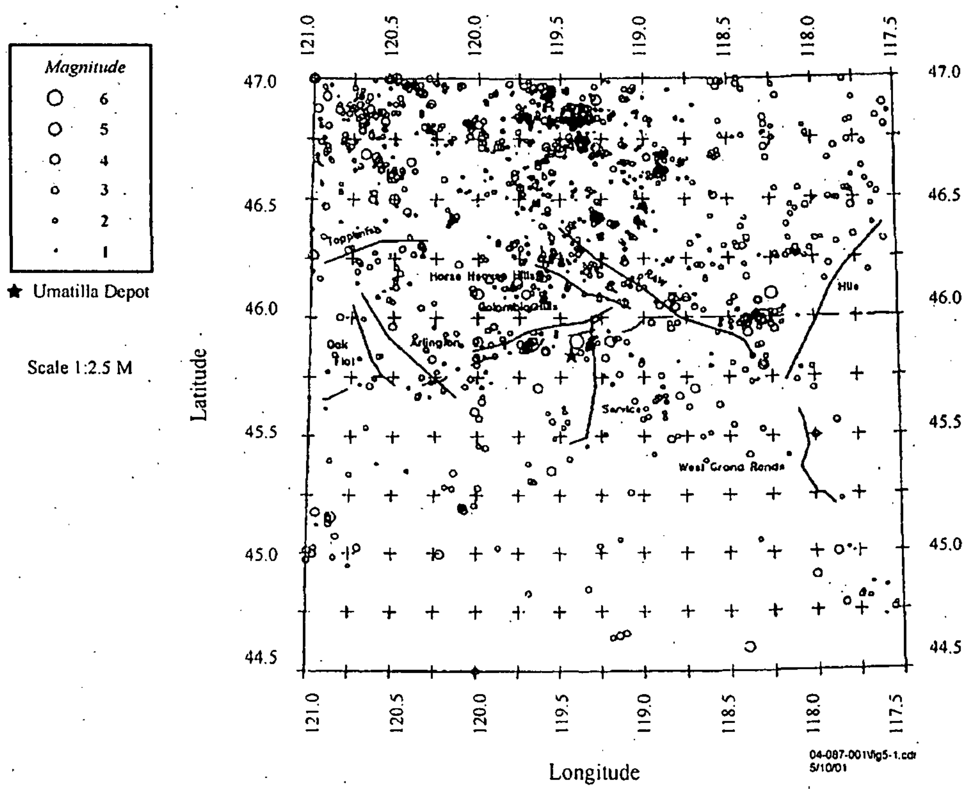


Figure 5-1. Earthquakes Within 320 Kilometers of the Umatilla Site

de Fuca, and North American plates. Note this later region is located well over 300 kilometers from UMCD. For illustrative purposes, table 5-3 provides a comparison of the Mercalli Intensity index versus the PGA and an approximate comparison to the familiar Richter Scale.

Table 5-3. Comparison of Mercalli Intensity Index Versus PGA and Richter Scale

Modified Mercalli Intensity Scale	Description of Effects (Masonry A, B, C, and D Are Defined in Note[a])	Maximum Acceleration (g)	Approximate Richter Magnitude Comparison
I	Not felt; marginal and long-period effects of large earthquakes evident		2 to 2.5
II	Felt by persons at rest, on upper floors, or favorably placed		2.5 to 3.1
III	Felt indoors; hanging objects swing; vibration like passing of light trucks occurs; duration estimated; might not be recognized as an earthquake	0.003 to 0.007	3.1 to 3.7
IV	Hanging objects swing; vibration occurs that is like passing of heavy trucks, or there is a sensation of a jolt like a heavy ball striking the walls; standing motor cars rock; windows, dishes, and doors rattle; glasses clink; crockery clashes; in the upper range of IV, wooden walls and frame creak	0.007 to 0.03	3.7 to 4.3
V	Felt outdoors; duration estimated; sleepers waken; liquids become disturbed, some spill; small unstable objects are displaced or upset; doors swing, close, and open; shutters and pictures move; pendulum clocks stop, start, and change rate	0.015 to 0.03	4.3 to 4.9
VI	Felt by all; many are frightened and run outdoors; persons walk unsteadily; windows, dishes, glassware break; knickknacks, books, etc., fall off shelves; pictures fall off walls; furniture moves or overturns; weak plaster and masonry D crack; small bells ring (church, school); trees, bushes shake.	0.03 to 0.09	4.9 to 5.5
VII	Difficult to stand; noticed by drivers of motor cars; hanging objects quiver; furniture breaks; damage occurs to masonry D, including cracks; weak chimneys break at roof line; plaster, loose bricks, stones, tiles, cornices fall; some cracks appear in masonry C; waves appear on ponds, water turbid with mud; small slides and cave-ins occur along sand or gravel banks; large bells ring	0.07 to 0.22	5.5 to 6.1

Table 5-3. Comparison of Mercalli Intensity Index Versus PGA and Richter Scale (Continued)

Modified Mercalli Intensity Scale	Description of Effects (Masonry A, B, C, and D Are Defined in Note[a])	Maximum Acceleration (g)	Approximate Richter Magnitude Comparison
VIII	Steering of motor cars affected; damage occurs to masonry C, with partial collapse; some damage occurs to masonry B, but none to masonry A; stucco and some masonry walls fall; twisting, fall of chimneys, factory stacks, monuments, towers, and elevated tanks occur; frame houses move on foundations if not bolted down; loose panel walls are thrown out; changes occur in flow or temperature of springs and wells; cracks appear in wet ground and on steep slopes	0.15 to 0.3	6.1 to 6.7
IX	General panic; masonry D is destroyed; masonry C is heavily damaged, sometimes with complete collapse; masonry B is seriously damaged; general damage occurs to foundations; frame structures shift off foundations, if not bolted; frames crack; serious damage occurs to reservoirs; underground pipes break; conspicuous cracks appear in ground; sand and mud ejected in alleviated areas; earthquake fountains and sand craters occur	0.3 to 0.7	6.7 to 7.3
X	Most masonry and frame structures are destroyed, with their foundations; some well-built wooden structures and bridges are destroyed; serious damage occurs to dams, dikes, and embankments; large landslides occur; water is thrown on banks of canals, rivers, lakes, etc.; sand and mud shift horizontally on beaches and flat land; rails are bent slightly	0.45 to 1.5	7.3 to 7.9
XI	Rails are bent greatly; underground pipelines are completely out of service	0.5 to 3	7.9 to 8.5
XII	Damage nearly total; large rock masses are displaced; lines of sight and level are distorted; objects are thrown into air	0.5 to 7	8.5 to 9.0

Note:

[a] Masonry A: Good workmanship, mortar, and design; reinforced and bound together by using steel, concrete, etc.; designed to resist lateral forces. Masonry B: Good workmanship and mortar; reinforced, but not designed in detail to resist lateral forces. Masonry C: Ordinary workmanship and mortar. Masonry D: Low standards of workmanship; weak horizontally.

Historically, there have been two large earthquakes that occurred within 320 kilometers of UMCD. In 1949 a magnitude 7.1 event occurred near Olympia, Washington. This earthquake, which occurred approximately 287 kilometers from UMCD, had an epicentral MMI of VIII that caused extensive damage in Olympia and the Puget Sound area. The second large event occurred in 1872 near Lake Chelan, approximately 298 kilometers from UMCD, in the northwestern corner of the Columbia Plateau physiographic province. This event had an epicentral MMI of VIII+. Table 5-4 lists the ten largest events that have occurred in the region. The results are shown in the UMCD seismic hazard curves presented in figure 5-2.

Table 5-4. Largest Earthquakes Within Approximately 320 kilometers of UMCD

Earthquake	Magnitude or MMI	Tectonic Province	Distance (km)
13 April 1949	7.1	Coast Range	287
29 April 1965	6.5	North Cascades	285
16 December 1872	VIII+	Columbia Plateau	298
15 February 1946	5.8	Middle Cascades	311
6 July 1936	VII	Deschutes-Umatilla	73
29 April 1945	VII	North Cascades	245
13 November 1939	VII	North Cascades	298
7 March 1893	VII	Deschutes-Umatilla	10
12 October 1877	VIII	South Cascades	318
1 October 1964	V	Middle Cascades	263

From the hazard curve shown in figure 5-2, it can be seen that large seismic events (6.1 or higher on the Richter Scale) occur about once every 500 years in the UMCD region. Earthquakes with the potential to cause more damage (i.e., those measuring 6.7 on the Richter Scale or higher) are shown to occur about once every 3,000 years in the area. Typically, however, these earthquakes are still not strong enough to cause significant enough damage to structures or components at UMCD to result in large releases of agent. In the next section it will be shown that most of the components and structures at UMCD are likely to withstand most earthquakes. However, high magnitude earthquakes, though extremely rare, are capable of significant damage, including the collapse of storage igloos.

5.1.2 Structural and Equipment Seismic Fragilities. Earthquakes may affect UMCD in two general ways: 1) by compromising system components, thus causing system faults and possible accidents, or 2) by direct damage, such as failing site structures around munitions or toppling of the munitions themselves if they are stacked. Both types of effects have been considered in this

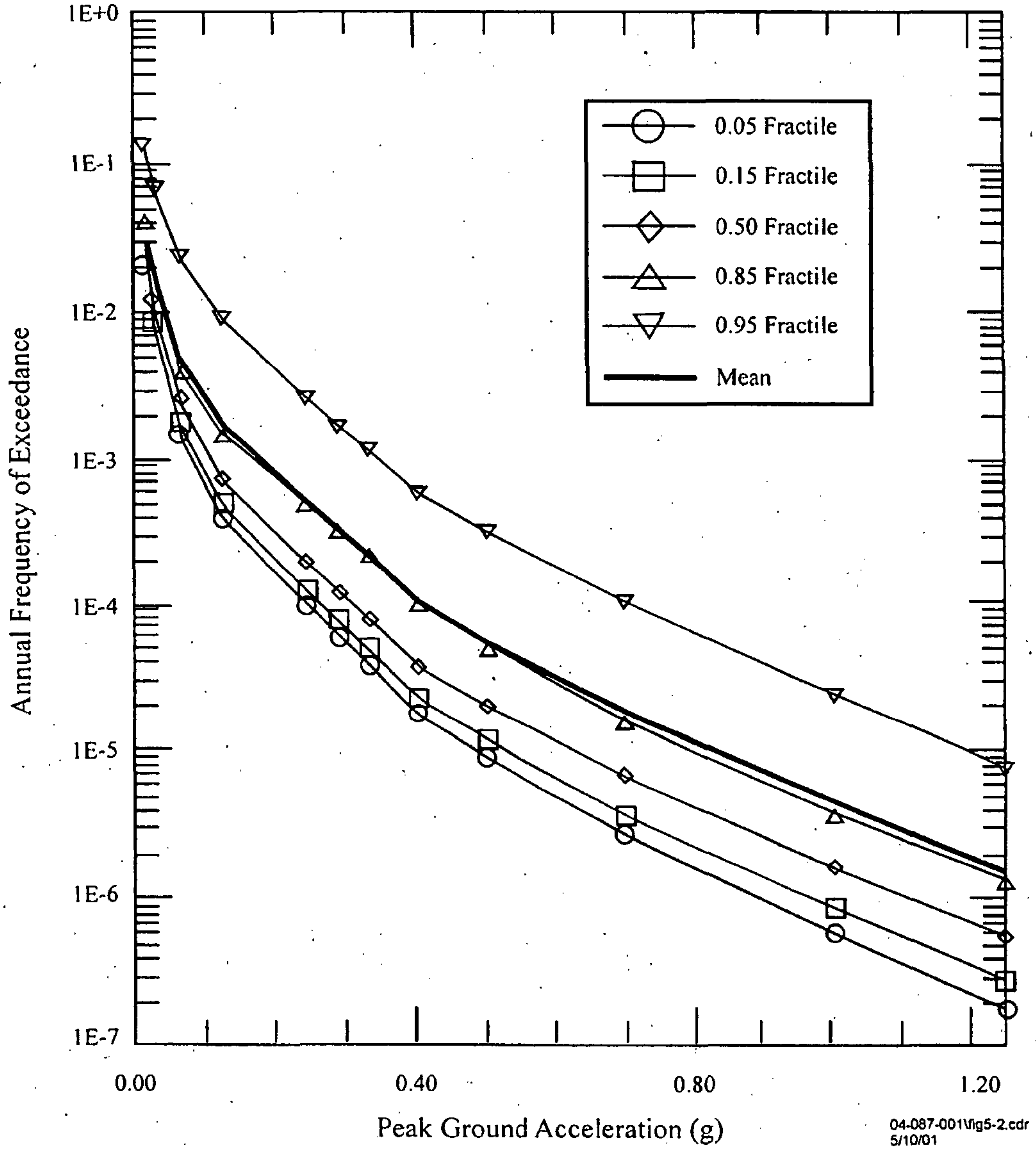


Figure 5-2. UMCDF Seismic Hazard Curve

analysis; however, results show that system-oriented effects are not nearly as important as direct damage effects. This result is due to two factors: 1) in cases where important systems, such as instrument air, may be lost, the systems have been shown to have very low failure probabilities for seismic events of interest, and 2) for most of the systems and processes at UMCDF, component failure will only cause a process stop, which will not lead to an accident.

Direct seismic effects have the potential to involve much larger quantities of agent than system-oriented effects. Most of the systems in UMCDF handle one munition at a time, and any system fault would usually only involve this single munition. On the other hand, there are several areas within UMCD where large quantities of agent could be released in a direct damage accident. These places include the CHB, through which all munitions pass as they enter the process; the CHB/UPA, where munitions are unpacked; the TOX tank, where all the agent is stored after being drained from munitions; the HVAC filters, which collect agent (as designed) over time; and the storage igloos.

A fragility analysis for significant components (structures and equipment) was performed by Stevenson & Associates (2000a-v) to assess the likelihood of component or system failure given an earthquake. This analysis was based on field walkdown inspections of the components, experience from previous analyses, review of design and construction documents (i.e., calculations, drawings, reports, and contractor submittals), and the plant configuration as of March 2000. At that time the plant was approximately 98 percent complete.

For chemical disposal facilities such as UMCDF, the prime concern for the safety of structures is the release of agent in liquid or gaseous form into the environment, and the safety of the personnel at the facility during and after the earthquake. Integrity of munitions before their destruction and safe storage of agent and contaminated components before they are incinerated, as well as the operability of equipment necessary to shut down the process without overloading any associated safety system formed the basis for determining the failure criteria for the MDB. The MDB is a reinforced concrete structure. Its general failure during earthquake is defined as losing the shear walls, which is the main component carrying the lateral load. The failure of the MDB is defined by a limiting displacement that could cause release of the agent in the structure.

Other structures that house the munitions are also important. These structures include the concrete igloos in I-Block and K-Block, the CHB, and the UPA.

The CHB is comprised of six prefabricated portal frame steel units and a reinforced concrete elevator and transfer structure connecting with the unpack area of the MDB. Failure of these structures was defined as complete collapse or dislodging of munitions handling equipment or collapse of munitions stacking devices inside the storage structure.

The mounded concrete igloos at the Umatilla site are semi-circular arches with reinforcement steel. The radius of the arch is about 14 feet. The thickness varies from 6 inches at the top to 1 foot near the bottom. The critical section of the igloos is the center section.

The rockets, projectiles, MC-1 bombs, HD ton containers, and mines are stored in stacks inside the igloos. (The VX spray tanks and MK-94 bombs are stored inside igloos as well; however, they are not stacked.) These munitions are also staged in the MDB during the handling and before the destruction. Falling of munitions during a seismic event was considered also as failure since it could lead to leaks or explosion of the munitions.

The seismic fragility of a component is defined as the probability of failure of that component as a function of the earthquake ground motion. Hence, the fragility is defined in terms of a single ground motion parameter such as PGA, or in terms of average spectral acceleration, S_a, and the probability of failure at various levels of earthquake motion. The determination of capacity in terms of earthquake level requires consideration of several parameters, which vary due to randomness and uncertainty. Hence, the fragility of each component is ultimately expressed in terms of a double lognormal model as defined by the following three parameters: 1) median PGA capacity or median ground spectral acceleration capacity, S_a [in terms of 5 percent damped average spectral acceleration between 5 and 10 hertz (Hz)]; 2) logarithmic standard deviation for capacity due to randomness, β_r, and 3) logarithmic standard deviation for capacity due to uncertainty, β_u. These parameters and an overview of seismic fragility methodology are discussed in appendix H. A summary of seismic fragilities for all UMCD critical components is shown in table 5-5.

As can be seen in table 5-5, most of the agent-significant components are fairly robust and would likely withstand earthquakes of appreciable size.

5.2 Facility Fire Initiators

As mentioned previously, facility fires are categorized as external events in the UMCDF QRA. Although facility fires may be thought of as an internal event initiator in the sense that they occur within the facility as a result of equipment and disposal processes, they are better treated analytically in this section with other external events since they can impact many systems at once and potentially affect the facility as a whole. Many external events (such as an earthquake or aircraft crash) may result in facility fires; however, those fires are analyzed elsewhere (e.g., the likelihood that a fire follows an airplane crash is assessed as part of the aircraft crash analysis). Fire outcomes identified in the PODs (e.g., those that may result from munitions handling accidents) also are not included in this fire analysis because those outcomes are treated elsewhere as well. This section covers specifically facility fires that are initiated during the normal operations of the facility. The overall fire analysis is presented in appendices K1 (indirect fires) and K2 (direct fires).

A fire in the MDB or CHB can generate consequences including detonations, agent release, equipment damage, and personnel injury. The purpose of the QRA facility fire analysis is to evaluate the risk associated with the direct effects of fire-initiating events at a CDF. A direct effect fire scenario is defined as an event where a fire directly causes agent release, requiring no

Table 5-5. UMCDF Seismic Probabilistic Risk Assessment Critical Component Fragilities

Component	PGA Median (g)	S_a (5-10 Hz, 5%) Median (g)	Logarithmic Standard Deviation			Comments
			β_r	β_u	β_c	
MDB Structure	2.79	6.99	0.26	0.29	0.39	Shear wall failure
CHB Structure	0.47	1.18	0.26	0.42	0.49	Cross bracing
CHB/UPA	0.50	1.25	0.26	0.21	0.34	Shear lug welding
LPG Tank	0.97	2.44	0.27	0.27	0.38	Anchor bolt in shear
TOX Tank	4.18	10.46	0.23	0.25	0.34	Diagonal channel
Surge Tank	0.55	1.37	0.27	0.37	0.46	Expansion anchor bolts
SDS Tanks	0.47	1.19	0.27	0.37	0.46	Tank legs
AQS Tanks	0.79	1.97	0.27	0.40	0.48	Base plate bending
DFS Furnace	0.59	1.47	0.25	0.30	0.39	Inlet section
MPF						
Afterburner	1.51	3.79	0.23	0.28	0.36	Embedded studs
	1.12	2.80	0.24	0.22	0.33	Anchor point connection failure
LIC						
Primary	3.01	7.53	0.24	0.22	0.33	Anchor bolts
Secondary	0.96	2.41	0.24	0.22	0.33	Anchor bolts
Diesel Generator						
Day Tank	0.71	1.79	0.25	0.31	0.40	Base plate yielding
Muffler	1.02	2.54	0.25	0.55	0.60	Anchor bolts of columns
Electrical Cabinets						
Motor Control Center	1.13	2.83	0.28	0.58	0.64	Anchor bolts
(MCC)	1.46	3.66	0.28	0.58	0.64	Anchor bolts
Distribution Panel	1.44	3.60	0.28	0.58	0.64	Anchor bolts
Battery Disconnect	0.49	1.24	0.28	0.36	0.46	Tap screws
UPS Control						
UPA 20-Ton Crane	0.98	2.44	0.26	0.28	0.38	Crane dislodging
Concrete Igloos	1.41	3.53	0.26	0.29	0.39	Concrete shell bending
Munitions Stacking						Pallets falling
Ratio = 3.89	0.76	1.90	0.29	0.35	0.45	
Ratio = 6.08	0.44	1.10	0.29	0.35	0.45	
Ratio = 9.67	0.24	0.60	0.29	0.35	0.45	
M55 Rockets	0.60	1.50	0.29	0.35	0.45	
Ton Containers	0.64	1.60	0.29	0.31	0.42	Containers falling
Filter Banks	0.69	1.73	0.22	0.32	0.39	Filter bank sliding
ACAMS						
Unanchored	0.15	0.38	0.28	0.53	0.60	Bottles overturning
Anchored to Wall	1.0	2.5	0.28	0.53	0.60	ACAMS sliding off cart
Natural Gas Piping	Screened		0.21	0.21	0.30	
Fire Suppression	0	0				Water tank failure
Scissor Lift	1.5	3.8	0.21	0.21	0.30	Will be governed by structure
Charge Car	Screened		0.21	0.21	0.30	
UPA Elevator	2.36	5.91	0.21	0.21	0.30	Will be governed by structure
Conveyors	Screened		0.21	0.21	0.30	

other system or component failures to do so. Fires as the result of other initiators (e.g., explosions) are already considered in the internal events accident progression models. The fire analysis identified potential ignition sources (including transient sources), targets for the ignition sources, types of suppression available, and general fire-related characteristics of the fire-rated zone.[3] Individual rooms containing agent or munitions were analyzed to determine the frequency and potential consequences of a fire involving agent.

The evaluation of fires has the following aspects:

- Fire Initiating Event Frequency
  - Frequency of Ignition
  - Probability of Propagation to Agent Source

- Response of Agent Source to Fire
  - Probability of Fire Duration (Hazard)
  - Probability of Agent Source Failure (Fragility)
  - Probability of Filter Release from Heating.

Fire-initiating event frequency is assessed using historical fire data.

The *Chemical Agent Disposal Facility Fire Hazard Assessment Methodology* (SAIC, 2002c) outlines an approach to estimating fire frequencies specifically for the CDFs and for characterizing the spread of a fire within the facility. This approach uses historical fire data over a 10-year period, 1988 to 1997, from databases maintained by the NFPA and facility census data maintained by the U.S. Census Bureau. These databases are used to develop estimates for the total frequency of fires in a CDF, the distribution of fires within the facility, and the probability that a fire in one area will spread to an area with chemical agent. Further discussion of these data is provided in appendix K2, section K2.3.

In determining the frequency of fire ignition in a CDF, the data used were limited to industrial chemical, plastics, and hazardous chemical facility types. Using these data, the frequency of potentially significant fires in these facilities was determined to be approximately 8×10^{-6} fires per hour, or 1 fire in 13.5 years (SAIC, 2002c). Two parameters are used to analyze the distribution of this building fire frequency among smaller groupings of rooms in the CDF: 1) functional area and 2) equipment (i.e., ignition source) type.

Since the type of construction used in the facility is considered a key parameter in the ignition and propagation of fires, the analysis was limited to fires in facilities of noncombustible construction. There are three types of noncombustible construction: 1) fire-resistive,

[3] A fire-rated zone is an area of the facility enclosed within fire-rated construction.

2) protected noncombustible, and 3) unprotected noncombustible. Fire-resistive construction refers to buildings where the structural elements are noncombustible, there is no exposed structural steel, and the coverings over the steel are very robust (e.g., concrete, concrete block, etc). The difference for protected noncombustible facilities is the steel is still covered, but the coverings are less robust. Unprotected noncombustible construction includes exposed structural steel.

As a result of the suitability of the database and the similarity of operations, NFPA data were applied and extrapolated to estimate the fire occurrence frequency for several similar areas in UMCDF. The CDF Fire Hazard Assessment frequency distributions are presented in terms of functional areas. To allow ignition frequency determination, the CDF rooms were grouped into a set of functional areas with similar characteristics: process area; service machinery, HVAC, and electrical areas; product storage/receiving/loading/conveyor areas; structural areas; trash/rubbish/incinerator/maintenance/laboratory areas; and other areas. An inventory of ignition sources for each room as well as frequency of fire ignition for each room was developed. Appendix K2, section K2.3.1, contains the data used to estimate the fraction of the total fire frequency that should be assigned to the various functional areas and room of the UMCDF.

In general, a fire does not start directly at a munition (or other agent source), but rather someplace in a room where agent is present. It also may start in another room, then spread to a room where agent is present. Therefore, the frequency of ignition of a fire is only part of the definition of an initiating event. The probability that the fire reaches an agent source also must be considered. Where this is the case, the probability of the fire propagating to the munition is assessed. The approach taken to determining this probability uses actual data on the propagation of fires in facilities of similar nature and construction as a CDF.

Rooms in the CDF were grouped into fire-rated zones based on fire-rated construction that bounded and separated the zones. Fires originating in a single room may propagate to an adjacent room. One- and two-hour fire-rated walls lessen the rate of propagation between rooms. Multiroom fire-rated zones were evaluated based on the assumption that fires could propagate quickly between rooms contained by non-fire-rated walls. Fire-rated zones are defined as rooms, or groups of rooms, enclosed by fire-rated construction (i.e., walls and floors). One- and two-hour fire-rated walls, explosion containment walls, floors, ceilings, and external walls were considered as boundaries between fire-rated zones. The functional area designations and ignition source inventories were considered in the assessment of propagation. In addition, the analysis provided by NFPA also considered the extent of flame damage as a function of whether an automatic suppression system was present and functioned properly; therefore, the presence of such a system was considered in the propagation analysis. A detailed discussion of this analysis is presented in appendix K2, section K2.3.2.

Summarized in table 5-6 below are the initiation frequencies for fires at UMCDF that spread to threaten agent sources within the area of concern. These values are derived in appendix K2 and are presented in this section. From table 5-6 it can be seen that fires that affect large portions of the facility are fairly frequent compared to other external events that cause similar releases of agent. For example, the data suggest that on average once every 800 years a fire will ignite, which spreads throughout the entire facility. (This frequency also must be combined with the probability that the fire burns long enough and hot enough to affect munitions and agent sources that are present.) Compare this to the 100,000-year recurrence rate of a 7.9 Richter Scale earthquake (which is likely to result in significant damage to the facility).

Table 5-6. Fire Initiation Frequencies for Fires Affecting Agent in Rooms/Fire-Rated Zones

UMCDF Area	Frequency (per year)
Toxic Maintenance Area	1.2×10^{-3}
Lower Munitions Corridor	1.1×10^{-4}
Buffer Storage Area	3.2×10^{-4}
Deactivation Furnace System	1.3×10^{-3}
TOX Room	5.6×10^{-4}
Primary Liquid Incinerator	8.1×10^{-4}
Upper Munitions Corridor	5.8×10^{-4}
Explosive Containment Vestibule	2.8×10^{-4}
Unpack Area	5.8×10^{-4}
Explosion Containment Room	2.5×10^{-3}
Munitions Processing Bay	3.3×10^{-3}
Metal Parts Furnace	1.8×10^{-3}
First Floor Fire	3.0×10^{-3}
Second Floor Fire	3.7×10^{-3}
Two Floor Fire Between ECR and DFS	6.0×10^{-4}
Total Facility-Wide Fire	1.8×10^{-3}

Once a fire reaches a point where it threatens an agent source, there is a probability that agent source will become involved in the fire. This considers both the severity of the fire (the hazard) and the capacity of the agent source to withstand the fire fragility. The probabilistic hazard curve derived for the UMCDF QRA expresses fire severity as the duration of the fire. In the context of this study, this duration is from the perspective of the target (i.e., the agent source(s) that could be compromised by the fire). Therefore, the hazard is the amount of time a particular agent source is exposed to the fire, not necessarily the amount of time a fire burns. As an example, a fire that propagates through a building over a 4-hour period is not a 4-hour hazard to a particular target. In calculating the exposure time for a specific target, it does not matter whether the fire started in the room where the target is, or started in another room and ended where the target is, or passed through the target room between its beginning and end. The exposure duration is how long the fire burns while consuming combustibles in the vicinity of the target. This allows for a single hazard curve to be developed representing the probability of fire (i.e., exposure) duration for any fire regardless of how it arrived at the target, based on estimates of the duration of typical single room fires.

In order to develop this curve, data on typical fire durations are required. A number of sources were used to get an idea of the range of expected durations of typical fires. Given that a fire has occurred that becomes a threat to agent sources within the facility, it then was necessary to calculate the probability that the fire would last long enough and produce enough heat to affect the munitions and agent sources. Because UMCDF has many rooms in the facility, some of which employ fire suppression while most do not, hazard curves were derived for rooms with and without fire suppression. Details of this analysis are presented in appendix K2, section K2.4.1.

The hazard curve presents the probability that a fire will be of a particular duration. In order to determine the probability that an agent source will become involved in a fire, the hazard needs to be combined with the probability that the agent source will fail (i.e., release its agent into the fire) when exposed to a fire of the particular duration. This is referred to as the fragility of the agent source. It is in the fragility analysis that all the parameters other than fire duration that affect the failure of the agent source are addressed in a probabilistic fashion. These include both fire parameters and agent source parameters. The reason fire parameters are included is the hazard only considers fire duration, and this is not a complete characterization of the severity of a fire. Other fire and physical parameters treated in the context of the fragility analysis include: 1) the range of possible heat release rates from the fire, 2) the range of possible orientations of the fire to the agent source target (e.g., distance to the fire, angle/profile facing the fire), 3) the range of agent source temperatures resulting in failure of the agent source (depending on the failure mode being considered, this could be the temperature of the agent, the burster, or the propellant), 4) ranges of heat transfer parameters in the heat transfer model, and 5) the range for the effect of fire suppression in reducing the net heat transfer from the fire to a munition.

The analysis team developed a probabilistic distribution for the fire and physical parameters based on judgment. A Microsoft® Excel add-in, Crystal Ball®, was used to perform Monte Carlo simulation of the agent source failure using these distributions, calculating a time to agent source failure for each simulation. This resulted in a probabilistic fragility curve for agent source failure as a function of the fire duration. Details of the analysis are provided in appendix K2, section K2.4.1.

A summary of agent source failure probabilities (components and munitions) is presented in table 5-7. These values were derived based on combining the fire hazard curves with the individual component fire fragility curves. These analyses are detailed in appendix K2, section K2.4.3.

Table 5-7. Summary of Agent Source Failure Probabilities in Fire

Munition	Suppression Status	Failure Probability
HD Ton Containers	No Suppression	7.2×10^{-2}
	Suppression	5.1×10^{-4}
GB MC-1 Bomb	No Suppression	3.0×10^{-1}
	Suppression	9.2×10^{-3}
GB MK-94 Bomb	No Suppression	4.0×10^{-1}
	Suppression	1.7×10^{-2}
M55 Rocket	No Suppression	6.8×10^{-1}
	Suppression	5.5×10^{-1}
GB 8-inch Projectile	No Suppression	4.3×10^{-1}
	Suppression	2.0×10^{-2}
VX 8-inch Projectile	No Suppression	4.2×10^{-1}
	Suppression	1.8×10^{-2}
GB 155mm Projectile	No Suppression	4.9×10^{-1}
	Suppression	2.9×10^{-2}
VX 155mm Projectile	No Suppression	4.8×10^{-1}
	Suppression	2.7×10^{-2}
VX 23 Mine	No Suppression	7.6×10^{-1}
	Suppression	1.1×10^{-1}
VX Spray Tank	No Suppression	2.8×10^{-1}
	Suppression	4.9×10^{-3}
TOX Tank	Suppression	$<5.0 \times 10^{-5}$

There is one agent source that is not covered by the fragility assessment previously presented. This is the HVAC filter banks, which can contain agent accumulated over the course of facility operation and/or as a result of a fire involving agent. Release of this agent from the filters occurs as a result of heating of the filters by the hot gases from the fire, and can occur in a number of ways. Three modes of release were evaluated: 1) desorption, 2) well ventilated fire, and

3) underventilated fire. Three considerations are taken into account when evaluating the probability of a release from the filters from one of these modes: 1) the temperature of the exhaust gases at the filters, 2) the duration of that temperature, and 3) the presence of forced airflow (from HVAC).

Five energy/duration combinations are considered in the analysis:

1. 4.5 megawatts (MW) for greater than 300 minutes
2. 6.0 MW for greater than 100 minutes
3. 7.5 MW for greater than 30 minutes
4. 9.0 MW for greater than 20 minutes
5. 12.0 MW for greater than 15 minutes.

The selection of these combinations is based on an assessment of filter desorption response performed by SAIC (Bailey, 2000a; Birk, 2001). The fire conditions required to reach these temperatures is based on an assessment of the flow of heated air to the filter banks (Bailey, 2000b). A room-by-room and fire-by-fire assessment was performed to determine the probability that each fire initiating event analyzed could result in each of the combinations shown. This was done based on the judgment of the analysis team. The residual probability was assigned to a sixth category, representing the probability that none of the above conditions occurred and hence the fire did not affect the filters. Further detail on this part of the analysis is provided in appendix K2, section K2.5.1.

Each of these cases is evaluated for each of the three possible release modes to determine what release faction should be applied to each case. These release fractions were also based on the separate filter response assessments (Bailey, 2000a,b; Birk 2001). Further detail on this part of the analysis is provided in appendix M, section M4.

Finally, a probability was assigned to each possible filter release mode for each energy/duration combination for two separate cases: forced airflow and nonforced airflow. These probabilities were based on the second of the three filter response assessments (Bailey, 2000b). Further detail on this part of the analysis is provided in appendix K2, section K2.5.2.

All of the previous information about fire initiating event frequencies, agent source response, and filter response is incorporated into a single APET. Included in the APET are all of the other events that can affect the ultimate probability and consequences of the fire accident scenarios, including HVAC system status, building integrity, and the agent sources present. A complete description of the fire APET is provided in appendix K2, section K2.6.

5.3 Aircraft Crash Initiators

The potential for an aircraft crash into the facility or a storage structure in K-Block or I-Block also was considered in the UMCDF QRA. As with other external event initiators, the likelihood of the crash was calculated; the ability of an aircraft to damage agent-containing structures was estimated; and APETs were developed to address the potential outcomes of the event.

Analyzed hazards associated with aircraft crashes into agent-containing structures are limited to those affecting the exposure of the public or site workers to chemical agent. Other hazards associated with a crash are not explicitly evaluated for their impact on the surrounding population separate from agent-related effects. For instance, a post-crash fire will be evaluated for its potential to increase the amount of agent released due to increased agent volatilization rates. The potential hazard presented by the fire alone (in the absence of agent release) will not be modeled. This illustrates the QRA focus on agent-related hazards only.

Aviation risk analysis for the UMCDF and UMCD is based on the method presented in section 3.5.1.6 of the U.S. Nuclear Regulatory Commission *Standard Review Plan*, NUREG-0800 (USNRC, 1981). The method and data used were updated for the findings of the Department of Energy (DOE) Aircraft Accident Crash Analysis Methodology (ACRAM) (DOE, 1996). The analysis is outlined in appendix I.

An evaluation of aviation activities near the UMCD was completed and the results compared to NUREG-0800 criteria. An area within a 20-nautical mile radius of the facility was surveyed for potentially risk-significant aviation uses. Airports, high- and low-altitude flight paths, and areas of potential military activity were identified using aviation charts. Further information on activity level and type was obtained from interviews with local Federal Aviation Administration (FAA) officials. This information then was compared to the screening criteria outlined in NUREG-0800 and was modified by new data presented in DOE-STD-3014-96. This analysis is presented in detail in appendix I.

A summary of UMCDF and UMCD crash frequencies per unit area are shown in table 5-8. These crash rates then are multiplied by effective areas of UMCDF and UMCD structures to produce the site-specific aircraft crash frequencies that are shown in tables 5-9 and 5-10. Appendices I2 and I3 contain the data and formulae used to calculate these effective areas.

As seen in these tables, aircraft crashes into agent significant structures at UMCDF and UMCD are extremely rare, especially when compared to seismic and fire initiators that have similar potential outcomes. For example, the most frequent crash—a small aircraft crash into the CHB—is expected to occur on average once every 1.1 million years.

Table 5-8. UMCDF and UMCD Crash Frequencies per Unit Area

Type of Aircraft	In-Flight Crash Frequency per Unit Area ($year^{-1}$-$mile^{-2}$)	Takeoff and Landing Crash Frequency per Unit Area ($year^{-1}$-$mile^{-2}$)	Total Crash Frequency per Unit Area ($year^{-1}$-$mile^{-2}$)
Commercial Operations			
Large	2.5×10^{-7}	0	2.5×10^{-7}
Medium	4.2×10^{-6}	0	4.2×10^{-6}
Military Operations			
Large	7.3×10^{-8}	0	7.3×10^{-8}
Medium	3.9×10^{-7}	4.7×10^{-8}	4.4×10^{-7}
General Aviation Operations			
Medium	2.2×10^{-5}	4.0×10^{-7}	2.2×10^{-5}
Small	8.8×10^{-5}	4.9×10^{-6}	9.3×10^{-5}
Helicopter Operations			
Helicopter	2.1×10^{-5}	0	2.1×10^{-5}

Table 5-9. Aircraft Crash Frequency Calculations for UMCDF Structures

	Frequency (F) ($year^{-1}$)		
Structure of Interest	Large Aircraft	Medium Aircraft	Small Aircraft and Helicopters
MDB	1.1×10^{-8}	3.1×10^{-7}	7.5×10^{-7}
UMC	N/A	1.1×10^{-7}	3.1×10^{-7}
MPB	N/A	6.6×10^{-8}	2.2×10^{-7}
TOX	N/A	3.0×10^{-8}	2.7×10^{-8}
UPA	N/A	9.5×10^{-8}	3.4×10^{-7}
CHB and CHB Transition Area	1.2×10^{-8}	3.7×10^{-7}	9.2×10^{-7}
MDB Filter Bank	6.1×10^{-9}	1.3×10^{-7}	2.6×10^{-7}

Structural calculations performed in appendix I show that UMCDF is not resilient enough to handle the impact of either a large or a small aircraft engine. Similarly, storage area structures do not provide sufficient protection of munitions contained therein with one exception. Igloos were predicted to have sufficient strength to withstand the impact of a small aircraft. Based on structural and frequency calculations, sequences involving all aircraft sizes were retained for UMCDF. Only large and medium aircraft frequencies were retained for UMCD igloos.

Table 5-10. Aircraft Crash Frequency Calculations for UMCD Storage Area Structures

	Frequency (F) (year^{-1})		
Structure of Interest	Large Aircraft	Medium Aircraft	Small Aircraft and Helicopters
Igloos	2.1×10^{-7}	1.7×10^{-5}	N/A

Agent release during an aircraft crash depends on the ability of the impacting aircraft to breach agent containment structures and on the post-crash environment. High-speed missiles generated upon impact provide a means to fail structures intended to contain agent. These include reinforced concrete walls, EONCs, and the munition casings. The quantity of agent released and its release characteristics will be affected by the post-crash environment.

In the event of a fire, the heat generated affects the mass released through its impact on the evaporation rate (an increase in temperature increases the amount of agent released) and its ability to destroy agent through a combustion reaction (destruction of agent decreases the estimated release.) Heat also may affect the stability of explosive components. If a decrease in stability leads to explosive initiation, agent could be released as an aerosol. (Evaporation would lead to a vapor release). If initiation causes neighboring munitions to leak, the agent release rate could be increased further due to evaporation. In the absence of a fire, the release will be characterized by evaporation from a pool surface (a vapor release) and would likely involve fewer munitions (explosions could breach more munitions than the aircraft alone). These effects were considered in the source term development for the modeled aircraft crash sequences (appendix O).

Agent-containing structures were next evaluated for their ability to withstand the impact. Structural integrity is dependent on the size of aircraft involved. As a result, aircraft statistics were gathered based on three size categories. These categories were selected to correspond with common aviation categories used by the FAA and are assessed to provide sufficient refinement for the QRA evaluations. Frequencies were calculated for each QRA size category as a sum of the frequencies for the FAA aviation categories within the QRA size range. The QRA large size category includes aviation activity associated with FAA-designated commercial air carriers and military bomber-type aircraft; the QRA medium size category includes FAA-designated commercial air taxis, military trainer-type aircraft, and general aviation jets; and the QRA small size category includes all other general aviation aircraft and helicopters (see appendix H for definitions).

5.4 Weather-Related Initiators

Severe weather and weather-related events may impact operations or the structures at UMCDF and UMCD. Several analyses were completed to determine the effects of various weather-related events. A detailed analysis of tornado hazards and frequencies was performed to determine potential initiators. Lightning also was analyzed for the potential to initiate accidents. Other events, such as heavy precipitation and floods, were considered and found to not present a risk to the facility.

5.4.1 Tornadoes/High Wind Initiators. While the tornado is clearly nature's most intense storm, it is a rare, generally localized event. A review of the literature indicates that considerable advances have been made in the understanding of tornado characteristics and life cycles. Much of this information is included in models used to predict tornado risk at UMCDF.

The degree of damage produced by a tornado strike is a function of the tornado intensity (measured in terms of peak wind speed), path length, and path width. Tornado researchers have found it convenient to classify tornado intensity using the Fujita-Pearson (FPP) rating scale, representing the Fujita force intensity and the Pearson path length and Pearson width scales (Twisdale, 1978). These scales have been used by the National Weather Service (NWS) Office to classify tornadoes since 1971.

The FPP system, as used by the NWS, includes six intensity classifications rating from F0 to F5. In addition, an F6 classification has been defined and used for analysis purposes (Reinhold and Ellingwood, 1982). Such tornadoes have not been recorded, and would be extremely rare. The FPP tornado classifications are summarized in table 5-11. Qualitative descriptions of each F-scale rating have been developed by the Institute for Disaster Research at Texas Tech University (McDonald, 1983). These ratings are based on the appearance of damage and coincide with the FPP tornado classifications. These classifications are provided in table 5-12.

Table 5-11. Fujita-Pearson Tornado Classifications

Scale	Intensity (mph)	Path Length (miles)	Path Width (yards)
F0	40 to 72	0.3 to 0.9	6 to 17
F1	73 to 112	1.0 to 3.2	18 to 55
F2	113 to 157	3.3 to 9.9	56 to 175
F3	158 to 206	10.0 to 31.5	176 to 555
F4	207 to 260	31.6 to 99.9	556 to 1,759
F5	261 to 318	100 to 315.9	1,760 to 4,963
F6	319 to 380	316 to 999	4,964 to 17,582

Table 5-12. F-Scale Classification of Tornadoes Based on Appearance of Damage

F0 Light Damage 40 to 72 mph Some damage to chimneys or TV antennas can occur; branches broken off of trees; shallow-rooted trees can be pushed over; old trees with hollow insides can break or fall; sign boards can be damaged.
F1 Moderate Damage 73 to 112 mph Beginning of hurricane wind speed. Surfaces of roofs peeled off; windows broken; trailer houses are pushed or overturned; trees on soft ground are uprooted; some trees snapped; moving cars pushed off road.
F2 Considerable Damage 113 to 157 mph Roofs torn off of frame houses leaving strong upright walls standing; weak structures or outbuildings are demolished; trailer houses are demolished; railroad boxcars are pushed over; large trees snapped or uprooted; light-object missiles generated; cars blown off highway; block structures and walls badly damaged.
F3 Severe Damage 158 to 206 mph Roofs and some walls torn off well-constructed frame houses; some rural buildings completely demolished or flattened; trains overturned; steel frame hangar-warehouse type structures torn; cars lifted off the ground and can roll some distance; most trees in a forest uprooted, snapped, or leveled; block structures often leveled.
F4 Devastating Damage 207 to 260 mph Well-constructed frame houses leveled, leaving piles of debris; structures with weak foundation lifted, torn, and blown off some distance; trees debarked by small flying debris; sandy soil eroded and gravel flies in high winds; cars thrown some distance or rolled considerable distance, finally to disintegrate; large missiles generated.
F5 Incredible Damage 261 to 318 mph Strong frame houses lifted clear off foundation and carried considerable distance to disintegrate; steel-reinforced concrete structures badly damaged; automobile-sized missiles fly distances of 100 yards or more; trees debarked completely; incredible phenomena can occur.
F6 319 to 380 mph Extent and type of damage beyond that expected for F5 tornado. F6 tornadoes have not been recorded, but the classification has been defined to cover tornadoes in excess of 318 mph.

Source: McDonald, 1983.

Although all types of extreme winds may pose a threat to UMCDF (i.e., microblasts, tornadoes, and straight winds), tornadoes represent the design basis wind levels for the facility and are the only source of high winds considered in the UMCDF QRA. Therefore, the methodology for a high wind risk assessment includes an analysis of tornado strikes within a given radius of UMCDF by intensity range, identification of facility vulnerabilities, and determination of the likelihood of tornado-generated missiles within a specified area around the facility.

Tornado occurrence at UMCD is extremely rare. In fact, between 1954 and 1995 only 50 tornado events have even been recorded within 125 nautical miles of the site, with none being categorized above 206 miles per hour (mph) (F3). The initiating tornado event frequency was developed for the UMCDF QRA using a modified Reinhold point strike model (Stringfield and Holderness, 2000) and is based on data collected by the Storm Prediction Center (SPC). The UMCD site-specific tornado strike and strike exceedance frequencies for each F-class are derived in appendix J1. These frequencies are summarized in table 5-13 and figure 5-3. The analysis to determine the tornado hazard curve also includes uncertainty as shown in figure 5-3.

Table 5-13. Tornado Strike Frequencies for UMCDF (Per Year)

	Tornado Class						
Wind speed (mph)	40 to 72	73 to 112	113 to 157	158 to 206	207 to 260	261 to 318	319 to 380
Class	F0	F1	F2	F3	F4	F5	F6
Class Strike Frequency	4.5×10^{-6}	1.7×10^{-6}	5.1×10^{-7}	9.0×10^{-8}	6.5×10^{-9}	2.6×10^{-10}	3.1×10^{-11}
Strike Exceedance Frequency	6.8×10^{-6}	2.3×10^{-6}	6.0×10^{-7}	9.6×10^{-8}	6.8×10^{-9}	3.0×10^{-10}	3.1×10^{-11}

As can be seen from these tables and figures, a tornado is an extremely rare occurrence at UMCD. Even the lowest category of tornado (F0) has a recurrence rate of over 220,000 years.

The ability of tornadoes and high winds to cause agent release was investigated to identify and quantify possible accident sequences resulting from direct or indirect tornado impact. Even though they are extremely rare events, as shown in table 5-13, tornadoes could cause widespread destruction of the facility. Direct tornado effects include process buildings and/or storage facilities collapsing or separating in extreme winds. Indirect effects include munition lofting

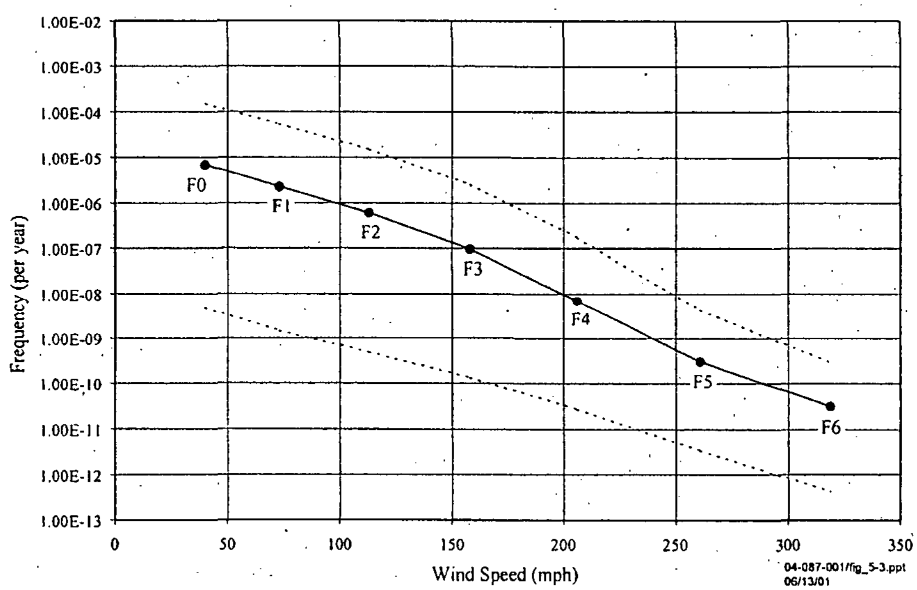


Figure 5-3. UMCD Tornado Strike Frequency of Exceedance

and/or tornado-generated missile impacts. This study accounts for tornado characteristics, number, and location of potential tornado missiles, and resistance of the plant/munition design to such missiles and tornado-strength winds. The complete tornado analysis is found in appendix J1.

The APET discussed in section 6 and appendix J1 is structured to identify and quantify the sequences that could result in agent release due to tornado occurrence. The initiator and accident progression models for tornadoes are blended, so the overall model will be discussed here at a very high level.

The most important factor to consider when assessing tornado damage to UMCDF or storage structures is the strength of the tornado. For this analysis, only F3-, F4-, and F5-classes are considered to have the potential to affect the facility or storage yard. (The recurrence rate for an F3 or higher tornado at UMCD is over 10 million years.) This is based on the UMCDF seismic and wind fragility analysis performed by Stevenson & Associates (2000d). Overall UMCDF was found to be very robust; however, the MDB composite panels were found to be vulnerable to high winds. This was because they are supported only at the edges on the outside. Therefore, suction at the leeward face or tornado depressurization would remove them. The HVAC exhaust ducts from the MDB to the filter banks also were selected as a potential hazard during a tornado. The ducts could deform or tear open due to the wind load and result in leakage before the contaminated air could be filtered. The metal straps connecting the duct to the supporting frame were found to govern the fragility. These components and their wind fragilities are summarized in table 5-14.

Table 5-14. UMCDF Tornado Probabilistic Risk Assessment Critical Component Fragilities

Component	Median Velocity (mph)	Logarithmic Standard Deviation			Comments
		β_r	β_u	β_c	
MDB Wall Panels	146	0.17	0.13	0.22	Panel fail in shear
HVAC Ducts	207	0.17	0.12	0.21	Straps

The effect of an F4 or F5 tornado on the facility is very hard to assess since few structures like UMCDF have been struck by tornadoes of this severity class. This analysis assumes that every F5 tornado that directly impacts UMCDF will result in total catastrophic destruction of the facility. This judgment is based on F5 tornadoes that have occurred in populated cities such as Jarrell, Texas (1997), Oakfield, Wisconsin (1996), and Moore, Oklahoma (1999). These F5 tornadoes resulted in near-complete devastation of all homes and industrial facilities in the path of the tornado. F4 tornadoes historically have caused incredible devastation in populated areas also. However, this class of tornadoes is judged less likely to cause near-complete damage to the facility compared to F5 tornadoes. (Thus, tornado logic in the UMCDF external event APET assumes that only 10 percent of F4 tornadoes will affect the whole facility, as compared to 100 percent of the F5 tornadoes.)

For F4 and F5 tornadoes that do strike the facility, it is important to consider whether this event also leads to a fire. Given the abundance of debris, possibility of furnace and incinerator hot debris, availability of natural gas, presence of hydrogen gas, and potential for sparks from fallen electric power lines [that may still be re-energized due to the remote location of the emergency diesel generator (EDG) and use of underground feeder cables], fire is assumed to occur in 50 percent of the facility-wide destruction scenarios. It is judged that tornado-induced fires affect the entire agent inventory within the facility. Because this was not a risk significant initiator (based on its extremely low probability of occurrence compared to other facility-wide fire initiators), this event was not refined any further.

Since the UMCDF UPA sandwich panel walls were identified as being vulnerable to F3 and higher tornado winds, two potential outcomes are modeled in the external event APET if the UPA wall is removed: 1) exposed munitions are lifted and lofted outside of the UPA or 2) exposed munitions are struck by tornado-generated missiles. These outcomes may result in munitions leaking, exploding, or being undamaged. The likelihood that munitions (rockets and mine drums) on the processing lines are pulled outside the UPA, given an F3 tornado is judged to be 0.5. Bulk items, projectiles, and palletized munitions are assumed to remain within the UPA. The likelihood that munitions inside the UPA are struck by tornado-generated missiles is calculated in appendix J1, section J1.3.2. This analysis is based on the number of available missiles, distance from UMCDF and exposed surface area of the munitions inside the UPA. Tornado generated missile scenarios were found to be a negligible contributor to total risk.

5.4.2 Lightning Initiators. Lightning is principally a concern during the processing of M55 rockets because the rockets employ an electro-explosive firing squib, which has been shown to be potentially sensitive to lightning-induced arcing and electromagnetic field(s) (EMF). The sensitivity of the M55 rocket (including the M2 squib, M62 igniter and M28 propellant grain) has been studied for many years under the direction of the Enhanced Stockpile Surveillance Program (ESSP) in an effort to better characterize the response of the rocket to lightning-induced effects. The testing program and overall findings are discussed in detail in appendix J2. In general, the M55 rocket was found to be vulnerable only when the rocket deviated from its normal design configuration; these anomalies included discontinuous or poor wiring connections, corrosion between metallic components (principally in the tail fin assembly and shunt), and excessive igniter cable exposure beyond the motor exhaust nozzles. The strength of the lightning strike also was found to be important, with extreme strokes (200 kA or more in peak amplitude) being the most important. Nominal strikes (35 kA) also were assessed and found to pose a risk in some circumstances.

Much of the ESSP effort to study the vulnerability of M55 rockets to lightning was focused on rockets in storage. This effort included characterizing the lightning environment within the igloo as well as the actual response of a rocket to the lightning.

The lightning environment at UMCDF was judged to be much less severe than the lightning environment in storage magazines due to the following factors:

a. Rockets are protected from lightning effects during most of the disposal process due to the use of protective EONCs. Thus, M55 rockets are only exposed to potential lightning effects when they are located in the UPA and ECV. The lightning protection afforded by the EONC is discussed in appendix J2.

b. While in the UPA or ECV, the rocket pallet distance to an external wall is much greater than the distance of the rocket to the igloo arch or headwall while in storage. During the igloo characterization analysis the rocket distance to the igloo arch or headwall was found to be the governing factor when lightning struck the magazine. Typically the safe standoff distance within an igloo is less than 1 foot for extreme lightning attachments, while within UMCDF these distances can be several feet (from the external walls).

c. The UMCDF walls contain large amounts of metal, including rebar and composite metal sandwich panels. The interconnections between the wall and floor rebar are judged to be adequate within UMCDF. In addition, there are many nearby metallic objects (such as switchboards and process line components) that would prove to be more attractive targets to stray arcs because they are grounded. The importance of rebar and rebar bonding is discussed in appendix J2.

d. UMCDF employs a lightning protection system (LPS) that is considered to be very effective at mitigating the effects of lightning. The LPS employed in storage is much less effective because the igloo rebar (not the LPS) was found to carry most of the return stroke current.

All other munitions are considered safe from the effects of lightning because they are encased in metal bodies and contain no exposed propellant nor have electro-explosive components.

UMCDF Site Analysis Using the National Lightning Detection Network®. To assess the likelihood of lightning-induced rocket ignition, it is first necessary to calculate the frequency of lightning at UMCDF. The UMCDF Phase 2 QRA uses the most comprehensive source of data available to predict the occurrence rate of lightning at the facility. The science of lightning prediction has advanced significantly in the last few years and this study takes full advantage of this new technology by using data from the National Lightning Detection Network® (NLDN). The NLDN is owned and operated by Global Atmospherics, Inc. (GAI) and uses a state-of-the-art lightning location system to provide reliable data on locations and severity of lightning strikes throughout the CONUS. The NLDN's archive data library contains over 160 million flashes from 1989 to the present and provides information on time, location, polarity, and amplitude of each lightning flash. GAI was contracted by SAIC to perform a Facility Site Analysis (FSA) on the Umatilla site for the UMCDF Phase 2 QRA. These data include lightning attachments recorded within a grid of 2,304 square kilometers (centered at UMCDF). The FSA is separated into five annual periods and includes one composite flash density summary to show the average lightning trend over a 5-year period (1995 to 1999). These maps are provided in appendix J2. Additionally, the FSA produced a composite statistical profile of the peak-current amplitudes in histogram format for easy interpretation of lightning exposure intensity, and a month-by-month lightning time trend analysis showing historical lightning patterns. These graphs also are presented in appendix J2. The 5-year regional composite for the UMCD site was used to determine the mean annual flash density (number of lightning strikes per square kilometer per year) for UMCD (see figure 5-4). From this map it can be seen that the mean annual flash density for UMCDF is extremely low, between 0.1 and 0.2 flashes per square kilometer per year. The method based on the NLDN data is described in greater detail, and compared to previously used lightning strike prediction methods, in appendix J2.

Effects of Lightning. Lightning strikes to significant buildings and/or structures at UMCDF can result in four general outcomes: 1) the generation of strong electromagnetic fields, 2) fires caused by strikes to combustible material, 3) structural damage from the blast and pressure waves associated with strikes, and 4) pitting and formation of small holes caused by localized heating at the strike location. These effects are briefly described in the following sections.

Generation of a Strong Electromagnetic Field. When lightning strikes the LPS, a massive amount of electric charge is moved through the down conductor in a very short amount of time. The changing magnetic fields can generate currents in other nearby conductors or cause arcing between conductors. As with storage, only M55 rockets are vulnerable. (Other munition types do not have exposed propellant and are totally encased in metallic bodies, making them nonsusceptible to EMF.)

Fire Initiation. The second effect of lightning is the possibility of a fire being started by a strike to a combustible material. The heat generated (i.e., power dissipated) in a conductive material struck by lightning is equal to the resistance of the object times the square of the current. Because the current of lightning is measured in tens of thousands of amperes, only *very low*

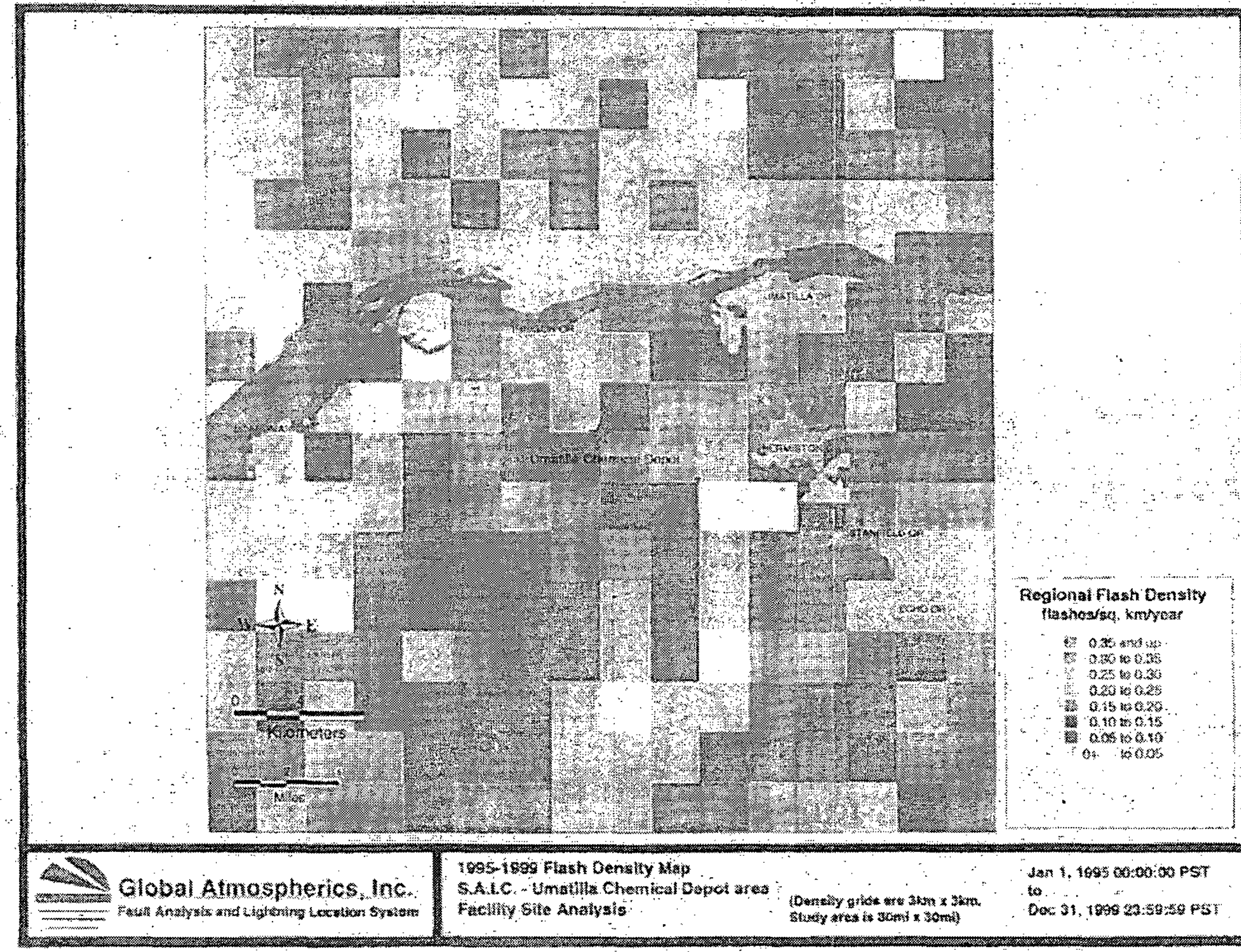


Figure 5-4. Composite Flash Density for UMCDF (1995 through 1999)

resistance conductors (e.g., metals) are able to withstand the power produced in a direct lightning strike. Lightning-initiated fires have been screened at UMCDF because of the effectiveness of the UMCDF LPS. The probability that the LPS will fail and that a fire will result is judged to be negligible since the building is made of metal and concrete and there are limited combustibles inside.

Structural Damage from the Blast and Pressure Wave. When lightning passes through air, the high resistance of air generates a very large amount of heat. The heated air rapidly expands, producing a pressure wave. This pressure wave quickly drops off with distance from the lightning channel, but it can damage structures that are hit by lightning. If the air terminal is not tall enough to sufficiently reduce the pressure to a level that a building can handle, the presence of air terminals may not protect buildings from this pressure wave. Air terminals are normally located above structural support members to prevent the pressure wave from exceeding the capacity of the building. Based on the Underwriters Laboratories (UL) approval of TOCDF LPS (UL, 1993), it is assumed that the air terminals are situated to avoid collapsing the roof. Therefore, structural damage to UMCDF caused by lightning has been judged to be negligible.

Pitting and Formation of Small Holes Caused by Localized Heating at the Strike Location. When lightning strikes an object, there is an intense amount of heat generated at the point of contact. This can result in pitting or even burnthrough of thin sheets of metal. The small holes generated by lightning strikes at UMCDF are considered important only if munitions are directly struck, producing an agent leak. Since munitions are transported from the storage yard to the UMCDF in EONCs, they are not vulnerable to direct lightning strikes outside. (Spray tanks are not transported in EONCs; however, they are transported in their protective overpacks, which are also resistant to lightning.) Steel with a wall thickness of 3/16 inch or greater has been shown to be capable of withstanding direct strikes without puncture or ignition of contents (Lee, 1979). The only munitions thinner than 3/16 inches are the M23 mine, and the M55 rocket; however, an event involving these munitions could only be possible if the UMCDF LPS failed, because that is the only potential way an arc can travel to interior portions of the MDB. Thus, combining the low frequency of lightning strikes not being mitigated by the LPS and low probability of munitions being close enough to the exterior wall, this event was screened.

Lightning-Initiated Accident Sequences. From section J2.3.3 in appendix J2, it was found that very few structures within UMCDF are vulnerable to lightning strikes. There are two potential lightning events that could result in a release of agent: 1) M55 rocket ignition due to magnetic coupling and 2) M55 rocket ignition due to arcing. The magnetic coupling outcome assumes that the performance of the LPS is irrelevant because the LPS cannot prevent EMF. This analysis considers both magnetic and electrical coupling; however, electrical coupling was judged to be far less likely than magnetic coupling and was not refined. A conservative probability of magnetic coupling was calculated based on analyses performed by U.S. Army Armament

Research, Development and Engineering Center (ARDEC) on actual rocket motors (section J2.6.2.2 of appendix J2).

For the arcing scenario, the effectiveness of the LPS is considered and the magnitude of lightning strike also is important. It is judged that nominal lightning could not create sufficient transient voltages inside the UPA due to the large amount of metal reinforcement used in the UPA floor and fire boundary walls (giving lightning-induced current many lower impedance paths to ground than through a rocket). Since the ARDEC analyses did not specifically address rockets inside the UPA, it is conservatively assumed that arcing to any rocket inside the UPA is as likely as within an igloo. (The differences between the UPA and igloo that make arcing within the UPA much less likely than inside the igloo were discussed previously.)

5.4.3 Other Weather-Related Events. Other weather-related events were considered at UMCDF and were not found to present a significant risk to operations. The following discussion describes the analysis for screening other weather-related external events.

Heavy precipitation was defined to include rain, snow, and hail. Each of these was analyzed separately but then screened from further analysis based on the criteria listed in section 5.1. Hail presents the most potential damage to the facility. Large hail could damage the HVAC ducts located outside the MDB, but no damage beyond small dents is considered possible. The rivers closest to the site include the Columbia River, which is located approximately 4 miles north of the UMCD boundary, and the Umatilla River, which is located approximately 6 miles east of the UMCD boundary. Both the Columbia and Umatilla Rivers are regulated by dams and reservoirs. There are several diversions on both rivers for irrigation of land within the river basin. During a flood, materials may be carried away by flood waters and cause damage to downstream structures. Because munitions will either be stored in EONCs (or spray tank containers) or inside the MDB, they are protected against flood-generated projectiles. Similarly, munitions stored in the igloos or the warehouse also are considered protected. Heavy rains were not considered capable of flooding the building due to the storm drain system and the ground slope of the area. Heavy snow also was not considered to be able to cause any potential agent release conditions. In addition to heavy precipitation, sandstorms were screened from further analysis. Only two possible effects were found. During transportation, truck drivers would not be able to see. The trucks could easily stop and wait until the storm passed avoiding any potential accident. The sand also could clog air intake filters for the HVAC systems. The intakes are located in the shelter area under the CHB/UPA and were considered capable of surviving a sandstorm without completely plugging. It should be noted that these other weather-related conditions may cause processing delays, as transportation activities would be curtailed; however, they would not present any risk to plant operations.

5.5 Hydrogen Explosions

The potential for hydrogen explosions exists at UMCDF from the use of hydrogen gas as an integral part of the ACAMS. Expert Panel review of the preliminary draft Phase 2 QRA noted the Umatilla facility will store ACAMS hydrogen cylinders outside of the facility and in a few perimeter rooms, and pipe hydrogen to ACAMS throughout the facility. Exterior storage of the cylinders and remote piping of hydrogen is similar to the procedure used at the Anniston Chemical Agent Demilitarization Facility (ANCDF). Thus, the hydrogen deflagration analysis conducted for ANCDF is used here for UMCDF with changes made for Umatilla local conditions. The ANCDF analysis, agent exposure risk due to hydrogen deflagrations proved to be a non-risk contributor. Consequently, it was judged unnecessary to perform a refined UMCDF hydrogen deflagration analysis.

Based on information obtained from ANCDF 326 Engineering Change Proposal (AN-0326-ECP), hydrogen gas cylinders are located outside of the facility and in perimeter rooms within the facility. Hydrogen is generated by the UPS batteries, but this analysis has shown that the agent-related risk from battery room scenarios is negligible.

According to analysis, hydrogen combustion at the CDF will be subsonic flame fronts that produce quasi-static pressures of less than 1 pound per square inch (psi) to a few tens of psi depending on conditions occurring at hydrogen concentrations around 4 percent. Deflagrations require as little as a few millijoules of energy (equivalent to an electrostatic spark), while higher order combustion events usually require ignition energies equivalent to high explosive charges (appendix K3 further characterizes deflagrations). Thus, hydrogen explosions henceforth will be referred to as deflagrations.

A listing was made of all hydrogen cylinder storage locations and rooms through which hydrogen supply lines pass to determine if a hydrogen leak could produce an explosive mixture in the area. All areas where accumulation of an explosive mixture is possible were evaluated to determine if an explosion in that area could result in a release of agent.

The analysis considered formation of localized pockets of hydrogen. For those areas in which hydrogen cylinders are stored or rooms through which hydrogen supply lines pass and there is forced airflow exchange (air handling unit or HVAC), deflagration in the upper half of a room is investigated. Deflagration of stratified layers of hydrogen in the upper 50 percent of area volumes when forced airflow exchange has failed is assumed to adequately represent this phenomenon.

The first areas considered were the MDB filter monitor houses. Hydrogen cylinders are located outside the monitor houses. The monitor houses were determined to have the potential for hydrogen deflagration if forced airflow exchange (air handling unit) is lost.

MDB rooms containing hydrogen cylinders or hydrogen supply lines were considered. All leaks from an ACAMS-hydrogen cylinder system would only occur in the rooms under investigation. Because the hydrogen cylinders contain a limited volume of hydrogen gas and most areas in the MDB have a significant room volume, if the entire contents of the cylinder were released to the room and forced airflow exchange (HVAC) from the room was lost, the hydrogen concentration would still be below the lower flammability limit (LFL) in most rooms. Only five of the sixteen MDB rooms that contain hydrogen cylinders or hydrogen supply lines were determined to have the potential for a hydrogen deflagration if HVAC is lost.

If a hydrogen leak occurred while forced airflow exchange was failed, or if forced airflow exchange failed following a hydrogen leak, it was calculated that an explosive mixture would be produced in the five MDB rooms and MDB filter monitor houses. Because a hydrogen-air mixture requires very little energy to ignite, it was assumed that if the explosive mixture forms, it would ignite.

In addition to the five MDB rooms and MDB filter monitor houses, there are two MDB rooms used to store hydrogen cylinders and there is another room through which hydrogen supply lines pass, all three of which are not part of the cascade HVAC system. Hydrogen deflagrations in these Category D rooms only require an undetected leak of hydrogen to the LFL. The consequences of hydrogen deflagrations in these areas were analyzed along with deflagrations in other areas.

With the HVAC operating, it was determined that only four of the rooms with hydrogen cylinders or hydrogen supply lines could reach the LFL in the event of a hydrogen leak. In addition, this could only happen if the cylinder failure occurred upstream of the pressure regulator, because only then would the hydrogen leak rate be sufficient to overcome hydrogen removal by the HVAC.

After analyzing the MDB rooms and filter area monitor houses, it was determined that a deflagration in monitor room 09-123 would have the greatest consequences. Other areas were not further analyzed based on the proximity of agent sources and the brief time above LFL (see appendix K3).

The model for evaluating the frequency of a hydrogen explosion in monitor room 09-123 considered two possibilities: 1) a hydrogen leak and an HVAC failure, and 2) a failure that results in a high hydrogen leak rate with HVAC operating. The frequency for a hydrogen deflagration in this room is 1.1×10^{-7} per hour. The overall frequency for the upset was dominated by failures that result in high pressure hydrogen leaks: pressure control valve rupture, shutoff valve rupture, and cylinder rupture. The next frequent contributors were a combination of an initiating rupture of the copper tubing leading to a hydrogen gas leak and an HVAC failure that lasts long enough for the LFL to be reached in the room.

5.6 External Events that Were Screened

Some events required a fairly detailed analysis before being screened or recommended for a detailed analysis. The process and reasoning behind each screening is described in this section.

5.6.1 Avalanche. Avalanches usually occur where large amounts of snow have accumulated in layers on steep slopes. When an avalanche occurs, a new layer of snow begins to slide when it separates from a weak layer underneath it. The slab of snow travels at an average of 80 mph. Avalanches that occur naturally are usually due to high winds or rapid melting from temperature increases (Tremper, 1999).

Due to the lack of snowfall and the topography of the region, avalanches can be screened from this analysis. This is because snowfall accumulations are low in the area. Also, slopes in the vicinity of the site are not steep enough to support or sustain the initiation of an avalanche. (The majority of the area surrounding UMCD is flat.) The highest peaks are at an elevation angle well below 10 degrees. This angle indicates that the avalanche hazard is negligible even with extreme snow accumulation.

5.6.2 Landslide. There were two basic types of landslides considered for UMCD: debris flow and simple. Debris flows (water, woody debris, mud, and rocks) normally pose an episodic risk in steep canyons. UMCD is located in a valley primarily made up of rolling hills. It is far from any steep canyons that would support debris flows. Debris flows are more likely to occur at higher elevations in areas where a disturbance has occurred (e.g., alpine forests that have been logged or burned). This type of landslide therefore was screened. Simple landslides are caused by a number of factors. Typically, soil saturation makes unstable slopes even less stable. The initiating slope is steep (greater than 90 percent grade), and in many cases is unstable because of manmade cuts into the slope. The travel distance of a simple landslide is a function of the grade, the slope and the shape of the falling material. Simple landslide materials tend to be angular and do not travel far when slopes are not extremely steep. The summits within a 15-mile radius of the site were examined and no slope steep enough to sustain this type of landslide was found. The angle of elevation was measured for each peak based on the height above sea level of the site and the summit and the distance between the two points. All summits were screened because they were less than 10 degrees of elevation. Based on this analysis and information on the nature of landslides, it was concluded that there is negligible landslide risk.

5.6.3 Meteorite Impact. Meteorites striking UMCD could lead to a significant amount of agent release. Data on meteorites that strike the United States are continually collected. Information on sizes and types of meteorites also is collected. Distributions of sizes and types were used for this analysis. It is assumed that all areas of the United States are at equal potential for meteorite strikes.

Two studies were referenced for this analysis. Both of those studies assessed the frequency of strikes and the probability of agent release from the facility and storage yard. The first study was completed for the FPEIS risk analysis (PMCD, 1987a). It included an examination of the storage yard (including igloos and transportation) and the MDB. Calculations were made to determine the impact required to breach these areas and the impact required to penetrate each type of container. The probability of a meteorite penetrating both the agent container and facility then was calculated. The second analysis (Winfrey, 1999) used the same methodology as the first, but relied on more recent data.

Although the CHB was not assessed in the original FPEIS, it is assumed to have the same protection as the holding/loading area assessed in the original FPEIS. (In the original report, the CHB was not a part of the design.) For the MDB/CHB, the most frequent meteorite able to penetrate the MDB or CHB had a frequency of 6.8×10^{-9} per year (or a recurrence rate of about 140 million years). Based on these calculations, a meteorite strike at UMCDF resulting in agent release was screened.

The analysis for I-Block and K-Block showed the frequency for meteorite strikes into storage structures was even rarer (on the order of once every 14 billion years). The analysis considered the barrier created by the igloo walls and the 2 feet of earth that cover the walls, as well as the different sizes and densities of meteorites that may strike the area. Thus, meteorite strikes to the UMCD storage yard also were screened.

5.6.4 Pipeline Accident. Pipelines carrying natural gas run south of UMCD site. The pipeline is approximately 8 miles from the storage yard and facility site. The likelihood of a pipeline rupture causing any damage to an igloo or the UMCDF is very unlikely. A calculation of the effects of blast waves from the ignition of TNT at some distance indicated that a *100-million pound* TNT blast causes essentially no damage at distances over 6.1 miles and greater. Using the same method, it was found that to do minimal damage at 8 miles it would require the equivalent of over a 100-million pound TNT blast. The explosions from pipeline accidents are not this intense; therefore, this event was screened from further analysis. Fires caused by pipelines were not considered because of the distance between them and the facility. These fires do have the potential to cause brush fires and their effects are considered in the wildfire section.

5.6.5 Sinkholes. A sinkhole is a land subsidence that occurs in regions where the bedrock consists of limestone, carbonate rock, or other rocks that can be dissolved by water flowing through them. As groundwater flows through the bedrock, underground caverns and hollows are formed. If the caverns become large enough, the overburden layer can fall into the hollow, forming a depression on the surface. The depressions created by a collapse of the overburden vary in size and time of development. The bedrock that underlies UMCD is predominantly basaltic. This type of bedrock is not prone to sinkhole formation and this event was screened from further analysis.

5.6.6 Tsunamis. A tsunami is a series of large, powerful water waves generated impulsively by a major undersea disturbance. Tsunamis are most often caused by underwater earthquakes, but also have been generated by volcanic eruptions, meteorite impacts, and underwater landslides. Unlike most water waves, which only displace the surface water, a tsunami displaces water from the surface to the ocean floor. This characteristic allows tsunamis to carry large amounts of energy great distances at high speeds. In the open ocean, tsunamis move quickly and they are very long in length. They usually do not have large heights in the open ocean where the water depth is great, but as they reach shallow water near the coast, the height quickly increases. When they hit the coast, tsunami waves can be as high as 100 feet and can travel up to 1 mile inland (González, 1999).

Historically, tsunamis occur approximately 57 times every decade. They predominantly affect pacific coastlines, but there have been a several occurrences along the east coast of South America and the Caribbean. The affects of tsunamis can be extremely severe. Since 1990, more than 4,000 deaths have been caused by tsunamis.

UMCD is not susceptible to tsunamis because it is located far inland and it is judged impossible for a tsunami to travel up the Columbia River. Thus, this event was screened from further analysis.

5.6.7 Fog. Although heavy fog could potentially interfere with transportation by reducing visibility, it was screened from the analysis. If heavy fog was present, any transportation activities would be postponed until the fog lifted. Fog poses no threat to indoor activities.

5.6.8 Drought. Droughts are not an uncommon occurrence in the UMCD area. Droughting, however, does not directly affect the storage yard or UMCDF. It is assumed that if water supplies were cut off, adequate warning would be given and the plant would shut down prior to water loss. For this reason, the event was screened from independent analysis.

The secondary effects of droughts are an important factor in the external events analysis. Some natural phenomena that can be triggered by drought include wildfire, landslides, and sinkhole development. Understanding how drought affects each of these events and how often droughts occur is incorporated into the analysis of these phenomena.

5.6.9 Wildfires. The land in the vicinity of the UMCDF is covered by desert scrub and brush with virtually no trees. During dry periods, fires in this brush can be hot and fast-moving. The Oregon Department of Forestry (ODF) collects data on wildfires that occur within the state. The data are collected by county and include information on number of fires, acres burned, and size classifications. Table 5-15 shows wildfire data for Umatilla and Morrow Counties for the last 12 years (Coyle, 2000).

Table 5-15. Wildfire Data for Morrow and Umatilla Counties (1987 to 1999)

	Morrow		Umatilla		Total	
Year	Number of Fires	Acres Burned	Number of Fires	Acres Burned	Number of Fires	Acres Burned
1987	8	4.7	33	3,312.3	41	3,317
1988	9	5.8	21	1,021.21	30	1,027.01
1989	3	0.3	25	127.51	28	127.81
1990	11	146.8	49	210.6	60	357.4
1991	8	0.8	30	162.71	38	163.51
1992	13	4.95	44	1,027.44	57	1,032.39
1993	4	0.55	22	3.59	26	4.14
1994	6	4.9	40	12,412.69	46	12,417.59
1995	6	2.5	37	175.75	43	178.25
1996	15	203.01	32	50,990.09	47	5,1193.1
1997	6	1.26	24	1,503.31	30	1,504.57
1998	8	23.79	43	2,116.5	51	2,140.29
1999	30	1,580.36	29	791.34	59	2,371.7

The fire department at UMCDF responds to less than 20 fires per year (Lisa, 2000). The corresponding fire frequency within a 3-mile radius of UMCDF is 2.8×10^{-6} fires per hour.

The UMCDF site is clear of brush and combustibles in all directions for a minimum of several hundred feet. High security fences reduce the chance of wind-borne movement of large burning material (e.g., tumbleweeds or other light combustibles) entering the building areas. Available fire protection service would be able to protect the facility from fire initiation. Thus, other than potential impacts on electrical power service from offsite, no direct impacts of the fire itself have been identified at the UMCDF. Loss of offsite power due to wildfires is included in the loss of power data used in the internal events modeling. Fire, therefore, may require a facility shutdown, but agent release would not be a direct effect.

The only potential effect on the building processes would be from airborne smoke and ash in the vicinity of the building HVAC intakes. In order to keep smoke from being pulled into the MDB, it is conceivable that the HVAC system would be purposefully turned off during a potential local wildfire if wind conditions were unfavorable and smoke would be drawn into the building. Loss of HVAC is modeled in the QRA. A wildfire will generally provide significant lead time, so adequate preparations to ensure worker safety and minimize potential agent migration from the building can be taken. Therefore, the current loss of HVAC models provides a conservative estimate of the consequences from any required reduction or turning off of the HVAC system. Also, the modeled frequency of HVAC failure (greater than one per year) is higher than any expected frequency of HVAC "loss" due to wildfires near the UMCDF.

5.7 Terrorism

The potential for acts of terrorism to affect the safety of communities living near chemical agent storage areas has been raised as a concern by local communities, review panels, and Congressional representatives. The concern was heightened by the events of 11 September 2001. Responsibility for protection of the chemical agent storage areas lies with the U.S. Army. In keeping with the heightened threat, all storage sites underwent significant changes in security to achieve a new standard of protection after 11 September. At their facilities with chemical agent, the U.S. Army coordinates efforts to deter potential acts of terrorism. Activities include evaluation of the potential threat, development of proactive plans to deter potential sabotage, development of response plans in the event of an act of sabotage, training personnel on these plans, and execution of readiness drills to evaluate and improve site response.

It is recognized that such an act could affect the safety and security of the chemical agent storage areas. To reduce the potential terrorist threat, a comprehensive system of intelligence gathering, threat monitoring, vulnerability assessment, and physical security design measures are maintained for each chemical agent storage area. By the nature of this issue, information on this program is classified. If included in the QRA, the QRA itself would become a classified document. This would hinder the primary objectives of the QRA: to provide the community with information on the facility and the associated risks with potential upsets and to provide the operating facilities with a tool for risk management. A classified report on terrorism risk at the chemical weapons storage sites has been completed using the basic risk models from the QRA. Measures to further reduce risk are being evaluated. For security reasons, insights from these studies cannot be generally reported. However, the concern over whether or not appropriate activities are being conducted to protect the public in the event of an act of sabotage is an important one. To address this issue, unclassified summary information on the surety and reliability program, along with some discussion of the ongoing evaluation, training, and response program, is provided in the following sections.

5.7.1 Internal Terrorism. Internal terrorism refers to the potential for an employee with access to either the disposal facility or the storage area to commit an act of sabotage. It is recognized that such an act could affect the safety and security of the chemical agent storage areas. To reduce the potential terrorist threat, a comprehensive system of intelligence gathering, threat monitoring, vulnerability assessment, and physical security design measures are maintained for each chemical agent storage area.

As one component of this program, U.S. chemical agent storage areas are required to complete and maintain a vulnerability assessment in accordance with Army Regulation (AR) 190-59. These assessments are reviewed annually and are used to prepare the physical security and tactical defense plans for the chemical storage areas. In addition, AR 190-59 provides for regular force-on-force exercises as a reality check for the vulnerability assessment.

Internal threats may be posed by workers who are disaffected or disloyal, allied with criminal elements, or become psychologically disturbed. The U.S. Army manages this issue at the national level through AR 50-6, *Chemical Agent Surety Program*. AR 50-6 requires that all personnel holding chemical duty positions be enrolled in the Chemical Personnel Reliability Program (CPRP). The CPRP provides a process for initial screening and continuing evaluation of an individual's health, attitude, behavior, and duty performance. In addition, the two-person concept ensures that two CPRP-certified personnel must be present during all operations involving chemical materiel, including inspections, monitoring, and small-scale chemical experiments. All visitors not enrolled in CPRP or the Unescorted Access Program must be escorted by CPRP-enrolled personnel, regardless of security clearance or military rank.

The Department of the Army Inspector General and Army Materiel Command separately conduct inspections of the installation's CPRP and security procedures. Each of these inspections includes a joint Chemical Surety Inspection and Physical Security Inspection and is conducted on an 18-month interval.

5.7.2 External Terrorism Summary. External terrorism refers to the potential for an enemy of the government to commit an act of terrorism. Measures for assessing both threats and vulnerabilities from external terrorist activities are coordinated at the national level. Installation commanders receive direct input from national agencies, supplemented with information from local law enforcement organizations. National-level expertise is directly applied in generating security analyses for each chemical storage site.

The Federal Bureau of Investigation (FBI) has the lead role in responding to terrorist threats. The FBI, in coordination with the Central Intelligence Agency (CIA), the military intelligence agencies, and the Departments of Defense, State, and Treasury, develops and disseminates threat information. If a terrorist crisis occurs, the FBI manages the crisis and the Federal Emergency Management Agency (FEMA) manages the consequences. Onpost and nonterrorist crises are handled directly by the U.S. Army.

Intelligence and law enforcement groups are proactive in detecting and stopping larger well-organized groups. Most typically, terrorism in the United States is carried out by small previously unknown splinter groups or loose associations of extremists. Autonomous disaffected and disenfranchised groups with an interest in overthrowing the social order exist in the United States, but these groups tend to be small. The Defense Intelligence Agency and the CIA monitor world events to identify potential threat conditions from other countries. These conditions are reported to U.S. commanders, who then implement preplanned defensive measures.

All U.S. chemical agent storage areas are required to have a vulnerability assessment under AR 190-59. Manual war gaming and table-top exercises are used to evaluate credible threats. These assessments are reviewed annually and used to prepare the physical security and tactical defense plans for the chemical storage areas. The assessments themselves are classified. Vulnerability assessments for chemical storage sites are validated by actual field exercises (AR 190-59) and by work performed in support of other DoD and DOE security missions.

Chemical surety materials are held and used only in specially designed chemical storage areas protected by double fencing, a guard force, and intrusion detection systems. The use of deadly force within these areas is authorized. The entrance to each chemical storage area is guarded by an entry control facility. The facilities are generally hardened against machine gun fire and have direct radio and telephone contact with an operations center on the installation. Since 11 September, there have been significant upgrades in protection in response to new threats.

The emergency operations center (EOC) handles chemical emergencies but is not itself staffed 24 hours a day. The main security desk is staffed 24 hours a day and can act as a temporary operations center until EOC staff arrive to take over the emergency.

The locations of specific chemical weapons within the storage areas are not posted on the igloos. However, the agent being stored is posted on the exterior of the igloo for fire department purposes.

5.7.3 Adequacy of the Security Force. The potential for an act of terrorism to succeed due to an inadequate security force has been raised as an issue. The U.S. Army addresses this concern through implementation of AR 190-59, *Chemical Agent Security Program*.

AR 190-59 requires that commanders ensure that "only personnel who are best qualified, physically fit, trained, capable, reliable and trustworthy are used to protect chemical agent." In general, civilian guards hired after 1992 are required to meet the physical standards in AR 190-56, *Army Civilian Police and Security Guard Program*. Under AR 190-56, an aggressive training program must be established to ensure continued proficiency of the guard force. This training must include physical training. The level of protection at the storage site has been significantly increased and will remain heightened until disposal is complete.

SECTION 6
ACCIDENT PROGRESSION ANALYSIS

In order to assess risk, the frequency of postulated accidents leading to agent release and the magnitude of the resulting agent release need to be determined. Sections 4 and 5 describe the identification and modeling of accident initiators. This section describes the models for the subsequent progression of disposal processing accidents from initiation to agent release. The accident progression analysis considers the impact of the initiator (e.g., a pallet is dropped from the forklift), the magnitude and mode of the initial release (e.g., a pallet of rockets explodes), the mitigating effects of engineered systems and barriers to release (e.g., facility structures and HVAC), and the potential for the accident to involve additional munitions. The models for progression of continued storage accidents are presented in section 14.

The accident progression analysis is closely coupled with the other analysis tasks. The internal and external event analyses define the accident initiating events and initiating event frequencies. These events and frequencies are provided to the accident progression analysis along with the relevant results from the mechanistic analysis developed in section 9. The accident progression analysis then calculates the frequency of each accident sequence and defines the characteristics of the accident progression sequences that control agent release. These characteristics are provided to the source term analysis, which defines the magnitude of the agent release. The consequences of the accidents then are calculated based on the quantity, duration, and time of day (daytime-only versus 24-hour) of the agent release. The worker risk analysis also uses the detailed information from the accident progression analysis concerning the type of accident sequences to assess the direct impact on workers near the accidents.

The Quantus Risk Management Workstation (also referred to as Quantus) is the application used to model accident progression and perform risk solutions, as depicted in figure 6-1. Although some portions of the analysis are performed outside of Quantus, most of the risk solution process is automated within Quantus. The use of Quantus in accident progression is discussed in further detail throughout this section.

Accident progression is modeled using an event tree to define the sequence of events that could occur following accident initiation and to determine the frequency of each accident sequence. Event trees are logic structures used to systematically define possible outcomes following an event. APETs have long been used in performing accident progression analyses for commercial nuclear plant and chemical industry risk assessments, and they were a key part of the methodology for the TOCDF Phase 2 QRA (SAIC, 1996b).

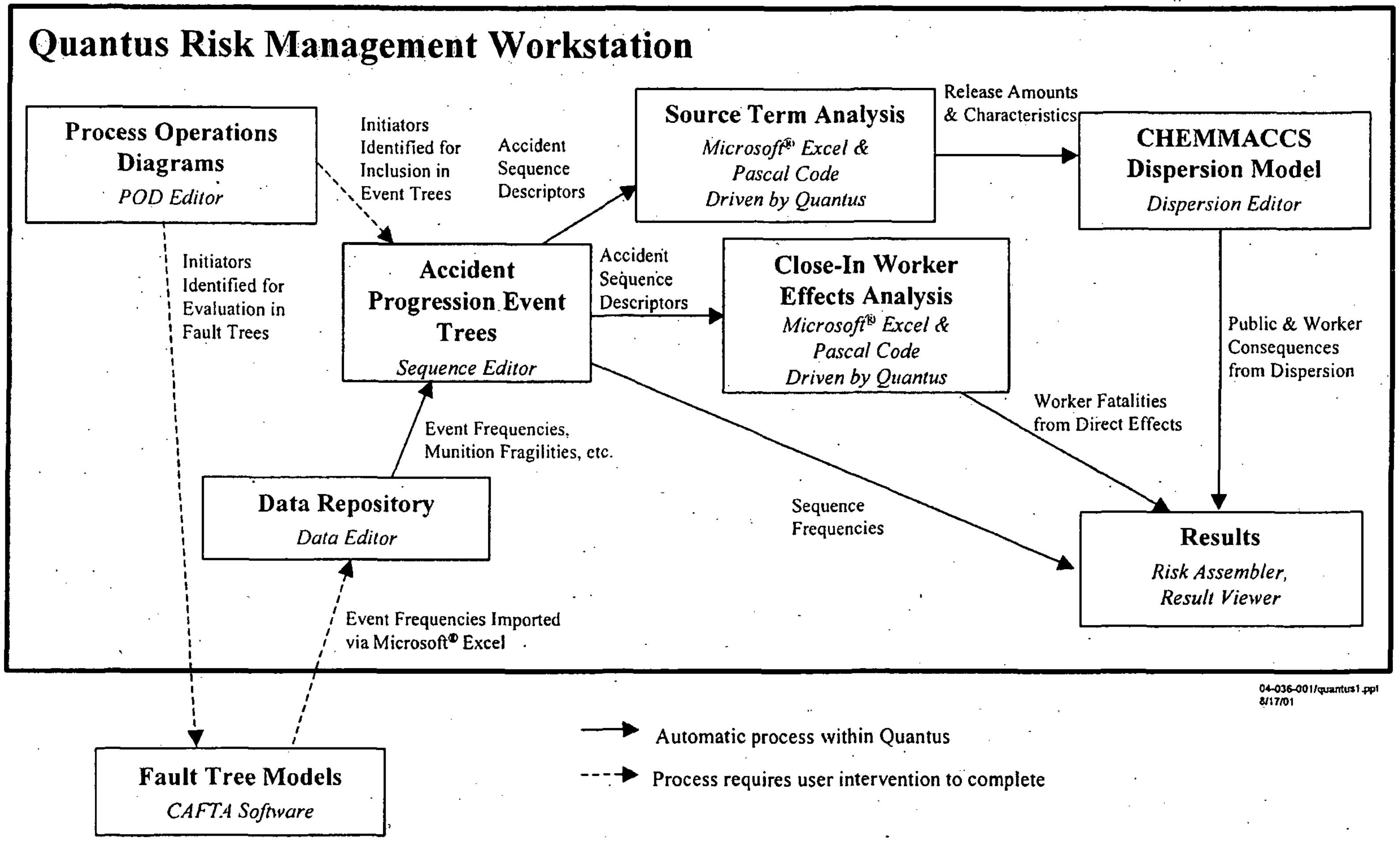


Figure 6-1. Data Flow Within Quantus

6.1 Overview of Event Tree Technology

Given that an offnormal initiating event occurs, it is necessary to consider all the possible sequences that could occur as a result. Some of the sequences will result in benign outcomes because the initiating event was not followed by any subsequent events that would lead to agent release. Other accident sequences will define ways that the initiating event was followed by other events that resulted in some agent release. Given the complexity of this process and the number of combinations of things that could occur after an initiating event, it is not possible to record the accident sequences by inspection. An event tree is a logic structure that allows a systematic delineation of possible outcomes.

The usefulness of event trees is best illustrated by example. Figure 6-2 illustrates a very small event tree. An initiating event, a forklift impact on a pallet of munitions, occurs. All internal initiators are first identified in PODs, as shown in appendix C. Given that the impact has occurred, it is necessary to determine what the initial outcomes are. As indicated in figure 6-2, the outcomes might include an agent leak from the munitions, an explosion or ignition of energetics, or no significant damage at all. This is a simple event tree. The three outcomes for the "What happens after the initiator?" question represent three *branches* of the tree for that question. Each subsequent question will have two or more branches describing the outcomes to that question.

There is analyst judgment on what should go in the tree and to what level of detail. For example, the event tree in figure 6-2 could include large leak and small leak as possible answers to the second question. Further discrimination also might be useful for some purposes. For the UMCDF QRA, the focus is on identifying the mechanisms of agent release in sufficient detail to allow estimation of public and worker risk. Therefore, decisions about the level of

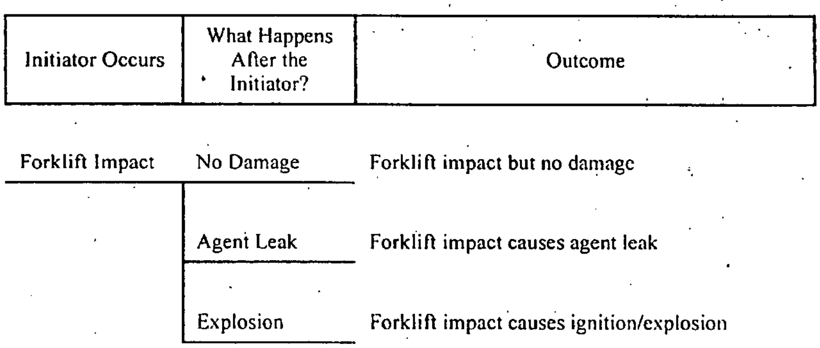


Figure 6-2. Start of an Accident Progression Event Tree

discrimination within the event tree are made by the event tree analyst in conjunction with the source term analyst, worker risk analyst, and other QRA analysts. As further levels of discrimination become necessary to differentiate accident sequences in the source term and worker risk analyses, these changes in accident sequences are made in the APET. Likewise, as different initiating events are identified, they are incorporated in the APET, and all their possible outcomes must be modeled in the source term and worker risk analyses. In the example in figure 6-2, the analyst has determined that an agent leak or explosion is possible, but no other accident sequence details are modeled. To understand public risk, it is necessary to understand how agent could be released from the controls provided in the facility design. The issue of completeness in the analysis is discussed in section 16.5, and the role of analyst judgment is discussed in section 12.4.1.

Figure 6-3 illustrates the continuation of the process by asking questions concerning what happens next. It is reasonable, because the QRA examines agent releases, to question whether the agent is contained in the building. If there is no agent leak to begin with, there is no concern about building integrity. If there is an agent leak from a munition, the building might function as designed or agent might migrate to otherwise uncontaminated areas (a building leak). A single outcome for a building leak is illustrated in figure 6-3. The actual development in the QRA is more complex, because the building leak could be a room seal leakage, a floor crack, or perhaps

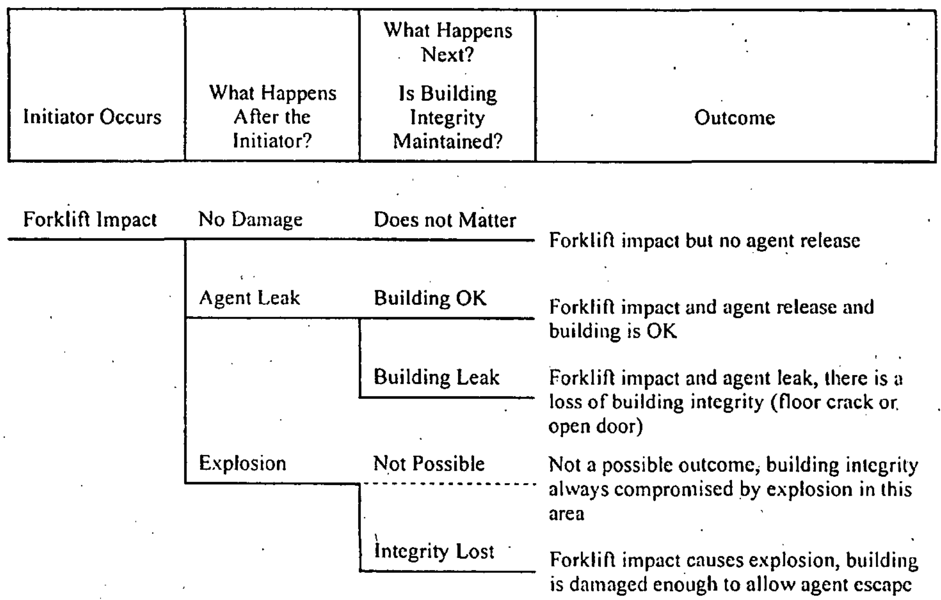


Figure 6-3. Further Development of an Accident Progression Event Tree

a door remaining open after evacuation of personnel from the spill area. The inclusion of these other outcomes creates more accident sequences and illustrates how the event tree can quickly generate or branch into many possible accident sequences for a single initiating event.

The explosion outcome introduces the possibility that the building is damaged. Depending on the room in the building and the type of explosion, building damage might be certain, as indicated in figure 6-3. In other cases, there might be some chance of building integrity being maintained; that branch would be considered also. The building damage outcome is different from the building leak outcomes described for agent leak events. As illustrated in figure 6-3, the accident sequences from figure 6-2 are better defined in terms of events that could affect the way agent might be released from the facility.

The event tree illustrated in figure 6-3 is not sufficient to fully determine the agent release. The facility design includes a cascade HVAC and carbon filtration system that would capture agent vapors resulting from an agent leak in the building. Thus, the event tree is continued in figure 6-4 by asking about the status of the HVAC. If there is an agent leak and the building integrity is maintained and the HVAC is working, agent release from the building is unlikely, because this is part of the design basis. If HVAC fails, even with the building essentially intact, the interior and exterior pressures will equalize and some agent could migrate from the building. If there is some loss of building integrity, the HVAC system still may function to remove most or all of the agent. The system efficiency may be affected by the status of the building, but it still would perform its basic function. If building integrity and HVAC failed, the agent would migrate outside more quickly than for a building without a specific leak pathway. Even for the explosion outcomes, HVAC still may be of interest. For example, the explosion would result in an exterior release of agent associated with the initial explosion. It is possible, however, that if the HVAC system were not damaged directly, the cascade airflow could be recovered after the initial blast, and any agent remaining in the building could be partially removed by the HVAC and filters.

This example illustrates the basics of the event tree development. It also indicates the complexity of the problem being addressed in the QRAs. As illustrated by the example, a single initiator could lead to many accident sequences. Inclusion of other branch outcomes (floor cracks, room seal failures, etc.) and consideration of still further events quickly expand the number of accident sequences. Event trees typically more detailed than shown in figure 6-4 are developed for all the hundreds of initiating events. As a result, there are thousands of accident sequences that describe the possible accident sequences initiated by the events described in sections 4 and 5.

The event tree purpose is twofold. The tree is developed both to describe accident sequences and to assess their frequencies. Figure 6-5 illustrates the assignment of values to derive the overall

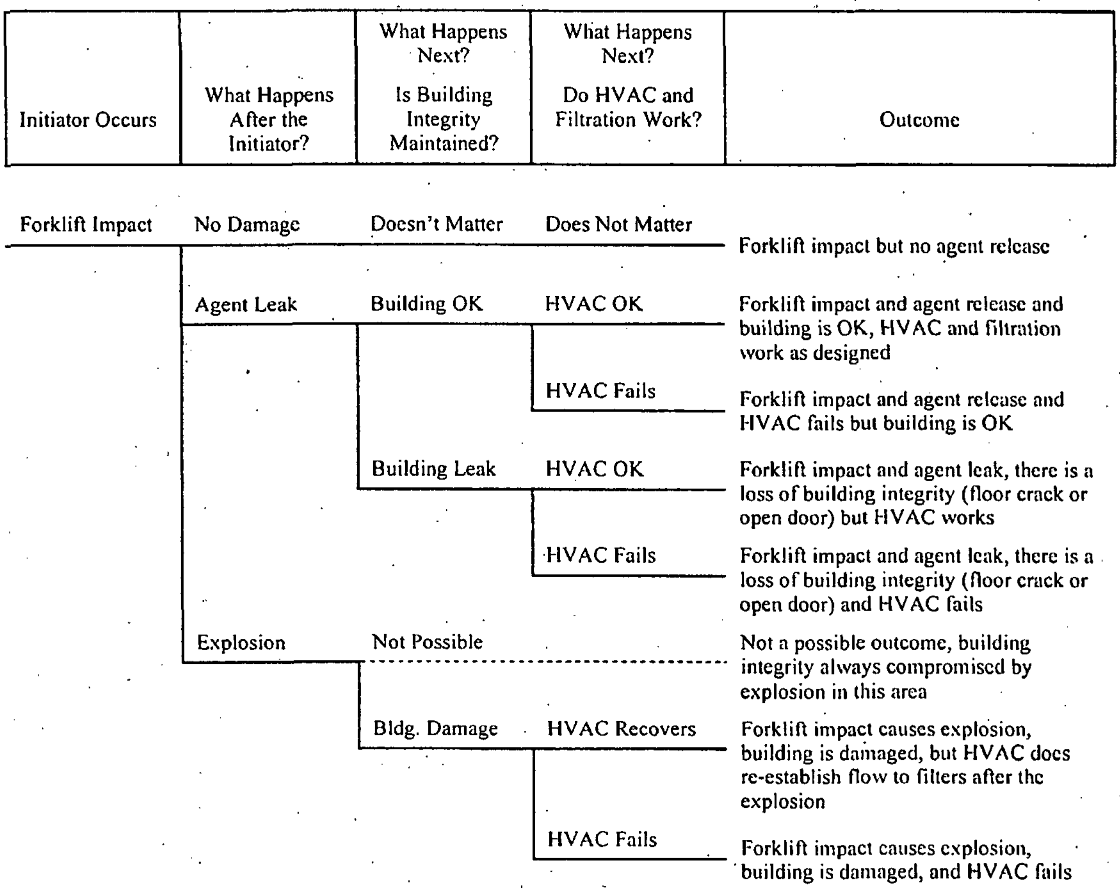


Figure 6-4. Expansion of an Accident Progression Event Tree to Refine Sequence Definition

accident sequence frequencies. Each branch is assigned a probability. In most cases, the sum of all branches for a given question is 1.0. (The preceding rule does not apply to initiating events, which are assigned frequencies based on an estimated rate of occurrence.) The mechanistic analyses, described in section 9, provide support for assigning conditional probabilities for the different paths defined by mechanistic events in the APET. For example, the probabilities of explosion or leak following a munition drop are developed in the mechanistic analyses. The probabilities are conditional on the specific prior event(s) in the accident, as defined by the event tree pathway. These events, therefore, account for the fact that an accident could proceed in several different ways, depending on the conditions of the accident or randomness in the phenomena.

Some illustrative values are shown in figure 6-5. (Numerical values are provided for example only and are not the specific values used in the APET.) For example, if there is a forklift impact,

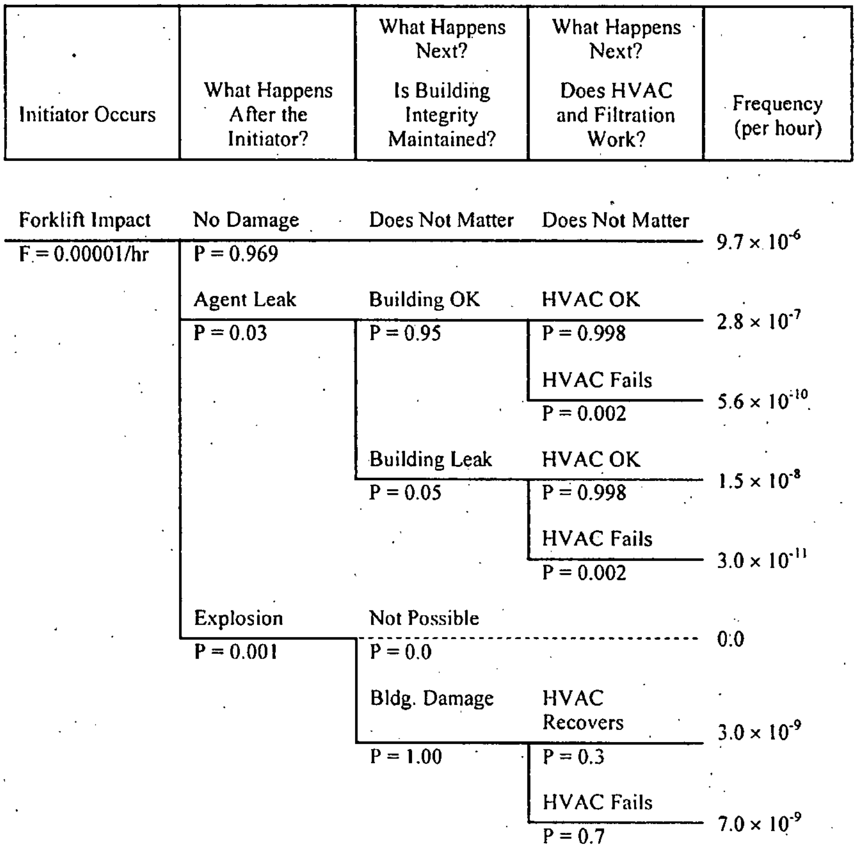


Figure 6-5. Assigning Probabilities to an Accident Progression Event Tree

the likelihood of a munition leak is 3 out of 100 (or 0.03). In the example, there is a 1 in 1,000 (0.001) chance that the munition might ignite or explode. Therefore, there is a nearly 97 percent chance that there would be no damage. The values used in the QRA are based on a combination of models and data that describe the likelihood of munition damage for specific types of accidents and are a function of munition type and initiating event. The models for forklift accidents include consideration of forklift speeds and weights that might be associated with the accident.

Similarly, in figure 6-5, probabilities are assigned for various levels of building integrity after a leak or explosion. If there is an explosion, the models of physical damage and response of structures indicate for this munition and this location that building damage is ensured (probability of 1.0). If there is no direct damage, models of other types of building failures indicate a 0.05 probability of loss of building integrity.

The HVAC availability also requires assessment. If the building integrity is maintained, there is a 0.002 probability of HVAC failure between the time of the initial spill until the spill is cleaned up. This would be developed from a fault tree reliability model of the system (as discussed in section 4). This would apply to all cases except for explosions. It is possible that the explosion could compromise the HVAC effectiveness. This could occur in a number of ways. The HVAC components or support systems such as electric power could be failed directly by the explosion. The damage to the building also might make it impossible to re-establish flow. In the example, the HVAC and filter systems have a 0.7 probability of being ineffective. Although not applicable in this example, any other dependencies between the initiators and the mitigative systems are solved with integrated logic in the APET to ensure proper modeling of interconnections. Thus, if the initiator involves failures of support systems that also would affect the HVAC operability, the APET recognizes this dependency explicitly within the HVAC failure logic.

The accident sequence frequencies are the product of the initiating event frequency and the probabilities of each successive branch in the event tree. The results are listed in the last column of figure 6-5. It is most likely that the initiating event will not lead to a significant outcome, with lower probabilities to successively more severe outcomes. The event trees are solved on a per-hour basis and then multiplied by the number of hours necessary to accomplish the disposal of all of that type of munition.

6.2 Description of Accident Progression Event Tree Logic Input for Internal Events

Although the event tree can be thought of graphically, as depicted in the previous section, it also can be considered in terms of questions with answers corresponding to the branches of the event tree. The question-and-answer format is actually more useful for large trees and for logic entry and maintenance. The APET logic is created, maintained, and solved in Quantus in a question-and-answer format. Visual representations of the graphical trees are available as user tools, but the basic format is in terms of questions and answers. See appendix L for further discussion of event tree structure in Quantus.

Figure 6-6 illustrates the basic structure of the APET in Quantus. Using this screen, the risk analyst is able to enter or view all the logic associated with an individual question. Similar to the POD structure and other Microsoft® Windows® programs, the basic structure is listed in the first column in terms of questions, expandable to illustrate answers. The right-hand side of the screen includes the information necessary to fully describe the detailed tree logic. As discussed previously, the outcomes for a question may be dependent on any or all of the previous questions, so Quantus needs to store the logical rules necessary for answering the question. For all rules applied to a question, one set of answers is available but different sets of answer probabilities may be proposed. As a rule is selected, the answers and values corresponding to

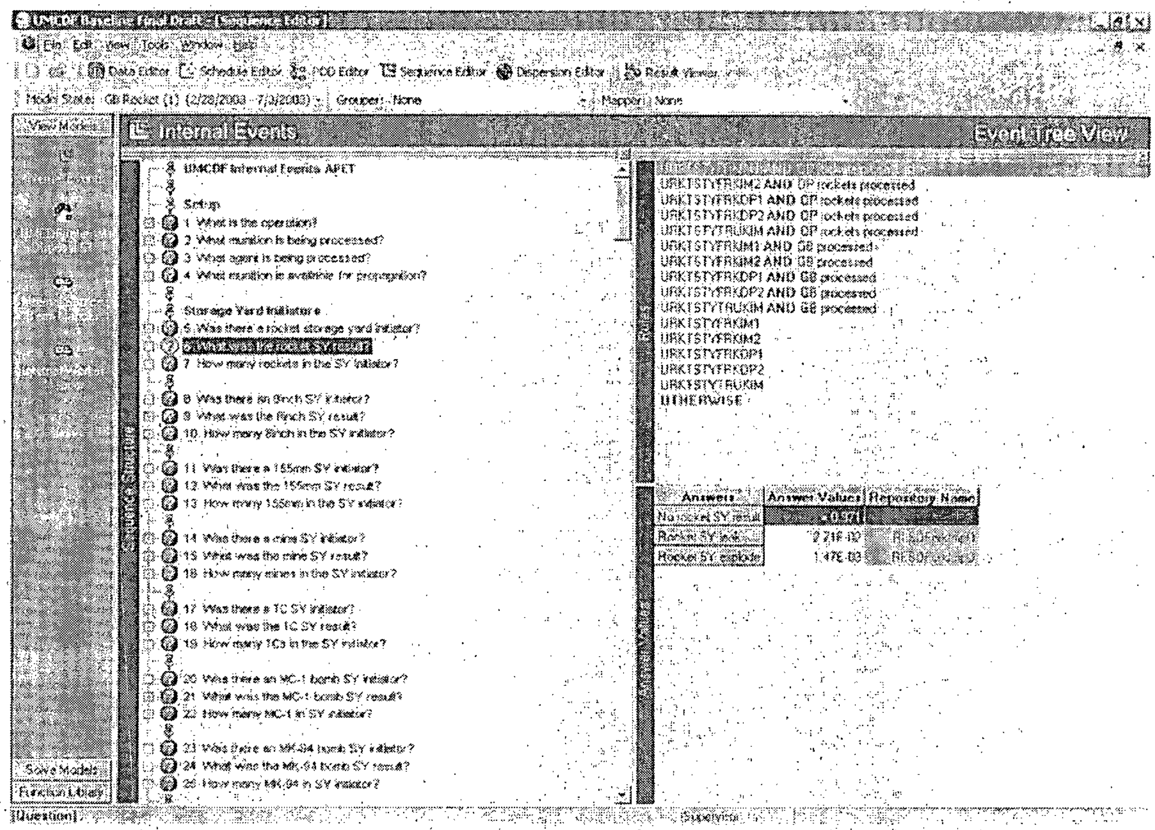


Figure 6-6. Illustration of Event Tree Logic in Quantus

that rule are displayed in the lower part of the screen under answer values. Quantus also contains a data repository name. For values used more than once and for all values requiring an uncertainty characterization, a repository name is assigned in Quantus that ties back to the central Quantus data repository. Aside from ease of data maintenance, this ensures that common values (such as the probability of a munition leak from a 3-foot drop) are assigned identical values everywhere that the same situation is being described in the tree. Section L.5.1 in appendix L provides information on the role of the Quantus data repository in supplying answer values for event tree questions. In addition, figure 6-1 shows the role of the Quantus data repository in the risk solution process.

Although the event tree is represented in a number of formats in section 6 and appendix L, it should be noted that the Quantus software is the main reference for the analysts using the event trees. The event tree and question-and-answer formats presented in this documentation are provided for informational purposes only, for readers who do not have access to the Quantus software with the UMCDF QRA model. Differing formats are used to present the event tree logic between section 6 and appendix L based on the level of detail intended. Section 6 is a high-level overview of the event tree, so this section presents an overview of the questions and answers in the event tree. Appendix L is intended as a detailed reference for all data stored in the event tree, so in addition to questions and answers, it also contains all answer values by rule. To accomplish these goals, different formats based on the same question-and-answer model are used.

Table 6-1 depicts the event tree logic for initiators at the storage yard. There are seven questions that describe the event tree for accidents at the storage yard. These questions are presented in much the same format as shown in figure 6-6 for the Quantus interface, with questions and answers displayed in the left column. However, the right column displays only the first rule for each question and the answer values corresponding to that rule. The question displayed in the Quantus interface in figure 6-6 is discussed in more detail in the second question within table 6-1. To see the complete list of answer values for each rule, refer to appendix L1.

As illustrated in table 6-1, the first question determines if there is an initiator. This ties directly to the PODs that define the initiators. The logic can be quite extensive, because initiators are considered separately for each munition for all the igloo unloading and EONC loading activities. In this case, logic describing dependencies on the previous question is not needed. The answer values are simply the frequencies of the initiators from the PODs. The initiator names and values are stored in the data repository. (The symbol, @1, in the first entry is necessary within the code to distinguish that the values in this case are frequencies, not probabilities, and need not sum to 1.)

The second question asks about the result of the initiator. This ties back to the possibilities that there could be a leak or explosion, or the outcome could be benign if there were no agent-related impact. In this case, the logic rules are important, because each separate case must be assigned appropriate probabilities. The probability of a leak given a forklift impact of a rocket pallet must be analyzed. Other initiators, such as forklift drops, would have a different probability of rocket leak or explosion from the impact probabilities. In addition, forklift drops from different heights are modeled because the response of munitions to these initiators would be different. Thus, the rules section is critical to the proper representation of the tree logic.

The next question in table 6-1 asks how many munitions were involved. This is obviously necessary to consider the outcome in terms of agent release. Some items may be handled individually (ton containers) while others are handled in pallets. Some handling is done with an EONC tray that contains multiple pallets, the number of which is dependent on the munition type. There also is a special case called out for events involving significant damage to a whole EONC tray rather than a forklift drop of the tray. The logic rules for this question look back at the type of initiator and determine how many items were involved.

Table 6-1. Storage Yard Accident Progression Event Tree Development

<table>
<tr><th>Branch Point Question</th><th colspan="4">Branch Point Logic Development and Data Values</th></tr>
<tr><td rowspan="5">Is there a (munition) storage yard initiator?
—•Munition Initiator 1
—•Munition-specific list of all accident initiators such as forklift and truck accidents</td><td>Rules</td><td colspan="3">Munition Processed
Logic rules are entered here to develop answer values specific to the case being considered. If rockets are processed, then rocket initiators must be considered. Likewise, some events are agent-specific, so logic rules are used to differentiate on an agent basis as well.</td></tr>
<tr><td rowspan="4">Answer Values</td><td>Answers</td><td>Answer Values</td><td>Repository Name</td></tr>
<tr><td>No Initiator</td><td>@1
approximately 1 – the "@" symbol indicates that the values need not sum to 1</td><td></td></tr>
<tr><td>Munition Init. 1</td><td>8.0×10^{-7}</td><td>URKTSTYFRKIM1</td></tr>
<tr><td>Other Initiators</td><td>Initiator-specific values</td><td>List of initiator names in Quantus database</td></tr>
<tr><td rowspan="5">What is the result of the initiator?
—•No agent-related outcome
—•Munition leak
—•Munition explosion (for items with energetics)</td><td>Rules</td><td colspan="3">Overpacked Rocket AND Forklift Impact
...
Logic rules describing the possibilities for each initiator. It considers cases that have to be considered separately, based on the type of munition and the type of accident. For example, a ton container can only leak, and the leak probability would be different depending on the type of forces involved in the accident. In addition, rockets have different probabilities of leakage based on agent fill and overpack status.</td></tr>
<tr><td rowspan="4">Answer Values</td><td>Answers</td><td>Answer Values</td><td>Repository Name</td></tr>
<tr><td>No Outcome</td><td>0.971
complement of other values</td><td></td></tr>
<tr><td>Leak</td><td>2.71×10^{-2}</td><td>RLSDForkImpO
repository name for a leak from an overpacked rocket pallet subjected to a forklift impact</td></tr>
<tr><td>Explosion</td><td>1.47×10^{-3}</td><td>RESDForkImpO
repository name for an explosion from an overpacked rocket pallet subjected to a forklift impact</td></tr>
</table>

Table 6-1. Storage Yard Accident Progression Event Tree Development (Continued)

<table>
<tr><th>Branch Point Question</th><th colspan="4">Branch Point Logic Development and Data Values</th></tr>
<tr><td rowspan="7">How many items were involved?
—•No item
—•Single item
—•Pallet
—•EONC Tray
—•EONC Tray Crush</td><td>Rules</td><td colspan="3">Forklift Impact
...
Logic rules describing how many items are involved for each initiator. It considers cases that have to be considered separately, based on the type of munition and the type of accident. For example, forklifts lift rocket pallets one at a time out of the igloo, and two at a time when loading the EONC tray.</td></tr>
<tr><td rowspan="6">Answer Values</td><td>Answers</td><td>Answer Values</td><td>Repository Name</td></tr>
<tr><td>No Item</td><td>0.0</td><td rowspan="5">Repository names are not shown because these answer values are entered directly within the event tree and are not drawn from the Quantus data repository.</td></tr>
<tr><td>Single Item</td><td>0.0</td></tr>
<tr><td>Pallet</td><td>1.0</td></tr>
<tr><td>EONC Tray</td><td>0.0</td></tr>
<tr><td>EONC Tray Crush</td><td>0.0</td></tr>
<tr><td rowspan="6">Did the storage yard initiator propagate?
—•No propagation
—•Leak of a pallet
—•Explosion of a pallet
—•Explosion of an igloo</td><td>Rules</td><td colspan="3">Rocket AND Forklift Impact AND In Igloo AND Explosion Results
...
Logic rules describing the potential for propagation to other items. For example, only forklift accidents involving the igloo could possibly propagate to the igloo.</td></tr>
<tr><td rowspan="5">Answer Values</td><td>Answers</td><td>Answer Values</td><td>Repository Name</td></tr>
<tr><td>None</td><td>0.5</td><td></td></tr>
<tr><td>Pallet Leak</td><td>0.0</td><td></td></tr>
<tr><td>Pallet Explosion</td><td>0.0</td><td></td></tr>
<tr><td>Igloo Explosion</td><td>0.5</td><td>Rkt_inIgloo_prop</td></tr>
<tr><td rowspan="7">How full was the igloo?
—•Not applicable
—•25 percent full 80-ft igloo
—•50 percent full 80-ft igloo
—•75 percent full 80-ft igloo
—•100 percent full 80-ft igloo</td><td>Rules</td><td colspan="3">If Igloo Explosion AND VX Rocket
...
Logic rules describing the mix of use of igloos and the probability that the accident would occur at anytime during unloading.</td></tr>
<tr><td rowspan="6">Answer Values</td><td>Answers</td><td>Answer Values</td><td>Repository Name</td></tr>
<tr><td>Not Applicable</td><td>0.00</td><td></td></tr>
<tr><td>25 percent Full 80-ft Igloo</td><td>0.250</td><td></td></tr>
<tr><td>50 percent Full 80-ft Igloo</td><td>0.250</td><td></td></tr>
<tr><td>75 percent Full 80-ft Igloo</td><td>0.250</td><td></td></tr>
<tr><td>100 percent Full 80-ft Igloo</td><td>0.250</td><td></td></tr>
<tr><td rowspan="5">Where was the impact of the storage yard initiator?
—•No event
—•Initiator in igloo
—•Initiator on apron</td><td>Rules</td><td colspan="3">If Rocket AND Forklift Impact
....
Logic rules describing where the event could occur. This depends on the initiating event. Some could occur only in one place, while others could possibly be split probabilistically.</td></tr>
<tr><td rowspan="4">Answer</td><td>Answers</td><td>Answer Values</td><td>Repository Name</td></tr>
<tr><td>Not Applicable</td><td>0.0</td><td></td></tr>
<tr><td>Impact in Igloo</td><td>1.0</td><td></td></tr>
<tr><td>Impact on Apron</td><td>0.0</td><td></td></tr>
</table>

Table 6-1. Storage Yard Accident Progression Event Tree Development (Continued)

Branch Point Question		Branch Point Logic Development and Data Values		
Was there a storage yard initiator? —•No storage yard initiator —•Storage yard initiator	Rules	*Logic is inserted here to account for all of the initiating events in this section. This is a bookkeeping question used by the analyst for ease of logic development.*		
	Answer Values	**Answers**	**Answer Values**	**Repository Name**
		No SY Initiator	0.0	
		SY Initiator	1.0	

Given an initial event, it also is necessary to know whether the accident progressed to involve other agent sources. For example, a rocket explosion would involve the pallet but may or may not propagate to other nearby pallets. For rockets, some events that occurred within an igloo could propagate to other rockets in the igloo. This is considered in a question with probabilities assigned by mechanistic analysis and judgment. Logic rules are used to define the cases that need to be considered. If an event did propagate in an igloo, it is necessary to consider the additional agent involved, as asked by the next question in table 6-1. The logic rules define the outcomes from the previous question that indicate a propagation, and then probabilities are assigned depending on the type of igloos being used for storage in the likelihood that the accident occurred when the igloo was first opened or after a significant fraction of the other pallets had already been removed.

The next question for the storage yard APET is the location of the impact. This question is asked to better define the possible consequences, particularly possible worker exposure. Two answers are provided, igloo and apron, and the answer values are assigned based on the type of initiator.

The final question "Was there a storage yard initiator?" is simply a bookkeeping question that enables easy reference back to this portion of the tree when additional logic is developed. These bookkeeping questions are included throughout the tree to ensure accurate quantification and to ensure that frequencies are not combined (accident sequences are assigned frequencies based on an initiator frequency and subsequent probabilities; frequencies cannot be multiplied together).

6.3 Development of UMCDF Internal Event Accident Progression Event Tree

Table 6-1 illustrates the basic tree logic for one very small portion of the tree and without all of the detail of each munition, which actually makes the logic considerably more extensive. Two separate APETs were developed to analyze the UMCDF QRA processing risk: one for internal events and one for external events, which are discussed in this and the next section.

This section includes a brief description of the APET logic associated with internal events during munition demilitarization. As with table 6-1, the questions and answers will be presented for each section of the event tree logic. However, examples of rules and answer values are not shown in the figures and tables in this section because examples are of limited value to a reader once the basic structure of an event tree is understood. A more detailed description of the APET logic for both internal and external events is included in appendices L1 and L2, respectively, including all answer values by rule for each question.

The logic is divided up into sections. Table 6-2 lists the APET sections. The APET is organized in the same manner as the PODs, essentially covering the disposal process from munition retrieval through total agent elimination. As indicated in table 6-2, the APET starts with setup questions that enable flexibility for use and solution of the tree. The setup questions establish the plant configuration to be considered, such as the specific munitions and agent being destroyed and any co-processing or other features of the plant arrangement that would affect risk. This allows the APET to be solved for specific campaigns and to reflect any plant-specific processing nuances.

The first part of the tree, dealing with storage yard operations, was described in some detail in the previous section. The next part of the APET is summarized in logic table LT-1. (For ease of display, all logic tables are placed at the end of section 6.) The transportation of the EONC from storage to the CHB considers the possibility of an accident. (The APET logic includes initial and/or closing questions in each section that assist the analyst in developing and structuring the tree. These questions do not affect the important logic structure of the tree that defines accidents and therefore are grayed out in tables illustrating the logic.) The APET structure considers the speed of the accident to better estimate the damage potential. Accident outcomes include leaks inside the EONC with no external leakage, as well as EONC breaches and the possibility of munition explosions that will directly fail the EONC. For internal EONC leaks, it is necessary for the consideration of worker risk to determine if the sampling properly detects leakage prior to subsequent opening. Another question asked in this part of the logic is whether a fire occurs. Some vehicle accidents could involve fires that could change the nature of the potential agent release.

The next portion of the APET deals with the unloading at the CHB. There are relatively few initiators that could be significant, but the entire process is covered. The logic is summarized in logic table LT-2. The logic for these initiators considers what happened, the agent-related outcomes, how much agent was involved, and the specific location. The initiators for this section are primarily failures during EONC handling operations. The failure of the elevator also is considered here. Similar to the transportation accidents, it also is necessary to consider the sampling of an EONC involved in an upset, because improper sampling could lead to worker agent exposure.

Table 6-2. List of Internal Event Accident Progression Event Tree Sections

APET Section	Description
Setup Questions	The questions are used internally in the solution process to determine how to solve the APET. The APET is solved to reflect the planned schedule, and each munition campaign is solved separately. The flexibility in the setup allows the risk analyst to solve for specific situations.
Storage Yard	All removal from the igloos and loading into EONCs
Transportation	Transport of the EONC from the igloos to the CHB
CHB	Unloading of the truck, transport on conveyors and lift to the UPA
UPA	Unloading of the EONCs through the loading on process lines
RHS	Rocket demilitarization
BHS	Bulk draining
PHS	Projectile demilitarization
Mine ECV & MHS	Special mine unpack operations in the ECV and mine demilitarization
ACS	Agent storage
LIC	Agent incineration
DFS	Energetics/agent destruction in the furnace
TMA	Handling and unpacking of leakers
MPF	All metal parts thermal decontamination
HVAC	Agent vapor collection on carbon filters, and control of agent throughout the building
Secondary Waste	Storage and destruction of DPE suits, contaminated waste, and carbon filter media
Worker Questions	These questions are used by the worker risk algorithm. Questions regarding worker populations are provided in the event tree so that the aleatory aspect of uncertainty could be properly characterized in the frequency of the accident sequence. Risk of maintenance activities during campaign changeovers also is assessed.
Initiator Classification	This is a question that does not introduce additional technical logic, but classifies initiating events by whether the frequencies are hourly or per munition, and adjusts per-munition rates to account for total munition throughput.

The UPA is the part of the process with the largest number of potential initiators. The initiators are defined for each munition type. The APET logic is summarized in logic table LT-3. The initiators are derived from activities beginning with handling and opening of the EONC and ending with the placement of items on the conveyors or munition input lines. Initiators occur due to handling equipment failures as well as human errors.

Questions are used to determine how each initiator might progress to an outcome and the amount of agent initially involved. Propagation is considered for explosive outcomes because more agent could become involved and for some items additional explosions or leaks could occur.

Explosions could lead to fires, involving still more agent, so the possibility of fire also is queried. The remaining questions examine the outcome of the accident. The location of the accident is the subject of one question. Accidents in the ECV are considered as part of the UPA logic, and some furnace events could arise because of mistakes initiated in the UPA. Given an accident, it is necessary to know whether the facility contains the release. If an explosion occurs, building damage would occur. Even for spill events, integrity could be failed by building faults or mistakes during evacuation. Finally, as with all accident sequences, it is necessary to know if the HVAC is working.

Logic table LT-4 illustrates the APET logic for the rocket disposal process. The initial questions establish the list of initiating events from the PODs. A separate question includes initiators associated with rockets processed without draining (intentionally undrained).

Rocket accidents could cause agent leaks or the energetics could ignite or explode. For events involving explosion, propagation is considered also. The APET logic then considers the location of the accident. Rocket accidents could affect the ECV, ECR, or DFS. Given a specific accident and location, the logic then examines the possibility of integrity breach, whether due to the accident or as a result of some other failure, such as room seal failures allowing agent migration. The final part of the logic considers the availability of HVAC for each accident sequence identified by the logic.

The logic for the BHS is summarized in logic table LT-5. The logic is very similar to the RHS in that there is a question for basic initiators as well as independent questions for initiators involving inadvertent and intentional undrained bulk items. Initiators include failures of gates and charge cars, as well as failures of the punch and drain processing equipment. The outcomes are quite simple for bulk items, because they do not have explosives. Either a bulk item retains its integrity in an accident, or an agent leak is created. One other type of outcome is associated with a bulk item explosion in the MPF due to placing the item in the furnace without punching and draining. Bulk item locations also are considered in an APET question. There are many locations because this portion of the tree covers from the ECV to the MPF. Given an upset, the usual questions about building integrity and HVAC availability are asked.

The PHS logic summary is shown in logic table LT-6. It is very similar to the two previous portions of the APET logic. Gate and charge cars accidents, and processing equipment failures are considered for the whole path of the projectile process. Outcomes include leaks and explosions. As with bulk items, other outcomes are possible in the MPF due to placing a projectile tray in the furnace without pulling burster wells and draining. If there is a release of agent, the logic considers the building integrity and HVAC operation.

The processing of mines is considered in logic tables LT-7 and LT-8. Most mines are unpacked from their drums in the UPA; however, drums requiring special effort to open and those containing leaking mines will be opened in the ECV. Logic table LT-7 displays the section of the event tree for these special ECV mine unpack operations. Initiators for mine processing in the ECR following unpacking are shown in logic table LT-8. As with other demilitarization line sections of the event tree, initiators include gate closures and drops.

The next section of the tree, illustrated in logic table LT-9, deals with the portions of the disposal process beyond the processing lines. The first section of logic is associated with agent piping and storage (the ACS). The logic is relatively simple: accident sequences that could result from pipe or tank leaks are identified in the PODs. Large or small leaks are possible in all areas where agent piping is located. Only large leaks of the ACS tank are modeled because the TOX room is an area where some level of agent contamination is expected.

The next portion of the APET deals with the LIC (summarized in logic table LT-10). The LIC initiators examine upsets that could cause direct agent releases or explosions of natural gas or agent vapor that, in turn, cause agent releases. Building integrity and HVAC availability questions are asked after any agent release or explosion outcomes.

The logic continues with the DFS, as pictured in logic table LT-11. The DFS has separate considerations for processing of rockets, mines, and projectile energetics. Outcomes of initiators may include agent release to the room or natural gas explosion. If there is an explosion, the building integrity is considered in the logic. As with all other portions of the APET, HVAC availability is also questioned.

The TMA logic in logic table LT-12 considers the processing of leaking munitions. Because munitions leaving the TMA first are moved backward through the facility to the beginning of the disposal process lines, many initiators could occur. Items could be misdirected, or mishaps involving gate closures and drops and charge cars could damage munitions. The APET logic delineates all the locations for the TMA upsets.

The last furnace, the MPF, is considered in logic table LT-13. The actual logic is quite extensive because the logic must be developed for each munition type. The MPF is like other furnace models in that it considers explosions and other malfunctions, and the items could be undrained. Building and furnace integrity are important issues for MPF accident sequences and therefore are included in the logic.

The next two portions of the APET logic deal with the HVAC system and secondary waste. Although the status of the HVAC system has been asked throughout the tree as a mitigation to other accident sequences, failures of the HVAC system could be the initiator. The initiators generally describe the outcome, so very little APET logic is required. Logic table LT-14 shows the HVAC logic. Similarly, the QRA scope includes consideration of all agent sources. Until the carbon from the spent carbon filters is destroyed, it remains a possible agent hazard. The last section of the APET, in logic table LT-15, covers the possible accidents associated with secondary waste, namely spent carbon filter media.

In the Quantus APET file, there are two additional sections of logic at the end of the tree. The first of these APET sections is logic pertaining to worker risk models. The range of worker populations in the building is defined, and maintenance activities during changeovers are modeled. The last is a bookkeeping section used to classify the initiators as hourly or per munition, and to ensure that the per-munition initiators are multiplied by the throughput rate so that all accident sequences have correct hourly frequencies.

6.4 Development of UMCDF External Event Accident Progression Event Tree

The sequence development for external initiators is completed in a separate APET. This APET has a section devoted to each type of initiating event. The logic is simpler because the effects of the initiating events are a function of facility design and therefore do not require delineation of every process step for every munition unlike the internal event APET. Table 6-3 provides an overview of the APET sections.

Table 6-3. List of External Event Accident Progression Event Tree Sections

APET Section	Description
Setup Questions	The questions are used internally in the solution process to determine how to solve the APET. The APET is solved to reflect the planned schedule, and each munition campaign is solved separately. The flexibility in the setup allows the risk analyst to solve for specific situations.
Seismic	Earthquake initiators
Tornado	Tornado winds and tornado-induced missiles
Lightning	Lightning effects in the building
Aircraft	Aircraft crashes
Wildfires	Wildfires and their impact on HVAC availability
Fires	Fires that lead to agent involvement
Hydrogen Explosions	Explosions resulting from leaking hydrogen tanks that supply ACAMS units

The seismic logic is summarized in logic table LT-16. The logic represents the potential accident sequences for agent release based on the seismicity, equipment, and structural capacities described in section 5. The logic steps through possibilities of agent release from individual scenarios that could involve agent release. It includes one structural failure. Due to the nature of seismic events, many components can be expected to fail in an earthquake. Because response of every piece of equipment to an earthquake cannot realistically be modeled in detail and some equipment and structural failures were screened based on high capacity, other failures not modeled individually are grouped together in "surrogate" events. These surrogate sequences are defined to model the response of equipment not modeled in detail. The use of surrogate events is an accepted practice in seismic analyses for nuclear plant risk assessments.

The seismic logic is different from most of the APET logic because it uses parameters. The parameters are used to compare the seismic capacities or fragilities of equipment and components to the level of earthquake motion. Probabilities are assigned to discrete ranges of motion and to seismic capacities of components to determine the probability of equipment or structural component failure. Following determination of seismic failure probabilities, other portions of the accident sequence are modeled to completely characterize the size and conditions of agent release. Only agent-related effects are considered, so the logic does not describe all of the damage that could occur.

The tornado logic shown in logic table LT-17 is the next section of the APET. The tornado logic covered ranges from the possibility of catastrophic facility damage to individual scenarios that cause specific types of agent release. The likelihood of tornado damage is assessed by the severity of the tornado as described in section 5. For each tornado, the effects of high winds and tornado-generated missiles are considered. Only agent-related effects are considered, so the logic does not describe all of the damage that could occur.

The lightning section of the APET illustrated in logic table LT-18 examines the potential for having an accidental rocket initiation in the UPA. The lightning logic examines the energy of the strike, the effectiveness of the lightning protection system, and the likelihood that an M55 rocket could ignite because of the incident.

Logic table LT-19 illustrates the aircraft crash logic. The aircraft crashes are divided into three plane sizes and consider the possibility of impacting the MDB, HVAC carbon filters, CHB, or igloos storing spent carbon. Given a crash, the consequences are determined by the energy of the crash, which depends on the plane size and whether or not a fire occurs as part of or after a crash.

The next small section of logic includes the possibility that the building ventilation would be affected by a nearby wildfire. The HVAC system may be shut down if smoke from a nearby wildfire is being pulled into the building. The logic is summarized in logic table LT-20.

The final section of the APET deals with fires. Fires could occur in any area of the building, and many rooms were analyzed as part of the fire analysis. However, fire logic was input to the APET only for specific rooms with high agent inventory. In addition, fires throughout a floor of the facility and a facility-wide fire also were included in the APET. The APET illustrated in logic table LT-21 shows the logic developed for fires. Questions are asked to determine if agent is present in the area, and if so, if it would become involved in the fire. To generate the source term, the number of munitions affected and the probability of building breach are determined. The next four questions determine the role of the HVAC filters in an agent release.

The final section in the external event APET involves hydrogen explosions, as shown in logic table LT-22. Hydrogen explosions are only considered for one room, MR 123. The outcome of this event is modeled as a loss of HVAC.

6.5 Solution of the Event Trees for Source Term and Close-In Worker Calculations

As described in section 6.1, the purpose of the APET is twofold. The event tree logic is constructed to characterize agent releases so that consequences of the various accident scenarios can be determined. In addition, all the branches (or *questions*) in the event tree are assigned probabilities (or *answer values*) to calculate a frequency for the entire sequence. When risk is assembled, the sequence frequencies are multiplied by the sequence consequences to determine risk. In order to calculate consequences, the accident sequences must be classified to interact efficiently with the source term and close-in worker analyses.

6.5.1 Accident Sequence Descriptors. The APET is developed to describe the accident progression in enough detail to estimate the agent release and determine close-in worker effects. As described previously, this effort required interaction with the development of the source term and close-in worker algorithms to ensure that sufficient accident discrimination was provided by the APET. In the end, the source term is determined by key characteristics of the accident. The accident sequence characteristics critical to the appropriate source term estimation are discussed in section 10. In order to ensure a proper interface between the APET and the source term, the APET needed to be solved in terms of the sequence descriptors necessary for the source term. This is a different solution from the solution of the entire event tree. For example, the solution of an event tree was illustrated in figure 6-5 for one accident. There could be dozens of accidents resulting in the same outcomes, but occurring as a result of different initiators. The source term estimation does not require information on all the ways the unique outcomes could occur; it just needs a frequency of the sum of all accident sequences resulting in that unique outcome. Therefore, additional APET tools are developed to enable efficient calculation of the source terms for all unique sequence outcomes.

This is accomplished in Quantus using the event tree solutions in terms of only those characteristics needed in the source term assessment. Categories of characteristics are termed descriptors. Thus, an accident descriptor called *agent* could have characteristics of GB, VX, or HD. Figure 6-7 illustrates a portion of the APET logic devoted to establishing this solution. Logic must be developed to establish the accident sequence characteristics to be included in the solution process. In figure 6-7, the descriptors *release, propagation release, agent, munition,* and *location* are specified in the left column, and the *release* dimension has been expanded to show all the possible characteristics that describe unique modes of agent release. In the right column are rules that ensure all accidents are categorized by whether or not they could lead to a specific type of release. For example, in figure 6-7, three types of agent spills not originating from a munition are highlighted in the logic. This signifies that the event tree is solved by grouping these three outcomes into one characteristic because all that is of interest is that there was a release due to an agent spill. A subsequent descriptor *amount* is used to differentiate the three spill amounts. Thus, many accident sequences that may have the same outcome can be grouped together for the source term calculation.

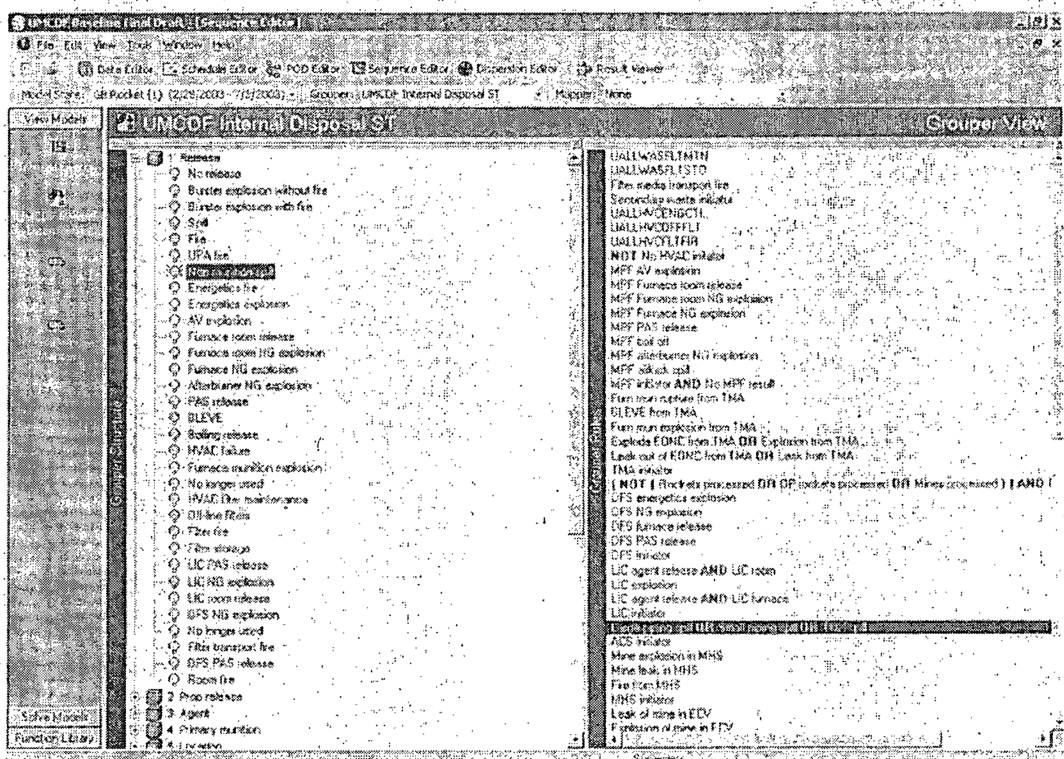


Figure 6-7. Example Quantus Display of Accident Progression Event Tree Solution Logic

The source term analysts established the different characteristics required to determine the source term. Two accident sequence solutions were developed to enable the source term analysis—one for internal events and one for external events. The set of unique accident descriptors for internal events is listed in table 6-4.

Table 6-4. Internal Event Accident Descriptors for Source Term Specification

Accident Descriptors	Application
Release	Source term analysis
Propagation Release	Source term analysis, close-in worker analysis
Agent	Source term analysis, close-in worker analysis
Primary Munition	Source term analysis, close-in worker analysis
Location	Source term analysis
Amount	Source term analysis
Drain Status	Source term analysis
Co-processed Munition	Source term analysis
Propagation Amount	Source term analysis
Propagation Drain Status	Source term analysis
HVAC Status	Source term analysis
Building Breach	Source term analysis, close-in worker analysis
Furnace Damage	Source term analysis, close-in worker analysis
Mode	Source term analysis
Number of Primary Workers Affected	Close-in worker analysis
Number of Secondary Workers Affected	Close-in worker analysis
Campaign Type	Close-in worker analysis
Special Worker Category	Close-in worker analysis
Day/Night	CHEMMACCS consequence analysis
Population	CHEMMACCS consequence analysis
Campaign	Source term analysis
Worker Release	Close-in worker analysis
Worker Location	Close-in worker analysis

The table also details how each descriptor is used—whether it is used in the source term analysis, close-in worker analysis, or CHEMMACCS consequence analysis directly. Logic table LT-23 summarizes the internal event accident sequence descriptors.

The event tree is solved using this logic to determine the frequency of every valid unique combination of accident sequence characteristics. "Valid" means the combination of events could occur. Event combinations that are not "valid" are not analyzed (for example, ton container accidents never involve the DFS). The solution using this logic is the link between the APET and the source term, as discussed in section 6.5.2.

Similarly, a set of descriptors was developed for external events. The descriptors are listed in table 6-5. They cover the basic type of release sequence occurring and are more directly associated with the initiating events than the internal event accident sequence descriptors. The type of accident (e.g., seismic event) keys the source term analysis to a particular type of calculation. The descriptors are very similar to those for internal events, but are customized to ensure appropriate source term assignment for every type of accident. Logic table LT-24 summarizes the accident sequence characteristics associated with these descriptors and their subsequent use in the analyses.

Table 6-5. External Event Accident Descriptors for Source Term Specification

Accident Descriptors	Application
Release	Source term analysis, close-in worker analysis
Propagation Release	Source term analysis
CHB Collapse	Source term analysis
CHB/UPA Collapse	Source term analysis
Forklift Drop	Source term analysis
Mode	Source term analysis, close-in worker analysis
Agent	Source term analysis, close-in worker analysis
Munition	Source term analysis, close-in worker analysis
Location	Source term analysis, close-in worker analysis
Quantity	Source term analysis
Co-processed Munition	Source term analysis
Filter Temperature Level	Source term analysis
Propagation Amount	Source term analysis
Co-processed Drain Status	Source term analysis
Drain Status	Source term analysis
HVAC Status	Source term analysis
Building Breach	Source term analysis
Day/Night	CHEMMACCS consequence analysis
Population	CHEMMACCS consequence analysis
Aleatory Uncertainty	Source term analysis
Campaign	Source term analysis

The calculation of close-in worker consequences is discussed in section 11. Close-in consequences are those that result from close proximity to the initial accident rather than effects due to dispersion of chemical agent in the atmosphere. The same set of accident sequence descriptors used for source term analysis is used in the analysis of close-in worker consequences. As shown in tables 6-4 and 6-5, some descriptors are used in both calculations, and some are used in only one. When descriptors are used in both calculations, the same answers are passed to each algorithm for analysis.

6.5.2 Connection of Accident Sequence Descriptors to Source Term and Close-In Worker Algorithms. After the event tree has been solved such that agent release scenarios are categorized and described for subsequent evaluation, the accident sequence descriptors must be connected to the source term and close-in worker analyses so that data can be passed between them. This function is performed within the Quantus sequence editor through the use of "mappers." As shown in figure 6-1, the process of passing accident sequence descriptors to these analyses is performed automatically within Quantus once the event tree has been solved. Mappers are created to start specific algorithms for various agent release scenarios, pass inputs from the accident sequence descriptors, and receive the outputs from the algorithms for future use in consequence analysis or risk assembly. It is possible for one set of accident sequence descriptors to be mapped to multiple destinations through the use of separate mappers. For example, one set of accident sequence descriptors exists for disposal internal events, but two mappers for this set of descriptors are used to call upon source term and close-in worker algorithms.

Each source term and close-in worker algorithm is identified within Quantus as a *function*. The file names and locations, as well as the necessary inputs and outputs, are stored within Quantus for all functions. To associate an accident sequence descriptor with a function, the descriptor must be designated as a *trigger*. Because the source term and close-in worker algorithms are built based on different agent release mechanisms, triggers are identified within a few accident sequence descriptors. Table 6-6 shows the accident sequence descriptors with trigger characteristics. Refer to section L.4 for a listing of accident sequence descriptor characteristics and the specific algorithms they trigger.

Table 6-6. Accident Sequence Descriptors Containing Triggers

Event Tree	Mapper	Accident Sequence Descriptors
Disposal Internal Events	Internal source term mapper	Release, Propagation Release, HVAC
Disposal Internal Events	Internal worker mapper	Worker Release, Special
Disposal External Events	External source term mapper	Release
Disposal External Events	External worker mapper	Release

Figure 6-8 shows the mapper interface within Quantus. The left column displays the accident sequence descriptors and characteristics. When a characteristic acting as a trigger is selected in the left column, the right column displays information about the function to which it is mapped. The function name is displayed at the top of the right column, with the function inputs and outputs displayed underneath.

As shown in figure 6-8, the "Burster explosion without fire" characteristic triggers the *MunsExplodeEvap* function. The inputs required for this function (*agent*, *munition*, *quantity*, *drain status*, *location*, *breach*, and *HVAC status*) are displayed on the left side of the Function Input box (which appears on the upper right quadrant of the window). An accident sequence descriptor has been mapped to the right of each of these necessary inputs. The characteristic within the *Agent* accident sequence descriptor in each sequence then will be passed to this function to satisfy the *Agent* input. For example, the GB, VX, or HD characteristics within the *Agent* descriptor will be passed to satisfy the *Agent* input for various sequences that trigger the MunsExplodeEvap algorithm.

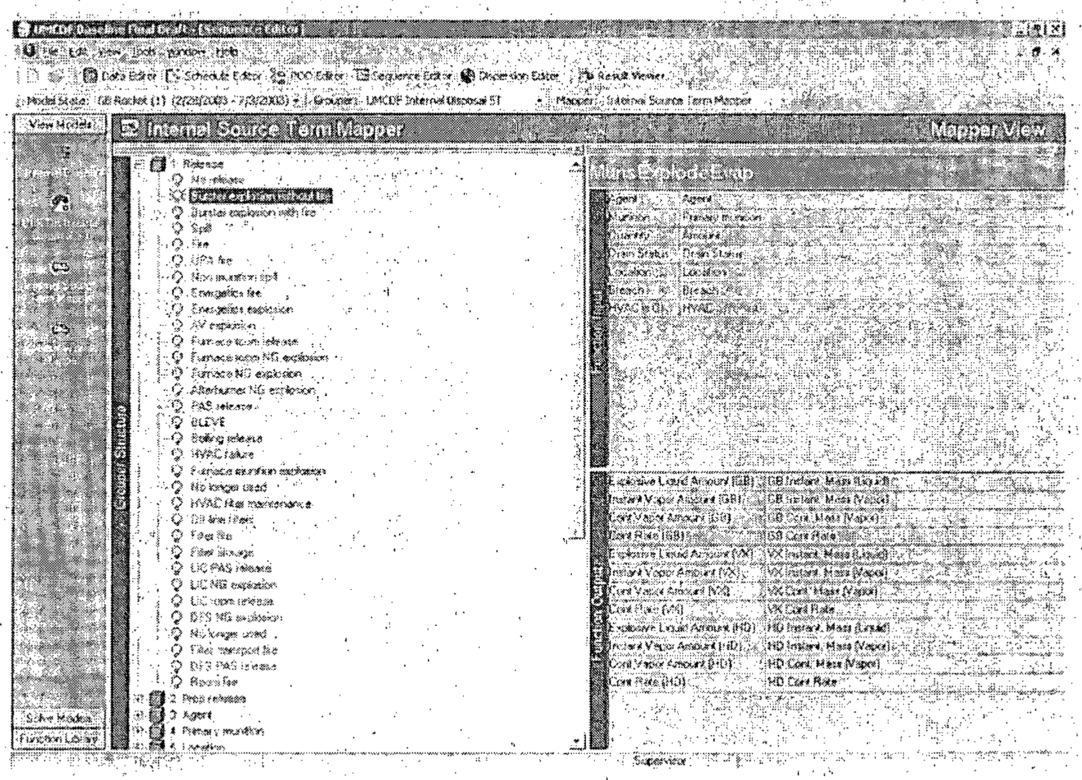


Figure 6-8. Example Quantus Display of Mapper

The Function Output box (which appears on the lower right quadrant of the window) displays the outputs generated by this function and the outputs desired for this particular trigger. In most cases, the outputs are standard for all source term functions, with the only exception being that some functions do not generate explosive releases. All close-in worker functions generate only one output: fatalities. Further discussion of the functions, their inputs, and outputs is provided in appendices O3 and Q3 for source term analysis and close-in worker analysis, respectively.

Logic Table LT-1. Transportation Initiator Logic in the Accident Progression Event Tree

Branch Point Question	Description of Question and Answers
Was there a pre-transportation initiator? —•No pre-transportation initiator —•Pre-transportation initiator	Used as bookkeeping in the event tree to ensure that frequencies are handled correctly.
Was there a transportation initiator? —•No transportation initiator —•Transportation initiator 1 —•Etc.	Transportation accident initiator frequencies are derived from an analysis of accident statistics as they apply to the site.
What was the impact velocity of the transportation initiator? —•No accident —•0-5 mph —•5-15 mph —•15-25 mph —•> 25 mph	Four speed regimes are established to help break down the energy involved in the accident.
What was the outcome of the transportation initiator? —•No (agent-related) outcome —•In-EONC transport leak —•Out-of-EONC transport leak —•Transport explosion	The outcomes consider if agent was released, and whether it is contained. Because the EONC is not explosion-proof, explosions could cause an out-of-EONC release.
How many munitions were involved? —•None —•EONC Tray	The EONC inventory is all involved, although that does not mean that all the agent is involved. The source term function determines how much of the involved inventory actually leaks.
Did ACAMS detect the in-EONC leak? —•Not applicable —•Transport – ACAMS detects leak in EONC —•Transport – ACAMS fails to detect leak in EONC	If there was an accident without EONC failure, it would be necessary to test the EONC before opening to determine if there had been an in-EONC leak. If there had been an accident and testing failed, an agent leak and worker exposure could occur.
Did the transport accident lead to a fire? —•No fire —•Fire from transport initiator	A fire changes the release characteristics, and can also lead to involvement of more agent than initially leaked in the accident.
Where was the impact of the transportation initiator? —•No location —•Transport Location —•UPA Transport Location —•Sent to TMA	The location is important for the consideration of exposure of personnel and the public. If an EONC is intact but contains an agent leak that was not detected, it could impact workers in the UPA when it is opened. If the leak was detected, the EONC would be sent to the TMA.

Logic Table LT-2. Container Handling Building Initiator Logic in the Accident Progression Event Tree

Branch Point Question	Description of Question and Answers
Was there a CHB prior initiator? —•No CHB prior initiator —•CHB prior initiator	Used as bookkeeping in the event tree to ensure that frequencies are handled correctly and initiators do not occur together.
Was there a (munition) CHB initiator? —•No CHB initiator —•CHB 1 —•Etc.	CHB initiators include crane and lift faults, as well as possible leakage within an EONC during transport and during CHB storage without any accident occurring.
What was the outcome of the CHB initiator? —•No (agent-related) outcome —•In-EONC leak —•Out-of-EONC leak —•EONC munition explosion	The outcomes consider if agent was released, and whether it is contained. Because the EONC is not explosion-proof, explosions could cause an out-of-EONC release.
How many munitions were involved? —•None —•Single item —•EONC tray	The number of munitions involved in the accident is dependent on the type of accident. Out-of-EONC leaks and explosions would involve the contents of the EONC tray.
Did ACAMS detect the in-EONC leak? —•Not applicable —•ACAMS detects CHB leak in EONC —•ACAMS fails to detect CHB leak in EONC	If there were an accident without EONC failure, it would be necessary to test the EONC before opening to determine if there had been an in-EONC leak. If there had been an accident and testing failed, an agent leak and worker exposure could occur.
Where was the impact of the CHB initiator? —•No location —•CHB impacted by CHB initiator —•UPA impacted by CHB initiator —•Sent to TMA	The location is important for the consideration of exposure of personnel and the public. The UPA is considered because that is where the EONC would be opened. The TMA is included because an EONC could be intact after an upset but contain an agent leak. It was assumed here that EONCs in which leaks are detected would be opened in the TMA.
Has there been a CHB initiator? —•No CHB initiator —•CHB initiator	This is a wrap-up question used for bookkeeping in successive questions to ensure that initiator frequencies are handled appropriately.

Logic Table LT-3. Unpack Area Initiator Logic in the Accident Progression Event Tree

Branch Point Question	**Description of Question and Answers**
Was there an initiator prior to the UPA? —•No initiator prior to the UPA —•UPA prior initiator	Used as bookkeeping in the event tree to ensure that frequencies are handled correctly and initiators do not occur together.
Did the ACAMS read less than 40 time-weighted average (TWA)?	Not used at UMCDF at this time. This logic was developed based on TOCDF procedures that allow operations in the UPA even with positive EONC ACAMS readings.
Was there a (munition) UPA initiator? —•No UPA initiator —•UPA 1 —•Etc.	UPA initiators include crane and forklift accidents, and errors associated with any manual loading of munitions onto the process lines. The UPA accidents are actually considered in separate questions for each munition type.
What was the result of the UPA initiator? —•No (agent-related) outcome —•Munition leak —•Munition explosion	The outcomes consider if agent was released or if an explosion occurred. Additional outcomes (e.g., explosions in the MPF) are possible for overpacked munitions because the initiators differ from regular munitions.
How many munitions were involved? —•None —•Single item —•Pallet —•EONC tray	The munitions involved in the accident are dependent on the type of accident. For example, forklift accidents could involve a pallet, but loading of munitions on process lines usually involves a single munition.
Was there propagation in the UPA? —•No propagation —•UPA propagation	If there was an explosion, other agent could be involved due to the damage of the explosion, and for some munitions, other explosions could occur. The possibility of propagation is dependent on the initiating event and is only modeled for rockets.
What was the outcome of the UPA propagation? —•No (agent-related) outcome —•Explosion from propagation —•Leak from propagation	Given UPA propagation, leaks and explosions are possible propagation scenarios.
Was there a UPA fire? —•No UPA fire —•UPA fire	If there was an explosion, a fire involving munition packing materials, etc., could be initiated. The fire could spread to other munitions stored in the UPA.
Where was the location of the initiator's impact? —•No location —•UPA impacted from UPA initiator —•ECV impacted from UPA initiator —•MPF impacted from UPA initiator	The location is important for the consideration of exposure of personnel and the public. The ECV initiators are included in this portion of the event tree. An overpacked item could also be sent to the MPF.

Logic Table LT-3. Unpack Area Initiator Logic in the Accident Progression Event Tree (Continued)

Branch Point Question	Description of Question and Answers
Was there an integrity breach of the UPA? —•No UPA breach —•Breach of UPA by explosion —•Breach of UPA by door —•Breach of UPA by floor —•Breach of MPF by UPA	If there is an agent leak, it is important to know if the building is containing the leak as designed. An explosion could cause a large breach, a door left open would be a smaller breach, and there is a very small chance of minor leakage through floor cracks. In some cases, an error in the UPA results in an overpacked munition being inadvertently diverted to the MPF. The result would be an explosion at the MPF, as indicated in the question outcomes.
Was the HVAC operational for the UPA event? —•HVAC not applicable —•HVAC operational —•HVAC fails	Given an agent leak, the status of the HVAC and filtering is important.
Has there been a UPA initiator? —•No UPA initiator —•UPA initiator	This is a wrap-up question used for bookkeeping in successive questions to ensure that initiator frequencies are handled appropriately.

Logic Table LT-4. Rocket Handling System Initiator Logic in the Accident Progression Event Tree

Branch Point Question	**Description of Question and Answers**
Was there an initiator prior to the RHS? —•No initiator prior to the RHS —•RHS prior initiator	Used as bookkeeping in the event tree to ensure that frequencies are handled correctly and initiators do not occur together.
Was there an RHS initiator? —•No RHS initiator —•RHS 1 —•Etc.	RHS initiators include gate closures, drain and shear failures, and operational problems with the RHS that require special maintenance activities.
Was there an intentionally undrained RHS initiator? —•No RHS undrained initiator —•Undrained RHS 1 —•Etc.	It may not be possible to drain certain lots of rockets. These are intentionally sent to the shear station undrained. Some initiators are on a different POD because the agent involved in an upset would be different than for normal rockets.
Was the rocket drained? —•Not applicable —•Rocket undrained —•Rocket drained	There is the possibility that a rocket could be intentionally undrained, which influences the agent quantities associated with some initiating events. In addition, initiators that do not intentionally involve undrained processing could be either drained or undrained depending on the stage of the RHS process.
What was the outcome of the RHS initiator? —•No outcome —•Rocket leak —•Rocket fire —•Rocket explosion	The RHS events could involve leaks or explosions or fires involving the propellant.
How many rockets were involved? —•None —•Single item	The initial accidents for this system all involve single rockets.
Did the RHS initiator propagate? —•No RHS propagation —•Rocket propagation	If there was an explosion or fire involving a rocket, another could also become involved. Propagation is only modeled for events in which the rocket is being transported under the blast gate and into the ECR. Because these events occur while the blast gate is still partially open, another rocket in the ECV could become involved.
What was the outcome of the RHS propagation? —•No RHS propagation outcome —•Leak —•Explosion	If propagation occurs, either explosion or leak of other rockets can occur.
Where was the location of the initiator's impact? —•No location —•ECV impacted from RHS initiator —•ECR impacted from RHS initiator —•DFS impacted from RHS initiator	The location is important for the consideration of exposure of personnel and the public. The gate closure events could involve the ECV. Some RHS events could have an impact on the DFS.

Logic Table LT-4. Rocket Handling System Initiator Logic in the Accident Progression Event Tree (Continued)

Branch Point Question	Description of Question and Answers
Was there an integrity breach caused by the RHS? —•No breach —•UPA wall breach —•ECR blast gate open —•ECV wall breach —•Agent migration from RHS event —•Floor migration from RHS event	If there is an agent leak, it is important to know if the building is containing the leak as designed. Some RHS events could occur due to a blast gate closure on an item, so the ECV and UPA could be affected. Agent migration could occur due to seal and penetration failures, and floor cracks need to be considered for leakage.
Was the HVAC operational for the RHS event? —•HVAC not applicable —•HVAC operational —•HVAC fails	Given an agent leak, the status of the HVAC and filtering is important.
Has there been a RHS initiator? —•No RHS initiator —•RHS initiator	This is a wrap-up question used for bookkeeping in successive questions to ensure that initiator frequencies are handled appropriately.

Logic Table LT-5. Bulk Handling System Initiator Logic in the Accident Progression Event Tree

Branch Point Question	Description of Question and Answers
Was there an initiator prior to the BHS? —•No initiator prior to the BHS —•BHS prior initiator	Used as bookkeeping in the event tree to ensure that frequencies are handled correctly and initiators do not occur together.
Was there a BHS initiator? —•No BHS initiator —•BHS 1 —•Etc.	BHS initiators include gate closures and charge car transfer failures that cause the potential for agent leakage. Drain failure initiators are addressed in subsequent questions.
Was there an inadvertent drain failure initiator in the BHS? —•Not applicable —•Bulk undrained initiator 1 —•Bulk undrained initiator 2, etc.	There is the possibility that a bulk item could be unintentionally undrained and then have an initiator, such as a gate closure or charge car upset. These cases are considered separately because of the different agent inventory involved.
Was there an intentionally undrained BHS initiator? —•Not applicable —•Bulk intentional undrained initiator 1 —•Bulk intentional undrained initiator 2	Some items may be processed with greater than a 5 percent heel due to known problems with draining. These bulk items could be subject to further initiators that are captured in this question.
What was the result of the BHS initiator? —•No outcome —•Bulk item leak —•Bulk boiling-liquid expanding-vapor explosion (BLEVE) at the MPF —•Bulk furnace munition rupture from BHS	For bulk items, either the item is intact after an upset or there is agent leakage. There is one special case. If an item is unpunched and forwarded into the MPF, it could undergo heating of the closed volume followed by a BLEVE (explosion) or rupture of the munition and subsequent agent release in the furnace. Even though these outcomes happen at the MPF, the initiator occurs at the BHS.
Was the bulk item drained? —•Not applicable —•BHS undrained —•BHS drained	The estimation of the potential source term requires the drain status to be specified for each type of initiator.
Where was the location of the BHS initiator's impact? —•No location —•UPA impacted from BHS initiator —•ECV impacted from BHS initiator —•UMC impacted from BHS initiator —•MPB impacted from BHS initiator —•BSA impacted from BHS initiator —•LMC impacted from BHS initiator —•MPF impacted from BHS initiator	The location is important for the consideration of exposure of personnel and the public. The BHS includes all of the conveyor and charge car operations, so events may occur in many areas of the building. If an item is unpunched or undrained, the MPF would be affected.
Was there a loss of integrity from the BHS event? —•No breach —•Floor migration from BHS event —•Breach of MPF by BHS event	If there is an agent leak, it is important to know if the building is containing the leak as designed. For agent leakage in the areas of concern, floor cracks allowing agent migration are the specific concern. If a BLEVE occurs because a bulk item is sent to the MPF unpunched and undrained, the MPF is assumed to be breached.

Logic Table LT-5. Bulk Handling System Initiator Logic in the Accident Progression Event Tree (Continued)

Branch Point Question	Description of Question and Answers
Was the HVAC operational for the BHS event? —•HVAC not applicable —•HVAC operational —•HVAC fails	Given an agent leak, the status of the HVAC and filtering is important.
Has there been a BHS initiator? —•No BHS initiator —•BHS initiator	This is a wrap-up question used for bookkeeping in successive questions to ensure that initiator frequencies are handled appropriately.

Logic Table LT-6. Projectile Handling System Initiator Logic in the Accident Progression Event Tree

Branch Point Question	Description of Question and Answers
Was there an initiator prior to the PHS? —•No initiator prior to the PHS —•PHS prior initiator	Used as bookkeeping in the event tree to ensure that frequencies are handled correctly and initiators do not occur together.
Was there a (munition) PHS initiator? —•No PHS initiator —•PHS 1 —•Etc.	PHS initiators include gate closures and drops, charge car failures, energetics fires or explosions, projectile drops, and processing drain failures and operational problems with the PHS that require special maintenance activities.
Was there an undrained PHS initiator? —•No PHS undrained initiator —•Undrained PHS 1 —•Etc.	The outcome of some of the initiators is dependent on the drain status. The initiators that specifically involve both intentionally and inadvertently undrained items are listed in this question.
Is the burster well welded? —•Not applicable —•Burster well welded —•Burster well not welded	Projectiles with welded burster wells could have a different response to subsequent upsets and must therefore be treated separately.
What was the result of the PHS initiator? —•No outcome —•Projectile leak —•Projectile explosion —•Energetics fire —•Energetics explosion —•Projectile sent to MPF undrained —•Projectile BLEVE at MPF —•Projectile furnace munition rupture at MPF	The PHS events could involve leaks, explosions, or fires. There are also steps in the process involving the energetics separate from the munitions, so fire and explosion outcomes are described separately for those. In addition, projectiles could inadvertently be sent to the MPF undrained with burster wells intact. If the burster wells are welded, the projectiles could cause a BLEVE in the MPF. If the burster wells are intact but the projectiles do not cause a BLEVE, the outcome is modeled as a rupture of the munitions in the furnace, possibly causing a PAS release.
Was the munition drained? —•Not applicable —•Projectile undrained —•Projectile drained	There is the possibility that a projectile could be unintentionally undrained, which influences the agent release associated with some initiating events.
Where was the impact of the PHS initiator? —•No location —•ECV impacted from PHS initiator —•ECR impacted from PHS initiator —•UMC impacted from PHS initiator —•MPB impacted from PHS initiator —•BSA impacted from PHS initiator —•LMC impacted from PHS initiator —•MPF impacted from PHS initiator	The location is important for the consideration of exposure of personnel and the public. The PHS includes all of the conveyor and charge car operations, so events may occur in many areas of the building. If an item is undrained, the MPF would be affected.

Logic Table LT-6. Projectile Handling System Initiator Logic in the Accident Progression Event Tree (Continued)

Branch Point Question	Description of Question and Answers
Was there an integrity breach caused by the PHS? —•No breach —•UPA wall breach —•Floor crack leakage —•Seal leakage —•ECV wall breach —•MPF breach	If there is an agent leak, it is important to know if the building is containing the leak as designed. These PHS events could occur due to a blast gate closure on an item, so the ECV and UPA could be affected. Agent migration could occur due to seal and penetration failures, and floor cracks need to be considered for leakage. BLEVEs could cause breach of the MPF.
Was the HVAC operational for the PHS event? —•HVAC not applicable —•HVAC operational —•HVAC fails	Given an agent leak, the status of the HVAC and filtering is important.
Has there been a PHS initiator? —•No PHS initiator —•PHS initiator	This is a wrap-up question used for bookkeeping in successive questions to ensure that initiator frequencies are handled appropriately.

Logic Table LT-7. Mine Explosive Containment Vestibule Processing Initiator Logic in the Accident Progression Event Tree

Branch Point Question	Description of Question and Answers
Was there an initiator prior to the Mine ECV? —•No initiator prior to the Mine ECV —•Mine ECV prior initiator	Used as bookkeeping in the event tree to ensure that frequencies are handled correctly and initiators do not occur together.
Was there a Mine ECV initiator? —•No Mine ECV initiator —•Mine ECV 1 —•Etc.	Mine ECV initiators occur when mine drums are unpacked in the ECV because the mines are leaking or the drums are damaged. The initiators include drops of mines as well as items misdirected to the wrong locations.
What was the result of the Mine ECV initiator? —•No outcome —•Mine leak in ECV —•Mine explosion in ECV —•Furnace munition explosion from Mine ECV	The Mine ECV events could involve leaks or explosions of mines. Mines inadvertently included with waste could explode in a furnace.
How many mines were involved? —•Single mine —•Drum of mines —•Fuzes	The agent release analysis requires specification of the magnitude of the event.
Where was the impact of the Mine ECV initiator? —•No location —•UPA impacted from Mine ECV initiator —•ECV impacted from Mine ECV initiator —•MPF impacted from Mine ECV initiator	The location is important for the consideration of exposure of personnel and the public. The Mine ECV could affect the UPA or ECV and items could be sent to the MPF if they were inadvertently included with waste.
Was there an integrity breach caused by the Mine ECV initiator? —•No breach —•UPA wall breach —•Floor crack leakage —•ECV wall breach —•MPF breach	If there is an agent leak, it is important to know if the building is containing the leak as designed. The integrity of the building is dependent on the type and location of the explosion.
Was the HVAC operational for the Mine ECV event? —•HVAC not applicable —•HVAC operational —•HVAC fails	Given an agent leak, the status of the HVAC and filtering is important.
Has there been a Mine ECV initiator? —•No Mine ECV initiator —•Mine ECV initiator	This is a wrap-up question used for bookkeeping in successive questions to ensure that initiator frequencies are handled appropriately.

Logic Table LT-8. Mine Handling System Processing Initiator Logic in the Accident Progression Event Tree

Branch Point Question	Description of Question and Answers
Was there an initiator prior to the MHS? —•No initiator prior to the MHS —•MHS prior initiator	Used as bookkeeping in the event tree to ensure that frequencies are handled correctly and initiators do not occur together.
Was there an MHS initiator? —•No MHS initiator —•MHS 1 —•Etc.	MHS initiators include gate closures and drops and other problems during processing in the ECR.
What was the result of the MHS initiator? —•No outcome —•Mine explosion —•Mine leak —•Fire from MHS	The MHS events could involve leaks, explosions, or fires.
Was the mine drained? —•Not applicable —•Mine drained —•Mine undrained	The consideration of accident consequences requires knowledge of drain status.
Was there an integrity breach caused by the MHS initiator? —•No breach —•ECR blast gate open —•Agent migration	If there is an agent leak, it is important to know if the building is containing the leak as designed. These MHS events involve an open blast gate. Agent migration could occur due to room seal and penetration failures.
Was the HVAC operational for the MHS event? —•HVAC not applicable —•HVAC operational —•HVAC fails	Given an agent leak, the status of the HVAC and filtering is important.
Has there been an MHS initiator? —•No MHS initiator —•MHS initiator	This is a wrap-up question used for bookkeeping in successive questions to ensure that initiator frequencies are handled appropriately.

Logic Table LT-9. Agent Collection System Initiator Logic in the Accident Progression Event Tree

Branch Point Question	Description of Question and Answers
Was there an initiator prior to the ACS? —•No initiator prior to the ACS —•ACS prior initiator	Used as bookkeeping in the event tree to ensure that frequencies are handled correctly and initiators do not occur together.
Was there an ACS initiator? —•No ACS initiator —•ACS 1 —•Etc.	ACS initiators are leaks in different locations due to human errors or piping failures.
What was the result of the ACS initiator? —•No outcome —•Small piping spill —•TOX spill —•Large piping spill	All of the outcomes involve spills. The spills may be large or small spills associated with piping, or the TOX tank inventory itself may be involved.
Where was the impact of the ACS initiator? —•No location —•MPB impacted from ACS initiator —•UMC impacted from ACS initiator —•TOX impacted from ACS initiator —•LMC impacted from ACS initiator —•LIC impacted from ACS initiator	All locations containing ACS agent piping are considered. Leaks at the drain stations are considered as part of the processing lines.
Was the HVAC operational for the ACS event? —•HVAC not applicable —•HVAC operational —•HVAC fails	Given an agent leak, the status of the HVAC and filtering is important.
Has there been a ACS initiator? —•No ACS initiator —•ACS initiator	This is a wrap-up question used for bookkeeping in successive questions to ensure that initiator frequencies are handled appropriately.

Logic Table LT-10. Liquid Incinerator Initiator Logic in the Accident Progression Event Tree

Branch Point Question	Description of Question and Answers
Was there an initiator prior to the LIC? —•No initiator prior to the LIC —•LIC prior initiator	Used as bookkeeping in the event tree to ensure that frequencies are handled correctly and initiators do not occur together.
Was there a LIC initiator? —•No LIC initiator —•LIC 1 —•Etc.	LIC initiators cover the possibility of furnace explosion or upsets that lead to agent releases through or from the incinerator.
What was the result of the LIC initiator? —•No outcome —•LIC agent release —•LIC explosion	Agent may be released due to a furnace upset or an explosion may result in a release.
Where was the impact of the LIC initiator? —•No location —•LIC room —•LIC furnace	The agent release may be associated with the room or the furnace.
Was there an integrity breach caused by the LIC? —•No breach —•LIC wall breach	If there is an explosion, it is necessary to consider whether the structure (the LIC room) would be breached, leading to the potential for a release out of engineering controls.
Was the HVAC operational for the LIC event? —•HVAC not applicable —•HVAC operational —•HVAC fails	Given an agent leak or explosion, the status of the HVAC and filtering is important.
Has there been a LIC initiator? —•No LIC initiator —•LIC initiator	This is a wrap-up question used for bookkeeping in successive questions to ensure that initiator frequencies are handled appropriately.

Logic Table LT-11. Deactivation Furnace System Initiator Logic in the Accident Progression Event Tree

Branch Point Question	Description of Question and Answers
Was there an initiator prior to the DFS? —•No initiator prior to the DFS —•DFS prior initiator	Used as bookkeeping in the event tree to ensure that frequencies are handled correctly and initiators do not occur together.
Was there a DFS rocket initiator? —•No DFS initiator —•DFS rocket 1	DFS initiators cover the possibility of a furnace explosion or upsets that lead to agent releases through or from the incinerator.
Was there a DFS projectile initiator? —•No DFS initiator —•DFS projectile 1 —•Etc.	The DFS logic for projectile energetics does not include agent-related initiators, unlike the logic for rockets in the DFS.
Was there a DFS mine initiator? —•No DFS initiator —•DFS mine 1 —•Etc.	The DFS mine initiators are similar to those for rockets.
What was the result of the DFS initiator? —•No outcome —•DFS energetics explosion —•DFS natural gas explosion —•DFS furnace release —•DFS pollution abatement system (PAS) release	Agent may be released due to a furnace initiator or an explosion may result in a release. Explosions consider natural gas. There also is a possibility that a release could occur through the PAS.
Was there an integrity breach caused by the DFS initiator? —•No breach —•DFS ceiling breach —•DFS seal breach —•DFS door open	If there is an explosion, it is necessary to consider whether the structure (the DFS room) would be breached, leading to the potential for a release out of engineering controls.
Was the HVAC operational for the DFS event? —•HVAC not applicable —•HVAC operational —•HVAC fails	Given an agent leak or explosion, the status of the HVAC and filtering is important.
Has there been a DFS initiator? —•No DFS initiator —•DFS initiator	This is a wrap-up question used for bookkeeping in successive questions to ensure that initiator frequencies are handled appropriately.

Logic Table LT-12. Toxic Maintenance Area Initiator Logic in the Accident Progression Event Tree

Branch Point Question	Description of Question and Answers
Was there an initiator prior to the TMA? —•No initiator prior to the TMA —•TMA prior initiator	Used as bookkeeping in the event tree to ensure that frequencies are handled correctly and initiators do not occur together.
Has the TMA been activated? —•No TMA activation —•TMA activated	Some other initiators in the POD can lead to the use of the TMA. For example, an event that causes a leak contained in the EONC will lead to the use of the TMA to open the EONC.
Was there a (munition) TMA initiator? —•No TMA initiator —•TMA 1 —•Etc.	Because the consequences of initiators are dependent on the munition involved, separate questions are maintained for each munition type. TMA initiators include handling upsets as items are unloaded and decontaminated, gate closures and gate drops, and misdirection of a pallet to a furnace.
What was the result of the TMA initiator? —•No outcome —•Leak from TMA —•Explosion from TMA —•Leak in EONC from TMA —•Leak out of EONC from TMA —•Explosion in EONC from TMA —•BLEVE from TMA —•Furnace munition explosion from TMA —•Furnace munition rupture from TMA	The TMA events are associated with EONC handling as well as handling of pallets and munitions. Explosions and leaks are possible, depending on the munition. The BLEVE, furnace explosion, and furnace rupture outcomes refer to a potential outcome of putting unprocessed munitions in the MPF.
How many munitions were involved? —•No outcome —•Pallet from TMA —•EONC tray from TMA —•Processing tray of munitions	Depending on the initiator, different numbers of munitions might be involved.
Was there propagation in the TMA? —•No propagation —•TMA propagation	Rocket explosions during the TMA leaker handling process could propagate to other rockets.
What was the result of the TMA propagation? —•No TMA propagation outcome —•TMA propagation leads to leak —•TMA propagation leads to explosion	If propagation occurs, either explosion or leak of other rockets can occur.
Was there a TMA fire? —•No TMA fire —•TMA fire	Because of the other materials stored in the TMA, there is the possibility that an initiating event could cause a fire.

Logic Table LT-12. Toxic Maintenance Area Initiator Logic in the Accident Progression Event Tree (Continued)

Branch Point Question	Description of Question and Answers
Where was the location of the TMA initiator's impact? —•No location —•CHB impacted from TMA initiator —•LMC impacted from TMA initiator —•BSA impacted from TMA initiator —•MPB impacted from TMA initiator —•UMC impacted from TMA initiator —•ECV impacted from TMA initiator —•MPF impacted from TMA initiator —•TMA impacted from TMA initiator	The TMA portion of the APET logic includes moving munitions backward through the facility so that they can be entered into the process in the ECV. The initiators could then occur at many different locations, which are called out in the logic.
Was there an integrity breach caused by the TMA? —•No breach —•Agent floor migration —•Internal breach from TMA —•External breach from TMA	The greatest concern is the potential for an explosion that would cause a loss of room integrity and would likely cause an external breach. For events that are manifested in other areas, floor migration also is possible.
Was the HVAC operational for the TMA event? —•HVAC not applicable —•HVAC operational —•HVAC fails	Given an agent leak, the status of the HVAC and filtering is important.
Has there been a TMA initiator? —•No TMA initiator —•TMA initiator	This is a wrap-up question used for bookkeeping in successive questions to ensure that initiator frequencies are handled appropriately.

Logic Table LT-13. Metal Parts Furnace Initiator Logic in the Accident Progression Event Tree

Branch Point Question	Description of Question and Answers
Was there an initiator prior to the MPF? —•No initiator prior to the MPF —•MPF prior initiator	Used as bookkeeping in the event tree to ensure that frequencies are handled correctly and initiators do not occur together.
Was there a (munition) MPF initiator? —•No MPF initiator —•MPF munition 1 —•Etc.	MPF initiators include furnace upsets that lead to agent vapor releases to the room or through the PAS, as well as explosions of natural gas or agent vapor. Although the events are similar, MPF initiators are developed for each type of munition that undergoes MPF processing.
Was there an inadvertent drain initiator in the MPF? —•Not applicable —•MPF undrained initiator 1 —•MPF undrained initiator 2, etc.	There is the possibility that items going to the MPF could be inadvertently undrained. These cases are considered separately due to the different agent inventory involved.
What there an intentionally undrained MPF initiator? —•Not applicable —•MPF intentional undrained initiator 1 —•MPF intentional undrained initiator 2, etc.	Some items may be processed with greater than a 5 percent heel due to known problems with draining. These items could be subject to further MPF initiators that are captured in this question.
What was the result of the MPF initiator? —•No result —•MPF AV explosion —•MPF furnace room release —•MPF furnace room NG explosion —•MPF furnace NG explosion —•MPF PAS release —•MPF boil off —•MPF afterburner NG explosion —•MPF airlock spill	There are many outcomes defined for MPF initiators that describe the location and type of event. Events could occur in the airlock, room, furnace, or afterburner. The event might involve agent vapor explosions or natural gas explosions. A furnace upset might also cause a release to and through the PAS/PFS. The outcome called *boil off* refers to removing an item inadvertently from the furnace with agent still in it (requires failure of exit airlock monitoring).
How many items were involved? —•None —•Single munition involved in MPF —•Row of munitions involved in MPF —•Processing tray involved in MPF	The MPF events may involve a processing tray that has just entered the airlock or furnace. Other events that might involve failure to process a row or tray of projectiles at the drain station are also considered.
Was the processed item drained? —•Not applicable —•MPF drained —•MPF not drained	The estimation of the potential source term requires the drain status to be specified for each type of initiator.
Was there an integrity breach caused by the MPF initiator? —•No breach —•MPF external breach	If there is an explosion, it is necessary to consider whether the MPF would withstand the event. The room has composite panel walls to the exterior, so any breach would be an external breach.
Was the HVAC operational for the MPF event? —•HVAC not applicable —•HVAC operational —•HVAC fails	Given an agent leak, the status of the HVAC and filtering is important.
Has there been an MPF initiator? —•No MPF initiator —•MPF initiator	This is a wrap-up question used for bookkeeping in successive questions to ensure that initiator frequencies are handled appropriately.

Logic Table LT-14. Heating, Ventilation, and Air Conditioning Initiator Logic in the Accident Progression Event Tree

Branch Point Question	**Description of Question and Answers**
Was there an initiator prior to HVAC? —•No initiator prior to the HVAC —•HVAC prior initiator	Used as bookkeeping in the event tree to ensure that frequencies are handled correctly and initiators do not occur together.
Was there an HVAC initiator? —•No HVAC initiator —•HVAC 1 —•Etc.	HVAC initiators cover the possibility of system shutdown as well as upsets that lead to agent migration. These events are initiators, i.e., the first thing to happen. Other HVAC questions in the tree refer to the availability of HVAC after another initiator has already occurred. One initiator identifies the possibility of filter fire.
What agent was present on the filters? —•No agent on filters —•GB on filters —•VX on filters —•HD on filters	Some initiators occurring during changeover require additional classification for the type of agent present on the filters.

Logic Table LT-15. Secondary Waste Initiator Logic in the Accident Progression Event Tree

Branch Point Question	**Description of Question and Answers**
Was there an initiator prior to secondary waste? —•No initiator prior to secondary waste —•Secondary waste prior initiator	Used as bookkeeping in the event tree to ensure that frequencies are handled correctly and initiators do not occur together.
Was there a secondary waste initiator? —•No secondary waste initiator —•Secondary waste initiator	Secondary waste initiators occur during removal, transportation, and storage of carbon filter media.
Did the filter media transport initiator lead to a fire? —•No filter media transport fire —•Filter media transport fire	Agent release from filter media can only be caused by heating or burning, so it is important to consider the possibility of fire.
What agent was present on the spent HVAC filter media? —•No agent on filter media —•GB on filter media —•VX on filter media —•HD on filter media	To determine source terms, the type of agent on the spent HVAC filter media must be specified.
Has there been a secondary waste initiator? —•No secondary waste initiator —•Secondary waste initiator	This is a wrap-up question used for bookkeeping in successive questions to ensure that initiator frequencies are handled appropriately.

Logic Table LT-16. Seismic Initiator Logic in the Accident Progression Event Tree

Branch Point Question	Description of Question and Answers
Was there a seismic event? —•No seismic event —•Level 1 —•Level 2 —•Etc.	Earthquakes are considered as a function of ground motion. While there is a continuous curve of ground motion versus frequency, the curve is divided into 12 discrete levels to account for different size earthquakes.
Name some seismic parameters. —•No seismic event —•Seismic event	The APET for seismic events is different because the probability of equipment failure is related to the size of the earthquake. Whereas most probabilities in the APET are discrete values, seismic analysis requires comparison of curves, describing earthquake strength to probability of system failures. That comparison is done within the Quantus code using event tree parameters. This question establishes the parameters. For important structures and equipment, seismic fragility curves are input.
Was an ACAMS bottle improperly secured? —•No unsecured ACAMS —•Unsecured ACAMS	In an earthquake, one major concern is the possibility of hydrogen leaks and explosions due to relative motions of the ACAMS and the connected hydrogen bottles. If one or more items are unsecured, a hydrogen leak could occur.
Did an improperly secured ACAMS bottle fall? —•Seismic ACAMS fall —•Seismic ACAMS OK	If an ACAMS hydrogen bottle is improperly secured, it can fall as determined by the seismic fragility analysis.
What was the outcome of the hydrogen bottle fall? —•No outcome —•Hydrogen fire —•Hydrogen explosion	The hydrogen leak will cause either a fire or an explosion (deflagration) depending on the size of the leak and the availability of ignition sources.
Does the hydrogen event propagate to agent sources? —•No propagation —•Propagation from hydrogen event	Fires and explosions have the possibility of causing additional agent involvement due to propagation.
What was the propagation result from seismic ACAMS? —•No propagation —•LIC agent line involvement —•TMA fire	Two locations were selected as representative of possible agent involvement: the LIC room and the TMA.
Was the furnace exhaust damaged? —•Furnace exhaust damaged —•Furnace exhaust OK	If the furnace exhaust ducts are damaged during an earthquake, a fire could result.
What was the result of the furnace exhaust damage? —•No furnace exhaust result —•Furnace exhaust global fire —•Furnace exhaust local piping fire	A fire resulting from damage to the furnace exhaust ducts could be contained locally or could spread throughout the facility.

Logic Table LT-16. Seismic Initiator Logic in the Accident Progression Event Tree (Continued)

Branch Point Question	Description of Question and Answers
Did the surrogate event happen? —•Surrogate event —•No surrogate event	In seismic analysis, it is not possible to fully analyze every item. Part of the methodology is to define an upper earthquake level where the entire structure is assumed to fail (the surrogate event). This allows completeness without expending unnecessary resources studying very large earthquakes.
What was the surrogate event result? —•No result —•Global fire —•Local BSA fire —•Local piping fire	The risk is determined by agent involvement. The surrogate event could result in near complete destruction and fire, or it could cause localized effects, as indicated by the outcomes selected for this question. The localized fires were modeled for two worst-case, small-scale fires.
Did the CHB fail? —•CHB fails —•CHB holds	Individual structures are studied to determine if they would fail in the earthquake. This question considered the CHB.
Did the CHB/UPA fail? —•CHB/UPA fails —•CHB/UPA holds	The CHB/UPA elevated area is potentially subject to earthquake-induced failure and must be considered because of the relatively large amount of agent that could be there.
What was the result of the CHB/UPA failure? —•No result —•CHB/UPA fire —•CHB/UPA spill	Given that the CHB/UPA fails, some fires would be likely for burstered items and other items would spill. The releases would be increased if there were a post-collapse fire.
Was there a seismic scissor lift drop? —•Seismic scissor lift drop —•No seismic scissor lift drop	The scissor lift, in the extended mode, could be subject to seismic failure.
What was the result of the scissor lift drop? —•No result —•Scissor lift drop explosion —•Scissor lift drop leak	Consideration of outcomes, as with other events.
How many items were involved in the scissor lift drop? —•No result —•EONC tray	Specification of the amount of agent involved.
Did the switchyard fail? —•Switchyard failure —•No switchyard failure	Electric power is an important post-earthquake system, especially for HVAC. This question examines physical effects on the switchyard and incoming power lines.
Did the diesel day tanks fail? —•Diesel day tank failure —•No diesel day tank failure	The day tank tends to be the limiting component on diesel system from a seismic standpoint.
Did the diesels start? —•Diesel fails to start —•Diesels OK	The reliability of diesel is such that even without earthquake failure, there is a chance that the units could fail.

Logic Table LT-16. Seismic Initiator Logic in the Accident Progression Event Tree (Continued)

Branch Point Question	Description of Question and Answers
Did the HVAC fail? —•No seismic HVAC failure —•Seismic HVAC failure	Failure of HVAC due to an earthquake can affect the extent of the release.
Was there a breach from the seismic initiator? —•Seismic breach —•No seismic breach	This question just established the condition of the building when examining the resultant release.

Logic Table LT-17. Tornado Initiator Logic in the Accident Progression Event Tree

Branch Point Question	Description of Question and Answers
Was there a pre-tornado initiator? —•No pre-tornado initiator —•Pre-tornado initiator	Used as bookkeeping in the event tree to ensure that frequencies are handled correctly and initiators do not occur together.
Has there been a tornado initiator? —•No tornado —•F3 tornado —•F4 tornado —•F5 tornado	Tornadoes are classified according to an accepted scale of wind speed and damage potential. The F3 through F5 categories, which have different frequencies, could damage the facility. Subsequent questions will have answers dependent on the category of tornado described here.
Does the tornado cause catastrophic MDB damage? —•No catastrophic damage —•Catastrophic MDB damage	The largest tornadoes have the capability of causing catastrophic damage to the entire site including the MDB. While total MDB collapse is not likely, exterior walls could be removed, gas lines could fail, and most equipment could be damaged.
Does the catastrophic event result in fire? —•No MDB-wide fire —•MDB-wide fire	The involvement of agent sources could be either evaporative or due to fire. The wide spectrum of possible scenarios is covered by two extremes here, one involving fire and one without fire.
Are the UPA walls removed by the tornado? —•No UPA wall removal —•UPA wall removal	If the building does not suffer catastrophic damage, the composite panel walls can still be affected by the high winds, the greatest concern in the UPA.
Are munitions pulled out of the UPA? —•No munitions pulled out of UPA —•Munitions pulled out of UPA	It is possible to loft some munitions in very large tornadoes.
What was the result of munitions pulled from the UPA? —•No result —•Explosion outside —•Leak outside	Depending on the munition types present in the UPA, different outcomes are possible when items are pulled from the UPA in a tornado. Only rockets, mines, and projectiles can be lofted in a tornado.
Did a tornado-generated missile strike munitions in the UPA? —•No missile strike —•Tornado missile strike causes leak —•Tornado missile strike causes explosion	Given that the walls may be torn off, a missile could cause direct damage.
Was there a CHB collapse? —•No tornado CHB collapse —•CHB collapse from tornado	Although the CHB could collapse, the EONCs would protect munitions. This event was included for completeness.
Where was the impact of the tornado? —•Tornado fails CHB —•Tornado fails UPA —•Tornado fails MDB —•Tornado impact outside	The location of the damage is important to specification of the release.

Logic Table LT-17. Tornado Initiator Logic in the Accident Progression Event Tree (Continued)

Branch Point Question	Description of Question and Answers
How many munitions were involved in the tornado event? —•No munitions —•Single munition —•Two munitions —•Pallet of munitions —•Multiple pallets —•CHB inventory —•UPA inventory —•Mine drum —•MDB inventory	The agent release outcomes range from single munitions to the entire MDB.
Was there an external breach? —•No tornado breach —•Tornado external breach —•Breach not applicable	The building status is important to the release calculation.
Did the tornado fail HVAC? —•HVAC OK —•HVAC fails	The HVAC question is asked to determine if there is any mitigation of associated releases.

Logic Table LT-18. Lightning Initiator Logic in the Accident Progression Event Tree

Branch Point Question	**Description of Question and Answers**
Was there a pre-lightning initiator? —•No pre-lightning initiator —•Pre-lightning initiator	Used as bookkeeping in the event tree to ensure that frequencies are handled correctly and initiators do not occur together.
Has there been a lightning strike? —•No lightning strike —•Lightning strike	This is the initiator, a lightning strike to the UPA, where rockets are out of EONCs.
Was the lightning strike extreme? —•Not applicable —•Nominal strike —•Extreme strike	The possibility of arcing is dependent on the energy. Two cases were considered, nominal (99%) and extreme (1%).
Did the lightning protection system (LPS) work? —•LPS works —•LPS fails —•LPS not applicable	The LPS can fail either as a result of problems with the system or wiring or due to some characteristics of the lightning.
What was the result of the lightning strike? —•No result —•Lighting rocket ignition	This study is only interested in agent release outcomes, which for this phenomena are limited to munition ignitions or explosions (for M55 rockets only).
Did the lightning event propagate? —•No propagation —•Pallet leak from lightning propagation —•Pallet explosion from lightning propagation	Ignition of a rocket in the UPA can lead to leaks or explosions of other rockets.
Was there an external breach? —•No lightning breach —•Lightning breach	The location of the outcome is tracked here to ensure proper source term evaluation.

Logic Table LT-19. Aircraft Initiator Logic in the Accident Progression Event Tree

Branch Point Question	Description of Question and Answers
Was there a pre-aircraft initiator? —•No pre-aircraft initiator —•Pre-aircraft initiator	Used as bookkeeping in the event tree to ensure that frequencies are handled correctly and initiators do not occur together.
Has there been an aircraft crash? —•No aircraft crash (AC) —•Lg AC CHB —•Md AC CHB —•Sm AC CHB —•Lg AC MDB —•Md AC MDB —•Sm AC MDB —•Lg AC HVAC —•Md AC HVAC —•Sm AC HVAC —•Lg AC filter igloo —•Md AC filter igloo	To assess damage, it is necessary to know the size of the aircraft (large, medium, or small). In addition, the aircraft could hit different structures, including the CHB, MDB, filter banks, or the agent carbon storage igloos.
Which filter igloo was hit by an aircraft? —•Not applicable —•GB filter igloo —•VX filter igloo —•HD filter igloo	The last two answers in the previous question identify the possibility that a filter storage igloo could be hit. This question determines which agent is involved.
Was there a fire from the crash? —•No fire from crash —•Fire from crash	The amount and mode of agent release is dependent on whether or not the crash involves a fire.
Did the HVAC function? —•HVAC OK —•HVAC fails	The HVAC question is asked for impacts into the CHB, because flow could be re-established.

Logic Table LT-20. Wildfire Initiator Logic in the Accident Progression Event Tree

Branch Point Question	Description of Question and Answers
Was there a pre-wildfire initiator? —•No pre-wildfire initiator —•Pre-wildfire initiator	Used as bookkeeping in the event tree to ensure that frequencies are handled correctly and initiators do not occur together.
Has there been a wildfire initiator within 3 miles? —•No wildfire initiator —•Wildfire within 3 miles	If a wildfire comes within 3 miles of the CDF, the HVAC may need to be shut down to prevent smoke from being drawn into the building. Agent migration within the CDF due to HVAC shutdown is the only sequence included for wildfires, and it only has the potential to impact workers.

Logic Table LT-21. Fire Initiator Logic in the Accident Progression Event Tree

Branch Point Question	Description of Question and Answers
Was there a pre-fire initiator? —•No pre-fire initiator —•Pre-fire initiator	Used as bookkeeping in the event tree to ensure that frequencies are handled correctly and initiators do not occur together.
Has there been a fire initiator? —•No fire initiator —•UPA fire —•TOX fire —•UMC fire —•MPB fire —•First-floor fire —•Second-floor fire —•Facility-wide fire —•Room fire (nonagent)	Although fires could be initiated in many areas, a set of fires that covers the types of fires and agent involvement was included in the APET. These include a facility-wide fire, as well as floor fires and room fires. All room fires that occur in rooms without agent were combined into one initiator. Although agent would not be directly involved in the nonagent room fire, the possibility exists for release of agent from the filters.
Was agent present in the area during the fire? —•No agent present during fire —•Agent present during fire	Agent may not be present in some rooms at some times. For example, no potential for agent involvement would exist in the MPB during mine processing. This question is used to determine, by campaign, whether agent would be present in certain parts of the facility.
Were the TOX and other areas involved in the fire? —•No TOX plus other area involvement —•TOX plus other area involvement	Even if munitions were present in a room during a fire, the fire could be small enough that the munitions would not become involved. This question and the next three are used to determine the level of agent involvement. This question represents the highest level of agent involvement—the TOX plus the three subsequent levels of munitions.
Were undrained munitions in suppression plus other areas involved in the fire? —•No undrained suppression in fire —•Undrained suppression in fire	This question models involvement of undrained munitions in an area of the facility with fire suppression, plus the two subsequent levels of munitions.
Were undrained munitions without suppression plus other areas involved in the fire? —•No undrained no suppression in fire —•Undrained no suppression in fire	This question models involvement of undrained munitions in areas of the facility without fire suppression, plus the level of munitions in the next question.
Were drained munitions involved in the fire? —•No drained munitions in fire —•Drained munitions in fire	This question models involvement of drained munitions.
Was any agent involved in the fire? —•No agent in fire —•Agent involved in fire	This bookkeeping question wraps up the answers to the previous four questions, and is used for ease of event tree maintenance.
Are the filters isolated from the heat of the fire? —•Fire isolation N/A —•Fire isolated —•Fire not isolated	Fire isolation greatly affects the probability of filter involvement.

Logic Table LT-21. Fire Initiator Logic in the Accident Progression Event Tree (Continued)

Branch Point Question	Description of Question and Answers
Are the HVAC exhaust fans running during the fire? —•HVAC exhaust fans running —•HVAC exhaust fans not running	The status of the HVAC fans impacts the type of filter involvement, if any, in a fire.
What is the energy level of the exhaust to filters? —•Fire heat N/A —•Fire too cool to heat filters —•Fire passes 4.5 MW to filters —•Fire passes 6 MW to filters —•Fire passes 7.5 MW to filters —•Fire passes 9 MW to filters —•Fire passes 12 MW to filters	A fire may not be hot enough to cause filter involvement. The large fires (floor- and facility-wide) and room fires have different probabilities of passing elevated temperature levels to the filters.
What intensity was the filter fire? —•No filter involvement from fire —•Well-ventilated filter fire —•Under-ventilated filter fire —•Filter desorption	The type of filter release mode builds upon the level of heat passed to the filters in the previous question. Depending on the availability of the HVAC exhaust fans, different release modes exist for agent on the HVAC filters.
Was the building breached by fire? —•No fire building breach —•Building breach from fire	The release is dependent on whether the fire causes a breach of the MDB to the outside. Filter involvement in the fire is modeled as a building breach because the filters would not be providing a means of preventing agent release from the building.

Logic Table LT-22. Hydrogen Explosion Logic in the Accident Progression Event Tree

Branch Point Question	Description of Question and Answers
Was there a pre-hydrogen initiator? —•No pre-hydrogen initiator —•Pre-hydrogen initiator	Used as bookkeeping in the event tree to ensure that frequencies are handled correctly and initiators do not occur together.
Was there a hydrogen explosion? —•No hydrogen explosion —•H2EXPMR123	A hydrogen explosion in only one room is modeled.
What was the result of the hydrogen explosion? —•No hydrogen explosion result —•HVAC loss from hydrogen explosion	If a hydrogen explosion occurs, the outcome is modeled as a loss of HVAC, which is primarily a worker exposure scenario.

Logic Table LT-23. Internal Event Accident Sequence Description for Source Terms

Accident Sequence Descriptors and Characteristics	Description of Accident Sequence Descriptors
Release? —•No release —•Burster explosion without fire —•Burster explosion with fire —•Spill —•Fire —•*Over 25 other principal release modes*	This categorizes accidents by the key element of the source term. The definition of the characteristics needed is developed in the source term analysis described in section 10. There are over 30 primary release modes.
Propagation release? —•No propagation release —•Fuze/burster explosion —•Igloo propagation —•Spill —•*Fire release modes*	This is used to categorize events where the initial release has been followed by propagation to other significant agent sources.
Agent? —•No agent —•GB —•VX —•HD	Categorizes all accident sequences by the type of agent involved. This is obviously needed for determination of the source term.
Munition? —•No munition —•Rocket —•8-inch projectile —•*All other munitions*	Categorizes all accident sequences by the type of munition involved.
Location? —•No location —•Igloo 80ft —•Apron —•Transport —•CHB —•*Other locations in the facility*	This determines where the initial accident occurs so that the appropriate agent inventories can be considered.
Amount? —•None —•Single munition —•Munition pallet —•Transportation (EONC) tray —•Processing tray —•*Other categories defining agent involved*	This accident characteristic determines what amounts of agent are involved. There are over a dozen categories that determine the amount of agent involved in the accident.
Drain Status? —•Not applicable —•Drained —•Undrained	The involvement of munitions or bulk items does not explicitly determine the potential amount of agent involved. The drain status needs to be defined also. This is based on where the item was in processing when the incident occurred.

Logic Table LT-23. Internal Event Accident Sequence Description for Source Terms (Continued)

Accident Sequence Descriptors and Characteristics	Description of Accident Sequence Descriptors
Propagation Amount? —•None —•Single munition —•Munition pallet —•Igloo, 100 percent full —•Igloo, 75 percent full —•*Other categories defining agent involved in propagation*	Accident propagation also is critical to specification of the total agent source term. The different types of propagation scenarios are identified here. The most significant propagation to a rocket igloo has been subdivided to consider how much inventory remained in the igloo if an accident occurred during unloading.
HVAC? —•Not applicable —•HVAC on —•HVAC off	HVAC status is used to determine how much agent involved in the facility could possibly get out of the facility.
Breach? —•No breach —•External breach —•Internal breach —•Floor breach —•Not applicable	As with the previous question, the status of the building is used to calculate how much agent gets out of the building.
Furnace Damage? —•Not applicable —•Furnace OK —•Furnace damage	For accidents involving furnaces, the unique characteristics affecting the release require knowledge of the status of the furnace.
Mode? —•Not applicable —•Handling —•Spontaneous filter smolder —•Filter blaze —•Filter smolder —•Medium —•*Fire levels of involvement*	Filter fires and igloo fires due to handling accidents require special consideration for source term analysis.
# Primary Workers Affected? —•None —•High —•Low	For each location, there is a consideration of the variability in the number of workers that might be in the area. Two categories are defined: high and low. The worker risk calculations for close-in effects assign values to these outcomes.
# Secondary Workers Affected? —•None —•High —•Low	Workers in locations other than the specific location where the incident occurred could still be impacted by close-in effects.
Campaign Type? —•Single —•Co-processing —•Complementary processing	If munitions are co-processed, the plant state is designated here for use in the close-in worker analysis.

Logic Table LT-23. Internal Event Accident Sequence Description for Source Terms (Continued)

Accident Sequence Descriptors and Characteristics	Description of Accident Sequence Descriptors
Special Worker Characteristics? —•No special characteristics —•DPE entry —•Maintenance —•DFS chute jam	Some events could not be fully categorized for worker risks by the existing accident descriptions. A set of special cases was called out so that the proper calculation could be performed.
Day/Night? —•Anytime —•Day-only	There is a significant difference in weather conditions between day and night. Weather is critical to the dispersion analysis, which determines offsite consequences. Some activities, such as igloo unloading, only occur during the day and must therefore be appropriately categorized for an accurate risk estimate.
Population? —•Facility accident —•Storage yard accident	The dispersion analysis code CHEMMACCS needs to know which population grid to use. This information is passed through the source term by including it directly in the source term sequence description.
Campaign? —•Not applicable —•GB Rockets (1) —•*All other munition campaigns and changeovers*	This is used to track munition and filter inventories in calculations.
Worker Release? —•No release —•Burster explosion without fire —•Burster explosion with fire —•Spill —•Fire —•*Over 25 other principal release modes*	This categorizes worker accidents by the key element of the source term. Because some of the logic for the worker releases differs from that for the source term releases in the first accident sequence descriptor, a separate descriptor was established.
Worker Location? —•No location —•Storage yard – Igloo —•Storage yard – Apron —•Storage yard – Road —•Transport —•*Other locations in the facility*	This determines where the initial accident occurs so that the appropriate worker populations can be considered. Some of the worker locations differ from the locations used in the source term (descriptor #5).

Logic Table LT-24. External Event Accident Sequence Description for Source Terms

Accident Sequence Descriptors and Characteristics	Description of Accident Sequence Descriptors
Release? —•No release —•Explosion with fire —•Explosion with spill —•Fire —•Aircraft filter fire in igloo —•Filter fire at MDB —•Seismic event —•Hydrogen —•Seismic ACAMS explosion —•Seismic surrogate —•Lightning explosion —•Tornado explosion —•Tornado spill —•HVAC agent migration —•MDB filter impact without fire	This categorizes accidents by the key type of accident involved. This characteristic is combined with others to determine the source term. The definition of the characteristics needed is developed in the source term analysis described in section 10.
CHB collapse? —•None —•Collapse/spill —•Collapse/fire	The seismic events must be broken out to determine the agent-related impact. All munition types except for spray tanks would be protected inside EONCs.
CHB/UPA Collapse? —•None —•Collapse/fire —•Collapse/spill —•Drop/explode —•Drop/spill	The type of damage associated with a collapse of the CHB/UPA is considered here. The "drop" events model munition drops from the scissor lift during an earthquake.
Forklift drop? —•None —•Drop/explode —•Drop/spill	In an earthquake a forklift accident could occur, and this distinguished the types of outcomes.
Mode? —•No mode —•Tornado —•Small aircraft —•*About 15 other types of accident initiators*	The source terms are developed by the type of initiator involved, so this separates out all the accident modes, from tornadoes through fire and lightning. It somewhat duplicates the result dimension, but not completely.
Agent? —•No agent —•GB —•VX —•HD	Categorizes all accident sequences by the type of agent involved.

Logic Table LT-24. External Event Accident Sequence Description for Source Terms (Continued)

Accident Sequence Descriptors and Characteristics	Description of Accident Sequence Descriptors
Munition? —•No munition —•Rocket —•155mm projectile —•*All other munitions*	Categorizes all accident sequences by the type of munition involved.
Location? —•No location —•CHB —•UPA —•MDB —•*Other locations in the facility and storage yard*	Determine where the initial accident occurs so that the appropriate agent inventories can be considered.
Quantity? —•None —•Single munition —•Row of munitions —•Munition pallet —•Processing tray —•*Other categories defining agent involved*	This accident characteristic determines what amount of agent is involved. There are over a dozen categories that determine the amount of agent involved in the accident.
Filter Energy Level? —•Not applicable —•Flow045MW —•Flow060MW —•Flow075MW —•Flow090MW —•Flow120MW —•*Other energy levels for stagnant air flow*	For filter desorption models, the level of heat passed from a fire to the filters affects the source term. All temperature levels reflect degrees Fahrenheit.
Drain Status? —•Not applicable —•Drained —•Undrained	The involvement of munitions or bulk items does not explicitly determine the potential amount of agent involved. The drain status needs to be defined also. This is based on where the item was in processing when the incident occurred.
HVAC? —•Not applicable —•HVAC on —•HVAC off	HVAC status is necessary for the calculation of source term released from the facility.
Breach? —•No breach —•External breach —•Not applicable	Building integrity helps determine what agent could be released from the building.

Logic Table LT-24. External Event Accident Sequence Description for Source Terms (Continued)

Accident Sequence Descriptors and Characteristics	Description of Accident Sequence Descriptors
Day/Night? —•Anytime —•Day-only —•Seismic	There is a significant difference in weather conditions between day and night. Weather is critical to the dispersion analysis, which determines offsite consequences. Seismic events can, of course, occur anytime, but they are categorized separately for CHEMMACCS because evacuation routes may be affected.
Population? —•Facility accident —•Storage yard accident	The dispersion analysis code CHEMMACCS needs to know which population grid to use. This information is passed through the source term by including it directly in the source term sequence description.
Aleatory Uncertainty Level? —•Not applicable —•Medium	This descriptor was created to model aleatory uncertainty for munition inventory levels associated with some events. Currently, all sequences requiring this input are modeled at Medium level.
Campaign? —•Not applicable —•GB rockets (1) —•*All other munition campaigns and changeovers*	This is used to track the munition and filter inventories to be used in calculations.

SECTION 7
DATA ANALYSIS

This section addresses the efforts conducted to fulfill the UMCDF QRA's need for statistical information on CDF equipment performance to permit the quantitative evaluation of the risk models. Sections 7.1 through 7.7 provide a detailed discussion of the data sources used, the analysis performed, and the data selections made to produce a thorough component reliability database for the equipment and failure modes (FMs) modeled in the UMCDF QRA. Section 7.8 discusses the development of estimates of selected CDF component unavailability due to preventive maintenance (PM). In section 7.9, calculations of the probability of degraded munitions for use in the assessment of munition fragility are presented. The estimation of the ratio of welded to unwelded projectile burster wells (for use in the BLEVE initiator estimates) is described in section 7.10, while section 7.11 addresses the analysis of forklift incident data. Section 7.12 points the reader to data-related analyses in other sections of the UMCDF QRA report.

7.1 Introduction

Historical information on serious accidents is rare, but the need exists to understand not only those incidents that have already occurred, but also those that could conceivably occur in the future. For these reasons, the risk models of a QRA are developed to evaluate the interactions between hardware, software, and human failures that can lead to undesirable consequences. However, to resolve the models such that these failure combinations can be ranked according to their likelihood of occurrence, some measure of probability is needed at the individual element failure level. Data analysis therefore is performed to obtain these likelihoods of failure, and the uncertainty surrounding these estimates, for input to the QRA fault tree models. Human error rates for the risk models were developed through the Human Reliability Analysis, as discussed in section 8.

7.1.1 General Overview. The data analysts were provided early on with Basic Event (BE) lists from the UMCDF QRA CAFTA fault tree models. These lists provided the component Type Codes (TCs) and FMs (the data identification fields in CAFTA) included in the QRA models, and therefore indicated the specific items for which component level data were needed, in terms of requirements placed upon the QRA database by the QRA models.

Other database requirements were established in initial meetings between the data analysts and the QRA modeling team. Specifically, it was decided that CDF-specific data would be developed not only in terms of time-related failure rates, but also as demand failure probabilities.

This meant that in addition to population and exposure time data, demand data had to be collected at the component level and assembled at the TC level.

SAIC has refined, over many years of experience across a variety of industries, a specific process for the development of QRA project databases, as shown in figure 7-1. As this figure demonstrates, it is unusual to find sufficient historical information contained in a single source or repository of data to meet all the data needs of a QRA, nor is it preferable to do so. Not surprisingly, then, the data analysis took advantage of a variety of sources to obtain the necessary data for the UMCDF QRA. In fact, this data effort was unique in that data were often available from several sources, namely JACADS and TOCDF facility maintenance reports/records or published industry data, to address a single given data need. Applicable and appropriate data were compared, selected, integrated, and aggregated using a set of uniform criteria and combination processes. Still, the available information had to be balanced against the requirements from the QRA models, for traceability from final data back to the original source, and for documentation for future reference. The remainder of this section discusses the data sources available to the project and the requirements placed upon the UMCDF QRA database.

Optimal data sources for any project are those that are generated from the actual operating experience of a directly comparable facility. The UMCDF QRA had the benefit of two such sources, albeit for a limited time window of operational experience. As a supplement to this data, searches were made among literature to obtain relevant data from other industries, also known as "generic" data. These various data sources are discussed in further detail in the following sections.

7.1.1.1 Tooele Chemical Agent Disposal Facility. TOCDF has begun processing munitions and has been operating in that capacity since September 1996. As such, TOCDF can be considered the most applicable facility from the standpoint of obtaining operational data relevant to the UMCDF QRA. SAIC QRA project staff visited TOCDF in July 1999 to identify available sources of equipment reliability information, retrieve them, and review them to determine their usefulness for the QRA data needs. This trip uncovered the MP2 database, stored in Microsoft® Access and available on compact disk, read-only memory (CD-ROM), as a viable source of component failure and repair information. The bulk of the QRA data analysis effort was invested in the review, extraction, analysis, and statistical calculation of data from the TOCDF MP2 data set. This process is described in much greater detail in section 7.2.

7.1.1.2 Johnston Atoll Chemical Agent Disposal System. A Phase 2 QRA of TOCDF was conducted by SAIC and completed in 1996 to estimate the potential risk drivers prior to placing TOCDF in operation. Additionally, data analysis was a task within that QRA's scope. At that time, the sole source of available CDF experience was confined to the Operational Verification Testing (OVT) campaigns conducted at JACADS. It was considered important to review and

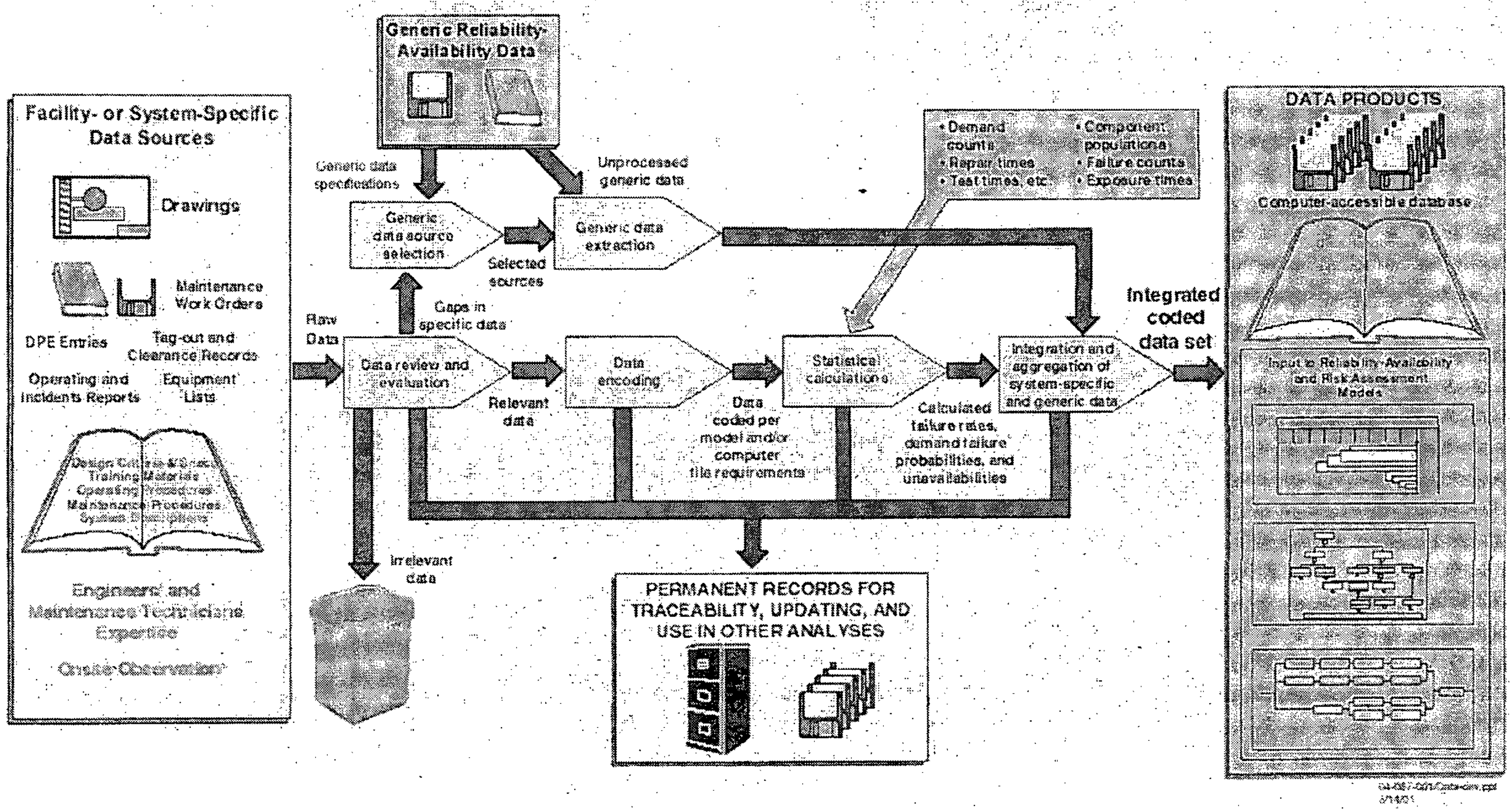


Figure 7-1. Data Development Process Flow

re-evaluate the JACADS data during the UMCDF QRA to determine whether it continued to be relevant as a component failure data source. At minimum, it was believed to be important to compare the JACADS statistics against the TOCDF data, if only from the perspective of evaluating lessons learned in the interim that may have already been factored into the TOCDF system design and would be revealed through the component failure information. The process involved in applying the JACADS data to the UMCDF QRA is discussed further in section 7.3.

7.1.1.3 Industrial (Generic) Sources. While data from the facility being studied are the preferred source of equipment failure rate information, it is common in a QRA for supplementary information from other industries to be used for particular component types and FMs for which industry-specific data are sparse. In this case, although the amount of TOCDF and JACADS data were sufficient to provide valuable failure rate data for the vast majority of the components modeled, it was considered important to complement and supplement these CDF data with information from a wider range of industries. The rationale for this comparison was that certain component types might not have experienced sufficient challenges or operational hours to permit rare FMs to present themselves. It therefore was decided to extract Industrial data for each UMCDF QRA component TC and FM combination, to the extent possible, to provide a basis for comparison with the TOCDF and JACADS data.

Over the course of many QRAs, SAIC has compiled an extensive library of Industrial data sources from the commercial nuclear power industry, the military (through the Rome Air Development Center Reliability Analysis Center handbooks), aerospace programs, and the chemical process industry. These sources were carefully reviewed to properly apply the industrial component types and FMs with those from the QRA. A detailed discussion of this activity is provided in section 7.4.

7.1.2 Documentation of Data Analysis. The structure for the UMCDF QRA database was established by data set conventions for QRA data sets developed by SAIC in response to early databases for nuclear power plant PRAs. These early databases proved deficient in that they did not allow the user to easily trace the final failure rate tables back to the origin of the data, and therefore called into question the validity of the data. For this reason, it was considered important to provide "traceability" of the component reliability database, meaning that the final data entered into the QRA can ultimately be traced back to the individual failure records and population/operational information, or the specific page of a given industrial data source. In the case of the UMCDF QRA, as previously described, data were available from TOCDF, JACADS, and industrial sources. The "traceability" for the final data table is provided sequentially back to its origins through the data tables included in appendix E, as shown in figure 7-2.

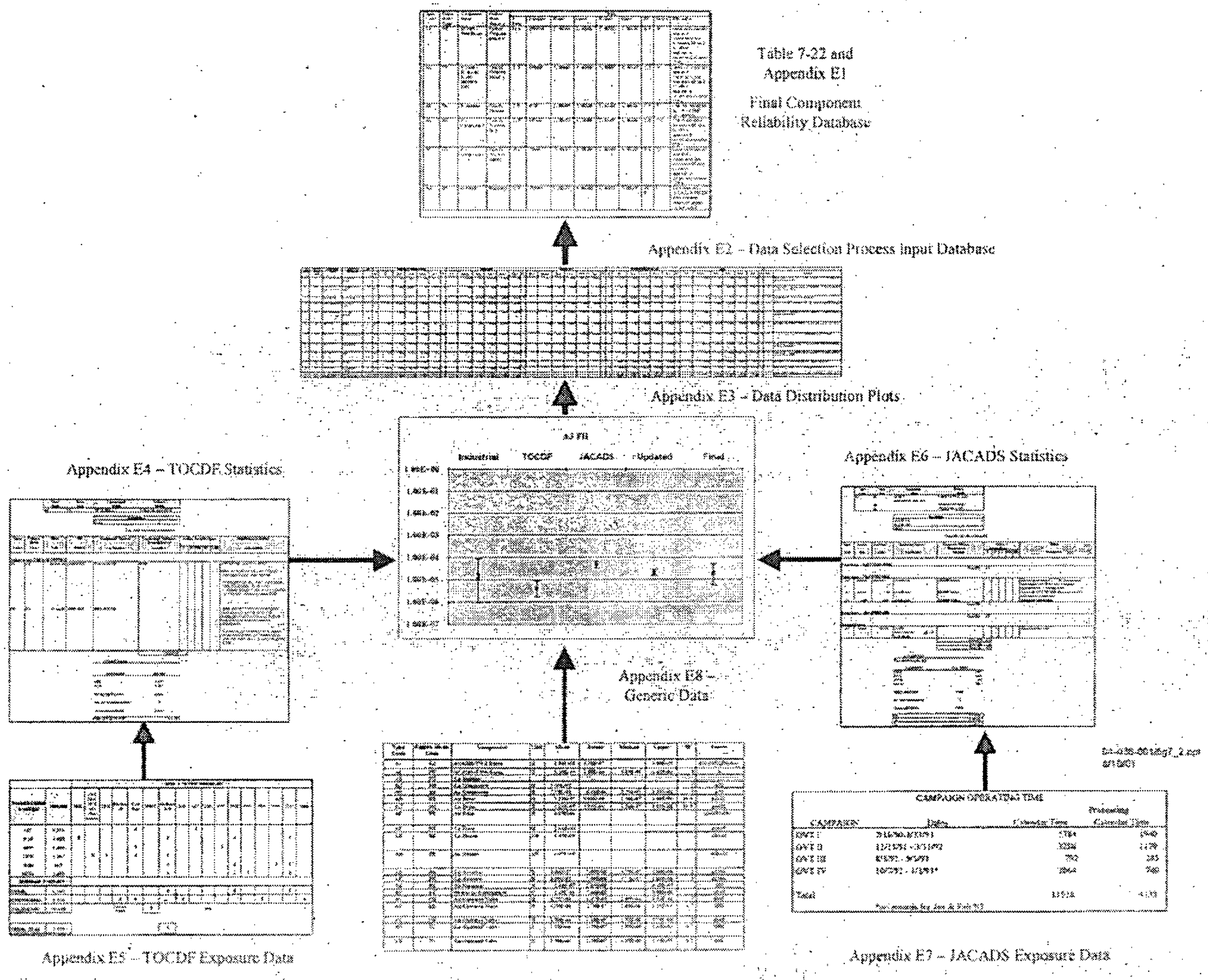


Figure 7-2. Data Traceability Flow

Appendix E1 is the Final Component Reliability Database, which provides a summary of the final data selections by component TC and FM.

Appendix E2 documents the inputs to the data selection process as well as the final selection and the rationale for each choice.

Appendix E3 shows the lognormal plots used by the data analysts to compare the available data distributions for each TC/FM combination.

Appendix E4 provides the calculations of the numerators and denominators, and thereby the mean values, of the TOCDF statistics for each TC as well as the FMs under each TC. These files show the TOCDF MP2 database entries used to calculate the number of failures in the TOCDF numerators and link this information to the exposure information used to calculate the denominators and the mean values by TC and FM.

Appendix E5 provides the details for the TOCDF exposure data, namely, the equipment populations, the operating hours calculated for the exposure times for the time-related failure rates, and the demand estimates developed for the demand probabilities.

Appendix E6 provides the calculations of the JACADS statistics for each TC as well as the FMs under each TC. These files show the JACADS Daily Operating Report (DOR) package dates from which the events were extracted that were used to calculate the number of failures in the JACADS numerators. Equipment population estimates also are provided in these files. This failure and population information is linked in these files to the exposure time estimates used to calculate the denominators and the mean values by TC and FM.

Appendix E7 provides the details for the JACADS exposure data, namely, the operating and calendar hours calculated for the exposure times for the time-related failure rates.

Appendix E8 provides a listing by TC and FM of the industrial (or generic) data sources used, including the specific source and page number where the data can be found.

An appendix E9 also has been included to provide details on the statistical methods used for the uncertainty distribution calculation using the lognormal and Fisher (F-) distributions and the Bayesian Updating process used to combine specific and industrial data.

The sections that follow discuss the processes and tools used to develop the UMCDF QRA database input from TOCDF and JACADS experience and industrial data sources, and their combination, comparison, and ultimate selection to form the final QRA data set. Finally, insights and recommendations resulting from the data analysis are provided.

The data described herein will be supplemented in the future by additional data collection from operating CDFs. Data from UMCDF operations also will be collected and analyzed as part of the UMCDF RMP.

7.2 Tooele Chemical Agent Disposal Facility Data

Corrective maintenance (CM) records from TOCDF located in Tooele, Utah, were archived in a set of Microsoft® Access database files known as the MP2 database. The information obtained from these records was used as the primary input to the development of failure rates for the components modeled in the QRA, through the process described in the following sections.

7.2.1 Advantages and Disadvantages of Using Tooele Chemical Agent Disposal Facility Data. With the use of any data set, there are advantages and disadvantages. However, in using the plant-specific data from TOCDF, one obvious advantage is that the components found in the facility's maintenance records are likely to be very similar to those components modeled in the UMCDF QRA. This alleviates most of the difficulties in matching component types and considering so-called component boundaries, namely the subcomponents and piece parts considered within the designation of a given component rather than standing alone.

Another advantage of using the TOCDF records is that they were contained within a computerized database and were organized by equipment identification number. This was extremely helpful to the data analysts in that the records could be easily searched to find relevant data, as well as copied and extracted into a standard format.

However, some disadvantages of using the TOCDF data were that they were somewhat limited as to the timeframe they covered (27 months) and included the start-up period for the maintenance record system. The first 6 records in the maintenance record system reported maintenance conducted in January 1997, then the seventh record abruptly skipped to maintenance conducted in April 1997. Subsequent records continued the reporting of maintenance performed in April 1997. Therefore, because the available maintenance information was sparse to non-existent for the first 3 months of 1997, it was decided to establish the "data window" of information used for the development of CDF-specific reliability data for the UMCDF QRA from April 1997 through June 1999 (the latter date being the latest information available at the time the data were collected).

7.2.2 The MP2 Database. The MP2 database was documented by TOCDF using Microsoft® Access software and provided to SAIC in the form of a CD-ROM during an SAIC visit to the site in July 1999. The MP2 database is used at TOCDF for CM work order tracking and PM scheduling through a variety of subdatabases. It therefore was necessary to conduct an initial review to identify which of these subsets would be most appropriate for the generation of the component reliability database by the QRA data analysts. The CM data subset accounts for all CM records from TOCDF over a 27-month period (April 1997 through June 1999) and consists of a total of 13,505 records. A sample CM record from the MP2 database is shown as figure 7-3. Prior to the initiation of a maintenance action, an entry is made into the MP2 database. Important pieces of information about the maintenance action are stored into this database for permanent record keeping, including: the close date, work order number, equipment identification number, description of the task, priority, and location of the ordered action. In addition, extensive record keeping is included on the amount of time until completion. However, because it was not clear whether this time was the actual repair time or the signoff/closeout time of the work order (which can extend beyond repair time by several hours or days), the time until completion was not used to develop equipment outage times for the QRA. Still, most of the MP2 maintenance information was considered appropriate and applicable, and therefore was extracted for use in the QRA, as described in the following section.

7.2.3 Data Extraction. It is common for maintenance record databases to contain much more information than is relevant to the data needs of a QRA. For example, often the records describe maintenance on equipment not modeled in the QRA or facilities related to habitability or security that are not within the QRA scope. The MP2 database was no exception in this regard. For this reason, the process was started by screening the maintenance records to identify those records relevant to the development of failure rates for each component modeled in the QRA. This screening process also narrowed down the amount of records requiring detailed analysis and, therefore, the data analysts' workload.

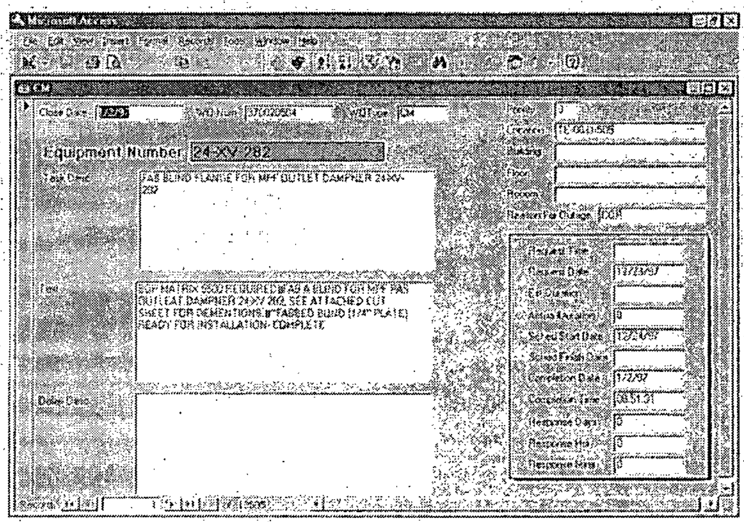


Figure 7-3. MP2 Database "Forms" View

Records that described equipment and maintenance actions considered essential to the overall process were considered "relevant." These relevant records included components such as ACAMS (agent sniffers and alarms), cranes, conveyors, and forklifts, as well as the components included in the demilitarization line equipment, such as chillers, pumps, valves, pipes, and tanks. Maintenance records on electrical equipment such as diesel generators and relays and instrumentation including level, flow, and pressure sensors also were identified as relevant to the QRA. In addition, those records that documented personnel actions or mishaps (e.g., descriptions noting that personnel were needed to perform an investigation or troubleshoot equipment) also were considered relevant.

Maintenance actions considered "irrelevant" and therefore not extracted for further consideration for the QRA database included: building and grounds-related maintenance records; repair actions on the Entry Control Facility (ECF) turnstiles, IDS-ZONE, or potable water system; installation or fabrication actions (unless specific equipment failure or repair was mentioned); making or installing tags; or Personnel and Maintenance Building (PMB) activities (unless they related to valves, pumps, panels, or the like). Repairs of trucks, minivans, and carts, and regularly scheduled actions such as "Verify accuracy of panel schedules" (which were considered more consistent with PM than CM), also were considered irrelevant to the data needs of the QRA.

The determination of relevance was primarily driven by equipment type rather than by location in the CDF and was made as the records review progressed, with input from the systems analysts when questions arose. This approach was taken so as not to screen out relevant equipment, such as ACAMS or conveyors, located in various areas of the facility. The issues of multiple failures on the same record and duplicate records were addressed later in the data analysis process, as described in section 7.2.5.

Each MP2 database record was reviewed by using the "forms" view of Microsoft® Access (figure 7-3) because this view made the information easier to read. Based on this review, the analysts determined whether each record was either relevant or irrelevant to the QRA data needs. The work order number of each relevant record was written on a piece of paper. Then, when the review of all the records was completed, the extraction process took place by searching and finding the relevant records by work order number in the MP2 database (using the Microsoft® Access "datasheet" view, as shown in figure 7-4).

The relevant records then were copied and pasted into a Microsoft® Excel spreadsheet format with standard information fields, which had been developed over the course of several QRAs, including the TOCDF Phase 2 QRA. Converting the data into a more usable format made them easier to manipulate and, by including the work order number, allowed each extracted relevant record to be traced back to the original entry in the MP2 database.

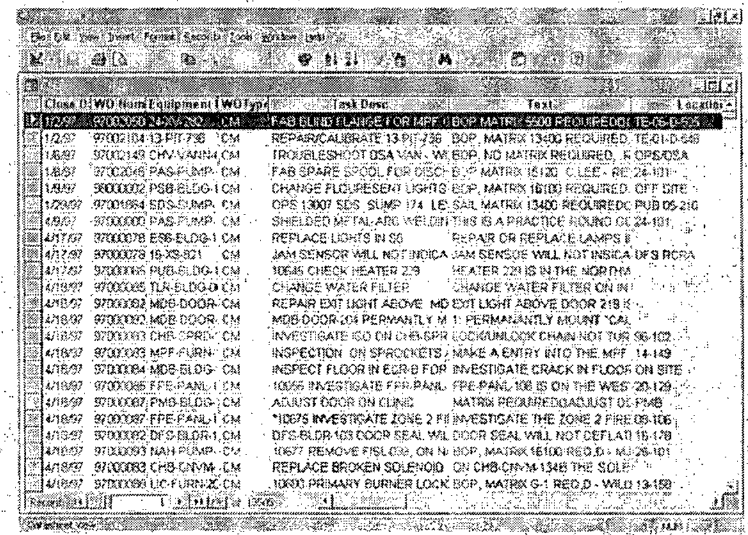


Figure 7-4. MP2 Database Datasheet View

The data fields from MP2 copied into the standard Microsoft® Excel spreadsheet format included the close date (of the work order), work order number, equipment identification number, equipment location, maintenance action description, and number of days to respond to the work order. Figure 7-5 shows an example of the spreadsheet format used.

Once all the records were extracted, the encoding process was initiated with the intent of filling in the columns for TCs and FMs shown in figure 7-5.

7.2.4 Encoding Extracted Data Records by Type Code and Failure Mode. The process of extracting the minimal set of information required for QRA quantification purposes is termed *encoding* and the resulting data set is referred to as *encoded data* (see figure 7-1 for a depiction of the data analysis task flow). Upon careful examination of the QRA model (more specifically, the BE file provided by the modelers), TCs and FMs were assigned to the extracted records and documented within the spreadsheet. TCs and FM Codes are used in the CAFTA fault tree program to classify the components and the nature of their failure modeled in the QRA. In addition, these codes are conventionally included in the naming scheme of the fault tree BEs.

Both codes are typically two characters long, e.g., the TC "AS" stands for "air separator" and "HX" represents "heat exchanger"; for FMs, "FH" designates "fails to operate" and "BK" signifies "rupture." To ensure consistent modeling and data assignment across the QRA, a list of approved TCs and FM Codes, shown as table 7-1, was developed and maintained by a designated systems analyst.

TOOELE SPECIFIC DATA (from MP2 Data Set)												
Type Code	Fail. Mode Code	Close Date	WO Number	Equipment Tag Number	Equipment Description	Equipment Subtype, Component or Piece Part	Action Severity/Type					Maintenance Action Description
							C	D	PM	HE	Calib	
MP	LK	4/18/1997	970000938	NAH-PUMP-102 &103	Pump	FISL-039, -045						Remove seal water FISL-039 on NAH-PUMP-102 and FISL-045 on NAH-PUMP-103; These seal water FISLs and their associated tubing and brackets are no longer used for these pumps; FISLs and brackets removed.
CY		4/18/1997	970000831	CHB-CNVM-134B	Conveyor	Stack valve		1				Solenoid on the stack valve is broken and needs to be replaced; Couldn't locate parts using CAMS equipment lists; no parts; had to change out whole stack valve.
BP or LC	SO	4/18/1997	970000889	LIC-FURN-201	Furnace	Burner Management System (BMS)		1				Primary burner lockout, but no change in BMS signal; worked with Con engineers; switched to backup PLC
FL		4/18/1997	970000799	CHB-HYPU-101A,B	Hydraulic filter		2					CHB filters A/B need to be changed out; changed filters
		4/18/1997	970000821	DFS-FURN-101	Furnace	16-XS-016 jam sensor		1			1	Jam indication on 16XS-016 coming in & out; jam sensor is locked out; investigate and restore to proper condition; trouble shot and ran cal on jam sensor
CH	FH	4/18/1997	970000785	PMB-BLDG-101		Chiller, Pressure gauge						Repair pressure gauge- chiller; Installed gauge on suction of the pump, chiller pump 102
MP	LK	4/18/1997	970000796	PAS-PUMP-212	Pump	Seal	1					Seal is leaking on Pump 212; investigate and repair; tighten seal and run 1 hour then let it shut down for 1 hour and ran 10 min; no leaks; tighten[ed] seal bolts and function tested; seal quit leaking.

04-087-001/datarec.ppt
8/19/01

Figure 7-5. Example of Extracted Data Records

Additions and revisions to this list could only be made by consulting with the designated analyst, thereby ensuring that the codes were mutually exclusive rather than redundant.

The data analysts developed data at the TC and FM Code level, ensuring that the data were applicable, from both a component function/failure and model input standpoint, to what was modeled in the QRA. In order to determine which specific CDF equipment applied to each TC, the data analysts reviewed the QRA model BE file that can be produced using CAFTA. The BE file lists all the events modeled in the QRA by event name. Because the QRA event names contained the TCs and FM Codes, as well as the relevant equipment identification number for the component modeled in the event, the data analysts were able to use the BE file to correlate equipment identification numbers to TCs. It then was possible to encode the CM records by associating the equipment identification number cited in each record to the TCs used by the systems analysts for those identification numbers in the BE files.

However, this encoding process was not as mechanical as it sounds. The data analysts considered it important to verify: 1) that the TCs were in fact being used by all the various systems analysts to describe the same type of equipment, and 2) that the failure described in a given maintenance record actually applied to the equipment identification number designated in the record.

Table 7-1. Type Code and Failure Mode List

Type Code	Failure Mode Code	Component	Failure Mode
A3	FH	ACAMS - TWA (Room)	Fails to respond
A5	FH	ACAMS - Discharge Airlock (ACAMS-290)	Fails to respond (Hourly)
AB	FH	Air Bubbler	Fails to operate
AC	RH	Air Compressor	Fails to run (hourly)
AC	SD	Air Compressor	Fails to start (demand)
AD	BK	Air Dryer	Break/rupture
AD	FH	Air Dryer	Fails during operation
AF	FH	Air Filter	Fails to draw air
AF	PG	Air Filter	Fails/plugs during ops
AH	BK	Air Header	Break/rupture
AH	FH	Air Header	Fails to maintain pressure
AR	BK	Air Receiver	Break/rupture
AR	FH	Air Receiver	Fails to supply air
AS	BK	Air Separator	Ruptures
AU	BK	Accumulator (hydraulic)	Break/rupture
AV	CH	Air-Operated Valve	Fails to close (hourly)
AV	LK	Air-Operated Valve	Leakage
AV	OH	Air-Operated Valve	Fails to open (hourly)
AV	TC	Air-Operated Valve	Transfers closed
AV	TO	Air-Operated Valve	Transfers open/rupture
BB	BK	Burner Block	Break/rupture
BO	BK	Boiler	Rupture
BO	RH	Boiler	Fails to continue to run
BP	FH	Burner Management System	Fails to operate
BP	DF	Burner Management System	Fails to detect and control given flame
BP	TP	Burner Management System	Transfers position
BS	FH	Bus	Fails to maintain power
BT	FH	Battery	Fails to provide output
CB	CD	Circuit Breaker	Fails to close (demand)
CB	OD	Circuit Breaker	Fails to open (demand)
CB	TO	Circuit Breaker	Transfers open
CH	BK	Room Air Chiller	Ruptures
CH	FH	Room Air Chiller	Fails to continue operating
CH	RH	Room Air Chiller	Fails to continue running
CH	SD	Room Air Chiller	Fails to start (demand)
CL	FH	Clutch	Fails to disengage
CN	BK	Condenser	Rupture
CN	RH	Condenser	Fails to continue to run

Table 7-1. Type Code and Failure Mode List (Continued)

Type Code	Failure Mode Code	Component	Failure Mode
CO	BK	Aftercooler	Break/rupture
CP	FH	Control Panel	Fails to respond
CV	CH	Check Valve	Fails to close (hourly)
CV	LK	Check Valve	Leakage
CV	OH	Check Valve	Fails to open (hourly)
CV	TC	Check Valve	Transfers closed
CV	TO	Check Valve	Transfers open/rupture
CY	FH	Conveyor	Fails during operation
DE	BK	Demister	Rupture
DG	RH	Diesel Generator	Fails to run
DG	SD	Diesel Generator	Fails to start (demand)
DP	FH	Drip Pan	Fails to operate
DT	BK	Duct	Break/rupture
EJ	BK	Expansion Joint	Ruptures
EL	DP	Elevator	Drops during operation
EL	FH	Elevator	Fails during operation
EV	TC	Seismically actuated valve	Transfers closed
FE	FH	Flow Element	Fails to operate
FE	PG	Flow Element	Plug
FE	TH	Flow Element	Transfers high
FE	TL	Flow Element	Transfers low
FH	BK	Flexible Hose	Break/rupture
FL	PG	Filter (not air)	Fails/plugs during ops
FN	RH	Motor-Driven Fan	Fails to continue running
FN	SD	Motor-Driven Fan	Fails to start (demand)
FP	FH	Fire Protection Panel	Fails to respond
FP	TP	Fire Protection Panel	Transfers position
FS	FH	Flow Switch	Fails to respond
FS	TH	Flow Switch	Transfers high
FS	TL	Flow Switch	Transfers low
FT	FH	Flow Transmitter	Fails to respond
FT	TH	Flow Transmitter	Transfers high
FT	TL	Flow Transmitter	Transfers low
GC	BK	Gas Cylinder	Ruptures
GH	BK	Gas Reheater	Ruptures
GT	DP	Gate	Drops during operation
GT	FH	Gate	Fails to respond
G2	CH	Blast Gate	Fails to close (hourly)

Table 7-1. Type Code and Failure Mode List (Continued)

Type Code	Failure Mode Code	Component	Failure Mode
G2	OH	Blast Gate	Fails to open (hourly)
HM	BK	Hydraulic Manifold Valve	Ruptures
HO	FH	Hoist	Fails during operation
HU	RH	Air Handler	Fails to continue to run
HU	SD	Air Handler	Fails to start (demand)
HX	FH	Heat Exchanger	Fails during operation
HX	PG	Heat Exchanger	Plugs
IC	BK	Intercooler	Break/rupture
IN	FH	Inverter	No output
LC	FH	Logic Controller (PLC)	Fails during operation
L2	FH	Logic Controller (PLC) - Support Systems	Fails during operation
LE	FH	Level Element	Fails to respond
LE	TH	Level Element	Transfers high
LE	TL	Level Element	Transfers low
LS	FH	Level Switch	Fails to respond
LS	TH	Level Switch	Transfers high
LS	TL	Level Switch	Transfers low
LT	FH	Level Transmitter	Fails to respond
LT	TH	Level Transmitter	Transfers high
LT	TL	Level Transmitter	Transfers low
ME	SD	Motor (Electric)	Fails to start (demand)
MH	SD	Motor (Hydraulic)	Fails to start (demand)
MO	TP	Motor Overload Switch	Transfers position
MP	LK	Motor-Driven Pump	Seals leak
MP	RH	Motor-Driven Pump	Fails to continue running
MP	SD	Motor-Driven Pump	Fails to start (demand)
MS	BK	Moisture Separator	Break/rupture
MV	CH	Motor-Operated Valve	Fails to close (hourly)
MV	LK	Motor-Operated Valve	Leakage
MV	OH	Motor-Operated Valve	Fails to open (hourly)
MV	TC	Motor-Operated Valve	Transfers closed
MV	TO	Motor-Operated Valve	Transfers open/rupture
NG	FH	Natural Gas Detector	Fails to respond
NZ	FH	Spray Nozzle	Fails
OC	BK	Oil Cooler	Rupture
OM	FH	Oxygen Monitor	Fails to respond
OM	TH	Oxygen Monitor	Transfers High
OM	TL	Oxygen Monitor	Transfers Low

Table 7-1. Type Code and Failure Mode List (Continued)

Type Code	Failure Mode Code	Component	Failure Mode
OS	BK	Oil Separator	Rupture
PD	CH	Damper, Pneumatic	Fails to close (hourly)
PD	LK	Damper, Pneumatic	Leakage
PD	OH	Damper, Pneumatic	Fails to open (hourly)
PD	TC	Damper, Pneumatic	Transfers closed
PD	TO	Damper, Pneumatic	Transfers open/rupture
PP	BK	Piping	Leak or break
PP	PG	Piping	Plugs
PS	FH	Pressure Switch	Fails to respond
PS	TH	Pressure Switch	Transfers high
PS	TL	Pressure Switch	Transfers low
PT	FH	Pressure Transmitter	Fails to respond
PT	TH	Pressure Transmitter	Transfers high
PT	TL	Pressure Transmitter	Transfers low
PV	TC	Pressure Control Valve	Transfers closed
PV	TO	Pressure Control Valve	Transfers open/rupture
QT	BK	Quench Tower	Rupture
RC	FH	Rectifier	No output
RL	TP	Relay	Transfers Position
RV	OH	Relief Valve	Fails to open (hourly)
RV	TO	Relief Valve	Transfers open/rupture
SB	BK	Scrubber Tower	Rupture
SC	BK	Venturi Scrubber	Break/rupture
SC	CH	Venturi Scrubber	Excessive throttle/closure
SL	FH	Scissor Lift	Fails during operation
ST	BK	Strainer	Break/rupture
ST	PG	Strainer	Plugs
SV	CH	Solenoid Valve	Fails to close (hourly)
SV	LK	Solenoid Valve	Leakage
SV	OH	Solenoid Valve	Fails to open (hourly)
SV	TC	Solenoid Valve	Transfers closed
SV	TO	Solenoid Valve	Transfers open/rupture
SW	TD	Static Transfer Switch	Fails to transfer (demand)
TE	FH	Temperature Element (Thermocouple)	Fails to respond
TE	TH	Temperature Element (Thermocouple)	Transfers high
TE	TL	Temperature Element (Thermocouple)	Transfers low
TK	BK	Tank	Break/rupture
TR	FH	Transformer	Fails to maintain power

Table 7-1. Type Code and Failure Mode List (Continued)

Type Code	Failure Mode Code	Component	Failure Mode
TS	FH	Temperature Switch	Fails to respond
TS	TH	Temperature Switch	Transfers high
TS	TL	Temperature Switch	Transfers low
TT	FH	Temperature Transmitter	Fails to respond
TT	TH	Temperature Transmitter	Transfers high
TT	TL	Temperature Transmitter	Transfers low
VL	FH	Conveyor Lift	Fails to operate
VS	FH	Vibration Switch	Fails to respond
VS	TH	Vibration Switch	Transfers high
WE	FH	Weight Element	Fails to operate
XR	BK	Manual Gas Regulator Valve	Ruptures (regulator fails)
XS	BK	Manual Shutoff Valve	Ruptures
XV	CH	Manual Valve	Fails to close (hourly)
XV	LK	Manual Valve	Leakage
XV	OH	Manual Valve	Fails to open (hourly)
XV	TC	Manual Valve	Transfers closed
XV	TO	Manual Valve	Transfers open/rupture
ZO	FH	Position Sensor	Fails to respond
ZO	OP	Position Sensor	Out of position
ZS	FH	Position Switch	Fails to respond
ZS	TP	Position Switch	Transfers position

A list was created by the data analysts using both the extracted maintenance records and the QRA model BE file to identify any conflicts or redundancies. This list included the facility-designated system identification codes and equipment identification codes, the TC used in the UMCDF model, and the description given from the record or model. An excerpt of this list is provided in table 7-2.

Items were coded as follows: *blue* = equipment found in the data only (not in the model), *black* = equipment found in both data and the model, *red* = equipment only found in the model, *green* = possible coding errors. The equipment that was only found in the data and not in the model was highlighted to provide the analysts an opportunity to ensure that despite historical evidence of equipment failure, the equipment in question was not risk-significant from a modeling point of view and did not need to be included. Conversely, items listed in red were denoted to the data analysts that there could be difficulty in producing data for these TCs because, although they were used in the model, they were not found in the MP2 database.

Table 7-2. Comparison Between Equipment ID and Type Codes: UMCDF Model Versus Tooele Chemical Agent Disposal Facility Data

System Identification Code	Equipment Identification Code	Type Code in Model	Description
2	HS	HS	(Hand switch)
2	ZS		Presence sensor
3	HS		
4	HS	HS	(Hand switch)
4	LIT		
4	XY		Solenoid-operated tray stop
4	ZS	ZS	(Position switch)
5	HS	HS	(Hand switch)
5	XY		
5	ZS		Presence sensor/limit switch (charge car)
6	PCV		
9	LV		Valve
10	HS	HS	(Hand switch)
10	ZS	ZO	(Position sensor)
11	AG	PP	Pipe
11	HV		Position indicator
11	LIT	LS	(Flow transmitter) [level indicating transmitter]

By developing this list, the data analysts provided a review and check to avoid cases where different systems analysts modeled the same equipment but classified them differently. For example, the TCs "PP" for piping and "FH" for flexible hoses were originally used by different analysts to TC the same equipment tag numbers 13-FG-4115P and 4129M.

Another example of a data issue requiring clarification, which was identified through the development of this list, surfaced when the data analysts noticed that equipment with the facility identification code "FV" (such as 20-FV-473) was variously type-coded in the model as SV (solenoid valve), XV (manual valve), and MV (motor-operated valve). This indicated to the data analysts that it was not possible to automatically attribute each failure related to a tag number containing FV to any one type of valve; each one had to be reviewed and the valve type identified using the UMCDF Master Equipment List or the plant drawings. Decisions regarding type coding had to be made in a systematic and thorough manner to ensure compatibility between the TOCDF data and the UMCDF model to which it would be applied.

The equipment identification numbers found in the data set but not in the models, and which could not readily be assigned TCs by the data analysts, were compiled into a list, which was sorted and printed by system identification code and distributed to the cognizant systems analysts. A sample list for System 14, the MPF, is provided in table 7-3; section 7.2.4.4 provides a more complete explanation as to how these issues were addressed. Finding answers to these questions was not only essential to the encoding process, but also helped to fine tune the BE coding decisions in the QRA model.

Table 7-3. Valve Question List for System 14

Equipment Tag Number
14-FY-249
14-FV-269
14-FY-229
14-FY-389
14-FY-422
14-FY-429
14-PCV-028
14-V-886
14-XV-247
14-XV-329
14-XY-008A
14-XY-502

Throughout the course of the data encoding process, some issues were raised that required further analysis and often, input from the systems analysts. This input was needed to obtain the level of understanding of the equipment design and function necessary to properly code the failures associated with the equipment found in the MP2 database. Some examples of these data analysis issues are: component boundaries as they relate to the subcomponents included in a given TC or designated as a separate TC, equipment identification/distinction as it relates to component TC assignment, and equipment function/failure as it relates to FM assignment. The consideration of these issues is presented in the following subsections.

7.2.4.1 Conveyors. One particular category of equipment that required further analysis was the conveyors. Table 7-4 shows some of the questions raised concerning the conveyors and an example of some of the initial system analysts' responses.

Table 7-4. Example Conveyor Data Issues

Questions Regarding Conveyors	Initial Responses from System Analysts
Is the tray stop a presence sensor (ZO)?	Yes.
Is the drive chain a part of the conveyor or motor?	Need to look into further.
Are the stack valves (on CHB conveyors) solenoid valves or part of the conveyor (CY)?	Not modeling the CHB conveyors.
Is it okay to assume that the drip pans (on BDS conveyors) are drip pan (DP)?	Yes.
Are the hydraulic leaks a part of the conveyor or a part of the motor?	They are a part of the conveyor.
Are the sprockets a part of the conveyor or the motor?	Need to look into further.

The data analysts also encountered conveyor equipment that appeared to be similar but was described with different names, such as scissor lift, implying different functions, despite the fact that the codes contained in the equipment identification numbers appeared to be related to conveyors, namely: CNVB, CNVM, CNVP, and CNVX. Because there were separate TCs for the conveyor (CY), scissor lift (SL), and conveyor lift (VL), this issue required further clarification from the systems analysts. The list shown in table 7-4 therefore was constructed by the data analysts based on what was described in the MP2 records and sent to the systems analysts for their input. (Note: the conveyor lift is on the BDS and lifts and lowers the conveyor so that the ton container can sit securely on the conveyor during the punch process.)

Input from the systems analysts, as well as the master equipment list and system description manual for the facility, was used to identify, sometimes by specific equipment identification number, which equipment should be considered CY versus SL versus VL. While it was recognized that several design, duty, and environmental factors may have influenced conveyor performance, it was believed that uncertainty bounds around the mean conveyor, scissor lift, and conveyor lift failure rates would cover the range of these variances. Further, the contribution of conveyors to the overall risk results did not ultimately warrant additional conveyor TC specificity and the further breakdown of already sparse data.

There also were issues related to the motors of the conveyors, which were separated out from the roller and belts into separate TCs of ME for electric motor and MH for hydraulic motor. It was not initially clear to the data analysts which conveyors were driven by hydraulic motors and which used electric motors. Because there are many different systems throughout the CDF that use conveyors, as table 7-5 shows, it could not be assumed that they were all the same. Input from the systems analysts, such as population information for the motors and descriptions

Table 7-5. Conveyor Descriptions in MP2 Database

Equipment Tag Identification	System	Description
CNVM	CHB	Conveyor
CNVP	MMS	Conveyor
	PHS	Conveyor
	BDS	Conveyor
	CHB/UPA	Scissor Lift Conveyor
	MDM	Conveyor
	MHS	Scissor Lift Conveyor
	MMP	Conveyor
	MMS	Conveyor
	MPF	Conveyor
	TMA	Scissor Lift Conveyor
CNVB	-	Conveyor
CNVX	-	Conveyor
	-	Conveyor Lift

of events from the BE file, also was needed in these cases to help determine the coding of repair actions found in the MP2 database.

7.2.4.2 Position Indicators, Sensors, and Switches. Sometimes input from the data analysts was used to consolidate and clarify TC distinctions that did not reflect the actual operation and modes of failure reflected in the maintenance records. A particular example of this situation is the distinction originally made in the QRA model between position indicators (ZI), position sensors (ZO), and position switches (ZS). In order to understand this distinction in terms of data allocation, the data analysts constructed a list of the equipment attributed to each of these three TCs in the model. Table 7-6 summarizes the findings in terms of how the equipment included in each TC category was described by the systems analysts.

Table 7-6. Position Electronics Descriptions from Original QRA Model Basic Event File

Type Code	Description from UMCDF QRA Model
ZI	Fireye® Ultraviolet Scanner
	Louver Controller
	Position Indicator
ZO	Position Sensor
ZS	Position Switch
	Infrared Detector
	Louver Switch

As table 7-6 shows, the ZI and the ZS TCs were being used to describe devices that appeared to function differently (and would therefore fail differently). For example, Fireye® is a brand name for the BMS, but in this case refers to the scanning devices that evaluate the strength and position of the flame inside the furnace. The Fireye® flame scanners were found in the BE file type-coded as "ZI," categorized as position indicators. However, this TC was used not only for Fireye® ultraviolet scanners, but also for louver controllers and position indicators. A similar pattern was true for the TC "ZS." This TC was used in the model to describe position switches, presence switches, infrared detectors, and louver switches. It was not clear that these should all be categorized as the same TC.

This issue became even more apparent when the data analysts attempted to assign the ZI, ZO, and ZS TCs to the position instrumentation failures extracted from the MP2 database. It was not obvious which of the codes should be attributed to which event; generally, when encoding confusion such as this exists, it indicates that the TC categories have not been sufficiently distinguished from each other, otherwise the choice would be clear.

To resolve this confusion, the data analysts provided the systems analysts with a list of the events coded ZI, ZO, and ZS in the model and requested that they be reviewed to verify that the coding was correct and consistent. The comments received resulted in louver controllers being removed from the ZI TC, the Fireye® components being re-type coded as BP to be included as part of the BMS, the infrared detectors re-coded from ZS to ZO, and the louver switch re-coded from ZS to a manual valve (XV).

As a result, the ZS TC was well defined as a position switch. However, some confusion still existed as to the difference between ZI and ZO. While it could be argued that the indicator ZI is the indicating alarm or light and the sensor ZO is the portion that actually senses the position, the data analysts determined that there was not sufficient evidence or description in the failure records to permit the ZI and ZO failures to be distinguished from each other, and therefore, to warrant separate TCs. Data therefore were developed for the sensor portion or ZO TC only and the systems analysts were advised to change any items coded as ZI to ZO.

One way in which such issues are resolved is through the definition of the so-called "component boundaries" of the components modeled. An example of a component boundary issue is that of the Fireye® scanners and the BMS. The Fireye® scanner is technically a piece of the BMS. But should the model and therefore the data be developed at the level of Fireye® scanners or should they be included as part of the BMS? Issues such as these require both the system modelers and the data analysts to agree upon the level to which the facility, system, and component are modeled and, correspondingly, the level for which data are developed.

7.2.4.3 Demilitarization Equipment. Maintenance records that provided important information on process-specific demilitarization equipment were extracted from the MP2 database, although the records did not directly correlate to the TCs being used in the model. Therefore, these records were grouped together in a separate Microsoft® Excel spreadsheet file that the data analysts named "Demil." Selected items from this file are listed in table 7-7.

Table 7-7. Examples of Demil Items

Systems	System Description	Description of Extracted Records
RHS-RSM	Rocket Handling System Rocket Shear Machine	PLS Sensors
BRA-DDYR	Brine Reduction Area Drum Dryer Package	Alarms, Drums, Belts, Wiring or Grounding Problems
MDB-BLDG	Munitions Demilitarization Building	Rope Switches
MHE-JACK	Material Handling Equipment	Hydraulic Leaks
MMS-BDS	Multi-Munitions System Bulk Drain Station	Drain Tubes, Tray Stop, Drain Probes
MMS-CHRG	Multi-Munitions System Charge Cars	Track Malfunction, Transformers
MMS-CHUT	Multi-Munitions System Chute	Leaks
MMS-EGGC	Multi-Munitions System Egg Crate	Teeth Repair on Egg Crate, Projectile Holder Repair
PHS-MDM	Projectile/Mortar Handling System Multipurpose Demilitarization Machine	Sensors, Collet Cylinder Replacement, Sticking Bucket, Projectiles Sticking in the Maghead, Drain Station Hydraulic Leak, Turntable, Cam Followers Replaced
PHS-MPL	Projectile/Mortar Handling System Multiposition Loader	E-Stops Replaced
PHS-PKPL	Projectile/Mortar Handling System Pick and Place Machine	Projectiles Sticking, Maghead Alignment, End Effect Grippers

As table 7-7 shows, however, among the descriptions are items such as sensors and hydraulic leaks that could potentially be attributed to TCs in the model. The data analysts therefore had to review each demilitarization event against the existing TCs and equipment descriptions in the model BE file to determine whether the failure events could be applied to any existing TC/FM categories. Those events that did pertain to existing TCs were removed from the "Demil" file and apportioned to the appropriate TC failure event file (as shown in appendix E4) and included in the failure estimates for that TC. The remaining events were retained and provided to the systems analysts to incorporate demilitarization equipment functional properties and failure issues into the QRA models and to address any questions regarding "non-TC" data issues;

namely, events at a higher level in the models than BEs and for which frequency of occurrence data were needed, if available, from the TOCDF MP2 records.

7.2.4.4 Valves. The TOCDF maintenance records provided sufficient detail, in some cases, to determine that the component affected was a valve. However, often the valve type or operator (motor, manual, air, solenoid) could not be readily identified and these events therefore could not be type coded properly. Therefore, the data analysts compiled a list of these "unknown valves" by equipment identification number. The valves were sorted by system identification (the first three digits of the equipment identification) and presented to the system analysts for further clarification in the form of a spreadsheet. For example, the system analyst responsible for modeling "System 14" (MPF) received only the list of questions for equipment tag numbers beginning with "14." This spreadsheet, including the excerpt shown as table 7-8, listed the equipment tag number of the valve, description, and provided an empty column for the system analyst to input the appropriate valve TC to be used for the QRA database.

These TCs represented a variety of valves such as air-operated valves (AV), check valves (CV), motor-operated valves (MV), relief valves (RV), solenoid valves (SV), and manual valves (XV). After all the lists were returned with TC determinations made by the appropriate system analysts, the valve TCs were entered into the master list of extracted records. It should be noted that the "unknown equipment" lists consisted primarily but not exclusively of valves, and the questions extended to the identification of other types of equipment, such as those listed in table 7-8. Other types of equipment are identified in table 7-9.

While the failure events related to equipment that could not be identified regrettably had to be omitted from use in the QRA database, the vast majority of data questions were successfully resolved via the combined efforts of the data and systems analysts.

As a result of this step of the process, as many as possible of the relevant records extracted from the MP2 database were encoded by equipment TC and FM Code, enabling the relevant TOCDF maintenance history information to be directly associated to the data needs of the QRA.

7.2.4.5 Safety-Related Equipment. CM records pertaining to safety system equipment, such as diesel generators (DG TC), cranes/hoists (HO TC), and HVAC equipment (including chillers, valves, air filters, ducts, dampers, piping, and strainers) were specifically extracted from the TOCDF MP2 database. It was clearly understood by both the data and systems analysts how important the consideration of CDF-specific data was to the development of failure data for this equipment. Particular attention was paid to the use of the data in terms of the FMs modeled in the QRA so as not to misrepresent the number of failures and provide inordinately high values that would skew the QRA results. However, those failures found to be appropriate and valid were included and applied to the QRA.

Table 7-8. "Mystery Equipment" Questions List

TC	Equipment Identification	Description in MP2 Record	Comments
SV	03-V-174		
	03-V-S294		CAN'T FIND
XV	04-24-3/4"-V-V662	Brine isolation valve, MPF density meter	
	04-35-1"-V-626		CAN'T FIND
SV	04-XY-331	Tray stop control solenoid?	
SV	04-96-XY-509		
SV	04-96-XY-652		
SV	05-XY-129		
	06-1"-V-113		CAN'T FIND
RV	06-PCV-057		
RV	06-PCV-127		
RV	06-PCV-135		
RV	06-PCV-377	Plant air to CDS-TANK-106	
XV	10-V-888		
	11-1"-V-045		CAN'T FIND
AV	11-HV-156		
AV	11-LV-001	Valve on SDS-TANK-101 A floor sump	
AV	11-LV-013	SDS-TANK-102	
AV	11-LV-016	Stop valve into SDS-TANK-102	
AV	11-LV-038		
AV	11-LV-059	From CAT A sumps to SDS-TANK-103	
AV	11-LV-061		
AV	11-LV-071	SDS tank outlet valve	
AV	11-LV-097		
AV	11-LV-249		
AV	11-PV-773		
	11-PV-774	Piping in SDS room	CAN'T FIND
	11-XV-321	3-way valve on SDS-TANK-102	CAN'T FIND

[shaded box] = Provided by Systems Analysis

Table 7-9. Types of Equipment Identified by Systems Analysts

Equipment Tag Numbers that Could Not be Coded	Systems Analysts Input
03-V-174	Solenoid Valve (SV)
11-HV-156	Air-Operated Valve (AV)
11-LV-001	Air-Operated Valve (AV)
12-1/2"-V-138	Manual Valve (XV)
13-AE-850E	Natural Gas Detector (NG)
13-FQI-127A	Flow Transmitter (FT)
13-PY-706	Pressure Transmitter (PT)

7.2.5 Sorting Data Records and Encoding by Failure Severity Category. Once the records were encoded, they were sorted and grouped according to TC and FM. The records were carefully examined to ensure they were properly encoded and that there was uniformity in the encoding decision making within each TC and FM category. Changes were implemented if needed. After the records were sorted, they were separated into individual spreadsheets, grouped by TC.

Next, each failure event in each TC grouping was encoded by failure severity using the following categories: catastrophic failure (C) and degraded failure (D). The severity designations are intended to indicate, as the name implies, the degree and type of equipment disablement involved in each maintenance action. Other descriptive categories also were used, as appropriate, to indicate whether these failures were related to PM, human error (HE), and/or calibration (Calib.).

Complete or catastrophic failure indicates that there was total equipment failure, with respect to the FMs being modeled for that equipment TC. For example, for the Plugged FM, a catastrophic failure would mean that the device (such as a filter) was plugged to the point where it could not perform its filtering function at all. Only catastrophic failures for the FMs modeled are used as the numerators of the failure rates input to the QRA model.

Degraded failures are characterized as only involving partial equipment failure; in other words, the equipment performs its function, but at a less than optimal level. Degraded failures are not assigned FM Codes. Both catastrophic and degraded failures are used to calculate: 1) equipment demands, because it is presumed that post-repair functional testing is performed, thereby challenging the equipment to perform, and 2) equipment unavailability due to maintenance, due to the outage time involved in the performance of the repair actions.

To perform the severity coding, each record was carefully reviewed from the standpoint of understanding the FMs available for a given TC and deciding, based upon the event description, how severe the failure was, given the available FMs. For instance, while a failure in the mode of Plugging could be considered a catastrophic failure for an air filter, it would most likely be considered a degraded failure for a strainer on a motor-driven pump, unless the plugging led to a Failure to Run for the pump itself. The data analysts entered a number into the appropriate failure severity category column of the spreadsheet to reflect the number of failures found within each maintenance record, as shown in figure 7-6.

For example, if two separate instances of a Pump Failure to Start on Demand were recorded in a single MP2 maintenance record, such as one automatic start failure and any subsequent failures upon operator actuation, the data analysts would count two failures and would have logged a number "2" in the "C" column for that event. In another example involving the cranes (TC HO for hoist), while numerous maghead issues were cited in the MP2 records, it was important to note that not each maghead failure necessarily involved an actual munition drop. It was therefore decided to consider them as partial failures when evaluating them against the munition drop FM modeled in the QRA. Because one record mentioned that one out of six magheads had failed, the 19 individual maghead failures were divided by six and the resulting number of 3 failures were counted as munition drop failures. The determination of the number of failures

Type Code	Failure Mode Code	Gen Date	W/O Number	Equipment Type or Tag Number	Action Severity/Type C	D	PM	HE	Calib	Maintenance Action Description
Failure Mode: FAILS DURING OPERATION										
CY	FH	17-Jun-97	970004644	BDS-CNVP-101	1					SAIL MATRIX C-8A REQUIRED (MJ) ONE OF THE ROLLERS HAS EXCESSIVE SIDE TO SIDE MOVEMENT. NORTH SIDE SET SCREW GUARD MIGHT HAVE COME LOOSE. REPARE AS REQUIRED. RESTORE TO PROPER OPERATING CONDITIONS ~CHECKED LINE A AND INE B ROLLERS ON BOTH SIDES ALLSET S
CY	FH	28-Jun-97	970005646	MDM-CNVP-102	1					MATRIX C-4A REQUIRED CONVEYOR WILL NOT GO FROM SLOW TO FAST SPEED ~RESET HYD MANIFOLD TO SPEC. BY OPS WITH MECHANICAL ON CONSOLE AT CON. DPE ENTRY
CY	FH	08-Jul-97	970006415	MPF-FURN-101	1					SAIL MATRIX G-4 REQUIRED ZONE 1 CONVEYOR MALFUNCTION REPAIR AS NECESSARY
CY	FH	09-Jul-97	970006426	CHB-CNVM-138	1					BOP MATRIX C-12-C REQUIRED 138D WILL NOT RAISE IN LOCAL OR REMOTE, TROUBLESHOOT AND REPAIR ~FUNCTION TESTED SEEMS OK NOW (KENT HARRIS WITNESSED) WE COULDN'T FIND ANY PROBLEMS AFTER FUNCTIONING.

54-087-001 [illegible]
05/11/01

Figure 7-6. Spreadsheet Depicting Failure Severity involved in each record, therefore, was based on the best analytical evaluation given the information presented in each record and given the operational information provided across records and from the systems analysts.

It is important to note that assignments of the failure severity category were carefully made and reviewed to ensure consistency of encoding. For instance, if a particular description of a failure of valve *x* was recorded as a catastrophic failure of the mode Fails to Open, all subsequent valve failures with this same description also were categorized as catastrophic failures to open.

7.2.6 Failure Rate Data Calculation. After the type-coded records were encoded by failure severity, they were placed into new spreadsheets in separate Microsoft® Excel files by TC and the events were grouped according to FM and failure severity categories, as shown in figure 7-7. The entire set of these spreadsheets is provided in appendix E4.

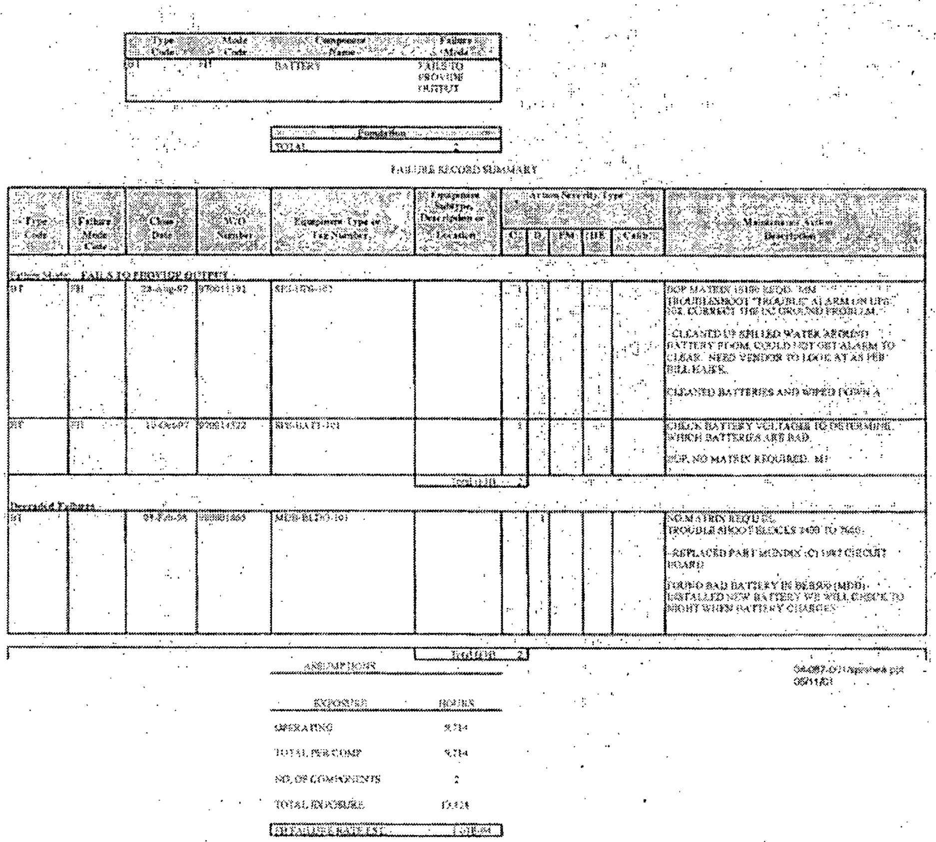


Figure 7-7. Failure Rate Calculation Spreadsheets

Within each TC file, the relevant maintenance records were separated by FM for the catastrophic failures that would be used to calculate the failure rate mean values. Degraded failures were grouped separately. Events relating to FMs not included in the QRA model were grouped under the heading "Other." These were retained for completeness, possible provision of further insight into the QRA model, and future reference in case data were required to be developed for other FMs.

As figure 7-7 shows, the failure information is not the only input to the calculation of the mean failure rates used in the QRA models. Other essential inputs to this process are the equipment population data and the equipment exposure information, which were compiled by the system analysts per guidelines provided by the data analysts to ensure the uniformity and usability of the information gathered. The development of the population and exposure data is discussed in the following sections.

7.2.6.1 Population Data. For the QRA models, data were being constructed at the level of component TC, which represents a grouping of all equipment of a similar type and function across the facility. The denominator data for the failure rates and probabilities at the TC level cannot be accurately estimated unless the population of equipment in a TC group is known. Therefore, it was necessary for population information to be compiled for each TC across the systems modeled in the QRA. To do this, a spreadsheet format was developed with the QRA systems modeled forming the columns and the QRA component TCs forming the rows. Each QRA system analyst was asked to determine the total number of components in her/his system in each TC category, not just the equipment modeled. This was done to reflect the fact that all events related to all equipment in the QRA-relevant systems had been extracted from the MP2 CM records and therefore the source population for those events had to be consistent. When the population information by TC was obtained on a system-by-system basis, it was summed across systems, as shown in table 7-10. The entire component population table is provided in appendix E5. It should be noted that the "Utility" system designation includes equipment from the following systems or locations: ACS, CHB, LPG, MDB, PAS, and secondary cooling water. Because the TOCDF data were already constrained by the amount of information available from the MP2 database, it was decided to include the Utility systems and components to provide as much information as possible to the QRA. Further, these support systems (particularly ACS and PAS) are likely to function as a result of munition processing, therefore, their inclusion was not considered to be of detriment to the overall data set. For the A3 (ACAMS) and LC (Programmable Logic Controller) TCs, it was necessary to have an analyst use population data from independent sources to verify that the total number of components was correct, because the individual system population data sources (e.g., diagrams) were incomplete for these equipment classes.

Table 7-10. Excerpt from Type Code Population Summary

Type Code	Description	Total Population in System per Drawing (not just the ones modeled)	Sum of System Data	BHS	DFS, PAS, PFS without Afterburner	DFS	Electrical	Fuel Gas	HVAC	Hydraulics	IAS	LIC	LSS	MPF	PCS	PHS	PLA	RHS	ACS	Utility
A3	ACAMS-TWA Room	84	15	0	4			0	3	1		4		3						
AB	Air Bubbler	2	2	2	0			0		0		0		0						
AC	Air Compressor	7	7	0	0			0		0	2	0	2	0		1	2			
AD	Air Dryer	4	4	0	0			0		0	1	0	2	0			1			
AF	Air Filter	73	73	0	2	2		0	36	0	6	3	14	3		1	6			
AH	Air Header	3	3	0	0			0		0	1	0	1	0			1			
AR	Air Receiver	10	10	0	0			0		0	1	0	3	0		1	1			4
AS	Air Separator	8	8	0	0	1		0	1			0		0						6
AU	Hydraulic Accumulator	8	8	0	0			0		8		0		0						
AV	Air-Operated Valve	106	86	14	3	21		1	28		2	5		5	3	3				1
BB	Burner Block	17	17	0	1			0		0		3		13						
BO	Boiler	2	2	0	0			0	2	0		0		0						
BP	Burner Management System	7	7	0	1			0		0		3		3						
BS	Bus	11	11	0	0		11	0		0		0		0						
BT	Battery	2	2	0	0		2	0		0		0		0						
CB	Circuit Breaker	80	80	0	0		80	0		0		0		0						
CH	Room Air Chiller	5	5	0	0			0	4	1		0		0						
CL	Clutch	14	12	0	0			0		0		0		6		6				
CN	Condenser	4	4	0	0			0	4	0		0		0						
CO	Aftercooler	7	7	0	0			0		0	2	0	2	0		1	2			
CP	Control Panel	19	18	3	0			0		0	1	1	1	1		10	1			
CV	Check Valve	314	302	16	8	12		1	19	13	8	30	12	80	2	11	2		9	79
CY	Conveyor	135	127	43	0	1		0	1	0	1	12	0	7	0	14	0		0	48

The appropriate population data from this summary spreadsheet were linked to each TC data file (such as that shown in the Population box at the top of figure 7-7) and were later used in combination with the exposure data to form the failure rate/probability denominator data.

7.2.6.2 Exposure Data. *Exposure* is a term used in data analysis to reflect the amount of functioning time or number of challenges to function during which a component could have failed. It also can be described as the window of opportunity presented to the component during which a failure could have occurred. The exposure is effectively used as the denominator of the time-related failure rate or the demand probability, with the number of catastrophic failures forming the numerator.

Exposure Time. The exposure time for the TOCDF data was separated into calendar time or munition processing time within the MP2 records data window (April 1997 to July 999). The appropriateness of calendar versus processing time for use as the failure rate exposure was dependent upon the component type and FM. For example, an ACAMS agent sniffer is called upon to detect the presence of agent 24 hours a day, 7 days a week so it is essentially functioning all the time; therefore, calendar time is an appropriate measure for the "exposure" to the possibility of ACAMS failure. However, an agent pump in a demilitarization equipment line only sees operation while that line is processing munitions; therefore, the exposure to failure for the agent pump is the time that munitions processing is occurring in that system on that demilitarization line. Because processing time is a subset of calendar time, there can be a noticeable impact on the failure rate depending upon which exposure time is used, and the distinction is therefore important, not only from a theoretical but from a data outcome standpoint.

Calendar Time. For the TOCDF data, calendar time was simply calculated as the number of hours within the 27-month data window, or 19,440 hours, per component. The calculation of processing time, however, required a more detailed analysis.

Processing Time. Munition processing time was logged in the TOCDF weekly reports, but this information had to be specifically retrieved and extracted by an analyst, and then entered into the format shown in table 7-11. The processing times were associated with particular furnaces and demilitarization equipment. However, the QRA data were being developed at the level of component TC, and similar equipment from different CDF systems was likely to be included in the same TC category. Therefore, it was necessary to correlate the subsystem level at which processing time data were available with the component type-across-systems level for which the QRA data were being constructed.

First of all, it was not possible given time and budget constraints, nor was it necessary, to calculate exposure data at the individual component level or for component types at the system level. What needed to be done was to provide the best estimate possible to reflect the operating

Table 7-11. Tooele Chemical Agent Disposal Facility Munition Processing Times by Demilitarization Line/Furnace

	Processing Minutes										
Package Date	LIC 1	LIC 2	BDS 101	BDS 102	MPF	DFS	RSM 101	RSM 102	MDM 101	MDM 102	MDM 103
2/21/99	256	3,823	67	346	4,684	3,169	1,021	3,169	271	2,974	3,015
2/28/99	2,247	264	0	192	3,794	2,181	555	627	1,312	2,049	1,967
3/7/99	0	3,387	39	179	4,121	1,227	947	0	316	2,586	2,376
3/14/99	0	4,243	29	204	5,378	6,792	5,755	427	2,159	2,540	2,537
3/21/99	0	3,185	140	0	4,786	2,304	850	1,145	2,747	696	4,071
3/28/99	0	2,809	64	5	5,468	4,308	1,687	1,973	2,944	1,790	4,412
4/499	0	3,653	108	0	7,261	2,029	294	1,161	3,047	3,315	4,163
4/11/99	0	3,178	143	0	5,620	1,736	0	1,444	2,996	2,939	3,952
4/18/99	0	3,496	0	24	7,020	32	0	0	3,846	4,618	4,577
4/25/99	2,564	2,351	402	0	6,594	3,706	0	3,199	2,567	3,743	5,465
5/2/99	4,424	1,131	814	0	7,502	2,658	0	1,824	4,372	2,421	3,838
5/9/99	4,443	0	512	0	7,680	1,454	0	1,348	5,289	4,832	2,151
5/16/99	6,838	0	1,131	0	7,369	2,794	0	3,261	4,768	1,854	5,356
5/23/99	7,028	0	758	0	7,892	4,650	0	4,747	3,999	1,985	5,214
5/30/99	6,344	0	923	0	6,921	5,398	0	4,936	3,412	2,011	2,640
6/6/99	5,813	0	927	0	5,886	2,136	0	2,002	2,777	3,060	2,253
6/13/99	0	0	0	0	160	0	0	0	0	0	0
6/20/99	1,624	814	198	0	6,800	59	0	18	1,165	1,898	3,679
6/27/99	3,317	4,506	1,298	0	7,233	71	0	5	1,714	2,195	3,670
7/4/99	3,889	4,685	1,544	0	6,700	8	0	0	833	3,330	4,784
Totals and Averages	**386,978**	**442,883**	**60,703**	**52,926**	**579,298**	**74,816**	**21,489**	**50,952**	**51,327**	**87,696**	**137,702**
Hours	**6,450**	**7,381**	**1,012**	**882**	**9,655**	**1,247**	**358**	**849**	**855**	**1,462**	**2,295**

time for a given component TC category. In other words, the data analysts attempted to reflect the most representative operating time for the majority of equipment within a TC category.

The first step in this process was to summarize the munition processing time data at the system level so that they could be correlated to the system level population data provided by the systems analysts, as discussed in the previous section and shown in table 7-10. Then, a decision could be made as to what system level processing time to use for each TC by identifying the system where the majority of the components in a given TC resided.

Processing time was provided in the TOCDF weekly reports for the following furnace and demilitarization lines:

- LIC 1
- LIC 2
- BDS 101
- BDS 102
- MPF
- DFS
- RSM 101
- RSM 102
- MDM 101
- MDM 102
- MDM 103.

The first step taken to summarize these data was to consolidate the data for the LIC, BDS, RSM, and MDM into a "maximum" processing time. In other words, each weekly report provided a number of processing minutes for LIC 1 and LIC 2. The data analysts identified the larger of the two LIC processing times for each weekly report and designated that as the maximum processing time for the LIC system. Therefore, a summary was built of the most processing minutes per weekly report by system, as shown in the example for the LIC in table 7-12.

The processing time by furnace and demilitarization system then was summarized as shown in the two left-hand columns of table 7-13. Because the processing time was provided in the TOCDF weekly reports as minutes and the failure rate information required hours, a conversion was made to processing hours.

Then, using the system categories from the component TC population spreadsheet shown previously as table 7-10, the data analysts identified which of the processing systems best represented the majority of equipment in each system modeled. For the LIC and MPF, this was a simple process because the systems matched directly with the systems for which processing hour

Table 7-12. Maximum Weekly Processing Minutes by System

Date	LIC 1	LIC 2	Maximum LIC Time
4/6/97	0	1,708	1,708
4/13/97	0	3,733	3,733
4/20/97	0	1,882	1,882
4/27/97	0	844	844
5/4/97	0	1,190	1,190
5/11/97	0	612	612
5/18/97	0	1,592	1,592
5/25/97	0	0	0
6/1/97	0	0	0
6/8/97	0	0	0
6/15/97	1,842	0	1,842
6/22/97	6,618	0	6,618
6/29/97	7,784	0	7,784
7/6/97	7,340	0	7,340

data were available. However, for other systems such as Hydraulic, IAS, or the ACS, it was necessary to consider the functions they provided to the demilitarization process and whether those functions were implemented during the time that processing was ongoing within any of the processing systems. In this way, the modeled systems could be correlated to the appropriate amount of processing time. An "X" at the junction of the modeled system columns and the processing system rows in table 7-13 indicates where the data analysts believed such correlations could be made.

Some of the modeled systems, however, were considered to be providing their functions for several of the processing systems. For example, the primary cooling and ACS systems were believed to be functional at the same time as all the demilitarization lines, namely the BDS, RSM, and MDM, so the maximum processing hours for these demilitarization lines were put into a processing hour category designated "Demil" hours. The 4,149 Demil hours therefore were designated as the processing time for equipment in the primary cooling and ACS systems.

Similarly, the Fuel Gas System (FGS) function was believed to be required and implemented for all the furnace systems, namely the LIC, MPF, and DFS. So, the furnace system with the most processing hours, the LIC, was used to form a processing hour category designated "Operating" hours. The 9,714 hours of LIC operation therefore were designated as the processing time for equipment in the FGS.

Table 7-13. Processing Hour Summary by System

		QRA System Modeled																
Processing System	Hours	BHS	DFS, PAS Without Afterburner	DFS	Electrical	Fuel Gas	HVAC	Hydraulics	IAS	LIC	LSS	MPF	PCS	PHS	PLA	RHS	ACS	Utility
LIC	9,714					X				X								
BDS	1,823	X						X					X				X	
MPF	9,655					X						X						
DFS	1,247		X	X		X		X										
RSM	957							X					X			X	X	
MDM	2,452							X					X	X			X	
Summary Hours																		
Demil	4,149												X				X	
Operating	9,714					X			X									
Calendar	19,440				X		X								X			X
Demil Sum	7,713							X										

This Operating summary hour category also was applied to those systems believed to be functioning whenever the CDF could be considered as in "processing" mode, but were not necessarily functioning during the entire calendar time in the data window, namely, the IAS.

It should be noted that a special category of processing hours called Demil Sum was developed specifically for the Hydraulic system, because it was realized that the total exposure for the hydraulic equipment was not the *maximum* processing time for any of the demilitarization lines, but the *total* processing time for all the demilitarization lines combined. This is because all the demilitarization lines contain hydraulic equipment so any time any of them are operating, the hydraulics are functioning.

Therefore, the Demil Sum processing hours consist of the processing time for the two BDS lines, the two RSM lines, and the three MDM lines over the data window, for a total of 7,713 hours.

It also should be noted that because the HVAC, Electrical, Plant Air, and Utility systems provide a continual function related to the CON and to the safe air conditions (i.e., non-agent contaminated) of the facility, the data analysts believed that calendar time was the appropriate exposure time to use in these cases.

These processing hour totals and assumptions are all summarized in table 7-13.

Exposure Time Calculations. To calculate the exposure time for each TC and FM, the number of components (from the population data collected as described in section 7.2.6.1) was multiplied by the exposure time, either calendar time or one of the categories of processing time, depending upon the system in which the majority of equipment in the TC category was located.

For certain components [e.g., motor-driven pumps (MP TC)] the component population was spread rather evenly across different systems with diverse operating times. In this case, the operating times were calculated by multiplying the population in a system with the system operating hours (per table 7-13) and summing the total operating time to form the failure rate denominator.

The appropriate exposure time from the summary spreadsheet in table 7-11 was linked to each TC data spreadsheet rate, such as was previously shown in figure 7-8, to calculate the mean failure rate(s) by FM.

Demands. Some measures of equipment failure are expressed as the probability of failure out of the number of challenges presented to the equipment to function. One simple example is the FM "Fails to Start" for a pump or a diesel generator. When a signal is automatically given to a pump to start based on a set of system conditions programmed into a controller, or when an operator

SYSTEM NUMBER: PLA 020

EQUIPMENT TYPE ->	PLA-COMP-101,102	
POPULATION	12	
DEMANDS PER COMPONENT PER MONTH BY CATEGORY		
TEST	1	<- INPUT
AUTOMATIC	4	<- INPUT
MANUAL	0	<- INPUT
TOTAL DEMANDS IN STUDY TIMEFRAME OF		
TEST	54	
AUTOMATIC	216	
MANUAL	0	
FAILURE-RELATED (input by data analyst)		
TOTAL:	270	04-087-001/format.ppt 05/11/01

DATA WINDOW	No. of MONTHS
4/1/97 to 12/31/97	9
1/1/98 to 12/31/98	12
1/1/99 to 6/30/99	6
	27

Figure 7-8. Example Demand Calculation Format

actuates a push-button to start a pump, these are considered as challenges on the pump to function, also known as "demands." Therefore, just as exposure time must be calculated for the denominators of the time-related failure rate estimations, the component demands must be calculated to provide a denominator for the demand probability estimations for FMs such as Fails to Start.

Table 7-14 shows the component types and FMs for which demand probability data were required for the UMCDF QRA model. While demand data are conventionally used for standby equipment challenged to function when front line equipment fails or is unavailable, the demand data were developed by the data analysts at the request of the systems analysts. Therefore, the use of these data was at the discretion of the individual systems analysts in reflecting equipment failure likelihood and FMs in their construction of the fault tree models.

Over the course of constructing many QRA data sets for a variety of industries, SAIC has developed a format for characterizing and estimating the various categories of demands placed upon components, shown as figure 7-8. This demand estimation format was provided to the systems analysts, who were requested to fill in the number of demands in the various categories (test, automatic, and manual) per month by major motive equipment or component TC category.

Table 7-14. Components in UMCDF QRA Model with Demand-Based Failure Modes

Component Type	Demand Failure Mode
Air Compressor	Fails to Start
Circuit Breaker	Fails to Close
Circuit Breaker	Fails to Open
Chiller	Fails to Start
Diesel Generator	Fails to Start
Motor-Driven Fan	Fails to Start
Air Handler	Fails to Start
Motor (Electric)	Fails to Start
Motor (Hydraulic)	Fails to Start
Motor-Driven Pump	Fails to Start
Rotary Motor-Driven (ACS) Pump	Fails to Start
Static Transfer Switch	Fails to Transfer

These demands by month then were multiplied by the 27 months in the study data window (to be consistent with the failures extracted during that same timeframe from the MP2 database) in the lower portion of the spreadsheet, to form the total demands by component type by system.

The demand data then were compiled across systems to form totals at the TC level, as shown in the table 7-15 example for the air compressors (AC TC). The data analysts then added in the failure-related demands, based on the number of both catastrophic and degraded failures from the MP2 maintenance records, to account for the demands placed on the components by post-repair functional tests. The total demands then were used as the denominator for the demand failure probability calculations. Further details on the demand data calculations are provided in appendix E5.

Table 7-15. Example Demand Calculation by Type Code

System/Type	Demands
IAS	270
LSS	270
PHS	9,000
Plant Air System	270
Catastrophic Failures	33
Degraded Failures	63
Total Demands	**9,906**

It should be noted that while the MP2 records provided some documentation of diesel generator incidents, maintenance, and repair, the estimated number of demands could not be verified using specific testing or actuation logs, as is usually the case. For the purposes of the QRA, therefore, it was decided to use industrial experience data for the diesels as input to the QRA models to reflect the overall experience of diesels across various industries.

7.2.7 Uncertainty Distributions. The sources for data uncertainty (USNRC, 1983) include: 1) the amount of data, 2) the diversity of data sources, and 3) the accuracy of data sources. Because it is important to characterize this uncertainty for the data being used in the QRA models, a spread about the central tendency, or mean value, is generated to reflect the magnitude (variance) and shape (skewness, tails) of the data distribution. Figure 7-9 shows an illustration of the concept of uncertainty distributions. For the TOCDF data, similar component type information across various systems was combined to form a component TC level data point. However, it was considered important to reflect the diversity of individual component experience within each data point in an uncertainty measure. In this instance, and especially in the case of industrial and Updated data, the spread between the lower and upper bounds is a reflection of the uncertainty and potential non-homogeneity of the input data and not necessarily the true behavior of a specific type of equipment in a particular application. The upper and lower bounds can therefore be considered not only to bracket the data, but to provide insight into the quality of the input data or data sets (CCPS, 1989b).

The lognormal distribution was chosen to represent the data uncertainty because of the general distribution shape, popularity among data analysts, and ease of calculation. The results generated give a very good representation of the range of the data tails (5th and 95th percentiles).

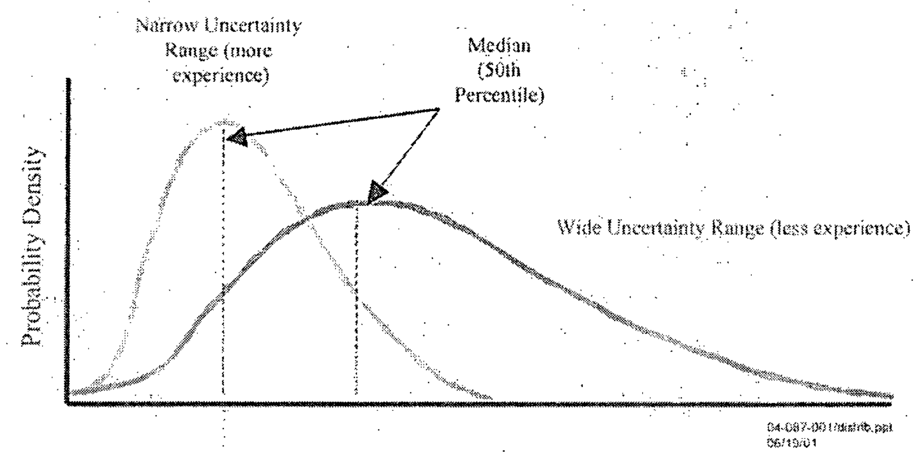


Figure 7-9. Example of Data Distributions

Demand-related data were calculated based on an F-distribution and then fit to a lognormal distribution. Formulas for the lognormal and F-distributions used to calculate the data uncertainty bounds are given in appendix E9. The formulas for the lognormal distribution and the resulting demand data from the F-distribution calculations were input into the data comparison Microsoft® Excel table in appendix E2 to provide the uncertainty distributions surrounding the mean values for the TOCDF data.

7.2.8 Addressing Zero Failures. The mean values of failure rates for components that had experienced zero failures during the study data window were calculated as (1/3)T and (1/3)D, where *T* is time, *D* is the number of demands, and 1/3 is the failure estimator. This is consistent with the treatment of zero failures for the JACADS database developed for the TOCDF Phase 2 QRA and constitutes a method that has been used in the reliability engineering community for several years (Welker and Lipow, 1974).

A more recent comparison of the one-third failure estimator against four other approaches (Bailey, 1997) found that it consistently yielded the lowest estimates for failure probability. However, as discussed further, it is believed that this result is not overly conservative, particularly when the issue of rare FMs (e.g., rupture) is considered.

The one-third failure estimator was used to calculate 37 of the TOCDF mean data points and 40 of the JACADS mean data points. However, when it came to selecting the final data set for input to the UMCDF QRA, the vast majority of these data were either used in combination with industrial data to form a Bayesian Updated number or rejected in favor of industrial data alone.

As a result, of the 175 total data points required for the UMCDF QRA, only *three* were ultimately quantified using data based on zero failures (or actually, the one-third failure estimator). This amounts to less than 2 percent of the QRA data being reliant on so-called zero failure data. These data points were related to the FM "Rupture" for the quench tower, scrubber tower, and venturi scrubber components. In general, the rupture FM is rare, and is particularly so for tanks and towers. In the absence of acceptable industrial data on the rupture of these components, it was necessary to use data from TOCDF and JACADS. As would be expected, no ruptures had occurred during the data window of operation for either of these facilities, nor would rupture necessarily be expected during the operating lifetime of these facilities. Therefore, it is believed that the use of the one-third failure estimator in this instance reflects a justifiably low estimate of the probability of these components rupturing.

It should be noted, however, that in two of these three instances, the TOCDF and JACADS data were combined to obtain the most robust estimate possible. Therefore, the numerators actually used were 1/3 + 1/3 = 2/3 or 0.667 failure.

7.3 Johnston Atoll Chemical Agent Disposal System Data

Data from JACADS was already available to the UMCDF QRA, due to a prior data analysis effort conducted by SAIC in 1994 and 1995 for the TOCDF QRA. The UMCDF QRA timeframe for completion did not allow for the collection and analysis of JACADS operational data after 1994. Still, it was decided to use the existing JACADS database for the UMCDF QRA because minimal additional effort was expected to be involved in applying these data to the UMCDF QRA data needs and because the JACADS data would provide some comparison with the TOCDF MP2 database in terms of CDF operating experience.

In 1994, when the TOCDF QRA was initiated by SAIC, the same need existed (as for the UMCDF QRA documented herein) for component level data for quantification purposes. Because JACADS served as the prototype for TOCDF, the great majority of its equipment and systems are identical or insignificantly different from those at TOCDF. However, the operating environment is potentially significantly different from that of TOCDF because JACADS was a prototype intended to discover and correct systemic and operational problems first, and only then to operate normally, disposing of some 6 percent of the U.S. chemical weapons inventory located on Johnston Island. The data from JACADS were available in three formats: raw or actuarial data that can be obtained from records such as the JACADS DORs; anecdotal data in incident and unusual event reports; and compiled data such as the reports on the experience of the OVT program. The DOR descriptions of equipment failure and repair actions occurring during the OVT munition processing campaigns conducted at JACADS served as the primary source of available CDF experience used for the QRA. These OVTs were a means for testing the capability and capacity for munition demilitarization of the systems installed at JACADS, prototypes for those to be used at the U.S. mainland CDFs, which at that time, had yet to be constructed.

The four OVT campaigns occurred, discontinuously, during the timeframe from July 1990 to January 1993 for a total calendar time of 16 months and actual processing time (considering processing halts and shifts of activity) of less than 6 months, as shown in table 7-16. While it would have been preferable to have had a more statistically significant amount of data, the JACADS information was, at the time, the most relevant data source available for the QRA and did provide insights into the process-specific nature of CDF component operation and failure.

The PMCD Risk Management and Quality Assurance Office provided the QRA analysts with a set of JACADS DORs for the period June 1990 through April 1994 (with the exception of January and February 1993). As the name suggests, a DOR describes occurrences during each day of munition processing, beginning with a Project Manager's Summary report of key events (such as attaining a certain level of throughput or major equipment repairs) and backed up by several pages of more detailed line item descriptions of equipment repairs, DPE entries, and

Table 7-16. Johnston Atoll Chemical Agent Disposal System Operational Verification Testing Campaigns and Durations

Campaigns	Dates	Calendar Time (hours)	Processing Time (shift hours)
OVT I	7/16/1990 to 2/27/1991	5,384	1,940
OVT II	11/15/1991 to 3/31/1992	3,288	1,170
OVT III	8/3/1992 to 9/5/1992	792	285
OVT IV	10/7/1992 to 1/1/1993	2,064	740
Total (Hours)		11,528	4,135
Total (Months)		16.0	5.7

process stops. Data on the munitions processed and furnace operating times also were provided. Early DORs constituted about four pages on average while the later (more current) DORs generally ranged from six to ten pages due to their inclusion of more detailed descriptions of the day's events. While the volume of this material indicated the potential for significant insight into JACADS operation, it was uncertain initially whether the DORs would provide the type of descriptions suitable for data collection. In other words, it was not known whether the level of detail would allow for the determination of equipment types, equipment FMs, or failure severity. Therefore, initial test cases were conducted by reviewing monthly samples each from older and newer records and evaluating their content. These test cases showed that the JACADS personnel had recorded information relevant to equipment reliability and risk analysis, and therefore the DORs were considered sufficiently detailed to provide data-related insights. In fact, the DORs can be seen as similar to the types of documentation commonly found in process facilities, namely repair work orders and CRO's logs. The DORs provide a good balance between these two sources by being more detailed than work orders, yet less difficult and time-consuming to review than operator's logs due to the DORs' structured format and more specific focus on equipment status issues. This evaluation included the understanding that the DOR information might not capture all systems and equipment if their failure did not adversely affect operations. On this basis, then, the data analysis proceeded to use DORs as the source. Because the QRA focus was on munition processing, it was decided to focus the data review efforts on those DORs issued for dates within JACADS OVT campaigns I through IV. The data analysis timeframe established in this manner is termed the *data window*, and this process is consistent with similar decision making on other QRA efforts to limit the data analysis to the operating times of the facility rather than include extended shutdown periods. Table 7-16 shows the duration dates for the four OVT campaigns used to establish the QRA data window.

During the test case review of the DORs, both familiarization with the nature of the reports and an understanding of the ultimate data needs of the QRA were used to identify the set of minimal information that had to be extracted from the JACADS history. Key considerations in the establishment of this information set were the required input to BE quantification and the ability to trace the extracted information back to its original source. To provide for traceability, the date on the first page of each DOR package, generally the Project Manager's Summary, was noted. Because the DORs were so detailed that activities before and after a night shift (hence a date change) were often logged in the same DOR, the date (and time, if available) of each actual equipment failure/repair entry was extracted also. Often, equipment failure diagnosis and repair actions would be continued over several days. Therefore, the most representative DOR entry description of the repair would be selected to characterize a failure/repair event. Equipment identification numbers and/or descriptions, their physical location and/or system, and a description of the failure/repair event itself were summarized as well. Finally, for purposes of quantification, an initial judgment of the failure severity was made. For completeness, notations also were made of PM actions, calibrations, and human errors cited in the DOR descriptions. In the encoding phase, the file cabinet drawers of information were reduced to approximately 100 pages of material. The dates and equipment identifiers in the spreadsheet-based database provided the important factor of traceability back to the original DORs.

As the systems analysis progressed and the models were better defined, equipment failure events were identified and assigned TC/FM Codes, and it became possible to perform an initial assignment of equipment TCs to each entry in the encoded JACADS database. The spreadsheet basis for the database then permitted the data to be sorted by equipment TCs. In doing so, it was possible to postulate which TCs could be quantified with JACADS data. The sorted data entries then were separated by TC, or categorized, and input to the files shown in appendix E6. Because the failure severity had been expressed numerically, meaning that a catastrophic failure would appear as a 1 in the C column, the entries could be totaled by column to calculate the number of failures by severity and hence the number of failures relevant to the numerator of the failure rates.

7.3.1 Advantages and Disadvantages of Johnston Atoll Chemical Agent Disposal System Data. The JACADS data set from the TOCDF Phase 2 QRA provided an important window into munition processing experience. While somewhat limited in its timeframe, the data set was still considered to provide valuable information which could still be of use to the current QRA effort. At the least, it was decided to compare the JACADS data against the TOCDF and industrial data for similar components and FMs. In fact, JACADS data were used to quantify 93 out of the 175 data points (53 percent of the cases) developed for the QRA.

In order to calculate failure rates from the JACADS information, it was necessary to estimate the opportunity for the equipment to function or the time within which a failure could potentially occur (or exposure time). The calculation of demand probabilities is more difficult because information related to the estimation of number of demands placed upon equipment to function is difficult to obtain from such a database. Demand failure calculations using JACADS data therefore were not originally performed for the TOCDF Phase 2 QRA. However, estimates of certain JACADS component demands were made for the UMCDF QRA based on the demands per component per month experienced at TOCDF times the number of JACADS components per TC and the number of months in the JACADS data window (5.7). Demand data were calculated for air compressors, circuit breakers, chillers, motor-driven fans, air handlers, motors, and motor-driven pumps, but not for diesel generators or static transfer switches because no data were available for these components from the DORs. Given the limited timeframe of the OVT campaigns, the exposure times were likely to be relatively small compared with the broader (though less specific) experience of industrial data. It therefore was considered sufficient to perform relatively rough calculations of exposure time for JACADS rather than detailed estimates based on DOR data. Instead, overall estimates of the calendar time and the time spent in munition processing were calculated for the four OVT campaigns, as shown in table 7-16. Estimates then were made of the functioning equipment population at JACADS for each TC and the appropriate measure (calendar or processing time) given the equipment type and use.

7.3.2 Comparison Between Johnston Atoll Chemical Agent Disposal System and Tooele Chemical Agent Disposal Facility Data. For the current study, it was considered important to compare the TOCDF data with the original JACADS data to understand whether the latter could 1) still be considered as a viable data source in light of the more extensive and current TOCDF MP2 information, and 2) be correlated to the component information in the UMCDF QRA models. The issue of the viability of JACADS data is discussed in section 7.6 while the second issue is addressed further in the following subsections.

7.3.2.1 Type Code Comparisons. As a result of additional insights into the component types gained since the TOCDF Phase 2 QRA, changes had been made to the list of component types modeled, as reflected in the two digit TCs. The first step in using the JACADS data, then, was to correlate the TCs from the earlier study to those used for the UMCDF QRA, as shown in figure 7-10.

As the figure shows, in some instances, there were no matches between the JACADS TCs and those for the UMCDF QRA (denoted by "NONE" in the JACADS columns). It was not considered to be necessary for the purposes of this study to return to the JACADS DOR data set to compile information for these TCs, due to the opportunity to use either TOCDF or industrial source data instead for these data needs.

In cases where TC matching could be done, it was still necessary to carefully examine each of the events in the JACADS data for each TC to ensure that compatibility existed. In other words, for some of the TCs, the component boundary, or the delineation of what is included in the definition of a particular component versus what is outside that definition, had changed since the TOCDF Phase 2 QRA. For example, figure 7-10 shows that items modeled as flow elements

UMCDF Type Code	UMCDF Failure Mode	JACADS Type Code	JACADS Failure Mode	
EJ	BK	EJ	RP	
EL	FH	HL	LF	
EV	TC	NONE		
FE	FH	FI	*	Need to review to find
FE	PG	FI	*	FE related events
FH	BK	PF	RP	
FL	PG	FL	PG	
FN	RH	FN	RS	
FN	SD	NONE		
FP	FH	FP	SO?	
FS	TH	FI	*	Need to review to find
FS	TL	FI	*	FS related events
FT	FH	FI	*	
FT	TH	FI	*	Need to review to find
FT	TL	FI	*	FT related events
GT	DP	NONE		

Figure 7-10. Example Comparison of UMCDF QRA and
Johnston Atoll Chemical Agent Disposal System Type Codes

(FE), flow switches (FS), and flow transmitters (FT) in the UMCDF QRA had previously been combined under the component boundary of FI, for flow indicators, when the JACADS data were originally developed. Therefore, it was necessary to read each of the JACADS entries under FI and separate them out into the distinct component categories of FE, FS, and FT.

Fortunately, as the example in figure 7-11 shows, the data analysts had retained files containing all the JACADS events relevant to each TC. This thorough record keeping allowed the JACADS data to be used again, with whatever modifications were necessary to maintain consistency of component boundaries, for the UMCDF QRA.

One key change between the TOCDF Phase 2 and UMCDF QRAs was the separation of the motors for the conveyors into their own TC categories. Therefore, the JACADS events that had been categorized as conveyor failures had to be carefully reviewed to attribute any motor failures to either the electric motor (ME) or hydraulic motor (MH) TCs.

7.3.2.2 Failure Mode Comparisons. In a similar case, as with the component TC comparison process, it was necessary to re-visit the original assignment of FM categories to the JACADS data. The first such screening addressed any changes in the two-letter FM Code used to reflect

Type Code	Mode Code	Component Name	Failure Mode
AD	BK	AIR DRYER	RUPTURE
	FH		FAILS DURING OPERATION

Population		
Instrument Air Dryer	IAS-DRYO-101 or 102	1
Plant Air Dryer	PLA-DRYO-101 or 102	1
TOTAL		2

FAILURE RECORD SUMMARY

Type Code	Package Date	Date/Time Action	Equipment Type or Tag Number	Equipment Subtype, Description or Location	Action Severity/Type C	D	I	PM	HK	Failure Description
Failure Mode: **BREAK/RUPTURE**										
				Total (BK)	0.3					
Failure Mode: **FAILS DURING OPERATION**										
AD	[illegible]	[illegible]	PLA-DRYO-102	Air Dryer (plant)	1					Charged with freon
				Total (FH)	1					
Degraded Failures										
AD			IAS-DRYO-102	Air Dryer (instrument)	1					Replaced tubing

04-007-001/Airysevere.ppt 03/11/01

ASSUMPTIONS

CAMPAIGN	CAL. TIME
OVT I	5384
OVT II	3248
OVT III	792
OVT IV	2064
TOTAL PER COMP.	11528
NO. OF COMPONENTS	2
TOTAL EXPOSURE	23056

BK	1.45E-05
FH	4.34E-05

Figure 7-11. Example Johnston Atoll Chemical Agent Disposal System Events

the same FM. For example, as shown in figure 7-10, the FM Codes for the EJ TC differed between the JACADS data (RP) and the UMCDF QRA listing (BK) although they referred to the same underlying FM of "Rupture."

The second and more challenging screening involved the reconsideration of FM assignment, based on any different modes added for the UMCDF QRA, or on any new events added as a result of the component TC comparisons discussed previously, or on further insights into the CDF operational process since the original encoding process.

7.3.2.3 Failure Severity Updates. The final set of JACADS data reviews were conducted to ensure that the failure severity coding was still valid, given any changes that had been made to the events listed, either in terms of TC or FM Code. In this case in particular, the failure event descriptions for each Component TC and FM grouping were compared with those obtained from the TOCDF MP2 database. The data analysts made every attempt to ensure that like events were considered equally severe failure events across both the JACADS and TOCDF data sets.

The format of the encoded data files was established during the original JACADS data development, which included columns for each failure severity wherein the number of relevant failures per event could be entered and summed, as shown in figure 7-12. This format greatly facilitated the process of recalculating the catastrophic (or complete) failures by FM for use as the numerator of the failure rates.

In general, the process for using the JACADS data required careful comparison with the type and FM Coding, as well as failure severity decisions made for the TOCDF data, to ensure that both data sets would be consistent. In this way, it provided the opportunity for a valuable cross-check of the TOCDF data with the JACADS data and verification of the data sets. For this reason, while JACADS data were not used alone, it was possible to use them in combination with the TOCDF data or in a Bayesian Update with TOCDF and industrial data in over 60 percent of the final data distributions selected for input to the QRA.

7.3.2.4 Additional JACADS Data. TOCDF is very close in design to UMCDF and the QRA resources were therefore primarily focused on gathering and interpreting the TOCDF data. Because JACADS data had already been processed for TOCDF, they too were used as a valuable resource. It would be possible to derive some additional reliability data from more recent JACADS experience, if that process was deemed an effective use of resources. It should be noted that even though reliability data have not been developed for more recent experience,

UMCDF		TOCDF		JACADS		Industrial	
Type Code	Failure Mode	Type Code	Failure Mode	Type Code	Failure Mode	Type Code	Failure Mode
		A1	FH				
A3	FH	A3	FH	A3	LF	A3	LF
A4	FH	NONE		NONE		A4	LF
AB	FH	AB	FH	NONE		AB	FH
AC	RH	AC	RH	CM	RS	CM	RS
AC	SD	AC	SD	NONE		CM	DS
		AC	RH				
AD	BK	NONE		AD	RP	AD	RP
AD	FH	AD	FH	NONE		AD	FH
AF	PG	AF	PG	AF	PG	AF	PG
AH	BK	AH		NONE		AH	BK
AH	FH	AH		AH	LK	AH	FH
AR	BK	NONE		NONE		AR	RP
AR	FH	NONE		NONE		AR	FH
AS	BK	AS		SP	RP	AS	BK
AU	BK	NONE		HC	RP	AM	RP
AV	CH	AV	CH	NONE		AV	OO
AV	LK	AV	LK	NONE		AV	LK
AV	OH	AV	OH	NONE		AV	CC
AV	TC	NONE		NONE		AV	OC
AV	TO	NONE		NONE		AV	CO
BB	BK	BB		BR	RP	BR	RP

Orange indicates "No Jacads Data" prior to further review

Need to find industrial data

Figure 7-12. Side-By-Side Type Code and Failure Mode Comparison

JACADS performance has been captured through extensive analysis and inclusion of PLL issues in the fault tree models. The consideration of PLL issues is discussed in appendix D.

7.4 Industrial (Generic) Data

Industrial data consist of component reliability parameter estimates based on actual equipment failure experience from industrial facilities, information compiled and aggregated from various sources, or expert opinion. Data from several industrial data sources were used to supplement or complement the data already compiled from TOCDF and JACADS experience. SAIC maintains a library of industrial data sources of reliability data from nuclear power industries, offshore oil-drilling installations, other military sources, and chemical processing plants. In addition, industrial data were extracted from reliability data tables previously compiled by organizations such as the Institute of Electrical and Electronics Engineers (IEEE, 1983) and the American Institute of Chemical Engineers (CCPS, 1989b). Table 7-17 provides a listing of the industrial data sources used for the QRA. However, it was necessary to analyze the industrial data to compare the relevancy of the component data selected from the industrial data sources with the equipment in the UMCDF QRA models. This process is described further in the following sections.

7.4.1 Description of Industrial Data Sources. The origin, scope, and quality of the industrial data sources were important factors considered during the industrial data selection process. The origin of the data source had to be appropriate for and applicable to the components modeled in the QRA in that the information gathered from the data sources needed to be relevant to the equipment types and CDF environment, as much as possible.

The data source scope needed to be sufficiently broad to cover a reasonable number of the equipment types modeled, yet with enough depth to ensure that the subject matter was appropriately covered. For example, a separate source might have been used for electronics data versus mechanical data, so long as the detail and the applicability of the information provided justified its use. Lastly, the quality of the data source was considered to be a measure of the source's credibility. Higher quality data sources are based on equipment failures documented by a facility's maintenance records. Lower quality sources use either abbreviated accounts of the failure event and resulting repair activity, or do not allow the user to trace back to actual failure events. Every effort was made by the data analysts to use the highest quality data source available for each TC/FM combination.

Some of the data sources included descriptions of the plant's components and the types of environments in which they were situated. This assisted in the data selection process in that the data source environment could be compared to the CDF environment to determine whether they were equivalent. Also, in some sources, the data were arranged in a taxonomy, or a hierarchical

Table 7-17. Industrial Data Sources Used in the QRA

Industrial Data Source List
Borkowski, R., W. Kahl, T. Hebble, J. Fragola, and J. Johnson, *In-Plant Reliability Data Base for Nuclear Power Plant Components - Valve Component*, NUREG/CR-3154, U.S. Nuclear Regulatory Commission, Washington, D.C., December 1983.
Blanton, C. and S. Eide, *Savannah River Site Generic Data Base Development*, WSRC-TR-93-262, Westinghouse Savannah River Company, Aiken, South Carolina, June 1993.
Center for Chemical Process Safety (CCPS), *Guidelines for Process Equipment Reliability Data with Data Tables*, American Institute of Chemical Engineers, New York, 1989.
Denson, W., G. Chandler, W. Crowell, A. Clark, and P. Jaworski, *Non-Electronic Parts Reliability Data*, NPRD-95, Reliability Analysis Center, Griffiss Air Force Base, Rome, New York.
Derdiger, J., K. Bhatt, and W. Siegfriedt, *Component Failure and Repair Data for Coal-Fired Power Units*, EPRI AP-2071, Electric Power Research Institute, Palo Alto, California, October 1981.
Drago, J., R. Borkowski, J. Fragola, and J. Johnson, *In-Plant Reliability Data Base for Nuclear Power Plant Components - Pump Component*, NUREG/CR-2886, U.S. Nuclear Regulatory Commission, Washington, D.C., December 1982.
Henry, P., "Understanding and Improving Risk in PLC-Based Burner Management Systems," *www.boilercontrol.com*; BMS Risk and Reliability page, 1998.
IEEE, *IEEE Guide to Collection and Presentation of Electrical, Electronic, Sensing Component, and Mechanical Equipment Reliability Data for Nuclear-Power Generating Stations*, IEEE Std. 500-1984, Institute of Electrical and Electronics Engineers, New York, 1983.
IEEE, *IEEE Recommended Practice for the Design of Reliable Industrial and Commercial Power Systems*, IEEE Std. 493-1990, "IEEE Gold Book," Institute of Electrical and Electronics Engineers, New York, 1991.
ITT Research Institute, *Test Report on RAM of ACAMS for TWA Levels in Work Areas at CAMDS*, January 1989.
Jamali, K., *Pipe Failure Study Update*, EPRI TR-102266, Electric Power Research Institute, Palo Alto, California, April 1993.
Lees, F., *Loss Prevention in the Process Industries*, Volumes 1 and 2, Butterworth & Co., London, 1980.
Miller, C., W. Hubble, D. Sams, and W. Moore, *Data Summaries of Licensee Event Reports of Selected Instrumentation and Control Components at U.S. Commercial Nuclear Power Plants*, NUREG/CR-1740, EG&G Idaho for U.S. Nuclear Regulatory Commission, May 1981.
Offshore Reliability Data - 2nd Edition, OREDA-92, Det Norske Veritas (DNV), Technica, Høvik, Norway, 1992.
Ray, M., *Mechanistic Analyses for the QRAs*, SAF-452-95-0093, Revision 0, SAIC, Abingdon, Maryland, 1996.
Zentner, M., J. Atkinson, P. Carlson, G. Cole, E. Leitz, S. Lindberg, T. Powers, and J. Kelly, *N-Reactor Level I Probabilistic Risk Assessment: Final Report*, Table 6-1; N-Reactor Plant-Specific Data Base, WHC-SP-0087, Westinghouse Hanford Company, August 1988.

classification system that groups information based on common features or functional characteristics. A taxonomy gives the data analysts the option to either move down the hierarchy to more specific, though more sparse, data or to move up the hierarchy to less specific, though better founded, data.

Industrial data sources most often contain the following information: FM, failure rate for each FM (including uncertainty limits), component descriptions, their applications, environmental conditions (operational and testing), failure causes and descriptions of FMs, and component boundary descriptions and supportive information (number of events, time in service, and population). However, the extent to which these items are included can vary significantly from source to source. During the selection of the data, careful attention was paid to the correlation of the FM and failure data, component boundary specification, and application of the component from the industrial data source to the CDF QRA data needs as described by the TCs, FM Codes, and BE descriptions from the BE file.

7.4.2 Advantages and Disadvantages of Using Industrial Data Sources. The advantages of using industrial data sources include the following:

- Basic model logic checkout and validation may be performed by inputting industrial data while the facility-specific data are being collected and assessed.
- Industrial data can be used in lieu of plant-specific data if the plant operating experience is limited.
- Plant-specific data on certain components may prove to be impossible to collect.
- Industrial data may form the basis for the prior distribution in a Bayesian Updating process.
- Industrial data bring a larger exposure rate and/or population to the data set.

However, use of industrial data also involves the following disadvantages:

- Using plant-specific data is the desired choice for developing a QRA data set. Component issues inherent in the maintenance records of the modeled facility will rise to the top of the QRA because the failure rates for that specific facility were used. Introducing industrial data into the model may provide failure rates that are not realistic for the given facility.

- The industrial source environment, either physical or operational, may not correlate to the facility modeled. Similarity between the environment of the plant being modeled and that are represented in a given data source is necessary to ensure data appropriateness.

7.4.3 Selection Criteria. Data were selected from the industrial data sources listed in table 7-16 using the following criteria:

- The component TC and FM used in the data source had to match those in the BEs specified in the fault tree. For every component modeled, a comparison was made between the modeled component and the component found in the data source to ensure its suitability for the QRA. Also, every attempt was made to match the FMs. Often, the source described the FM as "all modes," whereas the fault tree required "fails to operate." In cases such as this, sources with more general FMs were not used unless they were the only available sources.

- The estimate contained in the industrial data source had to be based on unique information. Data sources derived from another source were removed and no longer considered.

- The industrial data source had to be widely available, not proprietary. This ensured traceability and scrutibility.

- As was stated earlier, mid level or low level quality data sources were used only when high level sources were not available.

- Wherever possible, sources created using a Bayesian Updating process were not used. These sources were considered to be "quasi-industrial" because they emphasize a specific plant's experience while de-emphasizing the broader industrial information.

- The operating environment is an important factor in the selection of industrial data sources. The environment of a component refers not only to its physical state, but also its operational state. The operating conditions of a component include the plant's maintenance policy and testing policy. If either of these states differed from the modeled facility's state, then the industrial data were reconsidered and usually rejected (unless no alternative existed).

- The scope of the sources selected for this data set was broad. The sources were based on the combined experience of many plants, not on a single plant. This ensured that the data would not be skewed towards the possibly atypical behavior of one particular plant.

The industrial data analysis began with the industrial data set that had been compiled for the TOCDF QRA completed in 1996 and additional sources were reviewed as required based on the UMCDF QRA data needs.

7.4.4 Industrial Data Comparison with Data Needs. Because the industrial data set had to match the BEs in the QRA fault trees, a list of the TCs and FM Codes from the industrial database developed for the TOCDF Phase 2 QRA (SAIC, 1996b) was compiled. This TC/FM list was compared to the list of TC/FM data needs for the UMCDF QRA and to the TCs and FMs used in the JACADS data set from 1996, as well as to the TC/FM combinations found in the TOCDF data set, as shown in the example in figure 7-12.

Making this comparison from left to right, the data analysts recognized that the TC/FM combination for the ACAMS-ASC_STACK (A1 FH) was not included in the UMCDF model, even though TOCDF data had been compiled for it. Therefore, the fact that no data were available for it from the JACADS data set or that industrial data had not been compiled for it was not a problem. Moving to the next item on the list, ACAMS-TWA_ROOM (A3 FH), it was noted that the FM had been changed from the 1996 TOCDF QRA's "LF" (loss of function) to "FH" (fails to respond – hourly). The failure rates determined from the JACADS and industrial data for "A3 LF" therefore were considered comparable to the UMCDF data need and the failure rate determined from TOCDF data for "A3 FH." (It should be noted that for the Final Component Reliability Database, the TOCDF, JACADS, and industrial data for A3 FH were aggregated together through the update process.) Highlighted items in the UMCDF list indicate that no JACADS data were available for those TCs, therefore, industrial data were important in this case particularly if there were no TOCDF data available. In short, figure 7-12 was used to find the "holes" in the data set. This ensured that wherever TOCDF or JACADS data were not available, industrial data would be provided to quantify the BEs.

A list was made of those TC/FM combinations for which industrial data had not previously been compiled during the TOCDF Phase 2 QRA. For each item on this list, the industrial data sources were searched and failure rates were recorded. A few cases were found where either a specific component could not be found within any of the sources or the FMs found were considered to be an inappropriate match. In this situation, an extensive Internet search for technical papers or Web sites was performed and/or expert opinion was used. Along with the failure rates, the source names and page numbers were recorded to ensure complete traceability.

7.4.5 Example of Data Retrieval. An example of how data were retrieved from the various industrial data sources is described in the following example for check valves. The FMs modeled in the QRA for the check valve are CH (fails to close), LK (leaks), OH (fails to open), TC (transfers closed), and TO (transfers open). Table 7-18 shows a comparison between the failure rates for the check valve and its FMs from three different industrial data sources.

Table 7-18. Data Source Comparison for Check Valve

Industrial Data Source	Equipment Description	Failure Modes	Bounds	Equipment Boundary Given?	Taxonomy Given?
AIChE Chemical Process Safety Data Book	Valve-non-operated, Check	• Fails to Check • Significant Back Leakage	Lower, Mean, Upper	Yes	Yes
IEEE-500-1984	Driven Equip. Valves, Check	"All Modes"	Low, Recommended, High	No	Yes
Savannah River Site Generic Database	Check	• Fails to Open • Fails to Close • Plugs • Internal Leakage • Internal Rupture • External Leakage • External Rupture	Mean	No	No

Table 7-19 shows the actual numbers extracted from the industrial data sources for the five FMs of the check valve modeled in the QRA. (Note that these numbers represent only those compiled for the Industrial data set and may or may not be the final numbers selected for input to the QRA models.)

Table 7-19. Failure Rates Chosen from Various Data Sources for Check Valve

Failure Mode Description	Failure Mode Code	Industrial Data Source	Lower	Median	Upper	EF
Fails to Close (hourly)	CH	SRS	1.27×10^{-7}	7.74×10^{-7}	4.70×10^{-6}	6.1
Leaks	LK	SRS	6.98×10^{-7}	3.49×10^{-6}	1.75×10^{-5}	5.0
Fails to Open (hourly)	OH	SRS	1.27×10^{-7}	7.74×10^{-7}	4.70×10^{-6}	6.1
Transfers Closed	TC	IEEE-500	8.00×10^{-8}	7.81×10^{-7}	3.27×10^{-4}	5.0
Transfers Open	TO	IEEE-500	8.00×10^{-8}	7.81×10^{-7}	3.27×10^{-4}	5.0

The results of the industrial data search were documented in an industrial database, organized by UMCDF QRA TC and FM, an excerpt of which is shown in table 7-20.

7.5 Bayesian Updating

The Bayesian estimation method takes its name from the use of Bayes' theorem and the philosophical approach embodied in the 18th-century work of the Rev. Thomas Bayes (Bayes, 1958). This method is used to update the so-called "prior" distribution (often and in this case based on industrial data sources) with more directly applicable, but more sparse, facility-specific observed data (USNRC, 1983). The term "prior" reflects the distribution's description of the analyst's prior knowledge or opinions about the parameter.

In the particular case of the UMCDF QRA, the "observed data" consisted of the information obtained from the TOCDF MP2 maintenance records and the JACADS DORs.

Bayes' theorem was used to update the prior distributions with this facility-specific evidence, with the effect of "specializing" the prior to the specific facility, in this case, a CDF. The updated or specialized prior is called the "posterior distribution" because it can be derived only after the facility-specific evidence is incorporated. The prior reflects the analyst's degree of belief about the parameter before such evidence; the posterior represents the degree of belief after incorporating the evidence (USNRC, 1983).

It is important to note that this updating method is based on the premise that the industrial data and the data obtained from actual facility experience (in this case, TOCDF and JACADS), are from the same, or sufficiently similar, population to combine in the Bayesian manner. Figure 7-13 shows the steps in the updating process.

While Bayesian Updating was performed across the board on all data points for the QRA BE TCs, the decision as to whether to use these data for QRA quantification depended upon the analysis of the robustness and applicability of each input to the updated distribution.

In addition, the Bayesian Update strategy often yields a posterior distribution (i.e., the combined or updated distribution) whose dispersion (i.e., the ratio of the 95th percentile and the 5th percentile, or EF^2) is smaller than either input dispersion. For this reason, when the Updated value was selected as the Final value to be input to the QRA for a given component TC/FM Code, the data analysts sometimes elected to increase the lognormal error factor (EF) to 3 or 5. (Note: the calculated EF values for the Updated data are shown in table E2-4 of appendix E2 and the adjusted EF values are shown in appendix E2, table E2-5.) This was done to reflect the added uncertainty involved in the application of the posterior distribution based on industrial, TOCDF, and JACADS information to the specific case of UMCDF.

Table 7-20. Excerpt from Industrial Data Set

Type Code	Failure Mode Code	Component	Unit	Mean	Lower	Median	Upper	EF	Source[a]
BS	FH	Bus	H	2.40E-07	2.97E-08	1.49E-07	7.44E-07	5	800[b]
BT	FH	Battery	H	2.25-06	2.79E-07	1.39E-06	6.97E-06	5	141[c]
CB	CD	Circuit Breaker	H	1.00E-08	1.74E-10	2.59E-09	3.87E-08	14.9	108[b]
CB	OD	Circuit Breaker	D	1.16E-03	1.44E-04	7.19E-04	3.59E-03	5	144[c]
CB	TO	Circuit Breaker	H	4.00E-07					108[b]
CH	BK	Chiller	H	2.38E-04	2.95E-05	1.47E-04	7.37E-04	5	1390[b]
CH	FH	Chiller	H	2.38E-04	2.95E-05	1.47E-04	7.37E-04	5	1390[b]
CH	SD	Chiller	D						No data found
CL	FH	Clutch	H	2.26E-05	2.80E-06	1.40E-05	7.00E-05	5	537[d]
CN	BK	Condenser	H	7.76E-05	1.94E-05		1.03E-04		1374[d]
CN	RH	Condenser	H	7.76E-05	1.94E-05		1.03E-04		1374[d]
CN	SD	Condenser							No data found
CO	BK	Cooler	H	1.19E-06	1.47E-07	7.37E-07	3.69E-06	5	261[d]
CP	FH	Control Panel	H	5.73E-06	7.10E-07	3.55E-06	1.78E-05	5	148[c]
CV	CH	Check Valve	D	2.20E-03	2.73E-04	1.36E-03	6.82E-03	5	198[c]
CV	LK	Check Valve	H	5.63E-06	6.98E-07	3.49E-06	1.74E-06	5	90[e]
CV	OH	Check Valve	H	1.41E-06	1.27E-07	7.74E-07	4.70E-06	6.1	90[e]
CV	TC	Check Valve	H	1.26E-06	8.00E-08		3.27E-04		1080[d]
CY	FH	Conveyor	H	9.42E-04	1.64E-05	2.45E-04	3.64E-03		196[c]

Notes:

[a] Numbers in Source column reflect page number from which data were extracted.
[b] IEEE 500-1984
[c] American Institute of Chemical Engineers Guidelines for Process Equipment Reliability Data
[d] OREDA-92, Offshore Reliability Data Handbook
[e] Blanton and Eide, Savannah River Site Generic Database

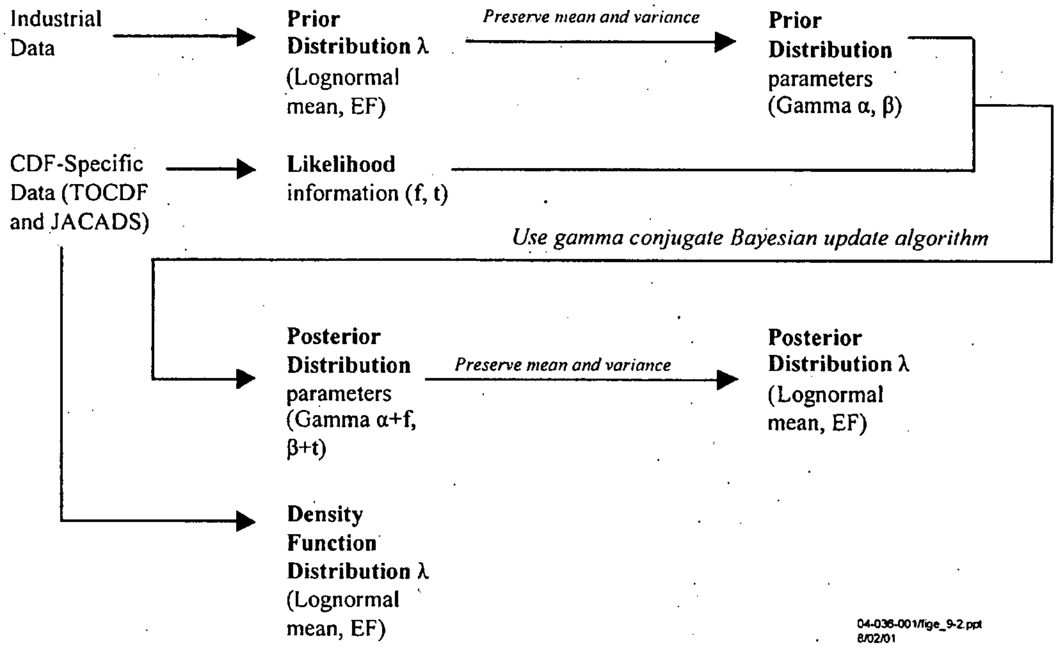


Figure 7-13. Bayesian Updating Process

Further details and formulae for the Bayesian Updating method are provided in appendix E9.

7.6 Data Comparison and Selection

The QRA data needs were based on a set of component TC and FM combinations extracted from the latest CAFTA fault tree model BE file and verified by the systems analysts. The data analysts attempted to compile data from three data source options (TOCDF, JACADS, and industrial data) for each of these 175 TC/FM combinations. Figure 7-14 demonstrates how many of these data needs were able to be addressed by each data source option, with TOCDF data available in 97 percent (169 out of 175) of the cases.

In 56 of these 175 cases (32 percent), two of these three data options were available, and in only six cases (4 percent) was just one data source available. As a result, a rare richness of data was available for each QRA model BE, albeit with varying applicability, certainty, and robustness. Bayesian Updating also was performed across the board, using the available input data sets. A decision on the part of the data analysts therefore was required to select among the available data to construct a final QRA database.

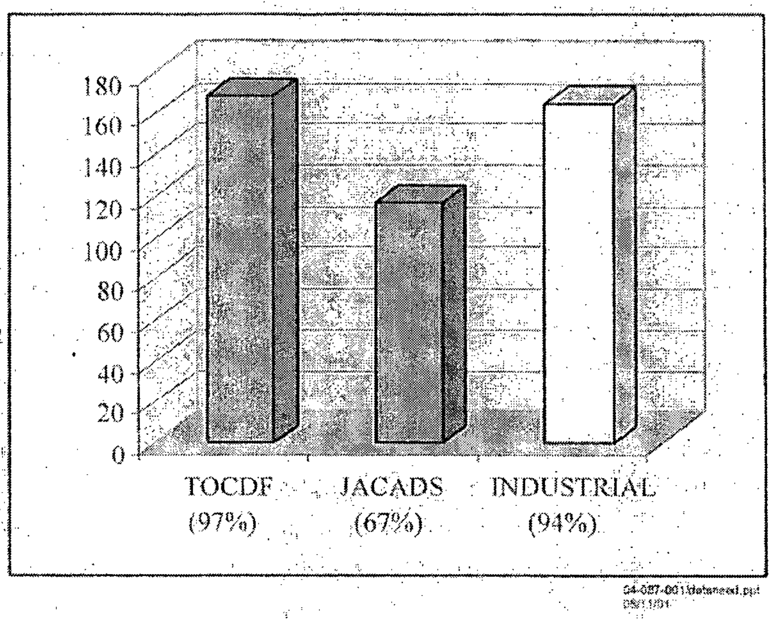


Figure 7-14. Applicability of Data Sources to UMCDF QRA Data Needs

7.6.1 Data Preparation. The data comparison spreadsheet in appendix E2, while a valuable means for summarizing the available information, was considered to be a rather unwieldy means for actually comparing the data. For its previous QRA/PRA database development projects, SAIC has translated the statistical information into lognormal plots of data distributions on a common axis. This visual presentation of the data has been found to be most useful in permitting the analysts to understand the degree of uncertainty surrounding each mean data point, as well as allowing the available data distributions to be cross-compared by eye. For the UMCDF QRA, this technique was further advanced by linking the appendix E2 spreadsheet containing the data to another Microsoft® Excel spreadsheet, which translated the data into a pivot table format. The pivot table feature of Microsoft® Excel allows the data to be organized into a pull-down menu, as shown in figure 7-15, in this case, by component TC and FM Code. This pivot table allows the user to select any TC/FM combination from the full data set and view the available data.

Then, the pivot table was linked to a lognormal plotting feature in Microsoft® Excel, as shown in figure 7-16, with the data plot changing automatically to reflect the data available for a given TC/FM selection made via the pull-down menu. As the figure shows, for each TC/FM combination, all available data were plotted in terms of lognormal distributions with tick marks for the lower and upper bounds (5th and 95th percentiles, respectively), as well as the mean and median (50th percentile) values. The entire set of these plots is provided in appendix E3.

TC	A3
FM	FH
Sum of Value	
Data Source	Total
BAYES Lower	1.58763E-05
BAYES Mean	2.16517E-05
BAYES Median	2.14853E-05
BAYES Upper	2.90759E-05
GEN Lower	0.000196
GEN Mean	0.00158
GEN Median	0.000979
GEN Upper	0.00489
JACADS Lower	3.3682E-05
JACADS Mean	4.76623E-05
JACADS Median	4.67277E-05
JACADS Upper	6.48262E-05
TOCDF Lower	1.603E-06
TOCDF Mean	4.28669E-06
TOCDF Median	3.75086E-06
TOCDF Upper	8.7766E-06
Grand Total	0.007944605

Figure 7-15. Pivot Table Pull-Down Menu by Type Code and Failure Mode

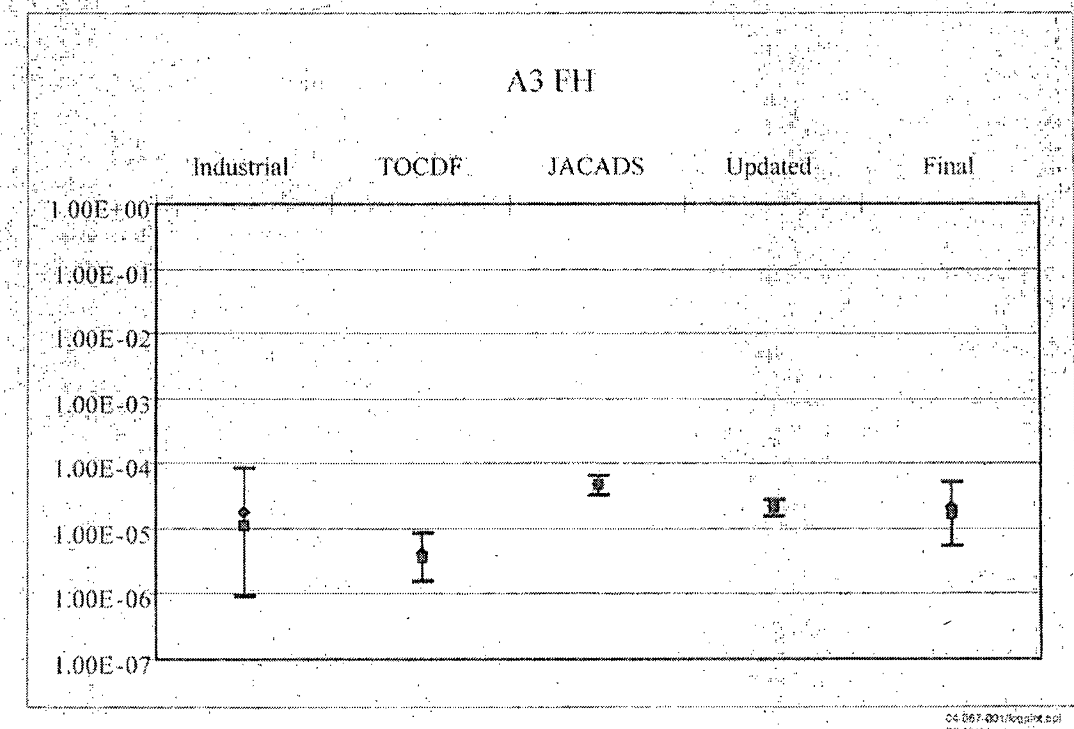


Figure 7-16. Example Data Distribution Comparison Lognormal Plot

The data comparison and decision-making process was conducted through a 2-day meeting using four data analysts. The entire set of lognormal plots for the UMCDF QRA TC/FMs was printed out so that the TOCDF, JACADS, industrial, and Bayesian Updated results could be visually compared side-by-side. The input data spreadsheets also were made available to the analysts to allow questions to be answered regarding the number of failures or amount of exposure for the CDF-specific data or the data source reference book used for the industrial data.

7.6.2 Guidelines for Data Decision Making. The guidelines shown in table 7-21 are a refinement of the guidance originally developed during the TOCDF Phase 2 QRA, based on observations of the analysts of their preferences and rationales during the data selection process between the JACADS and industrial data available at the time. These guidelines were provided to the team of data analysts, along with the data plot printouts and the input data spreadsheets, as an aid to the data decision-making process. More details on the guideline application results are provided in figures 7-17 through 7-19 and in appendix E2.

Table 7-21. Guidelines for Final Data Selection

Data Selection Guidelines
1. The specific data are considered to be appropriate, but the industrial data are not appropriate or available, so specific data are selected.
2. The industrial data are considered to be appropriate, but the specific data are not appropriate or available, so industrial data are selected.
3. Both industrial and specific data are considered appropriate and well-founded but they differ significantly. A decision between them is required based on: • Robustness and pedigree of the data (e.g., the number of failures experienced) • Amount of hours of experience in the denominator • Uncertainty bound.
4. The industrial and specific data distributions overlap, so a Bayesian Updated value combining them is used.
5. There is not a high degree of confidence (due to an error bound spread or an uncertain pedigree) in either the industrial or specific data, so the best analytical judgment must be made.

7.6.3 Data Selection Process. The plots were organized alphanumerically by TC and were divided equally amongst the four analysts, each of whom made a first cut determination of their data selections for each TC/FM combination in their packet, using the guidelines in table 7-21. These first cut selections were identified by circling the selected data distribution in red on each TC/FM plot printout. After the first cut selections had been made, a joint meeting was held among the four data analysts to discuss each selection and the rationale behind it, and to decide whether to reject or accept the selection. In some cases, questions were raised regarding the data, which required further investigation before the selection process could resume for that

Guideline Type	No. of Data Points
1. Specific	23
2. Industrial	18
3. Decision	40
4. Updated	83
5. Judgment	11
	175

04-036-001/fig_7-17.ppt
08/24/01

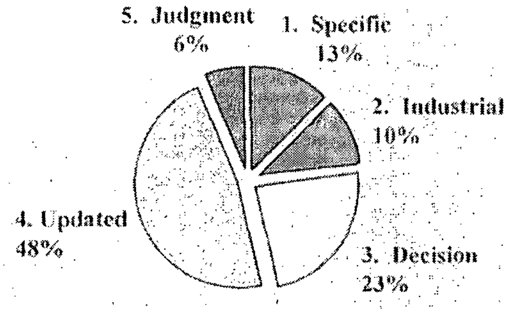


Figure 7-17. Guideline Use in Data Selection Process

3. Decision	
1. Specific	35
2. Industrial	0
4. Updated	5
	40

04-036-001/fig_7-18.ppt
08/24/01

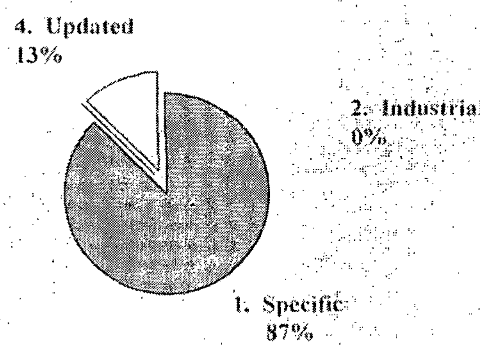
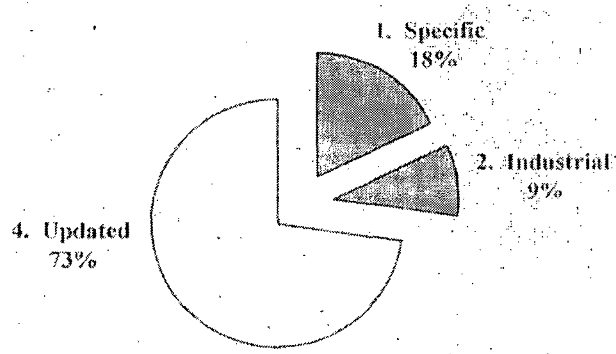


Figure 7-18. Data Selection Where Decision was Required

5. Judgment	
1. Specific	2
2. Industrial	1
4. Updated	8
	11



04-036-001/judreq.ppt
8/24/01

Figure 7-19. Data Selection Where Judgment was Required

TC/FM. For example, there might have been some question as to the equipment population or the accuracy of the number of failures. This was particularly the case for Rupture FM events, where the data analysts had originally considered the mode to reflect Leak/Rupture rather than complete Rupture, and for that reason the inclusion of leaks as failures in the numerators was driving the failure rate higher than would be expected for such a rare and catastrophic FM. These data points had to be revisited, the failure severity re-coded, the data recalculated, the spreadsheet revised, and the data plots re-generated.

7.6.4 Final Component Reliability Database. When the data set revisions had been made, based on analyst comments and questions, a second cut of decision making was made and was documented as the Final data selection for each TC/FM in the appropriate columns of the Final Component Reliability Database shown as table 7-22. The basis for the Final data (T, J, I, U for TOCDF, JACADS, industrial, or Updated, respectively) and the rationale behind each data selection also were documented for future reference. These data were provided to the systems analysts for the purposes of quantifying the QRA model.

Figure 7-17 shows the number of times each data selection guideline was applied to the available data for the 175 TC/FM combinations. In nearly half of the cases, it was decided to use all the available experience and to update the industrial and specific data together.

As figure 7-18 shows, in the instances where a decision was required among appropriate but diverse industrial and specific data (Guideline #3), a decision was made in the vast majority of the cases to use specific data (either TOCDF or both TOCDF and JACADS) and in no case were industrial data used alone. Data were combined by considering the data to be in the same population and therefore dividing the sum of the failures by the sum of the exposure data.

In the 11 cases when Guideline #5 was invoked, meaning that the best analytic judgment was required to decide among less robust data, the data were primarily Updated, as shown in figure 7-19.

The final data selection shown in table 7-22 for each data distribution used in the UMCDF QRA can be traced back to the input information through the tables in appendices E1 and E2, which in turn can be traced back to the input failures and exposures for the specific data (TOCDF and JACADS) given in appendices E4 through E7, which in turn can be traced back to the individual entries in the TOCDF MP2 database or the JACADS DORs. Similarly, the industrial data information can be traced via appendix E8 back to a particular page and entry in a given published source data book or report.

Table 7-22. Final Component Reliability Database

TC	FM	Component Name	Failure Mode Description	Final # Fails	Exposure	Mean	Lower	Median	Upper	EF	Basis	Rationale
A3	FH	ACAMS - TWA Room	Fails to Respond (Hourly)	58.6	2,772,514	2.11E-05	5.64E-06	1.69E-05	5.08E-05	3.0	U	Updated to use all available experience, but increased EF to 3 to reflect application uncertainty to other CDFs
A5	FH	ACAMS - Discharge Airlock (ACAMS-290)	Fails to Respond (Hourly)	2.3	133,002	1.73E-05	4.60E-06	1.38E-05	4.14E-05	3.0	U	Zero failure equivalent for industrial; specific data drove update, so updated to use all available experience, but increased EF to 3 to reflect application uncertainty to other CDFs
AB	FH	Air Bubbler	Fails to Operate	2.0	8,550	2.34E-04	3.55E-05	1.56E-04	6.86E-04	4.4	T	Only data available; specific to CDF environment
AC	RH	Air Compressor	Fails to Run (Hourly)	32.0	156,619	2.04E-04	5.45E-05	1.63E-04	4.90E-04	3.0	T+J	CDF experience; increased EF to 3 to reflect application uncertainty to other CDFs
AC	SD	Air Compressor	Fails to Start (Demand)	20.6	10,317	2.00E-03	5.33E-04	1.60E-03	4.80E-03	3.0	U	Updated to use all available experience, but increased EF to 3 to reflect application uncertainty to other CDFs
AD	BK	Air Dryer	Ruptures	0.4	670,640	5.23E-07	9.09E-09	1.36E-07	2.02E-06	14.9	I	Zero failures in JACADS and TOCDF and not in same range, so update not advisable
AD	FH	Air Dryer	Fails During Operation	5.0	81,364	6.15E-05	7.62E-06	3.81E-05	1.90E-04	5.0	T+J	CDF experience; increased EF to 5 to capture uncertainty range of inputs

Table 7-22. Final Component Reliability Database (Continued)

TC	FM	Component Name	Failure Mode Description	Final # Fails	Exposure	Mean	Lower	Median	Upper	EF	Basis	Rationale
AF	FH	Air Filter	Fails to Draw Air	23.3	374,396	6.24E-05	1.66E-05	4.99E-05	1.50E-04	3.0	U	Updated to use all available experience, but increased EF to 3 to reflect application uncertainty to other CDFs
AF	PG	Air Filter	Plugs	17.3	2,207,285	7.86E-06	2.10E-06	6.29E-06	1.89E-05	3.0	U	Updated to use all available experience, but increased EF to 3 to reflect application uncertainty to other CDFs
AH	BK	Air Header	Ruptures	0.3	3,819,727	9.10E-08	1.56E-09	2.35E-08	3.52E-07	15.0	I	Zero failures in TOCDF and not in same range, so update not advisable
AH	FH	Air Header	Fails to Maintain Pressure	2.3	273,929	8.57E-06	1.50E-06	6.01E-06	2.40E-05	4.0	T+I	Updated TOCDF and industrial to use all available experience, although zero failure equivalent for industrial and small denominator for TOCDF
AR	BK	Air Receiver	Ruptures	2.0	2,860,927	6.86E-07	1.02E-07	4.54E-07	2.02E-06	4.5	T+I	Updated TOCDF and industrial to use all available experience
AR	FH	Air Receiver	Fails to Supply Air	2.0	145,771	1.37E-05	2.08E-06	9.15E-06	4.02E-05	4.4	T	CDF experience
AS	BK	Air Separator	Break/ Rupture	2.0	9,206,040	2.13E-07	3.17E-08	1.41E-07	6.28E-07	4.5	T+I	Updated TOCDF and industrial to use all available experience
AU	BK	Accumulator (Pressurized Tank)	Break/ Rupture	2.0	1,079,890	1.82E-06	2.70E-07	1.20E-06	5.36E-06	4.5	T+I	Updated TOCDF and industrial to use all available experience

Table 7-22. Final Component Reliability Database (Continued)

TC	FM	Component Name	Failure Mode Description	Final # Fails	Exposure	Mean	Lower	Median	Upper	EF	Basis	Rationale
AV	CH	Air Operated Valve	Fails to Close (Hourly)	11.6	2,659,572	4.37E-06	1.17E-06	3.50E-06	1.05E-05	3.0	T+I	Updated TOCDF and industrial to use all available experience; increased EF to 3
AV	LK	Air Operated Valve	Leaks	5.1	2,353,443	2.15E-06	5.72E-07	1.72E-06	5.15E-06	3.0	T+I	Updated TOCDF and industrial to use all available experience; increased EF to 3
AV	OH	Air Operated Valve	Fails to Open (Hourly)	11.6	2,712,278	4.29E-06	1.14E-06	3.43E-06	1.03E-05	3.0	T+I	Updated TOCDF and industrial to use all available experience; increased EF to 3
AV	TC	Air Operated Valve	Transfers Closed	1.1	292,803	3.59E-06	2.78E-07	1.85E-06	1.23E-05	6.7	I	Zero failures in TOCDF and not in same range, so update not advisable
AV	TO	Air Operated Valve	Transfers Open	1.1	292,803	3.59E-06	2.78E-07	1.85E-06	1.23E-05	6.7	I	Zero failures in TOCDF and not in same range, so update not advisable
BB	BK	Burner Block	Ruptures	0.3	3,819,727	9.10E-08	1.56E-09	2.35E-08	3.52E-07	15.0	I	Zero failures in TOCDF and not in same range, so update not advisable
BO	BK	Boiler	Ruptures	0.7	393,756	1.73E-06	7.66E-08	7.00E-07	6.39E-06	9.1	T+I	Updated TOCDF and industrial to use all available experience (although both had equivalent of zero failures)
BO	RH	Boiler	Fails to Continue to Run	1.0	77,760	1.29E-05	9.27E-07	6.43E-06	4.46E-05	6.9	T	CDF experience; 1 failure

Table 7-22. Final Component Reliability Database (Continued)

TC	FM	Component Name	Failure Mode Description	Final								
				# Fails	Exposure	Mean	Lower	Median	Upper	EF	Basis	Rationale
BP	DF	Burner Management System	Fails to Detect and Control given Flame	41	156,596	2.62E-04	6.98E-05	2.09E-04	6.28E-04	3.0	T+J	CDF experience; increased EF to 3 to reflect application uncertainty to other CDFs
BP	FH	Burner Management System	Fails to Operate	51.0	156,596	3.26E-04	8.69E-05	2.61E-04	7.82E-04	3.0	T+J	CDF experience; increased EF to 3 to reflect application uncertainty to other CDFs
BP	TP	Burner Management System	Transfers Position	23.0	156,596	1.47E-04	3.92E-05	1.18E-04	3.53E-04	3.0	T+J	CDF experience; increased EF to 3 to reflect application uncertainty to other CDFs
BS	FH	Bus	Fails to Maintain Power	1.6	6,787,890	2.40E-07	2.97E-08	1.49E-07	7.44E-07	5.0	I	Insufficient CDF experience to build supportable electrical equipment failure data
BT	FH	Battery	Fails to Provide Output	1.6	724,042	2.25E-06	2.79E-07	1.39E-06	6.97E-06	5.0	I	Insufficient CDF experience to build supportable electrical equipment failure data
CB	CD	Circuit Breaker	Fails to Close (Demand)	18.6	11,312	1.65E-03	2.04E-04	1.04E-03	5.10E-03	5.0	U	Updated to use all available experience; increased EF to 5
CB	OD	Circuit Breaker	Fails to Open (Demand)	7.6	11,312	6.74E-04	8.36E-05	4.18E-04	2.09E-03	5.0	U	Updated to use all available experience; increased EF to 5
CB	TO	Circuit Breaker	Transfers Open	0.3	868,988	4.00E-07	6.88E-09	1.03E-07	1.55E-06	15.0	I	Numerous CDF failures, but uncertain as to validity, so selected well-founded industrial data

Table 7-22. Final Component Reliability Database (Continued)

TC	FM	Component Name	Failure Mode Description	Final # Fails	Exposure	Mean	Lower	Median	Upper	EF	Basis	Rationale
CH	BK	Chiller	Ruptures	4.3	162,544	2.67E-05	3.31E-06	1.66E-05	8.29E-05	5.0	U	Updated to use all available experience; increased EF to 5
CH	FH	Chiller	Fails to Continue Operating	28.6	157,802	1.81E-04	2.25E-05	1.12E-04	5.62E-04	5.0	U	Updated to reflect variety within industrial range; increased EF to 5
CH	SD	Chiller	Fails to Start	9.0	1,522	5.91E-03	1.58E-03	4.73E-03	1.42E-02	3.0	T+J	CDF experience; increased EF to 3 to reflect application uncertainty to other CDFs
CL	FH	Clutch	Fails to Disengage	1.6	72,084	2.26E-05	2.80E-06	1.40E-05	7.00E-05	5.0	I	Only data available
CN	BK	Condenser	Ruptures	2.0	98,754	1.99E-05	2.46E-06	1.23E-05	6.16E-04	5.0	T+I	Updated TOCDF and industrial; increased EF to 5
CN	RH	Condenser	Fails to Continue to Run	3.6	98,754	3.67E-05	4.55E-06	2.28E-05	1.14E-04	5.0	T+I	Updated TOCDF and industrial; increased EF to 5
CO	BK	Aftercooler	Break/ Rupture	3.0	1,802,278	1.64E-06	2.04E-07	1.02E-06	6.09E-06	5.0	U	Updated to use all available experience; increased EF to 5
CP	FH	Control Panel	Fails to Respond	33.0	427,424	7.72E-05	2.06E-05	6.18E-05	1.85E-04	3.0	T	CDF experience; 33 failures; increased EF to 3 to reflect uncertainty in application to other CDFs
CV	CH	Check Valve	Fails to Close (Hourly)	3.5	5,161,525	6.79E-07	8.42E-08	4.21E-07	2.10E-06	5.0	U	Updated to use all available experience; increased EF to 5
CV	LK	Check Valve	Leaks	15.6	4,596,166	3.40E-06	4.21E-07	2.11E-06	1.05E-05	5.0	U	Updated to use all available experience; increased EF to 5

Table 7-22. Final Component Reliability Database (Continued)

TC	FM	Component Name	Failure Mode Description	Final # Fails	Exposure	Mean	Lower	Median	Upper	EF	Basis	Rationale
CV	OH	Check Valve	Fails to Open (Hourly)	5.5	5,161,525	1.07E-06	1.32E-07	6.61E-07	3.30E-06	5.0	U	Updated to use all available experience; increased EF to 5
CV	TC	Check Valve	Transfers Closed	11.9	5,599.738	2.13E-06	2.64E-07	1.32E-06	6.60E-06	5.0	U	Updated to use all available experience; increased EF to 5
CV	TO	Check Valve	Transfers Open	12.9	5,599,738	2.31E-06	2.86E-07	1.43E-06	7.15E-06	5.0	U	Updated to use all available experience; increased EF to 5
CY	FH	Conveyor	Fails During Operation	163.4	1,286,110	1.27E-04	1.57E-05	7.87E-05	3.94E-04	5.0	U	Updated to use all available experience; increased EF to 5
DE	BK	Demister	Ruptures	3.0	252,070	1.18E-05	2.51E-06	8.79E-06	3.08E-05	3.5	U	Updated to use all available experience
DG	RH	Diesel Generator	Fails to Run	1.1	468	2.25E-03	1.70E-04	1.15E-03	7.72E-03	6.7	I	Insufficient CDF experience to build supportable electrical equipment failure data
DG	SD	Diesel Generator	Fails to Start (Demand)	1.6	93	1.76E-02	2.22E-03	1.09E-02	5.45E-02	5.0	I	Insufficient CDF experience to build supportable electrical equipment failure data
DT	BK	Duct	Break/ Rupture	2.0	12,686,587	1.55E-07	2.30E-08	1.02E-07	4.56E-07	4.5	T+I	Updated TOCDF and industrial
EJ	BK	Expansion Joint	Break/ Rupture	7.6	3,168,432	2.40E-06	2.97E-07	1.49E-06	7.43E-06	5.0	U	Updated to use all available experience; increased EF to 5
EL	DP	Elevator	Drops During Operation	10000.0	1.05E+15	9.51E-12	1.18E-12	5.89E-12	2.95E-11	5.0	I	Only data available

Table 7-22. Final Component Reliability Database (Continued)

TC	FM	Component Name	Failure Mode Description	Final # Fails	Exposure	Mean	Lower	Median	Upper	EF	Basis	Rationale
EL	FH	Elevator	Fails During Operation	11.0	38,857	2.83E-04	7.55E-05	2.27E-04	6.80E-04	3.0	T	CDF experience; 11 failures; increased EF to 3 to reflect uncertainty in application to other CDFs
EV	TC	Seismically-Actuated Valve	Transfers Closed	0.4	368,695	1.12E-06	2.47E-08	3.27E-07	4.32E-06	13.2	I	Only data available
FE	FH	Flow Element	Fails to Respond	8.3	4,175,135	2.00E-06	5.33E-07	1.60E-06	4.80E-06	3.0	U	Updated to use all available experience; increased EF to 3
FE	PG	Flow Element	Plugs	9.3	1,293,135	7.23E-06	8.96E-07	4.48E-06	2.24E-05	5.0	T+I	Updated TOCDF and industrial; increased EF to 5
FE	TH	Flow Element	Transfers High	5.0	4,164,272	1.20E-06	3.20E-07	9.61E-07	2.88E-06	3.0	T+J	CDF experience; set EF to 3 to reflect application uncertainty to other CDFs
FE	TL	Flow Element	Transfers Low	2.3	1,293,135	1.82E-06	3.18E-07	1.27E-06	5.09E-06	4.0	T+I	Updated TOCDF and industrial
FH	BK	Flexible Hose	Break/ Rupture	10.6	5,255,963	2.02E-06	2.50E-07	1.25E-06	6.25E-06	5.0	U	Updated to use all available experience; increased EF to 5
FH-G	BK	Flexible Hose – Furnaces	Break/ Rupture	1.3	1,977,403	6.41E-07	6.08E-08	3.58E-07	2.11E-06	5.9	U	Updated to use all available experience
FL	PG	Filter (Not Air)	Fails/Plugs	30.6	1,494,363	2.05E-05	2.54E-06	1.27E-05	6.35E-05	5.0	U	Updated to use all available experience; increased EF to 5
FN	RH	Motor-Driven Fan	Fails to Continue Running	23.0	226,479	1.02E-04	2.71E-05	8.13E-05	2.44E-04	3.0	T+J	CDF experience; set EF to 3 to reflect application uncertainty to other CDFs
FN	SD	Motor-Driven Fan	Fails to Start (Demand)	11.3	3,588	3.15E-03	8.40E-04	2.52E-03	7.56E-03	3.0	T+J	CDF experience; set EF to 3 to reflect application uncertainty to other CDFs

Table 7-22. Final Component Reliability Database (Continued)

TC	FM	Component Name	Failure Mode Description	Final								
				# Fails	Exposure	Mean	Lower	Median	Upper	EF	Basis	Rationale
FP	FH	Fire Protection Panel	Fails to Respond	10.5	944,515	1.11E-05	1.38E-06	6.89E-06	3.45E-05	5.0	U	Updated to use all available experience; increased EF to 5 to capture range of input experience
FP	TP	Fire Protection Panel	Transfers Position	67.0	330,480	2.03E-04	5.41E-05	1.62E-04	4.87E-04	3.0	T	CDF experience; increased EF to 3 to reflect uncertainty in application to other GDFs
FS	FH	Flow Switch	Fails to Respond	10.0	505,440	1.98E-05	5.28E-06	1.58E-05	4.75E-05	3.0	T	CDF experience; increased EF to 3 to reflect uncertainty in application to other CDFs
FS	TH	Flow Switch	Transfers High	3.0	505,440	5.94E-06	1.58E-06	4.75E-06	1.42E-05	3.0	T	CDF experience; increased EF to 3 to reflect uncertainty in application to other CDFs
FS	TL	Flow Switch	Transfers Low	2.9	4,048,030	7.25E-07	8.98E-08	4.49E-07	2.25E-06	5.0	U	Updated to use all available experience; increased EF to 5
FT	FH	Flow Transmitter	Fails to Respond	34.0	2,806,560	1.21E-05	3.23E-06	9.69E-06	2.91E-05	3.0	T+J	CDF experience; set EF to 3 to reflect application uncertainty to other CDFs
FT	TH	Flow Transmitter	Transfers High	13.0	1,769,040	7.35E-06	1.96E-06	5.88E-06	1.76E-05	3.0	T	CDF experience; increased EF to 3 to reflect uncertainty in application to other CDFs
FT	TL	Flow Transmitter	Transfers Low	19.0	1,769,040	1.07E-05	2.86E-06	8.59E-06	2.58E-05	3.0	T	CDF experience; increased EF to 3 to reflect uncertainty in application to other CDFs
GC	BK	Gas Cylinder	Ruptures	0.8	32,647,624	2.09E-08	9.25E-10	8.45E-09	7.71E-08	9.1	T+I	Updated TOCDF and industrial

Table 7-22. Final Component Reliability Database (Continued)

TC	FM	Component Name	Failure Mode Description	Final # Fails	Exposure	Mean	Lower	Median	Upper	EF	Basis	Rationale
GH	BK	Gas Reheater	Ruptures	0.3	91,766	3.79E-06	6.51E-08	9.77E-07	1.47E-05	15.0	I	No confidence in JACADS data
GT	DP	Gate	Drops During Operation	2.3	426,541	5.47E-06	9.54E-07	3.83E-06	1.54E-05	4.0	T+J	CDF experience; industrial pedigree uncertain
GT	FH	Gate	Fails to Respond	16.6	614,397	2.70E-05	3.35E-06	1.67E-05	8.37E-05	5.0	U	Updated to use all available experience; increased EF to 5
G2	CH	Blast Gate	Fails to Close (Hourly)	1.3	47,393	2.81E-05	2.82E-06	1.61E-05	9.16E-05	5.7	T+J	CDF experience; industrial pedigree uncertain
G2	OH	Blast Gate	Fails to Open (Hourly)	3.0	699,031	4.24E-06	5.25E-07	2.63E-06	1.31E-05	5.0	U	Updated to use all available experience; increased EF to 5
HM	BK	Hydraulic Valve Manifold	Ruptures	0.7	2,327,839	2.86E-07	1.23E-08	1.14E-07	1.06E-06	9.3	T+I	Updated TOCDF and industrial
HO	FH	Hoist	Fails During Operation	7.8	247,011	3.14E-05	3.90E-06	1.95E-05	9.74E-05	5.0	U	Updated to use all available experience; increased EF to 5
HU	RH	Air Handler	Fails to Continue to Run	10.0	136,080	7.35E-05	1.96E-05	5.88E-05	1.76E-04	3.0	T	Discarded JACADS since zero failures; increased EF to 3 to reflect uncertainty in application to other CDFs
HU	SD	Air Handler	Fails to Start	2.3	768	3.04E-03	1.50E-03	2.63E-03	8.72E-03	2.4	T+J	CDF experience
HX	FH	Heat Exchanger	Fails During Operation	4.6	313,108	1.47E-05	1.82E-06	9.11E-06	4.55E-05	5.0	U	Updated to use all available experience; increased EF to 5
HX	PG	Heat Exchanger	Plugs	3.9	313,108	1.26E-05	1.56E-06	7.79E-06	3.89E-05	5.0	U	Updated to use all available experience; increased EF to 5

Table 7-22. Final Component Reliability Database (Continued)

TC	FM	Component Name	Failure Mode Description	Final # Fails	Exposure	Mean	Lower	Median	Upper	EF	Basis	Rationale
IC	BK	Intercooler	Break/ Rupture	2.0	1,398,130	1.40E-06	2.09E-07	9.30E-07	4.14E-06	4.5	T+I	Updated TOCDF and industrial
IN	FH	Inverter	Fails to Provide Output	1.6	135,758	1.20E-05	1.49E-06	7.44E-06	3.72E-05	5.0	I	Only data available
LC	FH	Logic Controller (PLC)	Fails During Operation	46.0	1,125,746	4.09E-05	1.09E-05	3.27E-05	9.81E-05	3.0	T+J	CDF experience; set EF to 3 to reflect application uncertainty to other CDFs
L2	FH	Logic Controller (PLC) - Support Systems	Fails During Operation	8.0	424,844	1.88E-05	5.02E-06	1.51E-05	4.52E-05	3.0	T+J	CDF experience; set EF to 3 to reflect application uncertainty to other CDFs
LE	FH	Level Element	Fails to Respond	79.1	29,612,353	2.67E-06	3.31E-07	1.66E-06	8.28E-06	5.0	T+I	Updated TOCDF and industrial; increased EF to 5
LE	TL	Level Element	Transfers Low	82.1	29,612,353	2.77E-06	3.44E-07	1.72E-06	8.59E-06	5.0	T+I	Updated TOCDF and industrial; increased EF to 5
LS	FH	Level Switch	Fails to Respond	28.0	738,278	3.79E-05	1.01E-05	3.03E-05	9.10E-05	3.0	T	CDF experience; increased EF to 3 to reflect uncertainty in application to other CDFs
LS	TH	Level Switch	Transfers High	7.0	738,278	9.48E-06	2.53E-06	7.59E-06	2.28E-05	3.0	T	CDF experience; increased EF to 3 to reflect uncertainty in application to other CDFs
LS	TL	Level Switch	Transfers Low	16.0	738,278	2.17E-05	5.78E-06	1.73E-05	5.20E-05	3.0	T	CDF experience; increased EF to 3 to reflect uncertainty in application to other CDFs

Table 7-22. Final Component Reliability Database (Continued)

TC	FM	Component Name	Failure Mode Description	Final								
				# Fails	Exposure	Mean	Lower	Median	Upper	EF	Basis	Rationale
LT	FH	Level Transmitter	Fails to Respond	10.0	427,680	2.34E-05	6.24E-06	1.87E-05	5.61E-05	3.0	T	TOCDF had most current relevant CDF experience; increased EF to 3 to reflect uncertainty in application to other CDFs
LT	TH	Level Transmitter	Transfers High	16.0	427,680	3.74E-05	9.98E-06	2.99E-05	8.98E-05	3.0	T	TOCDF had most current relevant CDF experience; increased EF to 3 to reflect uncertainty in application to other CDFs
LT	TL	Level Transmitter	Transfers Low	7.0	427,680	1.64E-05	4.37E-06	1.31E-05	3.93E-05	3.0	T	TOCDF had most current relevant CDF experience; increased EF to 3 to reflect uncertainty in application to other CDFs
MD	TC	Fire (Motor) Damper	Transfers Closed	2.0	1,917,143	1.02E-06	1.52E-07	6.78E-07	3.02E-06	4.5	T+I	Updated TOCDF and industrial
ME	SD	Motor (Electric)	Fails to Start (Demand)	6.6	1,320,901	6.53E-06	1.74E-06	5.23E-06	1.57E-05	3.0	U	Updated to use all available experience; increased EF to 3
MH	SD	Motor (Hydraulic)	Fails to Start (Demand)	18.3	612,669	2.99E-05	7.99E-06	2.40E-05	7.19E-05	3.0	U	Updated to use all available experience; increased EF to 3
MO	TP	Motor Overload Switch	Transfers Position	1.0	58,285	1.72E-05	1.24E-06	8.58E-06	5.95E-05	6.9	T	Recommend screening with TOCDF
MP	LK	Motor-Driven Pump	Seals Leak	35.6	477,268	7.47E-05	1.99E-05	5.97E-05	1.79E-04	3.0	T+I	Updated TOCDF and industrial; increased EF to 3
MP	RH	Motor-Driven Pump	Fails to Continue Running	49.4	788,641	6.26E-05	1.67E-05	5.01E-05	1.50E-04	3.0	U	Updated to use all available experience; increased EF to 3

Table 7-22. Final Component Reliability Database (Continued)

TC	FM	Component Name	Failure Mode Description	Final # Fails	Exposure	Mean	Lower	Median	Upper	EF	Basis	Rationale
MP	SD	Motor-Driven Pump	Fails to Start (Demand)	18.6	5,983	3.11E-03	8.30E-04	2.49E-03	7.47E-03	3.0	U	Updated to use all available experience; increased EF to 3
MP-R	LK	Rotary Motor-Driven Pump (ACS)	Leak	2.0	112,261	1.75E-05	2.60E-06	1.16E-05	5.15E-05	4.5	T+I	Updated TOCDF and industrial; no JACADS available
MP-R	RH	Rotary Motor-Driven Pump (ACS)	Fails to Continue Running	6.6	112,261	5.91E-05	7.32E-06	3.66E-05	1.83E-04	5.0	T+I	Updated TOCDF and industrial; no JACADS available; increased EF to 5
MP-R	SD	Rotary Motor-Driven Pump (ACS)	Fails to Start (Demand)	3.3	656	5.08E-03	1.19E-03	3.91E-03	1.29E-02	3.3	T+I	Updated TOCDF and industrial; no JACADS available
MS	BK	Moisture Separator	Break/ Rupture	1.0	97,142	1.03E-05	2.75E-06	8.24E-06	2.47E-05	3.0	T	Selected CDF experience; increased EF to 3 to reflect uncertainty in application to other CDFs
MV	CH	Motor-Operated Valve	Fails to Close (Hourly)	7.0	2,065,689	3.37E-06	4.18E-07	2.09E-06	1.04E-05	5.0	U	Updated to use all available experience; increased EF to 5
MV	LK	Motor-Operated Valve	Leaks	4.0	2,065,689	1.92E-06	2.38E-07	1.19E-06	5.94E-06	5.0	U	Updated to use all available experience; increased EF to 5
MV	OH	Motor-Operated Valve	Fails to Open (Hourly)	7.6	2,065,689	3.69E-06	4.58E-07	2.29E-06	1.14E-05	5.0	U	Updated to use all available experience; increased EF to 5
MV	TC	Motor-Operated Valve	Transfers Closed	2.3	2,065,689	1.11E-06	1.38E-07	6.89E-07	3.44E-06	5.0	U	Updated to use all available experience; increased EF to 5
MV	TO	Motor-Operated Valve	Transfers Open	2.3	2,065,689	1.11E-06	1.38E-07	6.89E-07	3.44E-06	5.0	U	Updated to use all available experience; increased EF to 5

Table 7-22. Final Component Reliability Database (Continued)

TC	FM	Component Name	Failure Mode Description	Final # Fails	Exposure	Mean	Lower	Median	Upper	EF	Basis	Rationale
NG	FH	Natural Gas Detector	Fails to Respond	13.0	38,857	3.35E-04	8.92E-05	2.68E-04	8.03E-04	3.0	T	Selected CDF experience; increased EF to 3 to reflect uncertainty in application to other CDFs
NZ	FH	Spray Nozzle	Failure	4.0	976,215	4.10E-06	5.08E-07	2.54E-06	1.27E-05	5.0	T+J	Selected CDF experience; set EF to 5 to reflect application uncertainty to other CDFs
OC	BK	Oil Cooler	Ruptures	0.7	20,334	3.35E-05	4.15E-06	2.07E-05	1.04E-04	5.0	T+I	Updated TOCDF and industrial; increased EF to 5
OM	FH	Oxygen Monitor	Fails to Respond	14.0	273,421	5.11E-05	6.33E-06	3.16E-05	1.58E-04	5.0	U	Variable CDF experience, uncertain applicability of industrial; updated to use all available experience; increased EF to 5
OM	TH	Oxygen Monitor	Transfers High	14.0	273,421	5.11E-05	6.33E-06	3.16E-05	1.58E-04	5.0	U	Variable CDF experience, uncertain applicability of industrial; updated to use all available experience; increased EF to 5
OM	TL	Oxygen Monitor	Transfers Low	5.0	278,758	1.78E-05	2.21E-06	1.10E-05	5.52E-05	5.0	U	Variable CDF experience, uncertain applicability of industrial; updated to use all available experience; increased EF to 5
OS	BK	Oil Separator	Ruptures	0.6	3,339,648	1.80E-07	2.00E-08	6.76E-08	8.10E-07	10.0	I	Only data available
PD	CH	Pneumatic Damper	Fails to Close (Hourly)	21.6	4,050,876	5.34E-06	2.00E-06	4.27E-06	1.28E-05	3.0	U	Updated to use all available experience; increased EF to 3
PD	LK	Pneumatic Damper	Leaks	4.1	3,744,747	1.08E-06	2.89E-07	8.66E-07	2.60E-06	3.0	U	Updated to use all available experience; increased EF to 3

Table 7-22. Final Component Reliability Database (Continued)

TC	FM	Component Name	Failure Mode Description	Final								
				# Fails	Exposure	Mean	Lower	Median	Upper	EF	Basis	Rationale
PD	OH	Pneumatic Damper	Fails to Open (Hourly)	22.6	4,103,582	5.51E-06	1.47E-06	4.41E-06	1.32E-05	3.0	U	Updated to use all available experience; increased EF to 3
PD	TC	Pneumatic Damper	Transfers Closed	7.4	3,744,747	1.97E-06	5.26E-07	1.58E-06	4.73E-06	3.0	U	Updated to use all available experience; increased EF to 3
PD	TO	Pneumatic Damper	Transfers Open	10.1	3,744,747	2.68E-06	7.16E-07	2.15E-06	6.44E-06	3.0	U	Updated to use all available experience; increased EF to 3
PP	BK	Pipe	Leak/Break/Rupture	0.9	102,523,268	9.11E-09	6.05E-10	4.40E-09	3.20E-08	7.3	T+I	Updated TOCDF and industrial
PP	PG	Pipe	Plugs	30.3	80,092,800	3.79E-07	1.01E-07	3.03E-07	9.09E-07	3.0	T	CDF experience; increased EF to 3 to reflect uncertainty in application to other CDFs
PS	FH	Pressure Switch	Fails to Respond	36.0	3,148,714	1.14E-05	3.05E-06	9.15E-06	2.74E-05	3.0	T+J	CDF experience; set EF to 3 to reflect application uncertainty to other CDFs
PS	TH	Pressure Switch	Transfers High	8.3	3,148,714	2.65E-06	7.06E-07	2.12E-06	6.35E-06	3.0	T+J	CDF experience; set EF to 3 to reflect application uncertainty to other CDFs
PS	TL	Pressure Switch	Transfers Low	4.3	3,148,714	1.38E-06	3.67E-07	1.10E-06	3.30E-06	3.0	T+J	CDF experience; set EF to 3 to reflect application uncertainty to other CDFs
PT	FH	Pressure Transmitter	Fails to Respond	14.0	3,004,304	4.66E-06	1.24E-06	3.73E-06	1.12E-05	3.0	T+J	CDF experience; set EF to 3 to reflect application uncertainty to other CDFs
PT	TH	Pressure Transmitter	Transfers High	16.0	3,004,304	5.33E-06	1.42E-06	4.26E-06	1.28E-05	3.0	T+J	CDF experience; set EF to 3 to reflect application uncertainty to other CDFs

Table 7-22. Final Component Reliability Database (Continued)

TC	FM	Component Name	Failure Mode Description	Final								
				# Fails	Exposure	Mean	Lower	Median	Upper	EF	Basis	Rationale
PT	TL	Pressure Transmitter	Transfers Low	13.0	3,004,304	4.33E-06	1.15E-06	3.46E-06	1.04E-05	3.0	T+J	CDF experience; set EF to 3 to reflect application uncertainty to other CDFs
PV	TC	Pressure Control Valve	Transfers Closed	3.6	3,081,029	1.18E-06	1.46E-07	7.30E-07	3.65E-06	5.0	T+I	Updated TOCDF and industrial; increased EF to 5
PV	TO	Pressure Control Valve	Transfers Open	6.6	3,081,029	2.15E-06	2.67E-07	1.33E-06	6.67E-06	5.0	T+I	Updated TOCDF and industrial; increased EF to 5
QT	BK	Quench Tower	Leak/Break/Rupture	0.7	65,540	1.02E-05	4.39E-07	4.07E-06	3.77E-05	9.3	T+J	Not very good CDF experience, but could not find industrial data
RC	FH	Rectifier	Fails to Provide Output	0.3	1,158,651	3.00E-07	5.16E-09	7.74E-08	1.16E-06	15.0	I	Insufficient CDF experience to build supportable electrical equipment failure data
RL	TP	Relay	Transfers Position	6.6	10,280,369	6.45E-07	7.99E-06	4.00E-07	2.00E-06	5.0	U	Updated to use all available experience; increased EF to 5
RV	OH	Relief Valve	Fails to Open (Hourly)	1.7	1,726,045	9.74E-07	2.60E-07	7.79E-07	2.34E-06	3.0	U	Updated to use all available experience; increased EF to 3
RV	TO	Relief Valve	Transfers Open	5.7	4,140,570	1.37E-06	3.66E-07	1.10E-06	3.29E-06	3.0	U	Decided data were similar enough to update; increased EF to 3
SB	BK	Scrubber Tower	Break/ Rupture	0.3	29,143	1.14E-05	1.85E-07	2.86E-06	4.42E-05	15.5	T	CDF experience
SC	BK	Venturi Scrubber	Break/ Rupture	0.7	45,683	1.46E-05	6.29E-07	5.84E-06	5.41E-05	9.3	T+J	CDF experience
SC	CH	Venturi Scrubber	Excessive Throttle/ Closure	2.0	45,683	4.38E-05	6.64E-06	2.92E-05	1.28E-04	4.4	T+J	CDF experience

Table 7-22. Final Component Reliability Database (Continued)

TC	FM	Component Name	Failure Mode Description	Final # Fails	Exposure	Mean	Lower	Median	Upper	EF	Basis	Rationale
SL	FH	Scissors Lift	Fails During Operation	10.6	91,116	1.17E-04	1.45E-05	7.33E-05	3.61E-04	5.0	U	Updated to use all available experience; increased EF to 5
ST	BK	Strainer	Break/ Rupture	12.6	4,204,617	3.00E-06	3.71E-07	1.86E-06	9.29E-06	5.0	U	Updated to use all available experience; increased EF to 5
ST	PG	Strainer	Plugs	78.6	3,366,133	2.34E-05	2.89E-06	1.45E-05	7.33E-05	5.0	U	Updated to use all available experience; increased EF to 5
SV	CH	Solenoid Valve	Fails to Close (Hourly)	16.6	11,382,139	1.46E-06	1.81E-07	9.04E-07	4.52E-06	5.0	U	Although industrial and specific data differ, specific data drive the update, so updated for consistency with other FMs of this TC; increased EF to 5
SV	LK	Solenoid Valve	Leaks	5.0	8,683,152	5.71E-07	7.08E-08	3.54E-07	1.77E-06	5.0	U	Although industrial and specific data differ, specific data drive the update, so updated for consistency with other FMs of this TC; increased EF to 5
SV	OH	Solenoid Valve	Fails to Open (Hourly)	14.6	11,382,139	1.28E-06	1.59E-07	7.95E-07	3.97E-06	5.0	U	Although industrial and specific data differ, specific data drive the update, so updated for consistency with other FMs of this TC; increased EF to 5
SV	TC	Solenoid Valve	Transfers Closed	3.0	12,632,814	2.34E-07	2.91E-08	1.45E-07	7.36E-07	5.0	U	Updated to use all available experience; increased EF to 5

Table 7-22. Final Component Reliability Database (Continued)

TC	FM	Component Name	Failure Mode Description	Final # Fails	Exposure	Mean	Lower	Median	Upper	EF	Basis	Rationale
SV	TO	Solenoid Valve	Transfers Open	4.0	12,632,814	3.14E-07	3.89E-08	1.94E-07	9.72E-07	5.0	U	Updated to use all available experience; increased EF to 5
SW	TD	Static Transfer Switch	Fails to Transfer (Demand)	1.6	5,324	3.06E-04	6.69E-05	2.31E-04	7.95E-04	5.0	I	Insufficient CDF experience to build supportable electrical equipment failure data; increased EF to 5
TE	FH	Temp. Element/ Thermocouple	Fails to Operate	132.0	4,756,000	2.78E-05	7.40E-06	2.22E-05	6.66E-05	3.0	T+J	CDF experience; set EF to 3 to reflect application uncertainty to other CDFs
TE	TH	Temp. Element/ Thermocouple	Transfers High	17.0	4,756,000	3.57E-06	9.53E-07	2.86E-06	8.58E-06	3.0	T+J	CDF experience; set EF to 3 to reflect application uncertainty to other CDFs
TE	TL	Temp. Element/ Thermocouple	Transfers Low	26.0	4,756,000	5.47E-06	1.46E-06	4.37E-06	1.31E-05	3.0	T+J	CDF experience; set EF to 3 to reflect application uncertainty to other CDFs
TK	BK	Tank	Break/ Rupture	0.6	120,227,304	5.00E-09	1.88E-10	1.88E-09	1.88E-08	10.0	I	Insufficient CDF experience
TR	FH	Transformer	Fails to Maintain Power	2.7	1,177,625	2.33E-06	2.88E-07	1.44E-06	7.31E-06	5.0	U	Updated to use all available experience; increased EF to 5
TS	FH	Temperature Switch	Fails to Respond	17.0	3,356,320	5.07E-06	1.35E-06	4.05E-06	1.22E-05	3.0	T+J	Good CDF experience; set EF to 3 to reflect application uncertainty to other CDFs
TS	TH	Temperature Switch	Transfers High	4.0	6,026,966	6.57E-07	8.15E-08	4.07E-07	2.04E-06	5.0	U	Updated to use all available experience; increased EF to 5
TS	TL	Temperature Switch	Transfers Low	3.0	6,026,966	4.91E-07	6.09E-08	3.05E-07	1.52E-06	5.0	U	Updated to use all available experience; increased EF to 5

Table 7-22. Final Component Reliability Database (Continued)

TC	FM	Component Name	Failure Mode Description	Final # Fails	Exposure	Mean	Lower	Median	Upper	EF	Basis	Rationale
TT	FH	Temperature Transmitter	Fails to Respond	33.0	2,293,920	1.44E-05	3.84E-06	1.15E-05	3.45E-05	3.0	T	CDF experience; increased EF to 3 to reflect uncertainty in application to other CDFs
TT	TH	Temperature Transmitter	Transfers High	18.0	2,293,920	7.85E-06	2.09E-06	6.28E-06	1.88E-05	3.0	T	CDF experience; increased EF to 3 to reflect uncertainty in application to other CDFs
TT	TL	Temperature Transmitter	Transfers Low	11.0	2,293,920	4.80E-06	1.28E-06	3.84E-06	1.15E-05	3.0	T	CDF experience; increased EF to 3 to reflect uncertainty in application to other CDFs
VL	FH	Conveyor Lift	Fails During Operation	4.0	3,646	1.10E-03	2.93E-04	8.78E-04	2.63E-03	3.0	T	Used CDF experience instead of industrial with questionable applicability
VS	FH	Vibration Switch	Fails to Respond	3.0	1,237,360	2.42E-06	6.47E-07	1.94E-06	5.82E-06	3.0	T+J	CDF experience; set EF to 3 to reflect application uncertainty to other CDFs
VS	TH	Vibration Switch	Transfers High	6.0	660,960	9.08E-06	3.12E-06	7.78E-06	1.94E-05	2.5	T	CDF experience
WE	FH	Weight Element	Fails to Operate	2.0	155,520	1.29E-05	1.95E-06	8.57E-06	3.77E-05	4.4	T	CDF experience
XR	BK	Manual Gas Regulator Valve	Ruptures (Regulator Fails)	1.6	9,382,788	1.71E-07	2.08E-08	1.05E-07	5.31E-07	5.1	T+I	Updated TOCDF and industrial
XS	BK	Manual Shutoff Valve	Ruptures	0.9	54,431,064	1.72E-08	1.14E-09	8.29E-09	6.03E-08	7.3	T+I	Updated TOCDF and industrial
XV	CH	Manual Valve	Fails to Close (Hourly)	3.3	28,680,824	1.14E-07	1.41E-08	7.06E-08	3.53E-07	5.0	T+I	Updated TOCDF and industrial; increased EF to 5

Table 7-22. Final Component Reliability Database (Continued)

TC	FM	Component Name	Failure Mode Description	Final # Fails	Exposure	Mean	Lower	Median	Upper	EF	Basis	Rationale
XV	LK	Manual Valve	Leaks	5.3	28,680,824	1.84E-07	2.28E-08	1.14E-07	5.69E-07	5.0	T+I	Updated TOCDF and industrial; increased EF to 5
XV	OH	Manual Valve	Fails to Open	4.3	28,680,824	1.49E-07	1.84E-08	9.22E-08	4.61E-07	5.0	T+I	Updated TOCDF and industrial; increased EF to 5
XV	TC	Manual Valve	Transfers Closed	3.3	28,680,824	1.14E-07	1.41E-08	7.06E-08	3.53E-07	5.0	T+I	Updated TOCDF and industrial; increased EF to 5
XV	TO	Manual Valve	Transfers Open	2.3	28,680,824	7.90E-08	9.79E-09	4.90E-08	2.45E-07	5.0	T+I	Updated TOCDF and industrial; increased EF to 5
ZO	FH	Position Sensor	Fails to Respond	60.6	13,069,554	4.64E-06	1.24E-06	3.71E-06	1.11E-05	3.0	U	Updated to use all available experience; increased EF to 3
ZO	OP	Position Sensor	Out of Position	51.6	13,069,554	3.95E-06	1.05E-06	3.16E-06	9.48E-06	3.0	U	Updated to use all available experience; increased EF to 3
ZS	FH	Position Switch	Fails to Respond	26.0	29,115,273	8.93E-07	2.38E-07	7.14E-07	2.14E-06	3.0	T+J	Although CDF distributions did not overlap, decided to combine to get benefit of all CDF experience; set EF to 3 to reflect application uncertainty to other CDFs
ZS	TP	Position Switch	Transfers Position	6.0	29,115,273	2.06E-07	5.50E-08	1.65E-07	4.95E-07	3.0	T+J	Although CDF distributions did not overlap, decided to combine to get benefit of all CDF experience; set EF to 3 to reflect application uncertainty to other CDFs

7.7 Insights and Recommendations

The UMCDF QRA effort used a significant amount of CDF-specific data in the Final Component Reliability Database. As figure 7-20 shows, 89 percent of the TC/FM combinations were quantified using data from the TOCDF MP2 maintenance records and 53 percent were populated with JACADS data. To complement and supplement these facility-specific data, other industry source information was used in 66 percent of the cases.

These percentages reflect every instance in which the respective data source was used, whether individually or in combination with the other data alternatives. Figure 7-21 provides additional detail as to the percentage of use of CDF-specific data on their own, industrial data on their own, or a combination of industrial and specific data. As shown, in over half the cases the analysts decided to use a combination of general industry data with the CDF-specific data, using the Bayesian Updating process, to take advantage of the maximum information available. These decisions, however, were based upon careful review of the nature and content of the individual distributions and whether there was justification on the basis of data and equipment similarity to combine the data together.

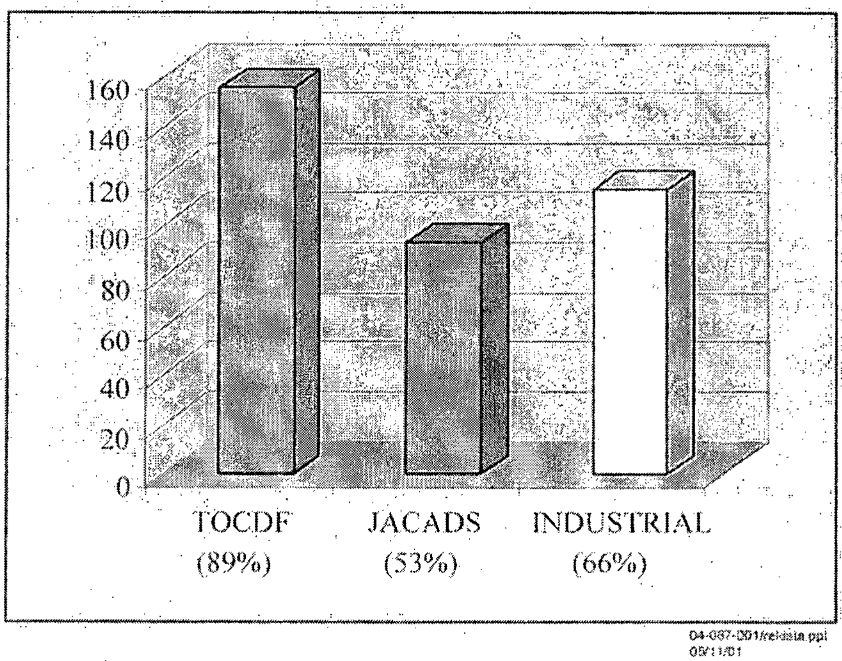


Figure 7-20. Data Use in Final Component Reliability Database

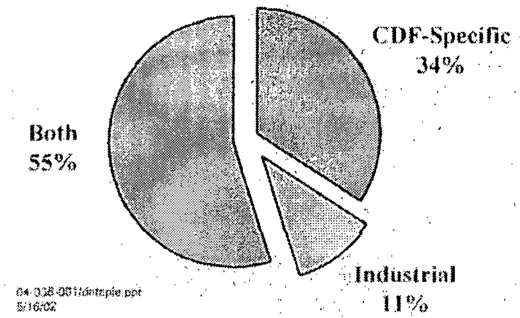


Figure 7-21. Specific Versus Industrial Data Use in Final Component Reliability Database

An even more detailed breakdown of the data use decision making is given in figure 7-22, which shows that in the vast majority of cases, a Bayesian Updated combination of TOCDF, JACADS, and industrial data was used.

7.8 Preventive Maintenance Unavailability Data

The failure rates shown in table 7-22 reflect the likelihood of CDF equipment being unavailable to function when needed due to CM. In order to be complete, the QRA also took into account the likelihood of certain equipment being unavailable due to PM or scheduled maintenance. During the course of fault tree modeling, the systems analysts identified the equipment impacted

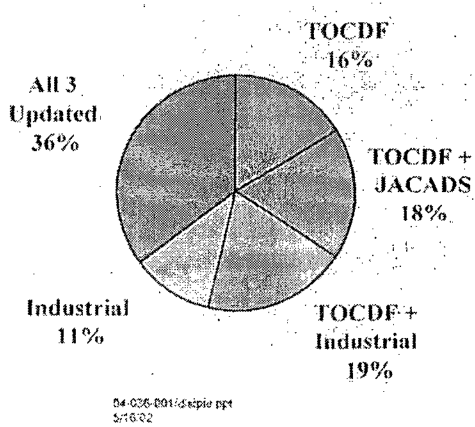


Figure 7-22. Distribution of Data Use in Final Component Reliability Database

by PM unavailability in their models and in the TC/FM code list with the FM Code of "MA." The data analysts were provided with the BE file and identified those component types for which MA data were needed, resulting in the list shown as table 7-23.

Table 7-23. Component Types Requiring Maintenance Unavailability Data

TC	FM	Component Type	Component(s) Modeled
AC	MA	Air Compressor	IAS-COMP-102**-IA
			LSS-COMP-102**-LS
			PLA-COMP-102**-PA
AD	MA	Air Dryer	LSS-DRYO-102**-LS
AU	MA	Hydraulic Accumulator	EHM-HYPU-106**-HY
DG	MA	Diesel Generator	PPS-GENX-101**-EP
			PPS-GENX-102**-EP
FN	MA	Motor-Driven Fan	PCS-COOL-101B*-PC
HU	MA	Air Handling Unit	HVC-AIRH-110**-HV
IN	MA	Inverter	SPS-UPS*-101**-EP
			SPS-UPS*-102**-EP
MP	MA	Motor-Driven Pump	CHW-PUMP-102**-HY
			PAS-PUMP-103**-MP
			PAS-PUMP-212**-LC
			PCS-PUMP-102**-PC
			PRW-PUMP-103**-PW
			SCW-PUMP-104**-HY

Using this list, a search was made of the TOCDF MP2 database section related to PM to identify the frequency of PM per component. The PMs were logged much like the CM in that an individual record was entered into the MP2 database each time maintenance was scheduled and performed. The PM records indicated the frequency with which a given maintenance was performed (e.g., weekly, monthly, annually, or semiannually). This database was searched by the component identification numbers in table 7-23 and the PM frequency was recorded, as shown in table 7-24. The number of PM activities on a yearly basis were determined (e.g., weekly PMs were 52 times per year and monthly PMs 12 times per year). These values by component type were summed together to provide the total PM per year. The PM per-year value then was multiplied by 2.25 to obtain the total PMs per component in the TOCDF data window of 27 months (2.25 years).

Table 7-24. Preventive Maintenance Frequency by Component Type

TC	FM	Component	MP2 PM Frequency	PM - Yearly Basis	Total PM Per Year	Total PM In Data Window
AC	MA	IAS-COMP-102**-IA	Weekly, Monthly, Annual, Semiannual PM	52+12+1+0.5	65.5	147.375
AC	MA	LSS-COMP-102**-LS	Weekly, Monthly, Annual, Semiannual PM	52+12+1+0.5	65.5	147.375
AC	MA	PLA-COMP-102**-PA	Weekly, Monthly, Annual PM	52+12+1	65	146.25
AD	MA	LSS-DRYO-102**-LS	Monthly PM	12	12	27
AU	MA	EHM-HYPU-106**-HY	Weekly PM	52	52	117
DG	MA	PPS-GENX-101**-EP	None Cited, but Assumed Monthly PM	12	12	27
DG	MA	PPS-GENX-102**-EP	None Cited, but Assumed Monthly PM	12	12	27
FN	MA	PCS-COOL-101B*-PC	None Cited, but Assumed Same as Monthly PM on 101A	12	12	27
HU	MA	HVC-AIRH-110**-HV	Monthly, Annual PM	12+1	13	29.25
IN	MA	SPS-UPS*-101**-EP	Monthly, Annual PM	12+1	13	29.25
IN	MA	SPS-UPS*-102**-EP	Monthly, Annual PM	12+1	13	29.25
MP	MA	CHW-PUMP-102**-HY	None Cited, but Assumed Weekly as for Other Pumps	52	52	117
MP	MA	PAS-PUMP-103**-MP	Weekly PM	52	52	117
MP	MA	PAS-PUMP-212**-LC	Weekly PM	52	52	117
MP	MA	PCS-PUMP-102**-PC	Weekly PM	52	52	117
MP	MA	PRW-PUMP-103**-PW	Weekly PM	52	52	117
MP	MA	SCW-PUMP-104**-HY	Weekly PM	52	52	117

The unavailability of a component type (say pumps) across a facility is usually obtained by summing the outage times and then dividing by the population to get the average outage time for the component and dividing by the total time (which is the same as summing the outage times and dividing by the population times the total time, which is the denominator for the failure rate calculation). Because individual outage times were not available in this case, a combined outage time per component type was estimated by summing the total PMs in the data window and multiplying this sum by the population of components in the TC, then multiplying this value by an outage time per PM of one-half hour (0.5 hour), based solely on the data analyst's judgment. The resulting outage time estimate was divided by the population times the exposure time (exposure hours times population), as shown in the figure 7-23 example for air handlers (HU TC). For the PM unavailabilities, the exposure time was always taken to be the calendar hours in the TOCDF data window, because it was presumed that PM could have been performed at any time rather than just during operational time.

Type Code	Mode Code	Component Name	Failure Mode
HU	MA	AIR HANDLER	MAINTENANCE UNAVAIL.

Population	
TOTAL	16
PREVENTIVE MAINTENANCE	
PMs per component in data window	29.25
Total PMs for all components	468
Total PMs/exposure	1.50E-03
Mean PM outage time (Est.) in hrs	0.5
EXPOSURE	
CALENDAR	19,440
TOTAL PER COMPONENT	19,440
NO. OF COMPONENTS	16
TOTAL EXPOSURE	311,040
PM Unavailability Rate	**7.52E-04**

Figure 7-23. Example Preventive Maintenance Frequency Calculation

A summary of the PM unavailability rates by component type is shown in table 7-25; calculation worksheets by individual component type are provided in appendix E10. The distribution information was calculated using the lognormal distribution parameter formulae discussed in appendix E9, with an assumed EF of 3 based on the data analysts' judgment.

Table 7-25. Preventive Maintenance Unavailability Rate by Component Type

Type Code	Component Type	Mean	Lower	Median	Upper	EF
AC	Air Compressor	3.79E-03	1.01E-03	3.03E-03	9.10E-03	3.0
AD	Air Dryer	6.94E-04	1.85E-04	5.56E-04	1.67E-03	3.0
AU	Hydraulic Accumulator	3.01E-03	8.03E-04	2.41E-03	7.22E-03	3.0
DG	Diesel Generator	6.94E-04	1.85E-04	5.56E-04	1.67E-03	3.0
FN	Motor-Driven Fan	6.94E-04	1.85E-04	5.56E-04	1.67E-03	3.0
HU	Air Handling Unit	7.52E-04	2.01E-04	6.02E-04	1.81E-03	3.0
IN	Inverter	7.52E-04	2.01E-04	6.02E-04	1.81E-03	3.0
MP	Motor-Driven Pump	3.01E-03	8.03E-04	2.41E-03	7.22E-03	3.0

7.9 Probabilities of Degraded Munitions

The calculation of munition response to an impact or drop includes consideration of the potential that the munition is already in a degraded state, meaning that its ability to contain its contents is compromised. Therefore, this section of the data report documents the calculation of the probability of encountering a degraded or leaking munition of a given type, to support the assessment of munition fragilities.

7.9.1 Input Data. Calculations of degraded munition probability were based on the number of leaking munitions of a given type divided by the amounts of these munitions stockpiled at the various national locations. This detailed information is provided in appendix E11, summarized in table E11-2. The number of leaking munitions was primarily obtained from leaker reports compiled by the U.S. Army Soldier and Biological Chemical Command (SBCCOM) Stockpile Tracking System (STS) for the years 1971 to August 2001 (SBCCOM, 2001). The munition stockpile inventories were based on declassified numbers provided by the U.S. Army (Blackwell, 1995) as well as information from SBCCOM on the original stockpile of weapons stored on Johnston Island. The U.S. Army and SBCCOM information is included in appendix E11.

7.9.2 Assumptions. In this analysis, all reports of leaking munitions were assumed to be applicable to the consideration of a munition being degraded when evaluated for an impact or drop. Vapor, liquid and exudate leaker information was used, under the premise that leakage of any sort was indicative of munition degradation that could be exacerbated by a subsequent physical insult such as a drop or impact. Due to the extensive nature of the calculations for munition response to drops and impacts, it was not considered practical to account for every munition, agent, and site combination. Rather, the average value of the leakage rate over the entire stockpile was used regardless of chemical agent fill with the exception of one munition, M55 rockets. The leakage rate was separated based on agent fill for the M55 rockets due to the substantial differences in leakage between rockets with a GB or VX fill. Although stockpile averages were used for the munition fragility calculations, site-specific data were available for direct use in other QRA models, such as the APET.

When the data indicated no leakage experience, it was assumed that the leakage rate was (1/3)N (Welker and Lipow, 1974), where N is total number of munitions of the type under consideration (i.e., in the stockpile) and 1/3 is the failure estimator.

7.9.3 Analysis Methods and Calculations. Previous munition fragility analyses were performed using the leaking munition experience data set compiled by the MITRE Corporation (AMCCOM, 1994). The MITRE data set was compared to the SBCCOM STS data set to determine whether any discrepancies existed. Based on this comparison, the SBCCOM database was used for the degraded munition probability calculations because it is more current (up to

August 2001) and contains more reports and leaker data than the MITRE database for the years 1971 to 1992 (except for the weteye bombs, none of which are stockpiled at UMCD).

Calculations of degraded munition probability by munition type located at UMCD are shown in table 7-26. The munition type is given in the first column, followed by "Grand Total Leakers," which is the sum of all leakers at all sites for that munition type. The data in the column labeled as "Grand Total Munition" are the sum of all stockpiled munitions of a given munition type across all sites. The data in the column labeled as "Fraction Degraded $P_{degraded}$" are the assumed probability of encountering a degraded munition, which was estimated by dividing the Grand Total Leakers by the Grand Total Stockpile. The Leakage/Year data are the average yearly leakage rate, obtained by dividing $P_{degraded}$ by 30, which represents the 30 years (1971 to August 2001) covered by the SBCCOM leaker database. The munition leaker probabilities calculated for the inventories at each site were compared to the values calculated over the entire stockpile. A ratio of the stockpile value to the site-specific value was calculated, and in all cases, the ratio between the two estimates was less than 5. It therefore was concluded that the $P_{degraded}$ values averaged over the stockpile inventory were sufficiently similar to the site-specific values

Table 7-26. Probabilities of Degraded Munitions at Umatilla Chemical Depot

Munition	Grand Total Leakers	Grand Total Stockpile	Fraction Degraded $P_{degraded}$	$P_{degraded}$ Used in TOCDF QRA (SAIC, 1996b)[a]	Leakage Rate (Munitions per Year)
GB M55 Rocket	2,265	364,707	6.21×10^{-3}	1.24×10^{-2}	2.07×10^{-4}
VX M55 Rocket	10	108,943	9.18×10^{-5}	1.24×10^{-2}	3.06×10^{-6}
155mm Projectile	936	927,083	1.01×10^{-3}	3.79×10^{-3}	3.37×10^{-5}
8-inch Projectile	12	65,541	1.83×10^{-4}	1.39×10^{-4}	6.10×10^{-6}
MC-1 Bomb	111	9,928	1.12×10^{-2}	4.93×10^{-3}	3.73×10^{-4}
MK-94 Bomb	79	2,517	3.14×10^{-2}	3.18×10^{-3}	1.05×10^{-3}
Ton Container (Gross Leaks)	5[b]	22,896	2.18×10^{-4}	1.75×10^{-4}	7.28×10^{-6}
Ton Container (Small Leaks)	272	22,896	1.19×10^{-2}	1.16×10^{-2}	3.96×10^{-4}
Spray Tank [c]	0.33	1,018	3.27×10^{-4}	1.16×10^{-3}	1.09×10^{-5}
Land Mine	121	101,186	1.20×10^{-3}	3.44×10^{-3}	3.99×10^{-5}

Notes:

[a] For further analysis of TOCDF QRA values, see Boyd (1996). For ton container values, see Salyer et al. (1996).

[b] The ton container leaker probability estimation process is discussed in appendix E11.2.

[c] When no leakers were reported, the probability of leakage was estimated as (1/3)N, where N is the total number of munitions of that type in the stockpile.

to permit their usage in the munition fragility calculations. A more detailed description of this analysis, which was performed once for all munition types stored at all locations, is provided in appendix E11.

7.10 Welded Burster Well Data

In considering the likelihood of BLEVE given an inadvertent placement of an unpunched, undrained munition in the MPF, it was necessary to evaluate the likelihood of the existence of a projectile with a welded burster well. Prior experience at TOCDF during projectile processing demonstrated that it was possible to encounter projectiles whose burster wells had been welded during the manufacturing process. It therefore became necessary for the UMCDF QRA to obtain estimates of the ratio of projectiles with welded burster wells to the total number of projectiles as input to the APET model calculations of BLEVE frequency.

Data from the Stockpile Tracking System (STS) developed by SAIC for the U.S. Army were used to determine the current stockpile of GB and VX projectiles and cartridges located at Umatilla Chemical Depot (UMCD) and Anniston Chemical Activity (ANCA), as well as the anomalies identified in that set of munitions.

Estimates were made assuming that 1, 10, 25, and 100 of the projectiles in these respective CDF and combined stockpiles have welded burster wells. In addition, mean values were calculated for the ratio of the anomalous (varnish- and/or silicone-coated) projectiles to stockpiled projectiles at ANCA. [Note: No such calculations could be made for UMCD, because no such anomalous projectiles were identified in the STS database.]

A mean value, based on an assumption of 10 "welded"/anomalous projectiles out of the GB and VX cartridge and projectile stockpile at each site, was calculated, along with lognormal data distributions using the formulae cited in appendix E9 to calculate an EF, as well as using an estimated (larger) EF.

The selection of 10 as the numerator was made because it was comparable to the number of varnished projectiles found at ANCA (13) and seemed like a reasonable round number for an estimate.

For calculating the distributions, the analytical preference was to use the judgment-based estimated EFs because they caused the site-specific lower bound to be consistent with one welded/anomalous projectile and the upper bound to be consistent with approximately 30 welded/anomalous projectiles.

The estimates per site then were compared against UMCD and ANCA combined data (with the mean value using an assumption of 20 welded/anomalous projectiles out of the combined UMCD and ANCA GB and VX projectile stockpile) and the varnish and silicone anomaly data for ANCA.

These data distributions are plotted in figure 7-24. Details of the data extracted from the STS database and the calculation of the data distributions are provided in appendix E12.

The value for UMCD from the plot sheet of the Microsoft® Excel file was input to the APET for the UMCDF QRA to represent the ratio of welded burster well projectiles to the total number of stockpiled projectiles of the type that could have been welded (GB or VX, not H/HD/HT).

The varnish and silicone data were provided for comparison, but they have been considered for use to represent various probabilities of anomalous projectiles that would have less serious consequences than the welded burster wells. The varnish and silicone finishes could create a similar effect to soldering if these items are put in the MPF, but would not be as bad as a BLEVE from welding. Because SAIC anticipates the need to evaluate the effects on the furnace of other situations in which projectiles with intact (but not welded) burster wells are fed to the MPF, eventually some of the situations, such as varnish and silicone that would have effects in-between welding and no sealant, may be modeled. The varnish data and silicone data are

Welded Burster Well Data – Estimated Means, Calculated Distributions Using Analyst-Selected Error Factors

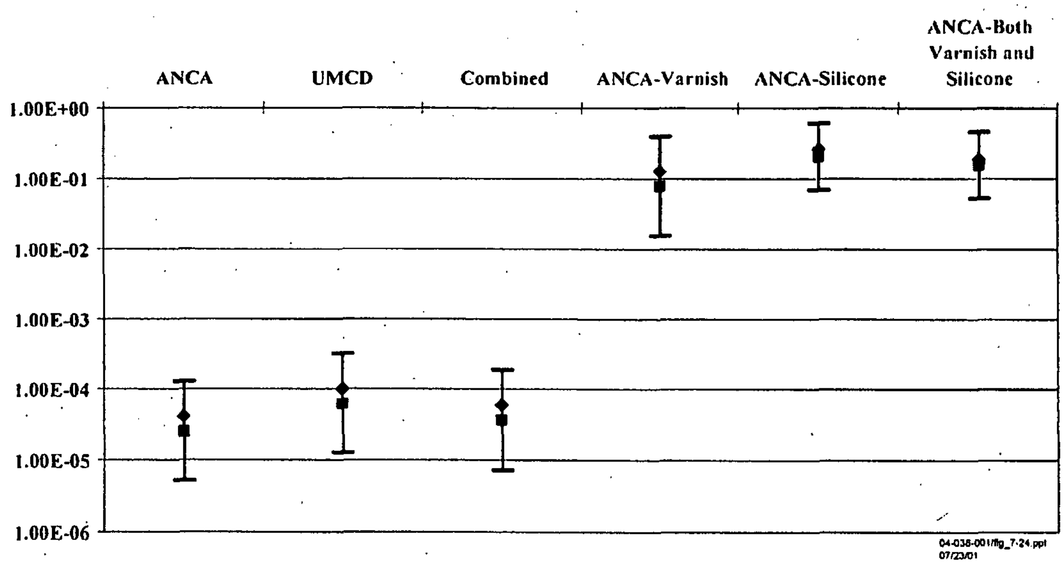


Figure 7-24. Welded Burster Well Estimate Distributions

quite a bit higher than the UMCD or ANCA values. But as long as the presumed consequences from silicone finished projectiles going into the MPF are not as severe as a BLEVE, it is believed that the use of these data could provide a way to reflect the relatively higher likelihood, relatively lower consequence situation that might be expected from projectiles that are not welded, but are anomalous nonetheless.

7.11 Forklift Handling Reliability

Forklift movement of chemical munitions is modeled in the PODs for storage and UPA handling. These events have proven to be important risk contributors in the TOCDF and Phase 1 QRAs. This section briefly discusses the data evaluation that has been completed for the Umatilla Phase 2 QRA; further details of this forklift data analysis are provided in appendix E13.

The reliability of forklift handling would be most accurately obtained through observation of a very large number of forklift activities applying specifically to chemical munitions. Because such data collection is impractical, it is necessary to estimate failure probabilities using analytical methods. One way to estimate forklift reliability is to infer success and failure results from historical information. Industrial and chemical weapons experience has been gathered for this purpose. Other assessments also have evaluated forklift accidents and those have been reviewed for relevance to the QRA models.

While forklift operations are largely human controlled, and therefore strongly subject to human reliability issues, it also could be argued that equipment reliability could influence the probability of failure. In addition, there are events not typically covered in generic human reliability assessments, such as a forklift operator health episode (e.g., heart attack) that also could impact the probability of an error. Because no adequate database was available to permit direct quantification of these events, evidence was collected from the various previously mentioned sources to permit thorough consideration of the factors that could influence forklift handling reliability.

Table 7-27 summarizes the information obtained from nationwide industry data, previous risk studies, chemical stockpile experience, and estimates using the Human Error Assessment and Reduction Technique (HEART) human reliability analysis method.

All this information was used to estimate the value for forklift handling failure rates. The distribution reflecting the value for this variable was selected based on a heavy influence from the chemical munitions handling data.

It also was recognized that the potential for mis-operations could be increased when the operators must wear protective clothing, which could impair the ability to see obstacles or to be

Table 7-27. Summary of Forklift Handling Reliability Information

Event	Source	Values (all per-operation)
Fatality Rate	Nationwide	10^{-8} to 10^{-9}
Serious Injury Rate	Nationwide	10^{-5} to 10^{-6}
Incident Rate	Chemical Stockpile Experience (rockets)	2×10^{-6} to 3×10^{-5}
	Chemical Stockpile Experience (all items)	2×10^{-7} to 4×10^{-5}
Drop or Impact in Transit	Portsmouth	6×10^{-6}
	FPEIS	3×10^{-5}
	TOCDF QRA	1×10^{-5}
Impact During Approach	Portsmouth	3×10^{-5}
	FPEIS	1×10^{-5}
	TOCDF QRA	1×10^{-5}
Human Reliability Estimates for this Type of Operation	HEART	4×10^{-4}

assured that loads are positioned properly. For this reason, the set of error-producing conditions (EPCs) identified by HEART was reviewed to identify any insights that might be applicable to the case of the forklift operations when protective clothing is employed. This evaluation resulted in a factor by which the nominal failure rate might be increased to reflect the effect of masking on forklift reliability, and in the calculation of another distribution for the forklift handling failure rate considering masking.

Another data analysis was performed to estimate the likelihood of a forklift rolling over with a pallet of munitions being transported to the EONC tray pre-positioned next to the igloo access road awaiting the EONC truck. (This scenario is described further in appendices C1 and D1.) Details of the forklift rollover data analysis are provided in appendix E13 but, in summary, the information was obtained from the National Response Center database of reported hazardous material (HAZMAT) spill incidents. Six rollover incidents were reported during the timeframe examined and estimates were made of the number of forklift operations for the failure rate denominator based on the number of reporting companies (3,545), the working days in the timeframe examined (325), the number of forklifts per company (2), and the number of forklift operations per day (3). The resulting rate is consistent with the results of the other forklift handling analyses discussed previously.

The results of all the forklift analyses, in terms of the failure rates that have been derived, are summarized in table 7-28.

Table 7-28. Forklift Handling Failure Rates

Event (per operation)	Factors	Mean	5th[a]	95th[a]
Forklift Impact with Load Being Picked Up	No Mask	1.2×10^{-5}	3.9×10^{-7}	4.4×10^{-5}
Forklift Load Drop or Impact with Other Object[b]	No Mask	1.2×10^{-5}	3.9×10^{-7}	4.4×10^{-5}
Forklift Impact with Load Being Picked Up	Mask	3.0×10^{-5}	1.5×10^{-6}	1.1×10^{-4}
Forklift Load Drop or Impact with Other Object[b]	Mask	3.0×10^{-5}	1.5×10^{-6}	1.1×10^{-4}
Forklift Rollover	N/A	8.7×10^{-7}	1.5×10^{-8}	3.4×10^{-6}

Notes:

[a] Lognormal distribution

[b] This one value covers the entire operation from initial pickup to placement at the destination.

7.12 Demilitarization Protective Ensemble-Related Worker Risk Data

Agent-related risk to CDF workers during DPE operations can come from the following four activities:

1. *PM.* Normal PM in toxic areas requires a DPE entry of at least two people.

2. *CM.* Response to process interruptions requires CM in toxic areas.

3. *Changeover.* Changeover between campaigns requires the DPE entry of possibly several teams.

4. *Cleanup.* Cleanup following accidents [i.e., agent spills (upsets)] requires entry into a toxic area, possibly one that was not anticipated to have agent prior to the spill.

Agent-related risk can simultaneously be accompanied by risk from munition explosion. It should be noted that some of the activities in toxic areas may lead to releases beyond what has already occurred and be additional instigators of public or worker risk. Workers could be subject to agent-related risk directly as a result of accidents. Additionally, site workers, who do not go into toxic areas, are also at agent-related risk solely from process upsets that release agent beyond engineering controls (i.e., site workers are like nearby public). The worker risk analysis is discussed in appendix Q3. The data input to the estimate of the overall agent-related risk to workers from operational activities involving DPE entries is summarized in the following section and described in detail in appendix E14.

Recent Chemical Agent Munitions Disposal System (CAMDS), JACADS, and TOCDF DPE experience documented in DPE tear reports (Nielson and Bowers-Irons, 2000a-c; Nielson and McEachern, 2001) and QRA modeling of the LSS, as discussed in appendix D14, provided input to the estimate of the likelihood of exposure to agent per DPE entry (i.e., torn DPE along with loss of LSS), as summarized in table 7-29.

Table 7-29. DPE Data Summary

Event	Mean	Data Source
Tear/Puncture of DPE	1.27×10^{-2}	70 tears out of 5,495 entries
Loss of LSS	7.44×10^{-5}	Results of QRA model for 1 hour duration
Frequency of Exposure to Agent per DPE entry	9.45×10^{-7}	Tear/puncture of DPE × loss of LSS

7.13 Other Data Analyses

Several other portions of the UMCDF QRA are supported by the analysis of data. The discussion of these other data analyses is covered in the following sections. The data from TOCDF weekly reports and unusual occurrence reports relating to loss of the HVAC system and regarding agent migration to a Category C area are listed in appendix D10, table D10-3. Data for loss of offsite power are addressed in appendix D11, table D11-2.

SECTION 8
HUMAN RELIABILITY ANALYSIS

The assessment of human interactions can be one of the most important tasks in a comprehensive QRA. Operating experience at facilities that employ potentially hazardous processes has repeatedly demonstrated that operators and other facility staff can have a strong influence on the potential for an accident to occur or for one to be avoided (Kletz, 1988; Lees, 1989). This influence has been reflected in the results of virtually every QRA that has been published. The importance of this area in the QRA is heightened because there are no universally accepted procedures for quantifying the probabilities of occurrence of interactions that could contribute to risk-relevant scenarios. Moreover, it can sometimes be difficult to predict the nature of interactions that might arise under upset conditions.

The methods applied in the assessment of human reliability for the UMCDF Phase 2 QRA are intended to support a reasonable and defensible assessment of the risk to the public and to workers at the facility. Beyond that, it is intended that they be able to support meaningful applications of the QRA models. To that end, they are reflective of the state-of-the-art and provide for a tractable treatment of the events important to the QRA. The details of the human reliability analysis are provided in appendix F.

8.1 Overview of the Approach

A systematic approach was taken in evaluating human reliability for the QRA. Consistent with other HRA frameworks, such as those developed by EPRI (Wakefield et al., 1990) and the U.S. Nuclear Regulatory Commission (Swain and Guttmann, 1983), this approach consisted of the following major elements:

- Identifying human interactions that could affect the potential for an accident to occur

- Incorporating into the logic models human failure events (HFEs) that account for those interactions that are determined to be credible and that represent opportunities to contribute to the occurrence of an accident or to respond in such a way that an accident is averted or mitigated

- Estimating the probabilities of the HFEs included in the logic models

- Examining the implications of the HRA with respect to the results and insights from the QRA.

Throughout this assessment, two terms are used extensively. These are "human interaction" and "HFE." Human interactions characterize opportunities for the operators or persons responsible for testing, maintenance, and calibration to play a role that contributes to the availability or unavailability of a system, or that could determine the course of an accident scenario. HFEs are the basic events that appear in the QRA logic models to reflect the human interactions in the context of failure of the affected systems or functions. They are, therefore, defined in a manner that is consistent with the basic events that account for failures of equipment. It is important to note that HFEs do not necessarily reflect "operator error." They may result from challenges due to instrument failures, inadequacy of procedural guidance or training for the particular scenario of concern, lack of time to diagnose a situation and act reliably, or other factors that can affect operator performance. Understanding the relevant human interactions is essential to developing meaningful and useful logic models. It is the corresponding HFEs that are evaluated quantitatively.

8.2 Human Interactions at UMCDF

The characterization of human interactions and HFEs relies on an understanding of the nature of the interface between the facility staff and the physical systems. This includes the makeup of the crews involved in various aspects of maintenance and operations, the man-machine interface (especially in the CON), and the structure and content of the procedures used to guide operations.

8.2.1 Crew Structure and Operator Interface. Each HFE assessed for the UMCDF QRA accounted for the members of the operating or maintenance staff that would be involved in the associated human interactions. The crew structure is different for different phases of the process and different types of interactions. For example, maintenance personnel might be responsible for tagging out and isolating a standby portion of a system for routine or CM, and for returning it properly to service. In other cases, skilled operators would be responsible for transporting (e.g., via forklift or crane) and performing some handling of munitions. Most commonly, there would be at least two staff members involved in such operations and, potentially, a supervisor monitoring their actions.

Although the demilitarization lines are designed to operate automatically, it is expected (based on experience at TOCDF) that some processing will be done in a remote manual mode. These actions would be taken in the main CON. The CON is configured as a series of control consoles, each dedicated to a particular portion of the CDF. An operator would monitor the control console for any process that was in use. Typically, in addition to the operators stationed at the control consoles, a CON supervisor and a plant shift manager would be present in the CON. These individuals would be able to monitor many of the actions taken by CROs. They also would be available to aid the response to any upset events that might occur.

Each of the control consoles is equipped with cathode ray tubes that can display mimics of various processes and that serve as the indicators of process status for manual control. Most control actions are accomplished via commands typed on a computer keyboard. The consoles also have video displays connected to CCTV cameras. The CCTV cameras enable the operators to observe the processes and to identify potential problems as they develop.

All of the facility staff members receive extensive training commensurate with their functions and responsibilities. In addition to onsite training, the CON crews receive training on a CDF simulator at the Chemical Demilitarization Training Facility (CDTF) in Edgewood, Maryland. There is adequate time during facility systemization and startup for all of the staff members to become very familiar with the facility. Therefore, for purposes of this assessment, all of the crewmembers are assumed to be well-trained and skilled at their jobs.

8.2.2 Procedural Guidance. Procedures are being developed to guide nearly all aspects of the operation of UMCDF. Two types of procedures are particularly relevant to the investigation of human interactions and the assessment of HFEs. The first type includes the Standing Operating Procedures (SOPs). These procedures identify the steps that should be taken to start up, operate, and shut down each of the processes that comprise the facility. The SOPs will be used to guide the operators in performing normal operations on a step-by-step basis. The UMCDF conduct of operations is to require step-by-step verbatim compliance. The procedure must be open and followed in order. The HFE assessment is based on UMCDF draft SOPs. For systems where the UMCDF draft SOPs have not been completed, ANCDF and TOCDF procedures were used.

The set of contingency procedures (CPs) accounts for the second type of procedure of interest to the HRA. These CPs are being prepared to address a set of offnormal situations that could be anticipated. The CPs provide guidance to ensure that the operators make appropriate internal and external notifications of an emergency situation. They also delineate steps that the operators would need to take to place the plant in a stable configuration. They also are valuable as a step to ensure that the types of offnormal events anticipated have been taken into consideration. Although an actual response to an offnormal or emergency situation would be expected to draw upon these procedures, it would rely largely on the CRO's knowledge of the plant processes and consequences of system malfunctions gained through training and operating experience. For most contingencies, sufficient time should be available to refine and develop an event-specific procedure that could be implemented in a systematic manner.

8.3 Integration of the Human Reliability Analysis into the Facility Models

The consideration of human interactions was an integral element in the process of developing the facility logic models, which are comprised primarily of the PODs and the system fault trees. The

HFEs that reflect failures associated with these human interactions fall into three general categories:

1. Events that account for interactions prior to an initiating event, and that usually leave a component or system in an undesired state that does not manifest itself until an initiating event or other upset occurs

2. Events that represent human actions that contribute to the occurrence of an initiating event or other upset

3. Events that attempt to capture failures with respect to the response of the operating staff to an initiating event or other upset.

The HFEs can be characterized in different ways. With regard to the human behavior, the taxonomy applied most often reflects two types of errors:

1. *Slips (which include lapses).* These are errors in the physiological processes of implementing an action (i.e., a particular action is intended, but fails to be carried out correctly). These are ordinary, everyday phenomena (Reason and Mycielska, 1982).

2. *Mistakes.* These are errors in knowledge, judgment, or decision making (i.e., they are cognitive-oriented failures) (Anderson, 1980; Janis and Mann, 1977; Reason, 1987).

A different type of differentiation reflects the effects on the system processes, and also can be defined by two types of errors:

1. *Errors of omission.* Omission errors account for actions that should be taken in the particular context of interest, but are not. They include such events as the failure to reopen a valve used to isolate a pump for maintenance (i.e., a pre-initiator event that is also a slip), or the failure to respond to an alarm by taking the necessary steps (which could be a mistake, if the operators fail to properly diagnose the need for action).

2. *Errors of commission.* Commission errors account for actions taken that are inappropriate for the context of interest. For example, the operator may rack in the wrong breaker when attempting to restore a pump to service (a slip). Alternatively, the CON crew may elect to pursue an inappropriate strategy when

responding to a plant upset (a mistake that entails taking an intentional but incorrect action as a result of a failure in diagnosis or decision making).

During the development of the systems fault trees, systems analysts reviewed the Functional Analysis Workbooks (FAWBs), SOPs, and CPs to identify the nature of potential human interactions and to ensure consistent incorporation of HFEs. These HFEs reflected slips and mistakes, as well as commission and omission errors, as previously defined. The fault trees also were reviewed by the human reliability analysts as a check on the consistency and thoroughness of the treatment of human interactions.

A word of caution is appropriate with respect to the treatment of cognitive errors of commission (i.e., mistakes that reflect actions undertaken intentionally but based on erroneous understanding or decision making) in the current assessment. This is a particularly challenging area in human reliability analysis, and methods continue to be developed to make the process of identifying potential errors more systematic and the characterization of their probabilities more meaningful. The effective use of these methods generally requires extensive reviews of operating practices and interactions with operations personnel, and may be of limited value on pre-operational facilities. It was judged that the resources required to implement these methods for the current assessments were not justified based on the existing understanding of the relative risk contributors and the additional insight into the risk profile that would be likely to be gained. Errors of commission that were identified and evaluated for this assessment were primarily those that could be characterized as slips.

An important element of the integration process was the review of operating experience, as captured in the PLL Database. Although there is not sufficient operating experience available to infer probabilities for most of the HFEs considered in this assessment, the PLL Database offers valuable qualitative insights into the nature of human interactions at the operating facilities.

8.3.1 Integration for Pre-Initiator Human Interactions. Interactions that leave equipment unavailable or in a degraded state prior to an initiating event are perhaps the most straightforward to define and include in the system fault trees. This was done in a two-stage process.

In the first stage, the fault tree logic for each train or other major portion of a system that would be in standby prior to an initiating event was checked to ensure that at least a general system-level pre-initiator human action was incorporated. A screening value was assigned to each of these general human actions. The screening values permitted those pre-initiator actions that could be important with respect to the frequencies of sequences to be highlighted during the quantification process. Interactions that were not important to any of the sequences based on use of the screening values were not necessarily modeled or quantified further.

The second stage entailed breaking down each of these general actions into a more detailed representation. This was done only for pre-initiator HFEs that played an important role in the frequencies of accidents.

The first step in this breakdown entailed a review of the FAWBs and other system design information to identify interactions that might affect the potential to leave specific pieces of equipment in an effectively unavailable state. These interactions typically arise as the result of one of the following activities:

- Change of position (in preparation for and/or following maintenance or testing, or for a different operating configuration)
- Calibration or testing
- PM or CM
- Monitoring or checking (e.g., verification that a valve was in the correct position).

The results of this review were organized to define the specific opportunities to leave equipment unavailable, along with the other interactions that could be possible. For example, one opportunity might be the failure to restore a pump train to operability following major pump maintenance. All of the relevant information would be assembled, including procedures that directed mechanical and electrical isolation of the pump, restoration of the pump train, post-maintenance testing, scheduled periodic walkdowns, etc.

The assembly in the final step provided the specific context for the general human action identified at the outset, including the potential to detect and correct errors prior to the actual need for this equipment. These specific contexts served as the basis for the quantification of the pre-initiator interactions, as described in section 8.4.1. By evaluating each opportunity in more detail, the important general pre-initiator events were assessed, and any screening values could be replaced by the resulting refined probabilities.

8.3.2 Model Integration for Human Interactions Affecting Potential Initiators. Many of the operations at UMCDF involve the movement of munitions from the storage yard to the point at which they enter the demilitarization process. Beyond that point, as indicated previously, most processing steps are designed to be accomplished automatically. Based on operating experience at TOCDF, however, it is anticipated that some processes or portions of processes will be operated manually for at least a portion of the demilitarization process. Therefore, at many stages involving transport and processing of the munitions, opportunities arise for inaction or inappropriate action to lead to a potential initiating event.

The FAWBs and SOPs were reviewed by the systems analysts to identify points at which an error could lead to the type of accident of concern. At each such point, a relevant HFE was defined that could be included in the system fault tree. During this process, it was necessary to coordinate with the data analysis effort. For example, some of the potential accidents involve the loading, movement, and unloading of munitions via forklifts. Clearly, there are a variety of opportunities for accidents to occur as a result of human interactions. These were captured, however, by reviewing the operating experience and calculating accident rates that were generally independent of the cause of the accidents.

Once again, the review of the systems fault trees by the human reliability analysts helped to ensure that HFEs that could contribute to the initiation of an accident are incorporated in a consistent and appropriate manner.

8.3.3 Model Integration for Post-Initiator Human Interactions. The third general type of human interactions relate to actions that might be taken by the operating staff as a result of an initiating event. As noted earlier, in some cases these responses might be guided by SOPs or CPs; in other cases, they would be logical actions in response to the specific situation that arose.

The modeling process was iterative in nature. As the fault trees were developed, actions that were clear and logical were included to a somewhat limited extent. This was done for cases in which there were clear indications of the need for action and there was judged to be sufficient time to take action. As the cutsets that comprise the accident scenarios were generated, additional opportunities for the operators to respond to the accident conditions were identified. Where there was reasonable confidence that these actions would be attempted, they were incorporated into the fault trees as well. In the quantification stage, it was particularly important that any potential dependence of post-initiator events on any previous HFEs were captured. This is discussed further in section 8.4.

8.3.4 Naming Convention for Human Interactions. A naming convention was used to uniquely identify each primary event in the study. In this convention, the last four characters were used to denote the nature of the human interaction. The first three of these characters were as follows:

1. HF1 – Slips that constitute errors of commission
2. HF2 – Slips that correspond to errors of omission
3. HF3 – Commission errors that are cognitive in nature, and therefore are mistakes
4. HF4 – Mistakes that involve errors of omission.

The final character was used to designate the type of crewmember involved in the human interactions reflected by the HFE. These were as follows:

- C – Operator in the CON
- F – Operator in the field (i.e., anywhere outside the CON)
- M – Personnel involved in CM or PM.

These four-character designators were defined by the systems analysts primarily as aids to remind the analysts of the types of human interactions that should be considered in the process of developing the fault trees. During the quantification process, the approaches taken were not necessarily tied directly to this initial characterization of the nature of the action. Examples of how these designators were used can be found in table 8-1.

8.4 Quantification of Human Failure Events

Once an HFE was defined, it was initially assigned a screening failure probability. The use of screening assessments is a common element of many aspects of the QRA, and has been used widely in previous HRAs. It allows the analysis to be focused on those HFEs that are most important to risk. For any HFEs that survived the screening process, a more detailed assessment was made. The approaches taken in these more detailed assessments of the HFEs depended on the nature of the associated human interactions.

For pre-initiator HFEs, a simplified form of the Technique for Human Error Rate Prediction (THERP) (Swain and Guttmann, 1983) developed for the Accident Sequence Evaluation Program (ASEP) was used (Swain, 1987). For other types of HFEs (those that could contribute to an initiating event or that would entail response to an upset), one of the following types of approaches was applied:

- For HFEs that correspond to interactions involving standard manipulations of components or controls, following a procedure in a step-by-step manner, THERP was used.

- For HFEs that relate to other types of interactions (such as skill-based movements of munitions) or for which a step-by-step procedure may not apply, an alternative approach was used. This was the HEART (Williams, 1988; Kirwan, 1994).

It should be noted that, in this assessment, results obtained using THERP and HEART are treated as equivalent. In fact, the analyses for some HFEs reflect a mixture of values obtained using both techniques. Comparisons of the two methods have been performed in the past (Kirwan, 1996, 1998; Kirwan et al., 1997). These comparisons have found that the two techniques yield

Table 8-1. Summary of Human Failure Events

Event Name	Description	Mean Probability	Error Factor
Munitions Handling			
STY-FAIL-DETCT-SYHF2F	Failure to monitor igloo properly using MINICAMS® prior to initial entry	7.5×10^{-3}	3
TMA-MUN*-2MPF*-TMHF2F	Munitions tray from TMA inadvertently selected for transfer to MPF	3.8×10^{-3}	3
UPA-OMUN-2MPF*-UPHF2F	Overpacked rocket left in its overpack and sent to MPF	1.5×10^{-5}	10
UPA-SCIS-LFTDR-UPHF3F[a]	Munitions drop during removal from scissor lift in UPA	1.0×10^{-4}	10
UPA-EONC-IMPCT-UPHF3F[a]	Movement of empty EONC impacts munitions on scissor lift	2.0×10^{-4}	10
CHB-TRAY-IMPCT-CBHF4F	Failure to include spacer tray while loading spay tanks onto CHB conveyor	1.3×10^{-4}	10
STK-LID-REMVAL-UPHF2F	Container lid impacts munition during removal operation	5.0×10^{-4}	10
CHB-EMTY-CNTR*-CBHF4F	Full spray tank hit by empty container being loaded onto truck	5.0×10^{-4}	10
Rocket Handling System			
RHS-FEED-101**-UPHF1F	Failure to orient rocket from TMA properly on ECV conveyor	8.3×10^{-5}	10
Projectile Handling System			
MMS-CNVP-119**-PHHF1C	MPF operator inputs incorrect tray number matching a valid tray	3.8×10^{-3}	3
Bulk Handling System			
MMS-BDS*-101D*-BHHF2C	Failure to resume the draining process after power is restored	5.7×10^{-3}	3
MMS-CNVP-119**-BHHF1C	Incorrect ton container number entered into tracking system, allowing processing of incorrect ton container	3.8×10^{-3}	3
MMS-CNVP-119**-BHHF2C	Failure to notice lack of punch holes prior to processing undrained ton container	1.6×10^{-2}	5
MMS-BDS*-101**-BHHF1C	Erroneous recording of punching of ton container when punch was not completed	1.5×10^{-4}	10
MMS-BDS*-101B*-BHHF2C	Failure to note drain failure indications for ton container that has not been punched	4.9×10^{-4}	10
MMS-BDS*-101A*-BHHF2C	Failure to return ton container for punching after repairs are completed	7.5×10^{-3}	3

Table 8-1. Summary of Human Failure Events (Continued)

Event Name	Description	Mean Probability	Error Factor
Mine Handling System			
MHS-MINE-MPF**-MHHF2F	Operators send drum containing at least one mine to be crushed	2.4×10^{-4}	10
HFE*MINE*CRUSH	Operators crush drum containing at least one mine	8.0×10^{-3}	3
ECV-FUZE-DROP*-MHHF1F	Operator drops fuze during transfer to cardboard mine	3.4×10^{-3}	3
ECV-FUZE-DRP**-MHHF1F	Operator drops cardboard mine as it is loaded onto conveyor	3.4×10^{-3}	3
ECV-MINE-IMP**-MHHF1F	Operator impacts mine during removal from drum	6.1×10^{-3}	3
HFE-MINEORIENT-MHHF2C	CON operator fails to orient mine	1.2×10^{-3}	10
ECV-DRUM-LID**-MHHF1F	Operator drops lid onto drum	9.3×10^{-3}	10
ECV-MINE-DP1**-MHHF1F	Operator drops mine during removal from drum	3.4×10^{-3}	3
ECV-MINE-MPF**-MHHF2F	Operator leaves mine in drum	3.1×10^{-4}	10
Heating, Ventilation, and Air Conditioning System			
HVC-AIRH-10102-HVHF1C	Failure to maintain correct air handler-to-filter ratio	6.9×10^{-3}	3

Note:

[a] These events were initially categorized as mistakes (hence the 3F in the name), but later it was recognized that they were actually slips (1F). Because the name was already encoded, it was not changed.

generally consistent results, although the results from HEART may be somewhat more conservative. Because HEART is used in this assessment for cases in which an interaction cannot be readily characterized as a step-by-step process that would be amenable to a THERP analysis, it may be especially appropriate that the results not err on the non-conservative side. The comparisons also provide some measure of the relative validity of the basic values in the two methods, because it was not possible to examine the origins of the data they reflect.

These approaches and the manner in which they were applied are discussed in the following sections.

8.4.1 Quantification for Pre-Initiator Human Failure Events. Pre-initiator HFEs are most commonly the results of slips that could be either errors of omission or commission. The overall process for evaluating pre-initiator human interactions consisted of assigning screening values for the events, and performing the detailed quantification for any events that were important to the risk results. It should be noted that most of the important systems and processes at UMCDF rely on normally operating equipment. Therefore, there are relatively few pre-initiator HFEs that were defined or evaluated for the QRA.

Screening values are useful for pre-initiator events that may have limited potential to be important contributors to the frequencies of any accident scenarios. A screening value of 0.003 was selected for events that implied failure of a single train, and a screening value of 0.0003 was assessed for common cause HFEs (e.g., for the miscalibration of redundant instrument strings). The screening value selected for single-train errors is not necessarily bounding in nature. The value of 0.003 is representative of the value that would typically be obtained for a latent error involving a mispositioning or other error when there would be at least some level of follow-up (i.e., an independent verification, post-maintenance test, etc.). This is a reasonable approach, because virtually every case in which errors could be important to the QRA models would incorporate some level of such follow-up. The value is high enough that any important events would be highlighted in the accident cutsets and be candidates for more detailed analysis. At the same time, it is not so high that unimportant events would arise and needlessly require detailed analysis. The value is further justified because very few detailed analyses produce higher probabilities of failure. The value of 0.0003 for multiple-train events can be considered to be bounding, but it is low enough that only the most important errors would survive the screening and require detailed analysis.

As noted previously, the more detailed assessments were performed using a simplified form of THERP (Swain, 1987). Nearly every QRA has used some form of THERP to assess pre-initiator human interactions. The detailed assessments included the following steps:

- Evaluating the basic probability of failure for each event
- Identifying the effective duration for the unavailability resulting from the event
- Evaluating the conditional probability for dependent events.

For each pre-initiator human interaction defined in terms of the specific failures of interest, the conditions that would affect their probabilities of occurrence were identified. These conditions, which were drawn from table 5-2 of the ASEP methodology, include the following:

- Whether status of the unavailable component would be indicated by a compelling signal in the CON

- Whether component status would be positively verified by a post-maintenance or post-calibration test

- Whether there would be a requirement for an independent verification of the status of the component after test or maintenance activities

- Whether there would be a check of the component status each shift or each day, using a written checklist.

An event tree was constructed that illustrates the conditions delineated in ASEP table 5-2; it is provided as figure 8-1. Table 5-3 of the ASEP methodology provided quantitative estimates corresponding to the nine relevant combinations of these conditions; these are indicated for the end states of the event tree in figure 8-1.

It is worth noting that the probabilities presented in figure 8-1 are characterized in the ASEP methodology both as screening values, and as the median values of a lognormal distribution. While this characterization in itself raises questions (for example, regarding the meaning of an uncertainty distribution about a screening or bounding value), most QRAs have used the values as though they were mean values, and ignored the ASEP characterization. Comparisons of these values to the results of detailed THERP analyses have, however, been made. The conclusion of these comparisons indicate that, even if the values are used as mean probabilities, they lead to higher results than would be obtained through explicit modeling using THERP. Consequently, it was concluded that use of the ASEP values as mean probabilities was acceptable; no claim is made in this assessment that they represent bounding or screening values.

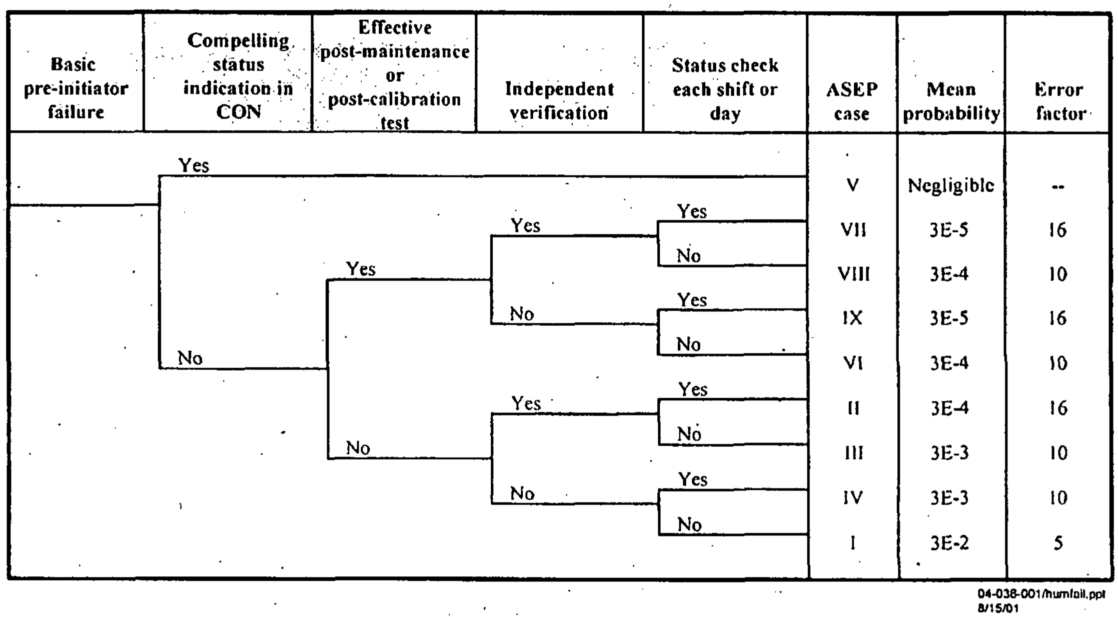


Figure 8-1. Basic Conditions for Assessing Pre-Initiator Human Failure Events

As described in NUREG/CR-1278 (Swain and Guttmann, 1983), the unavailability of a component due to a human interaction (U) can be expressed as follows:

$$U = \frac{pd}{T} \tag{8-1}$$

where:

- p = probability of the unrecovered human failure, selected from the appropriate end state in figure 8-1 (and based on the ASEP methodology as previously outlined)
- d = average time the error could exist
- T = average time between opportunities to make the error (the "make error interval" in the worksheet used to evaluate the events).

The average time the error could exist, d, reflects the opportunities to discover the error by testing or checking prior to the next time the component would be manipulated. For cases in which the opportunities to uncover the error are uniformly distributed with time (e.g., monthly or quarterly checks), the value of d can be calculated as follows:

$$d = \frac{h\left(1 - c^{T/h}\right)}{1 - c} \tag{8-2}$$

where:

- h = average length of time between checks (the "uncover error interval" in the evaluation worksheet)
- c = probability the error will not be detected at the check (a value of 0.1 was applied for follow-up independent verifications, and 0.01 for functional tests).

The time between opportunities for the error (T) can be estimated based on plant experience for maintenance practices, and on the periodicity of tests for errors associated with testing. The value of h also can be based on the interval between relevant verification steps. These could have included subsequent tests in which the opportunity to make the error would not arise, actual demands on the system during normal operation, periodic positive checks, etc.

No common cause failure events accounting for pre-initiator events were defined in the QRA; hence it was not necessary to perform detailed quantitative assessments for such events.

8.4.2 Quantification for Initiator-Related and Post-Initiator Human Failure Events. Both slips and mistakes were identified that could contribute to the occurrence of an initiator or that could involve response to an upset. As noted previously, the methods used for HFEs arising in both cases were evaluated using one of two methods: THERP (Swain and Guttmann, 1983) or HEART (Williams, 1988; Kirwan, 1994).

The THERP approach is widely used to evaluate slips that occur in relatively well-defined, step-by-step activities. Traditionally, THERP is implemented through the process of developing an event tree for each HFE. This event tree includes a branch point at each step in the activity. This could conceivably entail identifying, at a detailed level, one or more potential errors at each step in a procedure. THERP includes a database for the probability of failure for many types of steps that might be encountered in such an activity. Examples of the types of errors in this database include the following:

- Skipping a step in a procedure
- Misreading a value from a control indicator
- Selecting the wrong control or operating a control switch incorrectly.

THERP was applied in the UMCDF QRA to those HFEs that corresponded to well-defined stepwise activities. This included, for example, the failure to track munitions properly as they went through the demilitarization process. Instead of event trees, however, relatively simple fault trees were constructed to delineate the important points in the activities at which errors of omission or commission could contribute to the overall HFE. The data tables that guided the modeling process are provided in Chapter 20 of NUREG/CR-1278 (Swain and Guttmann, 1983).

The HEART approach also employs data collected from operating experience. It is a relatively straightforward approach that addresses a wide variety of potential interactions. The steps in implementing HEART include the following:

- Comparing the task for which the HFE applies to a list of eight generic tasks supplied in the HEART methodology. It is necessary to identify the generic task that corresponds most closely to the task at hand. These generic tasks are identified in table 8-2, along with the probability of failure that would be applied if all factors affecting the event were optimal.

- Identifying EPCs that could affect the reliability of the human interaction. A total of 26 EPCs have been defined, as summarized in table 8-3. EPCs are effectively equivalent to performance-shaping factors that are a standard part of most other HRA approaches. They account for factors that could make the task less reliable than would otherwise be represented by the generic task. For each EPC, the maximum factor by which the condition could increase the unreliability of the task is identified (i.e., when the EPC produces the worst conditions that can reasonably be conceived).

Table 8-2. HEART Generic Tasks

Generic Task		Failure Probability Nominal	5th	95th
(A)	Totally unfamiliar, performed at speed with no real idea of likely consequences	0.55	0.35	0.97
(B)	Shift or restore system to a new or original state on a single attempt without supervision or procedures	0.26	0.14	0.42
(C)	Complex task requiring high level of comprehension and skill	0.16	0.12	0.28
(D)	Fairly simple task performed rapidly or given scant attention	0.09	0.06	0.13
(E)	Routine, highly-practiced, rapid task involving relatively low level of skill	0.02	0.007	0.045
(F)	Restore or shift a system to original or new state following procedures, with some checking	0.003	0.0008	0.007
(G)	Completely familiar, well-designed, highly practiced, routine task occurring several times per hour, performed to highest possible standards by highly-motivated, highly-trained and experienced person, totally aware of implications of failure, with time to correct potential error, but without the benefit of significant job aids	0.0004	0.00008	0.009
(H)	Respond correctly to system command even when there is an augmented or automated supervisory system providing accurate interpretation of system stage	0.00002	0.000006	0.0009

- Assessing a proportion of effect for each EPC. This value is a fraction that is applied to adjust the EPC multiplier, because in nearly all cases the conditions are not the most severe conceivable.

- Quantifying the overall probability of failure.

For any given HFE, a large number of EPCs could be judged to apply to some extent. According to the HEART methodology, however, it is necessary to identify the two to five EPCs that are most relevant for the specific task being considered.

After the generic task and EPCs are selected, it is necessary to determine the proportion of effect representing the degree to which the EPC could apply in the specific instance of interest. This process entails a substantial degree of analyst judgment, and must account for two elements:

- The potential for the EPC to be relevant to the specific HFE
- The degree to which the EPC is likely to affect the HFE.

Table 8-3. HEART Error-Producing Conditions

Error Producing Condition		Maximum Effect
(1)	Unfamiliarity with a situation which is potentially important but which only occurs infrequently, or which is novel	× 17
(2)	A shortage of time available for error detection and correction	× 11
(3)	A low signal-to-noise ratio	× 10
(4)	A means of suppressing or overriding information or features which are too easily accessible	× 9
(5)	No means of conveying spatial and functional information to operators in a form which they can readily assimilate	× 8
(6)	A mismatch between an operator's model of the world and that imagined by a designer	× 8
(7)	No obvious means of reversing an unintended action	× 6
(8)	Channel capacity overload, particularly one caused by simultaneous presentation of non-redundant information	× 6
(9)	A need to unlearn a technique and apply one which requires the application of an opposing philosophy	× 6
(10)	The need to transfer specific knowledge from task to task without loss	× 5.5
(11)	Ambiguity in the required performance standards	× 5
(12)	A mismatch between perceived and real risk	× 4
(13)	Poor, ambiguous or ill-matched system feedback	× 4
(14)	No clear, direct and timely confirmation of an intended action from the portion of the system over which control is to be exerted	× 4
(15)	Operator inexperience	× 3
(16)	An impoverished quality of information conveyed by procedures and person-person interaction	× 3
(17)	Little or no independent checking or testing of output	× 17
(18)	A conflict between immediate and long-term objectives	× 2.5
(19)	No diversity of information input for veracity checks	× 2.5
(20)	A mismatch between the educational-achievement level of an individual and the requirements of the task	× 2
(21)	An incentive to use other more dangerous procedures	× 2
(22)	Little opportunity to exercise mind and body outside the immediate confines of a job	× 1.8
(23)	Unreliable instrumentation (enough that it is noticed)	× 1.6
(24)	A need for absolute judgments which are beyond the capabilities or experience of an operator	× 1.6
(25)	Unclear allocation of function and responsibility	× 1.6
(26)	No obvious way to keep track or progress during an activity	× 1.4

To be most effective in determining which EPCs might apply to a particular task and the proportion of effect for those EPCs, a thorough understanding of the manner in which the task is accomplished and the conditions that are relevant to it is important. Limited observations of operations at TOCDF were made, although these observations were inadequate to provide insight into a wide variety of human interactions. Moreover, UMCDF will be operated by a different operating contractor, and it appears that the operating philosophy, e.g., with respect to the manner in which SOPs are employed on a routine basis, may be different. It is possible, however, to make reasonable judgments regarding the EPCs likely to come into play for any given task. The assessment of these EPCs can be refined as operating experience is gained at UMCDF.

Once the EPCs are selected and their proportions of effect are assessed, the values are finally combined to estimate the overall probability for the event as follows:

$$p(HFE) = p_j \prod_{i=1}^{n} k_{epci} \tag{8-3}$$

where:

p_j = nominal (i.e., best-case) unreliability for the generic task corresponding to the HFE of interest

k_{epci} = effective multiplier for the *i*th EPC applied, calculated as follows:

$$k_{epci} = (m_i - 1) \times f_i + 1 \tag{8-4}$$

where:

m_i = the maximum multiplier for the *i*th EPC

f_i = proportion of effect assessed for the *i*th EPC for the task of interest.

Because the proportion of effect assessed for each EPC can significantly affect the overall probability for the HFE, the method was extended somewhat to provide for a more straightforward and systematic assessment process. This was accomplished by identifying influence factors that could characterize each of the EPCs. These influence factors were assembled in the form of a decision tree for each EPC, with multipliers for each of the branches in the decision tree. When the relevant path through the decision tree is identified for a particular EPC, the product of the branch multipliers provides the proportion of effect for the EPC.

The multipliers that comprise these branch values are, admittedly, arbitrarily assigned. It can be argued, however, that they are reasonable values. More importantly, they allow the EPCs to be evaluated in a much more consistent and traceable manner. Rather than attempting to characterize the proportion of effect in a single, purely subjective value, it is straightforward for a user or reviewer to understand the rationale behind the value obtained from the decision tree.

Moreover, the ability to reproduce calculations for HFEs subject to similar EPCs is significantly enhanced.

As an example, consider the first EPC. It is defined as "unfamiliarity with a situation which is potentially important but which only occurs infrequently or which is novel." This EPC has a maximum effect of 17. The decision tree constructed to address the factors that could affect this effect is provided as figure 8-2. The top events in this tree are described in the following:

- *Is the action routine?* This first question determines whether the EPC applies at all. If the action is routine, the EPC is not relevant, and the multiplier is 0. If it is other than routine, the remaining elements should be considered, and the multiplier is 1.

- *How unusual is the action?* If the action is not routine, the degree of familiarity may be affected by how often it arises. If it must be accomplished infrequently, the operators should be at least somewhat familiar with it. A multiplier of 0.5 was selected to account for the relative familiarity. If the action is novel, however, the full impact of unfamiliarity may still be relevant, and a multiplier of 1 applies.

- *Is there specific guidance available for this action?* If there is specific procedural guidance and/or training available to aid the operators, the impact of its

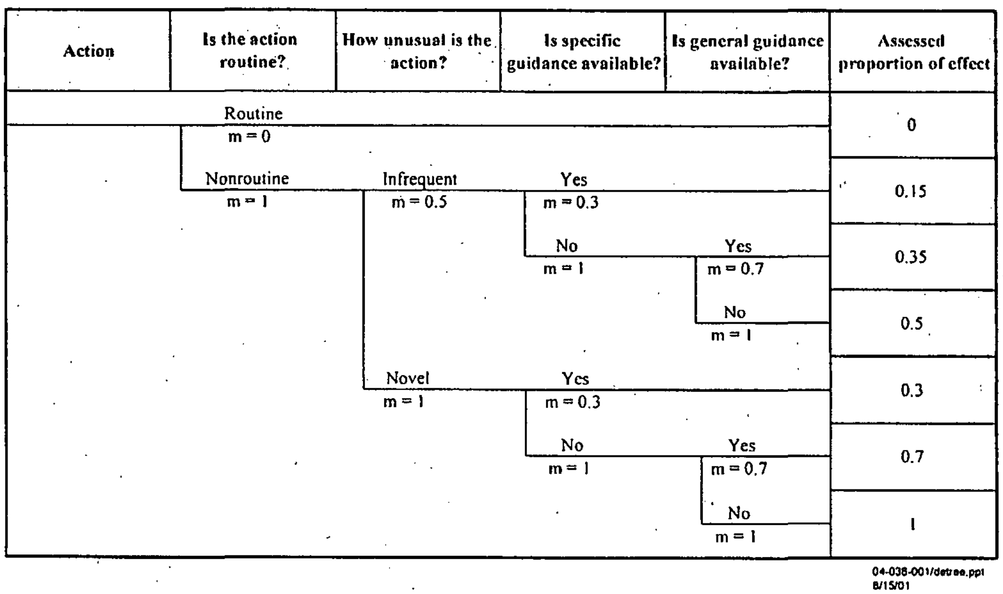


Figure 8-2. Decision Tree for Assessing Effect of EPC 1: Unfamiliarity

unfamiliarity should be mitigated substantially. Therefore, a multiplier of 0.3 is applied. If no specific guidance is available, the multiplier is 1.

- *Is there general guidance available for this action?* If specific guidance is not available, there may still be relevant training that would help to reduce the impact of unfamiliarity with the action. Because general guidance would not be as effective as specific training or procedures, a multiplier of 0.7 was selected. If no guidance is available, a multiplier of 1 applies.

Thus, the proportion of effect could range from 0 (for a routine action, in which lack of familiarity would not be relevant) to 1 (for the unlikely situation in which the required action is novel, and for which there is essentially no relevant guidance). There are five additional outcomes that characterize intermediate points between these extremes.

The proportions of effect are evaluated through this process for all of the EPCs. Those that produce the largest overall effect when combined with their corresponding maximum multipliers are retained in the HEART calculation. Up to five EPCs are retained through this process.

In some cases, there are opportunities for other members of the plant staff to prevent the initial error from leading to the system failure characterized by the HFE. This recovery potential could arise from other operators involved in the task (e.g., when two or more operators are involved in unpacking a munition from its container), or from supervisory personnel. In these cases, it is necessary to consider the potential that the ability to catch the initial error might be dependent on the initial error. In many cases, for example, the second operator might rely on the first operator not to skip a step in the operation, and the second operator would therefore not be an independent source of potential recovery.

When the event is assessed using THERP, these opportunities are incorporated explicitly into the THERP fault trees. In some cases, an event assessed using the HEART method may not directly reflect consideration of this error recovery mechanism. Therefore, the recovery potential was accounted for as an additional factor.

The roles of the personnel involved in each task were examined as the events were assessed. Where recovery potential was judged to apply, a qualitative level of dependence was assessed. These qualitative levels of dependence have corresponding quantitative interpretations, based on input from NUREG/CR-1278 (Swain and Guttmann, 1983). These dependence levels are defined in table 8-4.

Table 8-4. Qualitative Levels of Dependence

Level of Dependence	Calculation	Minimum Conditional Probability
Complete	$P(A \text{ and } B) = P(A)$	1
High	$P(A \text{ and } B) = P(A)\left[\frac{1+P(B)}{2}\right]$	0.5
Moderate	$P(A \text{ and } B) = P(A)\left[\frac{1+6P(B)}{7}\right]$	0.14
Low	$P(A \text{ and } B) = P(A)\left[\frac{1+19P(B)}{20}\right]$	0.05
Zero	$P(A \text{ and } B) = P(A) \times P(B)$	P(B)

8.5 Results of the Human Reliability Analysis

The HFEs assessed in this study and the results obtained are summarized in table 8-1. Detailed discussion of the HFEs and their assessments can be found in appendix F. A sensitivity study regarding quantification of HFEs is provided in section 13.

SECTION 9
MECHANISTIC ANALYSES

9.1 Introduction to Mechanistic Analyses

The term *mechanistic* (or *phenomenological*) describes analyses that address the physical phenomena accompanying potential accidents. For example, an initiating event might be identified that would lead to a natural gas leak in one of the furnace rooms. In order to determine whether such a leak could pose an explosive threat, an analysis is performed. This analysis might first look at the possible leak rate into the room and establish whether the ventilation system would be able to keep a well-mixed concentration below the LFL. If the ventilation system was found to be capable of preventing an LFL concentration, the analysis then might turn to identifying whether any sort of localized formation of gas was likely. If the collection of a flammable mixture were not precluded, then an estimate of the possible energetic yield (peak pressure, impulse, etc.) would be generated. Such analyses are termed mechanistic in that they try to simulate, based on scientific principles or proven engineering techniques, the behavior of physical systems or processes.

Mechanistic analyses, such as the ones mentioned previously, have been performed as part of the QRA process, and their results have been used to guide the construction and quantification of the QRA logic models. In particular, the development of the accident sequence logic in the APET (described in section 6) was performed in conjunction with the mechanistic analyses. In this section, these analyses and their applications to the risk assessment process are summarized. A more detailed description can be found in appendix M.

9.2 Description of Analyses and Results

The following are seven areas where mechanistic analyses have been performed to support the development and quantification of accident sequences:

1. *Munition response* – Assessing the potential for munition damage or energetic initiation from impacts, drops, or other upsets

2. *Furnace modeling* – Evaluating the performance of the various furnaces and their PASs under offnormal conditions, especially with respect to the degree of agent destruction and/or removal

3. *Agent indoor transport* – Modeling the airborne transport of chemical agent through the MDB via the HVAC system and assessing the system's effectiveness in mitigating releases to the environment

4. *Carbon filtration* – Simulating the adsorption/desorption of chemical agent by the HVAC carbon filters

5. *Energetic events* – Determining whether flammable gas mixtures could form, and modeling the challenges created by postulated detonations or deflagrations (both vapor and condensed phase)

6. *Structural response* – Investigating the response of plant/site structures to physical challenges such as energetic events or impacts

7. *Agent release* – Calculating the release of agent by evaporation, explosive dispersion, or other mechanisms.

The following sections discuss the analyses performed in the first six areas. The last area, agent release, is discussed in section 10.

9.2.1 Munition Damage or Energetic Initiation from Impacts. Some chemical munitions (rockets, projectiles, mortars, and mines) are explosively configured. Although the energetics in these munitions are designed not to initiate from accidental impacts (e.g., drops), such accidental initiations are conceptually possible. Furthermore, impacts could result in structural damage to the munitions, potentially causing chemical agent leaks. A limited number of impact tests have been performed by the U.S. Army to determine whether munitions could survive drops from various heights (GA, 1987a). However, many of the tests involved only one or two trials and resulted in no munition failures. In order to supplement the available test data and aid in estimating the likelihood of leaks or energetic initiations from impacts, mechanistic models were developed to simulate the behavior of the munitions and their energetic components under impact loadings.

9.2.1.1 Agent Leakage from Munitions due to Drops. The models used to predict the structural response of munitions considered two situations: 1) the munition impacts a smooth, flat, unyielding surface and 2) the munition strikes a *probe*, defined here as an external object strong enough to survive the impact with little or no yielding and narrow enough to concentrate the impact force over a relatively small portion of the munition casing. Both models assumed a deformation shape and calculated the amount of strain energy required to produce failure due to excessive plastic yielding. The output from each model was an estimate of the threshold drop height required for munition failure. If the agent reservoir were struck, such failure would lead to agent leakage. Examples of the calculated failure thresholds for several munitions are presented in table 9-1 (Christman, 2002a). From a deterministic point of view, this threshold is the minimum height from which the munition must drop in order for the casing to fail.

Table 9-1. Example Failure Threshold Heights for Munition Leakage from Drops

Munition	Flat Impact (feet)	Probe Impact (feet)
155mm Projectile (in pallet)	522	67
8-inch Projectile (in pallet)	684	113
M55 Rocket (in pallet)	36	3
M23 Land Mine (single)	19	19
Spray Tank in Container	18	18
Spray Tank (single)	9	7
MC-1 Bomb	280	205
MK-94 Bomb	209	158
Ton Container (single)	91	61

Due to random factors such as munition orientation, some variation in these thresholds is to be expected. Therefore, parameters within the mechanistic models were varied using Monte Carlo sampling to produce "probability versus failure threshold height" curves for both failure modes (flat or probe impact) (see, as an example, the median curve in figure 9-1).

Uncertainties in the models themselves should be considered. To account for these uncertainties, distributions were placed on the median failure heights to represent the level of confidence. One such distribution is illustrated in figure 9-1 by the 5 and 95 percent confidence curves. The confidence bounds were selected based on an examination of the assumptions in the models, the results from a sensitivity study on the model parameters, and a comparison with the limited amount of experimental data. Typically, a lognormal distribution on the median with an EF of 5 was assigned.

The environment surrounding the munitions was examined to determine the relative likelihood of encountering a probe during a drop. Based on this examination, conditional probabilities of hitting a probe, given that a drop occurred, were established for the various munition environments. In addition, it was recognized that some munition casings might be in a degraded state due to deterioration over their long storage period. Using data on the number of leaking munitions detected in the stockpile over the past 28 years, distributions on the probability of encountering a degraded munition ($P_{degraded}$) were developed (Mohamed, 2000). The median

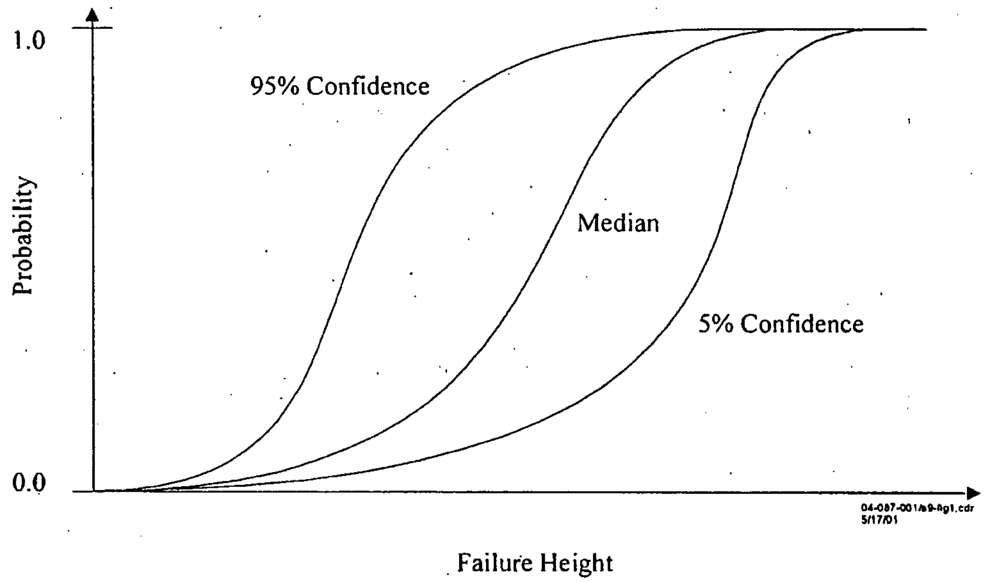


Figure 9-1. A Family of Probability Versus Failure Height Curves

values of these distributions are shown in table 9-2. Degraded munitions were assumed to leak from all impacts modeled in the QRA.

Table 9-2. Median Probabilities of Encountering Degraded Munitions

Munition	$P_{degraded}$
155mm Projectile	7.7×10^{-4}
8-inch Projectile	1.5×10^{-4}
M55 Rocket (GB)	7.0×10^{-3}
M55 Rocket (VX)	9.5×10^{-5}
M23 Land Mine	1.2×10^{-3}
Spray Tank	3.3×10^{-4}
MC-1 Bomb	1.1×10^{-2}
MK-94 Bomb	3.6×10^{-3}
Ton Container	1.4×10^{-4}

Ultimately, the probability distributions for flat and probe impact failures were combined with the probe strike distribution and the degraded munition distribution to yield one family of failure curves for each munition type/probe environment. This can be expressed in simplified form as:

$$P_{leak} = \{[(P_{hit\ flat}\ \text{AND}\ P_{flat\ fail})\ \text{OR}\ (P_{hit\ probe}\ \text{AND}\ P_{probe\ fail})]\ \text{AND NOT}\ P_{degraded}\}\ \text{OR}\ P_{degraded} \quad (9\text{-}1)$$

where:

P_{leak}	=	probability of leak given drop
$P_{hit\ flat}$	=	probability of flat impact given drop
$P_{flat\ fail}$	=	probability of casing failure given flat impact by the flat failure mechanism
$P_{hit\ probe}$	=	probability of probe impact given drop
$P_{probe\ fail}$	=	probability of casing failure given probe impact by either the probe puncture or flat failure mechanism
$P_{degraded}$	=	probability of encountering a degraded munition.

The actual combination process was performed by using Monte Carlo sampling techniques. For illustrative and comparative purposes, mean probabilities from the resultant distributions are listed in table 9-3 for two different drop heights (Christman, 2002a). More complicated configurations involving protective overpacks and containers also were considered. The detailed analyses and results for all modeled munitions and drop heights are provided in appendix M1.

Table 9-3. Example Mean Probabilities for Munition Leakage from Drops During Processing

Munition	3-Foot Drop	10-Foot Drop
GB/VX 155mm Projectile (in pallet)	6.1×10^{-3}	7.1×10^{-3}
8-inch Projectile (in pallet)	9.2×10^{-4}	1.2×10^{-3}
GB M55 Rocket (in pallet)	7.9×10^{-2}	1.5×10^{-1}
M23 Land Mine (single)	1.6×10^{-2}	2.3×10^{-1}
Spray Tank (single)	1.1×10^{-1}	6.0×10^{-1}
MC-1 Bomb (single)	2.1×10^{-2}	2.1×10^{-2} [a]
MK-94 Bomb (single)	7.2×10^{-3}	7.5×10^{-3}
Ton Container (single)	2.8×10^{-4}	5.0×10^{-3}

Note:

[a] Probabilities controlled by $P_{degraded}$

9.2.1.2 Initiation of Munition Energetics from Drops. The models used to predict initiation of munition energetic components considered two mechanisms: 1) deformation of the explosive material caused by the munition striking another object and 2) friction between hard surfaces with explosive material present, such as the rubbing of the broken edges of an explosive component's casing following structural failure as described previously. The overall probability of initiation of each munition was determined by combining probabilities of initiation of each explosive component by the two mechanisms.

Experimental initiation sensitivity data are available that relate the probability of energetic initiation to a range of energy levels imparted by the impact and friction mechanisms (Potter and Mughal, 1992). A mechanistic model was developed to relate the shear energy along the edges of a motor grain or burster of an impacting munition to the energy imparted to bare explosive material during impact sensitivity testing. The output from this model was a drop height for each munition corresponding to the impact energy resulting in 50 percent probability of initiation during the sensitivity testing. The friction sensitivity data were applied directly to the maximum friction pressure that could be experienced in contact with explosive materials in a structural failure event.

Because friction initiation is dependent upon casing rupture, the structural failure models described previously form an important part of the overall energetic initiation model. Parameters within the structural models were varied again to account for random factors such as munition orientation at impact. Uncertainties in the models themselves were considered by placing distributions on the median curves for structural failure of the various munitions. To treat the uncertainty in the initiation phenomena, distributions were placed on the energetic initiation probabilities. Separate distributions were developed for both impact and friction, based on statistical analysis of the experimental sensitivity data. Ultimately, the probability distributions were combined to yield one family of failure curves for each munition type for single munitions, pallets of munitions, and drums of land mines. Mathematically, the combination of probabilities can be expressed in simplified form as:

$$P_{init} = \{P_{hit\ flat} \text{ AND } [P_{impact\ init} \text{ OR } (P_{flat\ fail} \text{ AND } P_{fric\ init})]\} \text{ OR } \{P_{hit\ probe} \text{ AND } [P_{impact\ init} \text{ OR } (P_{probe\ fail} \text{ AND } P_{fric\ init})]\} \quad (9\text{-}2)$$

where:

P_{init}	=	probability of energetic initiation given drop
$P_{impact\ init}$	=	probability of initiation given flat or probe impact
$P_{fric\ init}$	=	probability of initiation due to friction given casing failure.

As in section 9.2.1.1, the combination process was accomplished using Monte Carlo sampling. Mean probabilities from the resultant combined distributions are listed in table 9-4 for two drop

Table 9-4. Example Mean Probabilities for Munition Energetic Initiation from Drops

Munition	3-Foot Drop	10-Foot Drop
GB/VX 155mm Projectile (in pallet)	$<10^{-8}$	2.1×10^{-5}
M55 Rocket (in pallet)	1.3×10^{-3}	5.5×10^{-3}
M23 Land Mine (single)	1.68×10^{-2}	2.5×10^{-2}

heights (Christman, 2001). Different trends are observed among the munitions depending on the dominant mechanisms by which they are initiated. Appendix M1 describes the analysis and results for all munitions and drop heights.

9.2.1.3 Application to Other Scenarios Besides Drops. The mechanistic/probabilistic models described previously also were applied to the analysis of forklift and process gate impacts with munitions.

For forklift impacts, a probability distribution on the forklift velocity was combined with the previous distributions to generate estimates for P_{leak} and P_{init}. Three types of forklifts were identified as being used to move munitions from the storage location to the transportation vehicle. Separate calculations were conducted for each forklift type to account for variations in mass and speed. Mean results for the Drexel® forklift, used to handle munitions within the igloo, are shown in table 9-5.

Table 9-5. Example Mean Probabilities for Munition Leakage and Energetic Initiation from Forklift Impacts Inside Igloo

Munition	P_{leak}	P_{init}
GB/VX 155mm Projectile	5.4×10^{-3}	7.6×10^{-5}
8-inch Projectile	2.3×10^{-3}	$<10^{-8}$
M55 GB Rocket (in tube)	3.6×10^{-2}	2.2×10^{-3}
M55 VX Rocket (in tube)	2.2×10^{-2}	2.2×10^{-3}
M23 Land Mine (in drum)	1.3×10^{-2}	5.9×10^{-6}
Spray Tank (in container)	6.9×10^{-4}	N/A
MC-1 Bomb	2.3×10^{-2}	N/A
MK-94 Bomb	9.1×10^{-3}	N/A
Ton Container	2.8×10^{-4}	N/A

A similar analysis was performed to investigate the effects of process gate impacts on munitions (Christman, 2002b). This analysis considered the same leakage and energetic initiation mechanisms described previously for drops. The models presented in sections 9.2.1.1 and 9.2.1.2 were adapted to the gate impact situations (see appendix M1).

9.2.2 Furnace and Pollution Abatement System/PAS Filter System Modeling. As described in section 3.7, UMCDF uses three separate types of furnaces (incinerators) in the chemical agent disposal process. Of prime concern are releases of agent from any of these furnaces to: 1) their PAS/PFSs and subsequently out of the common stack, or 2) the rooms in which they reside and potentially out of the MDB. Accordingly, analyses were conducted to determine the conditions required to produce such releases and to aid in the prediction of the release magnitudes. In each case, the performance of a furnace or its PAS/PFS during an upset was investigated.

9.2.2.1 Liquid Incinerator. UMCDF contains two LICs for the thermal destruction of chemical agent drained from munitions. Both LICs have separate primary and secondary combustion chambers, maintained at 2,700°F and 2,000°F, respectively. To assess the potential for an agent release from the furnace to the PAS, a series of numerical simulations was performed (Ray, 1996). These simulations considered the rate at which the furnace walls would cool down under the following upset conditions: 1) failure of the combustion air blower with continued agent feed and PAS induced draft (ID) fan operation, 2) failure of the PAS ID fan with continued combustion air blower operation and continued agent feed, and 3) failure of both the PAS ID fan and the combustion air blower with continued agent feed. In all cases, it was concluded that the release of agent to the PAS or the surrounding room would not take place for at least 8 hours following the failure (see appendix M2 for additional details regarding the analysis). This is primarily due to two factors: 1) the high initial operating temperature of the LIC, and 2) the high heat capacity and low thermal conductivity of its refractory. Releases through the PAS when the furnace temperature is far below the operating temperature (less than 1,000°F) are possible if the agent line feeding the LIC is not properly purged. The effectiveness of the PAS in mitigating PAS releases of this type was assessed, as described in section 9.2.2.5.

9.2.2.2 Deactivation Furnace System. The DFS is a rotary kiln-type furnace used to decontaminate sheared munition bodies and burn the energetic components present in some chemical munitions (see section 3.7.1). The agent load carried by the DFS is usually limited, with the largest destruction challenge being the agent in the sheared pieces of undrained M55 rockets (approximately 10 pounds per rocket). It has been demonstrated that the DFS is fully capable of thermally destroying the agent load from one undrained M55 rocket (Booth, 1982). However, agent releases to the DFS PAS are possible if failures occur that degrade furnace performance. Such failures have been considered in the QRA (for example, overventilation of the furnace that could lead to excessive draw of agent-contaminated air from the ECRs). The effectiveness of the PAS/PFS in mitigating such releases is assessed in section 9.2.2.5.

The DFS room is a blast enclosure designed to withstand the impulse and static loadings from a detonation of 28 pounds of TNT within the DFS. No credible mechanism of exceeding this quantity of solid explosives was identified. Calculations also indicated that, if the DFS kiln were to fill with natural gas, the explosive yield from the explosion of this gas would not exceed the TNT design basis. However, natural gas explosions within the DFS *room* could lead to quasi-static overpressures that exceed the design basis and could potentially breach the room. Natural gas explosions leading to agent releases from other locations were considered as described in section 9.2.6.2.

Other events that might lead to agent release from the DFS were found to be noncredible from a frequency standpoint, and no other mechanistic models of the DFS were developed.

9.2.2.3 Metal Parts Furnace. The MPF is used to thermally decontaminate the munition casings after they are drained and to destroy any residual undrained agent (heel) left within them. Upsets at the MPF that might lead to the release of agent vapor to the PAS or furnace room have been postulated. Therefore, analyses have been conducted (Ray, 1996) to determine: 1) the quantity of agent heel that would require extended processing time to achieve complete thermal decontamination, and 2) the degree of agent destruction prior to release to the MPF room should the furnace PAS become blocked. In all calculations, the agent vaporization rates within the furnace during normal processing reported in Maumee (1987, 1988) have been used to characterize the agent vapor source within the MPF.

The results of the first analysis predict that the MPF is capable of handling agent heel percentages of up to 40 percent for the currently established residence times, depending on the agent/munition in question. As expected, all the values are significantly in excess of the 5 percent design value, and they provide a basis for establishing success criteria for the evaluation of risk due to furnace operation. That is, if the quantity of agent remaining in a munition is greater than the predicted maximum allowable quantity, then failures of safeguards within the furnaces (e.g., temperature sensors) could lead to agent release due to insufficient residence time for destruction.

The second analysis indicates that if the furnace exhaust becomes blocked and the furnace shuts down, a large degree of agent destruction via combustion and pyrolysis is likely to occur before the agent vapor makes its way out of the furnace and into the room. The most likely pathway for agent migration is back through the combustion air ducts and blower housing. The predicted destruction efficiency is 99.4 percent or greater, due primarily to the slow refractory cooling rate in the absence of forced flow of air through the furnace (see appendix M2 for additional details).

9.2.2.4 Dunnage Incinerator. The DUN incinerates chemical munition packing materials, which are usually uncontaminated. Because the DUN will not be installed at Umatilla, no models of the DUN were constructed as a part of the QRA.

9.2.2.5 Pollution Abatement System and PAS Filter System. Each incinerator in the MDB is equipped with a PAS and a PFS. As mentioned previously, accidents involving agent release through the PAS with a failure of the PFS were identified for the MPF, LIC, and DFS. To assess the potential for a release of agent from the MPF PAS in the event of a shutdown of the MPF burners without shutdown of the ID fans, the conditions and results of CAMDS PAS tests were reviewed (Wagner, 1978). One of the tests was found to address this particular scenario, and its results were applied in this QRA. The test shows that most of the agent that evaporated from the munitions in the MPF would be thermally destroyed by the residual heat in the furnace and afterburner for the first few minutes after loss of the burners. If no mitigative actions were taken, the furnace would cool enough that adequate destruction within the furnace would no longer be ensured, but destruction within the PAS would still be substantial. Based on the test results, this degree of destruction/removal by the PAS (independent of the furnace) is estimated to be 99.98 percent. A similar destruction efficiency also was applied to potential agent releases from the LIC and DFS to its PAS. Appendix M2 presents the relevant test data and describes the PAS analyses in greater detail.

9.2.3 Heating, Ventilation, and Air Conditioning Modeling. The MDB uses a cascading HVAC system, designed such that airflow in the building moves from the less-contaminated to the more-contaminated areas, ultimately passing through a set of carbon filters before being exhausted to the environment. In order to determine the effectiveness of the HVAC system in containing agent releases, a detailed flow model of the MDB was developed. In addition, separate smaller models were used to assess the impact of thermal challenges (e.g., internal and external fires) on HVAC performance.

9.2.3.1 Modeling of the Munitions Demilitarization Building Heating, Ventilation, and Air Conditioning System Using MELCOR. In the CDF QRAs, the intercompartment ventilation transport computer code MELCOR (Sandia, 1991), developed for integrated analysis of severe nuclear plant accidents, was used to model agent transport through the complex network of interconnecting ducts in the MDB. MELCOR is modular in nature, permitting the development of a detailed representation of the MDB rooms and the HVAC ducts connecting them. As a transient transport code, MELCOR can track agent concentrations on a room-by-room basis under changing MDB conditions including pressure transients, fan failures, isolation damper closures, and wall breaches. In addition to the layout of the MDB itself, the model includes the inlet and exhaust fans, furnace combustion air blowers, flow isolation dampers, vacuum relief damper, TOX bypass damper, BSA bypass damper, HVAC exhaust filter units, and heat loads caused by the furnaces.

Agent may be released within the MDB as either a vapor or an aerosol (liquid droplets suspended in the air). In either case, MELCOR treats the airborne agent as a trace component of the air. That is, agent addition does not affect the thermodynamic properties of the building atmosphere (such as temperature and pressure). Rather, it assumes the properties of the air and water vapor and is transported as a fraction of the total flow field. (In MELCOR, if 5 percent of the atmosphere in a room flows to a second room, then 5 percent of the agent in the original room will be transported to the second room as well.)

The mitigative effects of the building (via the HVAC system, filtration system, and deposition and settling mechanisms) on agent releases to the environment were taken into account in the QRAs through the use of decontamination factors (DFs). A DF represents the amount of agent entering a specified volume divided by the amount of agent leaving the volume during a particular time period. The MDB is the volume of interest for the QRAs. Based on the DF, agent release to the environment is calculated as:

$$(\text{mass exiting MDB}) = (\text{mass released to MDB}) / DF_{MDB} \qquad (9\text{-}3)$$

MELCOR calculations were performed for 24 scenarios spanning the conditions associated with postulated accident progressions in the QRAs. The scenarios involved parametric combinations of the following parameters:

a. Release mode (explosive releases versus evaporative releases)

b. Release location (UPA versus MPB)

c. Status of the HVAC system (functional versus partially or totally disabled)

d. Condition of the building external walls (intact wall small breach, or total wall failure).

Both explosive (instantaneous) and evaporative (continuous) releases were considered. Explosive releases occur when the explosive charge within a munition is initiated or as a result of an energetic event within a furnace. Evaporative releases occur when the munition body is ruptured but the explosive charge, if present, is not initiated or when spills occur from other sources such as the TOX. Release locations were divided between external and internal rooms. External rooms share walls with the environment that, if breached in conjunction with an agent release to the room, would provide a direct avenue for an external release of agent. The UPA was chosen to represent these locations. Internal rooms are buffered from the environment by at least one other room on all sides. The MPB was chosen to be representative of these rooms. HVAC failure cases involved: 1) a CCF of all exhaust fans with inlet fans and combustion air blowers operating (partial failure), and 2) a station blackout or a PLC failure with all fans offline and the flow isolation dampers closed (total failure). For calculations where the building walls were modeled as having failed, the walls were assumed to be breached to some degree, either through buckling of the composite building panels or through gross wall failure. The UPA external walls were defined as the breach location.

For each scenario, an MDB DF value was calculated. Examination of the results showed similarities among many scenarios. As a result, building configurations leading to similar MELCOR-predicted DF values were grouped. In all, six building configurations were retained. DF values characteristic of each group were assigned to the groups as shown in table 9-6. Case 1 represents the facility operating as designed. Cases 3 through 6 represent the grouping of MELCOR calculations that produced similar results. The DF for the remaining case, case 2, was conservatively approximated by case 6.

Table 9-6. Munitions Demilitarization Building Decontamination Factors Used in the Chemical Agent Disposal Facility QRAs

Case Number	Location Within the MDB	HVAC Status	External MDB Wall Breach?	DF_{MDB}
1	Any	Fully Functional	No	350,000[a]
2	Any	Not Fully Functional	No	3.25[b]
3	External Room	Fully Functional	Yes	3,250[c]
4	External Room	Not Fully Functional	Yes	1.625[c]
5	Internal Room	Fully Functional	Yes	350,000[a]
6	Internal Room	Not Fully Functional	Yes	3.25[c]

Notes:

[a] Based on JACADS performance data for one filter bank.
[b] Conservatively approximated by case 6.
[c] Selected based on MELCOR runs.

The value 350,000 appearing in table 9-6 is the measured DF of one HVAC carbon filter bank at JACADS (Holgate et al., 1993) and is used to indicate that all the agent released within the MDB was swept to and trapped by the carbon filters in the HVAC exhaust system. This virtually eliminates any release to the environment. Additional details regarding the use of MELCOR can be found in appendix N.

9.2.3.2 Modeling of Thermal Challenges to the Heating, Ventilation, and Air Conditioning System. Upsets involving the redirection of furnace exhaust or the occurrence of fires within the MDB have been considered in the QRA. These upsets could result in hot gases being carried by the HVAC system to the carbon filters. The elevated gas temperature could heat the filters, potentially resulting in ignition of the carbon and/or desorption of adsorbed chemical agent. For this reason, mechanistic analyses were performed (Ray, 1996; Bailey 2000b) to estimate the maximum temperature of gases reaching the HVAC filters under upset conditions.

To determine the hot gas temperature at the carbon filter inlet, a simple mass and energy balance model of the relevant portion of the MDB and its HVAC system was constructed. Feed streams from the furnace rooms to the main HVAC duct were modified to reflect the specific upset conditions.

The most severe accident involving the furnaces was rejection of the *total* DFS heat load [1.3×10^7 British thermal units (Btu) per hour, or 3.8 megawatts (MW)] directly to the DFS room. The postulated initiator for this upset was blockage of the DFS PAS followed by failure to shut down the furnace. This case resulted in a filter inlet gas temperature of approximately 250°F (Ray, 1996). Other furnace upsets resulted in lower filter inlet gas temperatures. Calculations performed using the MELCOR model described in section 9.2.3.1 confirmed these results.

Fires within the MDB that propagate to several rooms and/or involve a substantial amount of combustible chemical agent were found to be capable of heating the HVAC exhaust stream significantly. The peak heating rates for such fires were in excess of 7 MW. Using the simple mass and energy balance model previously described, it was calculated that the temperature of the gas entering the HVAC carbon filter banks could exceed 350°F (Bailey, 2000b).

Additional details on the thermal modeling described are provided in appendices K2 and M3.

9.2.3.3 External Thermal Challenges to the Filters. If an external event (e.g., an aircraft crash) results in a fire near an HVAC carbon filtration unit, radiative heating could cause the filter to desorb its agent load. To assess the potential for this type of release, calculations were performed using a simple energy balance approach combined with radiative heat transfer correlations for fires. The specific scenario investigated involved a JP-4 (jet fuel) pool fire located approximately 6 feet from a filter unit. The results of the calculations indicated that this fire could cause heating of the filters to 300°F within 3 minutes (Ray, 1996). Filter desorption at this temperature can be relatively rapid (see section 9.2.4.1). If the fire were closer or if it engulfed the unit, heating would occur even more quickly, and the carbon might even catch fire. Therefore, filter desorption and burning due to external fires was included in the QRA. This analysis is described in greater detail in appendix M3.

9.2.4 Heating, Ventilation, and Air Conditioning Carbon Filter Performance. As mentioned previously, the MDB HVAC system is equipped with activated charcoal filters. Adsorption of agent onto the carbon was modeled in order to evaluate the effectiveness of cleansing the exhaust gas stream and the accumulation of agent on the filters. Desorption of agent was modeled to estimate the risk of agent release due to thermal upsets, both within and external to the MDB, as described in sections 9.2.3.2 and 9.2.3.3.

9.2.4.1 Adsorption/Desorption Modeling. Adsorption and desorption of agent onto and off of the HVAC filter carbon was simulated previously for the QRAs using an equilibrium finite element model (Ray, 1996). For the Umatilla Phase 2 QRA, a new set of calculations was performed using a newer, non-equilibrium model developed by the Edgewood Chemical Biological Center (Goldfarb et al., 1998). In both cases, the modeling shows that the filters are very effective in removing agent under normal operating conditions. The filter system design and changeout requirements also provide adequate protection of the environment and public in the event of credible internal upsets. Even if four of the six banks in a filter unit were saturated with agent (i.e., fully loaded to the point of requiring immediate changeout) and the filter inlet temperature reached 250°F, release through the stack due to agent desorption should not occur for nearly 2.5 hours (Bailey, 2000a) because agent would be adsorbed in the remaining two downstream filter banks.

Fires within the MDB and fires external to the filter units have the potential to raise the filter temperature above 250°F (see sections 9.2.3.2 and 9.2.3.3). In fact, temperatures exceeding 350°F could be achieved. At this temperature, desorption and breakthrough of a filter unit would take approximately 21 minutes (Birk, 2001). Higher temperatures would require less time.

9.2.4.2 Filter Loading over Time. As agent accumulates on the filters, the filter banks can eventually become loaded to the point that the agent concentration in the air stream leaving the first bank exceeds the TWA. If this happens, the first and second banks are replaced within 3 months of detection. If breakthrough of the third carbon bank occurs prior to changeover, then the filter unit is taken offline and all banks are changed immediately. The spent (saturated) carbon then is placed in temporary storage to await disposal. Resource Conservation and Recovery Act (RCRA) permit requirements actually include additional restrictions on filter changeout if breakthrough of the first bank occurs, but these restrictions are not included in this simplified discussion.

The agent load on the filters fluctuates during the demilitarization program as agent accumulates and spent carbon is removed. The maximum agent load (adsorptive capacity) on the filter units is defined (Christman, 2001) by the breakthrough capacity of the first three banks of all nine filter units, which is between 5 and 11 metric tons (depending on the agent). All nine units are considered, recognizing that HVAC units are likely to be rotated online and offline so that even offline units will contain agent. Because a disposal program has yet to be defined, the agent inventory on the filters in temporary storage was assumed to grow during the program. Eventually, almost all the agent removed from the filters, which could be as much as 4 tons over all UMCDF campaigns, would reside in storage (agent collected on filters less agent decomposed before used carbon sealed up and transferred to storage).

Calculations of agent loads on the filters are based on observed agent concentrations in the HVAC exhaust flow on days on which munitions were processed and on days during which no munitions were processed. The GB, VX, and HD concentrations of agent in the HVAC exhaust were determined from TOCDF data for 2000, JACADS data for 2000, and JACADS data for 1999, respectively. Decomposition rates for GB and HD were obtained from results of recent tests of agent decomposition and desorption from filter carbon (Karwacki et al., 1998, 1999). VX test results are not yet available, so an extremely low decomposition rate was assumed.

9.2.4.3 Carbon Fires. Within the HVAC filter units or spent carbon storage igloo, some heating of the carbon will occur due to slow oxidation, continued adsorption, or other chemical reactions. If this heat is not effectively removed, ignition of the carbon could result. In addition, the discharge of hot gas from the MDB to the carbon filters via the HVAC ducting could heat the carbon to above its autoignition temperature and result in a carbon fire. In either case, the agent adsorbed on the carbon could be released from the filters.

To account for these potential accidents, data on spontaneous ignition of carbon in still air and moving air tests were obtained, and probability distributions were constructed to estimate the probabilities of ignition under various conditions (e.g., gas temperatures and container geometries). Further description of the modeling of these events is provided in appendix M4.

9.2.5 Formation of Flammable Gas Mixtures and Energetic Event Modeling. As with most industrial facilities, some of the equipment within the MDB uses flammable gases to perform their functions or generates flammable gases during operation. Specifically, the furnaces require natural gas to fire, the UPS batteries generate hydrogen, and the ACAMS located throughout the building require hydrogen to operate. The chemical agent itself is combustible also. If a leak should occur within the facility, a flammable gas/air mixture could form, especially if the HVAC system fails to operate. Subsequent ignition of this mixture could result in detonation, deflagration, or fire. Explosions also could occur if the energetics within one of the chemical munitions initiated accidentally. A series of mechanistic analyses was performed to assess the potential for formation of flammable gas/air mixtures, determine whether HVAC operation could preclude them, and estimate the potential energetic yields from explosions or other combustion events (both vapor and condensed phase).

9.2.5.1 Formation of Flammable Mixtures Within Rooms. Leakage of a gas from a pipe break or a tank was modeled as isentropic compressible flow of an ideal gas through a choked flow nozzle (Ray, 1996). For hydrogen bottle leaks, the volumetric flow rate of hydrogen was conservatively assumed to remain at the initial calculated rate until the tank was emptied. In actuality, the rate would slow as the internal tank pressure dropped.

Two types of calculations were performed based on the operational status of the HVAC system. For a non-operational HVAC configuration, no sweeping of flammable vapors was assumed, and the analysis focused on identifying whether enough gas could be released to yield a flammable mixture within the room. For operational HVAC, an ordinary differential equation was solved to determine the maximum concentration within the room and the transient concentration history. If the LFL concentration was exceeded, then a combustion event was considered possible. The flammability limits in air for hydrogen, methane (the primary constituent in natural gas), GB, VX, and HD are listed in table 9-7.

Table 9-7. Flammability Limits in Air

	Concentration (volume percent)		
Gas	LFL	Stoichiometric	UFL
Hydrogen	4.0	29.6	75.0
Methane	5.0	9.5	15.0
GB	1.0	3.1	Not Available
VX	0.4	1.1	Not Available
HD	1.0	3.1	Not Available

Sources: U.S. Army, 1985; NFPA, 1988.

The results of the analyses indicate the following:

a. If a hydrogen leak from an ACAMS tank occurs downstream of the pressure regulator, a flammable concentration can occur only if HVAC is inoperable. A hydrogen leak upstream of the regulator discharges hydrogen so rapidly that flammable concentrations are possible in some rooms even with HVAC operating.

b. Breaks of larger natural gas lines (e.g., the main fuel line) could lead to flammable concentrations within the furnace rooms even if HVAC was operational, while breaks of smaller lines (i.e., 1/2-inch pilot fuel line) would not lead to flammable concentrations.

c. The formation of flammable agent/air mixtures within most rooms in the MDB is not credible, due primarily to the low vapor pressures of the chemical agents, the operational temperatures of these rooms, and the lack of external heat sources (Ray, 1996).

d. Flammable agent/air mixtures could form in the furnace rooms, which are at elevated temperatures; however, significant agent destruction should take place in the furnace prior to any release to the room.

e. Buildup of hydrogen to combustible levels in the UPS battery room is not credible due to the very slow hydrogen generation rate.

Additional details regarding these calculations are provided in appendix M5.

9.2.5.2 Formation of Flammable Mixtures Within Furnaces. Under normal operating conditions, natural gas (and in most cases, agent) is introduced into the furnaces and burned. However, if an upset occurred, natural gas or agent vapors could accumulate within a furnace and form an explosive mixture. Calculations similar to those described in section 9.2.5.1 were performed to assess the potential for formation of flammable mixtures in the furnaces (Ray, 1996). It was found that the accumulation of natural gas within all three furnaces due to valve leakage was possible, as was the accumulation of agent vapor within the LIC and MPF. Agent accumulation within the DFS was ruled out based on the small amount of agent available.

One additional scenario involving the MPF required analysis (Ray, 1996). Before the thermal decontamination process begins, munitions are placed in an airlock that is separated from the MPF interior by an insulated gate. It was postulated that if the heat transfer from the furnace to the munitions within the airlock were high enough, then residual agent could evaporate and form a flammable air/agent mixture within the airlock, prior to the introduction of these munitions to the MPF for decontamination. Thermal calculations indicated that the times required to vaporize enough agent to form a flammable mixture are greater than the normal airlock residence times (less than 5 minutes). However, extended residence times could enable the agent concentration to reach the LFL. As described in section 16.6.2, the U.S. Army installed an airlock venting system to provide an option for mitigating this scenario. However, the PMCD operations team has expressed preference for procedural controls. Therefore, the QRA assumes that procedural controls, rather than the venting system, will be used to mitigate this event. Details on this scenario are provided in appendix M5.

9.2.5.3 Energetic Yield. In order to assess the potential for damage to equipment and structures, estimates of the pressures from accidental energetic events were made.

Vapor Explosions. Vapor combustion can lead to a deflagration (subsonic flame front) or detonation (supersonic flame front). Detonations create shock waves that produce high pressure, short duration impulse loads on impacted structures. This can be very damaging unless the structures are specifically designed to handle such loads. Deflagrations do not produce shock loads; however, they can result in substantial quasi-static pressures (near-constant pressures sustained for several seconds). In fact, the pressure rise from a *confined* deflagration can approach that associated with adiabatic, constant-volume combustion (Kuchta, 1986; NFPA, 1988).

Detonations of flammable gas/air mixtures, although possible, are not often observed because the conditions required to initiate and sustain a detonation are not easily achieved. Detonations can occur through two mechanisms: direct initiation or deflagration-to-detonation transition. Direct detonations require large, instantaneous energy inputs and are typically initiated using high explosives (Tieszen et al., 1993). Such a high-energy initiation of a detonable, flammable gas mixture in the MDB is not credible. A deflagration-to-detonation transition occurs when the combustion event begins as a deflagration, but the flame front subsequently accelerates to sonic velocities. For a deflagration-to-detonation transition to occur, a strong degree of confinement is required. Constrictions or obstructions that facilitate turbulent mixing also must be present (Tieszen et al., 1993). Due to the relatively large volumes and lack of constrictions in the MDB rooms, gas explosions in these locations have been modeled as deflagrations (Ray, 1996). With regard to the MPF and LIC furnace, structural calculations have indicated that the furnaces will not maintain pressure integrity during deflagrations, so their failure is assigned for these cases. This was conservatively modeled as complete destruction of the furnaces and breach of the room walls. A deflagration in the DFS furnace would damage the furnace, but would not be able to breach the explosion containment walls. Deflagrations in the furnace rooms were predicted to fail the room walls for all three furnace systems: the LIC, MPF, and DFS.

In all deflagration calculations, the products and reactants were assumed to behave as ideal gases. Combustion was assumed to take place under adiabatic, constant-volume conditions with air as the oxidizer. Incomplete combustion and dissociation effects, which would tend to reduce the resultant temperatures and pressures, were not considered. The methodology employed is a standard thermodynamic approach and is described in detail in Wark (1983) and Van Wylen and Sonntag (1986).

The calculated final pressures and temperatures associated with the combustion of hydrogen and methane in air under adiabatic, constant-volume conditions are shown in table 9-8 (Ray, 1996). It is unlikely that vapor deflagrations would produce the temperatures and pressures shown in table 9-8, because dissociation, incomplete combustion, and heat transfer to the surroundings would occur. For *unconfined* vapor cloud explosive reactions, energetic yields are generally between 1 and 5 percent of the theoretical maximum (NFPA, 1988). In the QRA, the pressures resulting from vapor combustion in *confined* areas are conservatively assumed to be equal to the adiabatic, constant-volume values.

Table 9-8. Constant-Volume Combustion Results for Hydrogen and Methane[a]

Combustible Gas	Concentration (Volume %)	Adiabatic Flame Temperature (°F)	Final Pressure (psia)
Hydrogen	LFL (4.0)	880	36
	Stoichiometric (29.6)	5,020	128
	UFL (75.0)	2,140	68
Methane	LFL (5.0)	2,810	89
	Stoichiometric (9.6)	4,620	139
	UFL (15.0)	4,090	125

Note:

[a] Initial temperature of 77°F; initial pressure of 1 atmosphere.

Measured experimental pressures are provided in table 9-9. The values are the maximum measured pressures for confined hydrogen and methane gas explosions at various volume concentrations. A comparison of the pressures in table 9-8 and 9-9 for a given volume concentration yields the calculated pressures being greater than the experimental pressures. Even though the cited maximum experimental pressures are lower than the calculated pressures, the QRA uses the calculated values for conservatism.

Munition Detonations. The explosive yield from a munition detonation was determined by: 1) calculating the mass of TNT with the same energetic content as the explosive in question, and 2) using empirical curve fits of TNT explosion data (U.S. Army, 1990) to assess the resultant pressure challenges (Ray, 1996). For explosions that failed the furnaces, instantaneous adiabatic mixing of the combustion gases and the furnace room air was assumed to take place, and the resultant pressure rise within the room was calculated. Shock loadings were only calculated if the quasi-static loads did not result in furnace and/or room wall failure. The MPF and LIC furnace chambers and room walls were found to be vulnerable to munition detonations. The explosion containment design for the DFS room mitigates the effects of a munition detonation in this room.

Table 9-9. Experimental Maximum Pressures for Confined Hydrogen and Methane Gas Explosions

Gas	Concentration (Volume %)	Maximum Pressure (psig)
Hydrogen[a]	15	61
	20	65
	25	68
	30	99
	35	101
	40	99
Methane[b]	6	48
	7	68
	8	82
	9	89
	10	92
	11	91
	12	86
	13	74
	14	56

Notes:

[a] Measured in 0.35 ft^3 vessel (NFPA 68, 1974).
[b] Measured in 1.0 ft^3 vessel (NFPA 68, 1978).

Boiling-Liquid Expanding-Vapor Explosions. If one or more unpunched and undrained munitions were inadvertently sent to the MPF, the munitions would heat up and become pressurized internally, and could rupture violently within the furnace. This phenomenon, known as a BLEVE, could severely damage the furnace and the surrounding room, opening a path for agent to escape to the external environment. The explosive yield from a BLEVE was determined by: 1) calculating the mass of TNT with the same energetic content as would be released during combustion of the agent within the munition, and 2) using empirical curve fits of TNT explosion data (U.S. Army, 1990) to assess the resultant pressure challenges (Ray, 1996). The expansion energy associated with the BLEVE was assumed to be dominated by the chemical energy released by combustion of the flashing agent. If furnace rupture were indicated, instantaneous adiabatic mixing of the combustion gases and the furnace room air was assumed to take place, and the resultant pressure rise within the room was calculated. This pressure rise was compared with that required for wall failure. For all munitions, the MPF and MPF room were found to be vulnerable to damage due to a BLEVE.

9.2.6 Structural Analysis. In order to determine whether the furnaces and rooms would be able to survive the energetic events described in section 9.2.5, structural calculations were performed.

9.2.6.1 Furnace Response to Energetic Events. Two calculations were undertaken to assess the internal pressure required to fail the MPF and LIC furnace chambers (Ray, 1996). The first calculation considered simple yielding, while the second considered rupture as the membrane stresses in the furnace walls reached the ultimate tensile limit following substantial deflection. The results of these calculations are shown in table 9-10 (Ray, 1996).

Table 9-10. Internal Failure Pressures for the Metal Parts Furnace and Liquid Incinerator

Furnace	Internal Pressure to Cause Yielding (psi)	Internal Pressure to Cause Rupture (psi)
MPF	0.2	5.3
LIC	0.8	1.3

For the MPF, munition detonations, vapor deflagrations, and BLEVEs within the furnace produce pressures far in excess of those listed in table 9-10. Therefore, this furnace was considered to fail with high likelihood for any type of energetic event.

For the LIC, munition detonations within the furnace are not possible, but gas explosions would produce pressures far exceeding those in table 9-10. Therefore, failure of the LIC from such explosions also was considered highly likely.

9.2.6.2 Room Response to Energetic Events. Munition detonations were considered within the UPA (handling accidents) and the MPB (demilitarization equipment activities outside explosive containment) (Ray, 1996). The detonation of a munition within the UPA was calculated to result in failure of the composite building panel walls [failure pressure: 0.3 pounds per square inch (psi)]. The walls of the MPB are much stronger; however, when impulse loading effects were taken into account, failure of these walls was predicted also. (The MPB also contains Plexiglas™ windows that would not withstand blast effects.)

Natural gas deflagrations within the MPF and LIC rooms were considered certain to cause failure of the most vulnerable room walls, which are of the composite building panel type. In contrast, the DFS room has been constructed as a blast enclosure capable of withstanding the dynamic (shock) and quasi-static (gas) pressures associated with a 28-pound TNT-equivalent detonation

(Ray, 1996) [the maximum amount of TNT that could credibly be present within the furnace (Parsons, 1989)]. This TNT explosion was calculated by the design contractor to produce short-duration shock pressures between 14 and 191 psi at the various room boundaries. The maximum quasi-static gas pressure was found to be 9.2 psi, dissipating to normal pressure over 42 seconds. The DFS room design did not consider the possibility of a natural gas deflagration and the quasi-static pressures that could be generated from such an event.

Structural calculations (Ray, 1996) indicate that the DFS walls can withstand between 13 and 33 psi of static loading without failing, depending on the type of model used. The ceiling is predicted to sustain pressures up to 15.5 psi. This is consistent with the quasi-static pressure of 9.2 psi. The room walls and ceiling, however, will not sustain the much higher quasi-static pressures potentially associated with natural gas deflagrations (see section 9.2.5.3). Therefore, DFS room breach from such events was considered in the QRA.

9.2.6.3 Enhanced Onsite Container Drop in the Container Handling Building/Unpack Area. Scenarios have been postulated in which an empty EONC (weighing 18,000 pounds) is dropped while being moved by crane in the CHB/UPA section of the MDB (Ray, 1996). If sufficient structural damage occurred to the CHB/UPA floor, the empty EONC could fall 20 feet or more to the pavement below. Agent release might follow if the damage to the floor was severe enough to cause unloaded munitions, munition-filled EONCs, or bulk items (potentially present in the CHB/UPA) to fall through the floor as well.

A series of structural calculations was performed to assess the degree of damage from EONC drops of various heights. The approach used in these calculations was to estimate the amount of strain energy that could be absorbed by the floor prior to rupture and compare it with the amount of kinetic energy acquired by the EONC during its fall. The theoretical maximum energy required to cause structural failure of the floor was calculated by summing the ultimate concrete strain energy and the reinforcing steel elastic and plastic strain energy within a region of floor having twice the surface area of the impacting EONC face. If the initial kinetic energy of the EONC (KE_{ONC}) exceeded a specified fraction (η) of this theoretical failure energy ($SE_{max\,fail}$), then the EONC was presumed to have failed the CHB/UPA floor. This is expressed mathematically as:

$$KE_{ONC} > \eta\ SE_{max\ fail} \Rightarrow \text{floor failure} \tag{9-4}$$

The value of η was assigned based on engineering judgment and was varied parametrically between 10 and 25 percent. The results of these calculations indicate the EONC will not fall through the CHB/UPA floor.

9.2.6.4 Aircraft Crash Damage. Using an approach similar to that used for the EONC floor penetration analysis (see section 9.2.6.3), calculations were performed to estimate the amount of damage caused by an aircraft crash into the MDB, CHB, and igloos at the storage yard (Ray, 1996). The results indicate that a large or medium aircraft (e.g., a Boeing 767 or Fairchild F275) is capable of penetrating all three structures and damaging the munitions inside, while a small aircraft (e.g., a Piper Navajo) could penetrate the MDB or CHB but not the igloos. Additional details on mechanistic calculations performed to model aircraft crashes are provided in appendix I.

9.3 Summary and Conclusions

This section has presented a comprehensive but succinct description of the mechanistic analyses performed to support the CDF QRAs. By providing information about the physical aspects of demilitarization process accidents, these analyses have aided in the construction of the following:

a. PODs used to identify process initiators (see section 4)

b. Fault trees that model system failures (see section 4)

c. The APETs used to delineate the progression of accidents following upsets (see section 6).

In some cases, results suggested that events should be eliminated from consideration. At other times, results indicated that logic model development should be focused on specific scenarios.

Mechanistic models also have been used to aid in the estimation of probabilities for many types of events (e.g., probability of structural failure given an explosion). Some discussion of the methods used to translate deterministic results into probabilities has been included in section 9.2.1, which discusses munition failures from impacts. More information is provided in section 6 and appendix L, where the APET is described; in appendix M, where a more detailed description of the mechanistic analyses themselves is presented; and in section 12, where uncertainty is discussed.

(This page intentionally left blank.)

SECTION 10
SOURCE TERM ANALYSIS

A wide range of accident sequences is generated from the quantification of the APET. For each sequence, a source term must be determined in order to estimate health consequences. The expression *source term* refers to the following information characterizing a release of agent to the environment: 1) type(s) of agent released, 2) release duration and quantity of each agent, 3) physical state of the released agent (vapor or liquid aerosol), and 4) whether the release comes from a seismic or similar external event (which affects mitigative measures) or daytime only operations (which affects the relevant meteorology). This information then is passed on to the consequence analysis task, where the potential public health effects are estimated for each source term. The role of source term evaluation in the overall process of quantitative risk assessment is shown in figure 10-1.

Section 10.1 summarizes the process of selecting the information from the accident description necessary for estimating source terms. The physical phenomena considered in the evaluation of source terms are summarized in section 10.2. In order to estimate source terms efficiently, the process has been automated through creation of several Microsoft® Excel-based source term

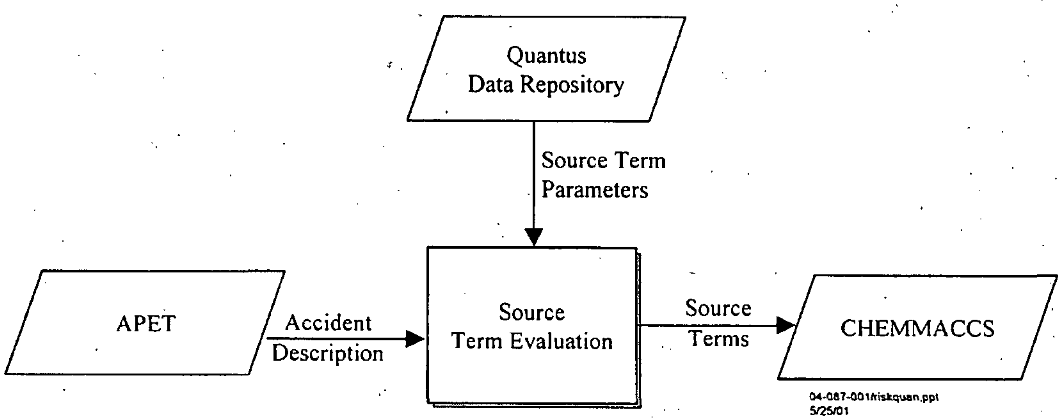


Figure 10-1. Role of Source Term Evaluation in Risk Quantification Process

model worksheets. The worksheets clearly display the equations and data used in calculating the source terms, and the use of worksheets simplifies the process of considering new release scenarios. Section 10.3 provides an overview of the source term calculation process. All the source term worksheets are briefly described in section 10.4. The combining of essentially identical releases into source term groups is described in section 10.5.

10.1 Accident Sequence Descriptions for Source Term Estimation

In general, the information generated by the APET for each accident sequence is in excess of that which is necessary to characterize the source term associated with the sequence. Thus, the first step in calculating the source terms for the accident sequences is to determine the minimum information needed to evaluate each source term. Once this information has been determined, accidents having identical descriptions (in terms of the minimal information) can be evaluated together. As described in section 6, the accident progression analysis includes the ability to solve the APET sequences in terms of specific sets of descriptors and characteristics. This provides the interface that passes the information from the APET to the source term analysis.

The descriptors for the accident description are carefully selected to yield the minimum number needed to allow full specification of the source term. For each descriptor, several answers (or characteristics) are possible. For example, a descriptor might be *type of agent being processed.* The possible characteristics for this descriptor could then be *GB*, *VX*, or *HD*. The descriptors for internal and external events are listed in tables 10-1 and 10-2, respectively.

The structure of the APET allows for multiple releases for each sequence to cover the wide range of effects of events such as explosions and earthquakes. As an example, the detonation of a munition in the UPA (instantaneous aerosol and vapor release) could cause nearby munitions to be breached and spill their contents (quasi-continuous evaporative release).

Each event identified in the APET has an associated frequency. When the descriptions of the events for determining the source terms are found to be identical, the events are combined for source term evaluation. The frequency assigned to the combined event is the sum of the frequencies of the contributing events. The frequency information is ultimately used in the overall QRA quantification process (see section 12).

10.2 Estimation of Source Terms for Accidents

An accident's descriptors identify information such as the release mode, the agent(s) involved, the number of munitions involved, and the availability of mitigative systems or barriers. The release mode determines the source term worksheet to be used, and the other attributes provide

Table 10-1. Internal Event Accident Descriptors for Source Term Specification

Accident Descriptors	Source Term Keyword	What It Helps Determine
Release Mode	Mode	Appropriate basic source term model suitable for the accident sequence and appropriate source term parameters to use with that model.
Propagation Release	Mode	Appropriate source term model for additional releases that occur as a result of the initial release
Agent	Agent	Physical properties that vary by agent type
Munition	Munition	Mass available for primary release
Quantity	Quantity	Number of munitions involved, mass available for release
Location	Location	Maximum agent pool area, DFs, indoor/outdoor releases
Amount	Amount	Other agent quantities (outside of munitions) available for release
Drain Status	DrainStatus	Mass available for primary release for accidents involving munitions or bulk containers, depending on when the accident occurs in the disposal process.
Propagation Munition	Munition	Mass available for propagation release
Propagation Quantity	Quantity	Number of munitions and quantity of agent involved in propagation events
Agent source	Condition	Whether the agent is contained in burstered, unburstered, or drained munitions
Inventory Level	AlUncLevel	Inventory of agent in the TOX tank or in munitions in the specified location(s) (high, medium, low) at time of event
HVAC Status	HVAC	DF, release mass
Building Breach	Breach	DF
Furnace Damage	Damage	Additional agent sources involved in furnace explosion
Day/Night	Not Applicable	This descriptor supplies information to the CHEMMACCS consequence code.
Population	Not Applicable	This descriptor supplies information to the CHEMMACCS consequence code concerning use of worker or public population grids.

the information required by that worksheet to estimate initial release masses and durations along with the effectiveness of any mitigation. The following sections give overviews of the models and parameters necessary to produce source terms. In addition to the release event attributes determined by the event tree, calculations involve source term parameters stored in the Quantus data repository. Each source term parameter discussed will have a point estimate of its value associated with it. For parameters to be sampled in the uncertainty analysis, the point estimate will define the mean or median of its uncertainty distribution. For parameters not sampled, the

Table 10-2. External Event Accident Descriptors for Source Term Specification

Accident Descriptors	Source term Keyword	What It Helps Determine
Result	Mode	Appropriate basic source term model suitable for the accident sequence and appropriate source term parameters to use with that model
CHB Collapse	CHBCollapse	Impact of seismic event on the CHB (Some seismic events need to be pulled out for separate analysis.)
CHB/UPA Collapse	CHBUPA	Impact of seismic event on the CHB/UPA (Some seismic events need to be pulled out for separate analysis.)
Forklift Drop	ForkliftDrop	Whether the seismic event causes forklift drops (Some seismic events need to be pulled out for separate analysis.)
Pallets Spilled	SpillLevel	Number of pallets of stacked munitions that fall and spill
Pallets Exploded	ExplodeLevel	Number of pallets of stacked munitions that fall and explode
Fire Intensity	FireLevel	Intensity of the fire determining the involvement of munitions present
Heat in HVAC Exhaust	EnergyLvl	Energy output of MDB fire affecting HVAC carbon autoignition and desorption
Agent	Agent	Physical properties that vary by agent type
Munition	Munition	Mass available for primary release
Location	Location	Inventories involved, maximum agent pool area, DFs, indoor/outdoor releases
Quantity	Quantity	Number of munitions and agent quantities available for release
Drain Status	DrainStatus	Mass available for primary release for accidents involving munitions or bulk containers, depending on when the accident occurs in the disposal process
Agent source	Condition	Whether the agent is contained in burstered, unburstered, or drained munitions
HVAC Status	HVAC	DF, release mass
Building Breach	Breach	DF
Day/Night	Not Applicable	This descriptor supplies information to the CHEMMACCS consequence code.
Population	Not Applicable	This descriptor supplies information to the CHEMMACCS consequence code concerning use of worker or public population grids.

point estimate is used across all uncertainty runs. See section 12 for a general discussion of the uncertainty analysis. Appendix O contains parameter distributions.

Two terms are used extensively in these subsections, namely, release fraction (RF) and DF. An RF is defined as the amount of material released divided by the amount available for release. A

DF is defined as the inverse of the RF; the amount of material available for release divided by the amount of material released.

Figure 10-2 shows the general information flow for estimation of source terms. The description of the accident from the APET is used to select the appropriate source term model and the appropriate information from the Quantus data repository via table lookups. The data repository also supplies information for the models, such as the physical properties of air used in evaporation calculations, that is not dependent upon the accident description. Source term calculations are performed to determine the mass of agent available for the release and the amount and rate of the release. The source term worksheet then determines the effectiveness of containment and HVAC recapture in reducing the agent release by using a DF also obtained by a table lookup based on the accident description. The resultant release to the environment is described in a form that can be used by the CHEMMACCS portion of Quantus to evaluate plume dispersion and the impact on the surrounding populations (consequence analysis) as described in section 11. The individual source term worksheets are summarized in section 10.4.

10.2.1 Initial Agent Releases. The term initial agent release is used here to describe the release of agent outside of its intended engineering controls or in quantities exceeding normal loads. For example, some agent spillage is expected in the ECRs during rocket processing. In this case, the HVAC system is an intended engineering control, because airborne agent is expected to be present in small quantities. However, if the entire contents of a rocket were dumped on the floor of the ECR, the agent load to the HVAC system would be expected to increase beyond that normally encountered during processing. This would be considered an initial release.

The first step in calculating an initial release mass is to determine the total agent mass potentially available for release. The accident description identifies the release amount in descriptive terms (single munition, two pallets, one igloo, etc.). Munition configuration data (see appendix O1) are used to convert this amount to available agent mass. Depending on the release mode, an appropriate RF is applied to arrive at an initial release mass.

Five possible modes for initial agent release are considered in the QRA: 1) evaporation and vaporization, 2) pool fire, 3) burster initiation, 4) other explosions, and 5) HVAC releases. These modes and the approaches used to model them are discussed in the following sections.

10.2.1.1 Evaporation and Vaporization. If agent is spilled onto the floor of a building or the ground outside, it can form a pool, which then evaporates. The pool area is determined by the volume of agent spilled and an assumed constant pool depth. For indoor spills, that depth is estimated to be 2 millimeters based on a concrete surface (SAIC, 2002c). For outdoor spills, the depth is estimated to be 1/4 inch based on a gravel surface (Whitacre et al., 1987). Rooms inside

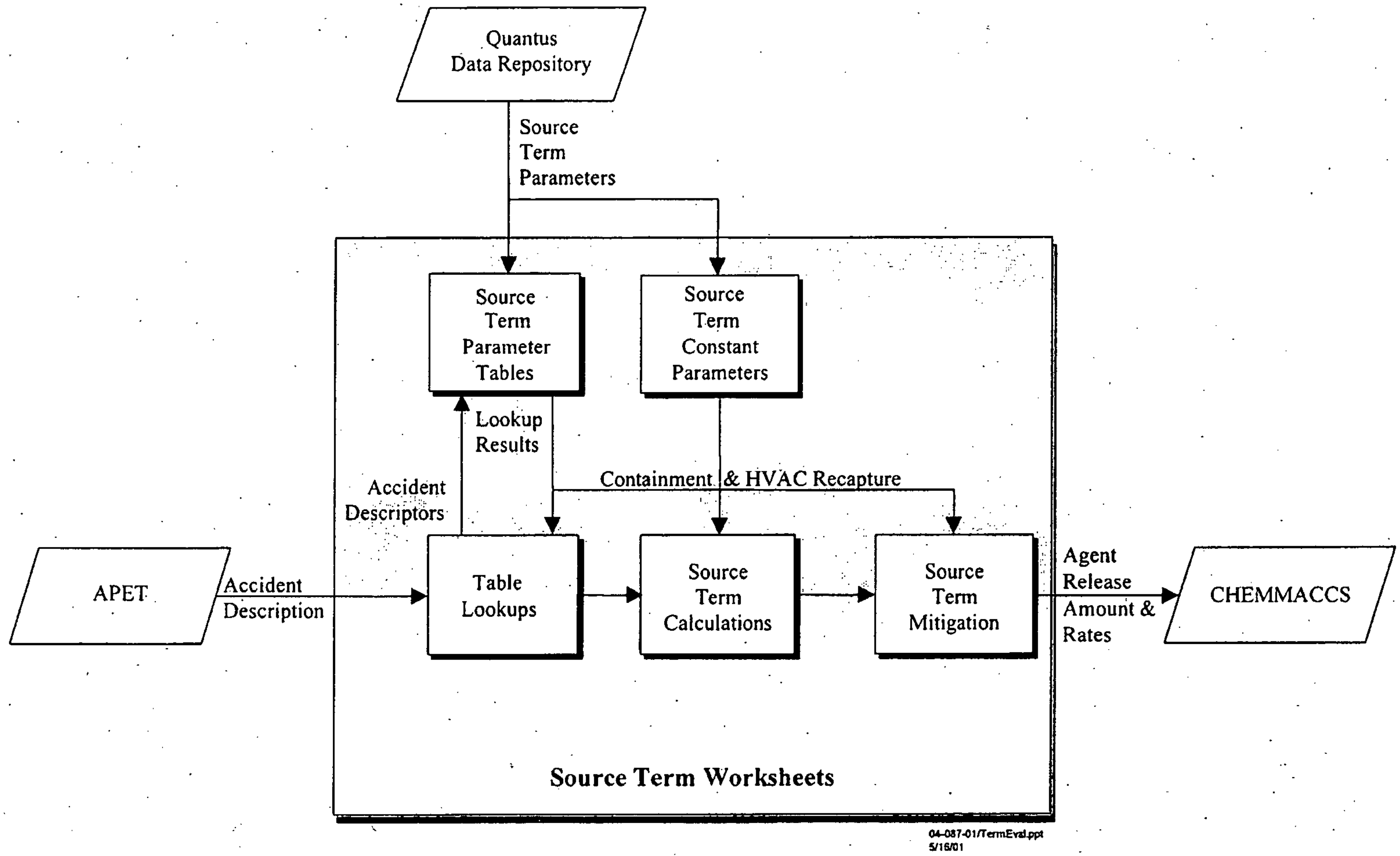


Figure 10-2. Information Flow for Source Term Evaluation

UMCDF can be smaller than the predicted spill area using these pool depths. If this is the case, the spill area is limited to the floor area of the room.

Spills within an igloo will tend to flow down the sloped floor, under the main door, and out the igloo. However, a portion of the spill's volume does not exit, since an area of the floor remains wetted. It is assumed that any igloo can hold a spill volume defined by half its floor area times a 2-millimeter pool depth. Any volume in excess of that threshold will flow outside and be subject to the outdoor evaporation rate.

The QRA recognizes that a munition puncture or impact could occur in such a place on the munition that a fraction of the agent inventory remains inside. That fraction is assumed to be 50 percent on average. That fraction is not applied to munitions that are crushed completely by severe events, such as room collapses and aircraft crashes.

Three scenarios have been identified in which agent spills after having been successfully drained from munitions. A TOX piping leak in the UMC will spill agent as it is drained from the ECR. It is assumed that agent from four munitions would spill before alarms are sounded and processing stops. Another possibility is a leak of the large TOX tank, which would spill the contents of up to 1,020 gallons of agent. A third scenario is a leak spilling the contents of 275 feet of piping from the TOX to the LIC, in which 6.3 gallons of agent would spill onto either the LMC or LIC room floor.

All spills not completely evaporated will eventually be contained. Their evaporative releases are limited due to the recovery actions of onsite personnel. Recovery times will vary depending on conditions at the time. The assumed spill release durations are 1 hour for an internal event without explosions, 6 hours for an internal event with explosions, and 24 hours for an external event. Of course, spill release durations will be less than these values if all agent has been evaporated.

The evaporation of agent has been considered in previous studies. Two conditions are addressed: evaporation into "nearly still air" (DDESB, 1980) and evaporation into a moving airstream (Rife, 1981). In either case, an empirical equation, based on experimental data, is used to determine the evaporation rates (see appendix O1). Agent properties, environment temperature, and freestream airflow velocity are considered. The assumed temperatures are 150°F for furnace rooms, 68.5°F inside the storage igloos (Lawrence, 1993), and 77°F elsewhere. Various airflow velocities based on the results of MELCOR modeling are assumed in the MDB rooms when the HVAC system is operating, and the nearly still air evaporation model is used. An airflow velocity of 0.03 meter per second in the MDB (nearly still air) is assumed when the HVAC system is not functioning. Other assumed airflow velocities include 0.03 meter per second in an igloo (nearly still air) and 3 meters per second outdoors (moving air).

Additionally, each furnace is designed to vaporize and subsequently destroy agent thermally. If an upset occurs such that a furnace continues to vaporize agent but not completely destroy it, agent may be released to the furnace room or through the PAS/PFS, depending on the specific accident sequence. In the MPF, munitions that are vaporizing agent may continue to do so if they are accidentally brought outside before decontamination has been completed. In all cases, the release rates are based on furnace performance calculations (see appendix M2).

At the MPF, the average vaporization rates in the furnace under normal conditions are used to characterize the vaporization rates for all munitions containing the same agent. The vaporization rates are based on the results of MPF tests performed for JACADS (Maumee, 1987). The available agent mass can be determined through the method outlined in appendix O1. The release duration is simply the agent mass divided by the vaporization rate. For munitions accidentally sent outside the MPF while vaporizing, the release duration is assumed not to exceed 6 hours. The 6-hour time period accounts for agent release, perimeter alarm, boil-off discovery, and release containment.

Due to extremely high temperatures associated with the LIC, it has been shown that releases to the LIC PAS or LIC room from the LIC during normal operations are not credible. However, if agent in the LIC piping from the isolation valves to the incinerator is not purged after shutdown, then 0.22 gallons of agent is estimated to be available for release to the PAS (the volume of unpurged piping). Release rates are based on feed rates to the LIC.

For the DFS, the vaporization rates are assumed to be double those determined for the MPF, recognizing that some agent could spill from the sheared pieces of munitions onto the already hot surfaces of the kiln interior.

10.2.1.2 Pool Fire. In the event of a fire involving a pool of agent, the agent will burn, but unburned agent can be vaporized and released to the air. Also, a pool is unable to sustain combustion when a minimum depth is reached, but would continue to evaporate. A recently completed study (Byrne, 2002a) concluded that, on average, agent RFs from pool fires would be approximately 0.206, 0.095, and 0.204 for GB, VX, and HD, respectively. The model considers self-extinguishment of the fire when the pool reaches a minimum depth, and RFs define the rapid release during the fire followed by the evaporative release. As with spills, the area of the pool may be confined by room walls. The initial release masses are calculated by multiplying the spill amount by the fire and evaporative RFs. The fire RFs for well-ventilated fires (without subsequent evaporation) also are applied for fires consuming the contents of rocket storage igloos.

10.2.1.3 Burster Initiation. If the burster of a chemical munition initiates, chemical agent will be dispersed as vapor as well as liquid droplets whose diameters span a considerable range. In order to determine the amount of aerosol generated and resultant droplet size distribution, a previously published model is used (Steindler and Seefeldt, 1981; Ayer, 1988; Mishima, 1993). This model correlates the mass of material aerosolized to the TNT equivalent of the burster. To determine the amount of agent that may be consumed in the heat and flame from the explosion of the burster, a methodology was adopted from empirical methods that were derived from analyses of test data. For GB-filled munitions, an approach developed by the Department of Defense Explosives Safety Board (1980) is incorporated into the QRA source term development. A temperature-dependent release fraction described in appendix O1 is used for GB. This is the methodology also used in the U.S. Army D2PC hazard prediction model. For VX munitions, no definitive documentation has been identified. The D2PC model releases 100 percent of the agent fill in an instantaneous release. However, anecdotal evidence (Parsons, 1988) suggests that up to 30 percent of the agent may be consumed in the detonation. The QRA assumes an 85 percent agent recovery, but will sample this factor as part of the uncertainty analyses between 70 percent and 100 percent. For HD, the Department of Defense Explosives Safety Board has published an elaborate model incorporating wind speed, atmospheric stability class, ambient temperature, and the time for subsequent evaporation on aerosol deposition for calculating the explosive RF (DDESB, 1980). This calculated RF is often less than that applied for VX releases under the same conditions. However, a recent study of hydrocarbon pool fires (Byrne, 2002b) concluded that a greater fraction of an HD spill than a VX spill would be dispersed unburned. Thus, the RF for an HD fire should be no less than that for a VX fire; the same RF is used. An explosive release is assumed to last 60 seconds, the shortest release duration allowed by the CHEMMACCS code used to estimate consequences (described in section 11).

If an undrained, burstered munition is accidentally fed into the MPF, the resulting explosion will cause agent to be released to an environment that is initially at a very high temperature (greater than 1,400°F). The furnace walls will likely fail from the blast, as may the furnace room walls, creating a direct pathway for agent release from the MDB. However, due to the high temperature of the furnace, the agent droplets should, to a large degree, ignite and burn. A mechanistic model was constructed to estimate the degree of agent destruction in these scenarios. The Steindler-Seefeldt model was used to predict the agent droplet size distribution, and empirical combustion correlations for burning hydrocarbon droplets were used to calculate the droplet burning rates. Ultimately, estimates of the RFs for different munition and furnace combinations were developed (Bailey, 1995) as shown in table 10-3.

If a mine explodes while in its drum, all three mines are assumed to explode. If an exploding munition is palletized, it may propagate, causing spills and, in the case of rocket pallets, detonation of neighboring munitions. Spilled munitions are treated according to the spill model. The assumptions of table 10-4 have been made with respect to propagation within a pallet. The rocket and mine data are based on the U.S. Army definition of the maximum credible event for rockets and mines (Yutmeyer, 1987). The projectile data are based on tests to determine extent

Table 10-3. Mean Release Fractions for Munition Detonations Within Furnaces Used for Estimation of Source Terms

Munition	RF
M55 Rocket	0.005
M23 Land Mine	0.036
155mm Projectile	0.003
8-inch Projectile	0.005

Table 10-4. Pallet Explosion Assumptions

Munition	Explosions/Pallet	Leaks/Pallet
M55 Rocket	2	13
M23 Mine	3	33
155mm Projectile	1	7
8-inch Projectile	1	5

of propagation or damage when an agent simulant-filled projectile detonates within a standard pallet (Hill, 1989). In the case of the 8-inch projectile, eight leaked in the two pallets. This assumption was modified to one explodes and five leak because there are only six 8-inch projectiles in a single pallet.

No sympathetic detonations occurred in any of the projectile tests; therefore, in the QRA, the detonation of a projectile within a pallet does not result in any additional detonations. For explosions involving multiple pallets, each pallet is treated independently. For instance, if four pallets of 155mm projectiles were involved in an explosion, then 4 projectiles would explode and 28 would leak.

10.2.1.4 Other Explosions. In addition to burster initiations, other types of explosions can lead to the release of agent. Vapor cloud explosions involving agent, natural gas, or hydrogen can lead to agent releases. When a vapor explosion occurs external to a munition, agent is consumed and released simultaneously, much like a fire. However, the explosion itself may cause splashing and inefficient agent consumption. With this in mind, the RFs for external vapor explosions are set to twice that of fire RFs.

A BLEVE is the violent rupture of a pressure vessel containing saturated liquid/vapor at a temperature well above its normal (atmospheric pressure) boiling point. BLEVE events have been postulated in the MPF. The resulting flash evaporation of a large fraction of the liquid produces a large vapor cloud that may ignite and burn in a fireball. A substantial amount of the liquid involved in a BLEVE may be consumed in the combustion process. The SFPE Handbook of Fire Protection Engineering (NFPA, 1988) states that the entire mass of combustible fluid in the vessel will be burned in the BLEVE fireball if the percentage of fluid vaporized is greater than 36 percent. Most BLEVE events summarized by the Society for Fire Protection Engineers Handbook are under well-ventilated conditions, such as a railroad tank car outside. The BLEVE events considered in the QRA may be underventilated inside the MPF. Therefore, the fire RFs (Byrne, 2002b) for underventilated fires, 0.248 (GB), 0.283 (VX), and 0.329 (HD), are used.

All explosive releases are modeled with a 60-second duration, a limitation of the CHEMMACCS code. Initial release masses are calculated by multiplying the available agent mass by the appropriate RF.

10.2.1.5 Heating, Ventilation, and Air Conditioning and Filter Releases. Five initial release scenarios directly involve the HVAC system. The first is failure of the cascading HVAC system to maintain the negative pressure relative to the outside. Out-leakage is postulated due to the thermal gradients from the furnaces, wind pressure effects external to the building, backflow through the fan inlets, and possible chimney effects from the PAS and HVAC stacks. Initial releases from this scenario are the result of agent evaporation from punched munition heels. Using the evaporation model of appendix O1, with an assumed pool area representing the sum of all the heel areas in the MDB, a release rate is calculated given loss of HVAC. HVAC failure release durations are estimated to be 24 hours for failure due to an external event and 6 hours otherwise. Initial release masses are calculated by multiplying the HVAC release rate by the release duration.

The other HVAC release scenarios involve release of agent from the HVAC filters. These carbon filters on the HVAC exhaust are capable of absorbing a substantial amount of agent. Four cases were considered: three fire scenarios and desorption. Filter inventories vary for each campaign and are a function of: 1) adsorption rates, 2) decomposition rates, 3) agent type currently being processed, 4) agent remaining on filters from previous campaigns, and 5) time since last filter changeout. These factors have been considered previously (see appendix M4).

If the filter housing is compromised, such as by an aircraft crash, the assumptions are that 50 percent of the agent inventory will be released due to desorption at high temperatures, while 50 percent will burn with a 10 percent RF based on the RF for pool fire without subsequent evaporation (Byrne, 2002b), resulting in an estimated overall RF of 55 percent. If the housing is not compromised, such as a fire ignited by high temperatures in the exhaust due to a fire in the MDB, three scenarios are considered. If air flow continues through the filter, the fire may burn intensely and consume most of the agent desorbed from the carbon. An RF of 0.008 (Birk, 2001) is assumed. If air flow is cut off, the fire may be starved for oxygen. In this case the carbon could smolder, desorbing agent at the elevated temperature, but not destroying the desorbed agent as efficiently. An RF of 0.1 is assumed. If the filter unit is heated up by hot exhaust from the MDB, but is not set on fire, the agent could be desorbed and not be burned. Because the entire filter unit would be hot, the remaining filter banks would not efficiently recapture the desorbed agent. Various RFs are assumed based on the size and intensity of the fire in the MDB and whether airflow continues (see appendix M4).

Table 10-5 contains a list of the number of filters affected by the various HVAC filter release accidents, including an aircraft crash into the filter storage igloo.

Table 10-5. Assumed Number of Affected Filters for Heating, Ventilation, and Air Conditioning Filter Releases

Cause of HVAC Filter Release	Burning Inventory
Large Aircraft Crash into Filter Units	All 9 Filter Units
MDB Fire Propagated to Filters	All 7 Filter Units in Use
Medium Aircraft Crash into Filter Units	3 Filter Units in Use
Small Aircraft Crash into Filter Units	1 Filter Unit in Use
Tornado-Induced Fire	3 Filter Units in Use
Transportation Accident	1 Filter Unit
Spontaneous Filter Fire	1 Filter Unit in Use
Large or Medium Aircraft into Filter Storage Igloo	All Changed-Out Filters of One Agent Type

10.2.2 External Events. Source terms for external events are calculated by computing the agent available for release, then applying the models of section 10.2.1. Often, for external events, the accident sequence description identifies release amounts in terms of rooms affected, rather than number of munitions affected. For this reason, it is necessary to know agent inventories of each room for each campaign. Appendix O1 contains a table of room munitions inventories for various campaign scenarios along with justifications for those values. The listed scenarios are not necessarily comprehensive. The Quantus software allows entering the appropriate agent inventories (calculated from munitions inventories) for the actual processing scenarios to be modeled. RFs have been developed previously (GA, 1987b) that determine what fraction of the affected inventory detonates, ruptures, or scatters intact for events similar to the external events modeled in this QRA. These estimates supply the majority of the RFs presented in the following sections. Specifics regarding external events are presented in the next few sections.

10.2.2.1 Seismic. Earthquakes are estimated to detonate some of the burstered inventory within any collapsed processing buildings and rupture the remainder. All bulk munitions not in EONCs are assumed to rupture. The APET also identifies whether a fire occurs, which will burn the agent from the ruptured munitions according to the fire model discussed in section 10.2.1.2. The fraction of the burstered inventory that detonates is greater if there is a fire.

10.2.2.2 Lightning. Lightning strikes are assumed to initially affect one rocket by current-induced EMF. Only M55 rockets, in particular their rocket ignitors, are considered to be potentially susceptible to ignition in the presence of strong EMF (see section 5.3). The explosion from that munition will propagate to its pallet, according to the explosion model (see table 10-4).

10.2.2.3 Aircraft Crash. The appropriate source term worksheet is selected depending on whether or not a fire results from the aircraft crash. For scenarios with fire, it is estimated that a fraction of the burstered inventory detonates with the same RF as determined in section 10.2.1.3, while the remainder burns according to the fire model. All the bulk munitions rupture and burn. For aircraft crashes without fire, it is estimated that a smaller fraction of burstered munitions detonate and the remainder spill their agent. All bulk munitions are assumed to spill their agent. The estimated numbers of munitions affected are summarized in table 10-6.

Table 10-6. Estimated Number of Affected Munitions for Various Aircraft Sizes

Aircraft Size	Crash at MDB	Crash at CHB
Small	UPA inventory	1 EONC
Medium	UPA + CHB/UPA inventory	5 EONCs
Large	MDB inventory	CHB inventory

10.2.2.4 Tornado. A tornado could breach the UPA and cause missiles to fly into the UPA or draw munitions out. If missiles fly into the UPA, a pallet of munitions could explode. If the tornado pulls munitions out of the UPA, they strike the ground and explode as described in section 10.2.1.3. The tornado could also cause collapse of the CHB, but the munitions are protected in the EONCs. A tornado striking the MDB filter units could destroy the units and scatter the contaminated filter carbon on the ground or disperse it into the air. The rate of agent desorption from the carbon under ambient conditions would be so little as to pose negligible risk to the public, but inhalation of agent-contaminated filter dust could result in injury. However, if the carbon were to be ignited, such as by burning natural gas, agent would be desorbed from the burning carbon of three filter units as described in section 10.2.1.5.

10.2.2.5 External Fire. Fires as a result of external events could involve the agent from drained munitions, undrained burstered munitions, undrained unburstered munitions, and the TOX tank, depending on magnitude, location, and the duration of the fire. The amount of agent released from a fire in the MDB is calculated from the amount of agent involved in the fire according to the pool fire model described in section 10.2.1.2. Heat from the fire also could lead to release of agent collected in the HVAC filter units as described in section 10.2.1.5.

10.2.3 Effects of Mitigation. Once the initial release of agent takes place within the facility, the potential pathways for aerosol and vapor transport determine the extent of contamination. As described in section 9.2.3, the effectiveness of the MDB and its various mitigative systems in containing agent releases is taken into account using DFs. The computer code MELCOR (Sandia, 1991) was used to simulate agent transport within the MDB and to determine DFs. Four different DFs were used in calculating the source terms for accident progression sequences within the MDB. Depending on the location of the initial release, building integrity, and HVAC status, one of the DFs listed in table 9-6 of section 9.2.3.2 was assigned.

In the scenario of an explosion followed by an exterior MDB wall breach, it is postulated that a fraction of the explosive mass will be immediately released from the building. This accounts conceptually for three things: the mass of agent propelled out of the building via momentum effects (greater for blasts near the wall and for larger breaches), the mass of agent released from the building during "blowdown" of the pressurized room that might not be correctly predicted by the spatially uniform MELCOR model, and the mass of agent that splashes off objects in the room (walls, floor, equipment, etc.) and is carried out during blowdown (the MELCOR resuspension models might not catch these accurately, as well). The remainder of the release will still be available for release but will be subject to the appropriate MELCOR-derived DF.

10.2.4 Estimation of Source Terms for Continued Storage. Numerous accident progression sequences were generated from quantification of the stockpile storage area APET. For each sequence, a source term was determined based upon the section 10.2 source term models (i.e., evaporation, seismic events, aircraft crashes). However, the following additional assumptions have been made:

a. Igloos at UMCD were assessed to be capable of withstanding earthquakes and the region does not have a history of sinkholes.

b. Spills within a standing igloo will tend to flow down the sloped floor, under the main door, and out the igloo. However, a portion of the spill's volume will not exit because the igloo floor area remains wetted. It is assumed that any igloo can hold a spill volume defined by half its floor area times a median 2-millimeter pool depth. Any volume in excess of that threshold will flow outside and be subject to the outdoor evaporation rate.

c. Based on the structural analysis, which indicates that the available kinetic energy involved in a large aircraft crash can result in considerable damage to the storage igloo and the munitions therein, the source term for this event assumed that the entire inventory of agent within the igloo was involved in the release.

The number of munitions and number of 80-foot igloos were taken into account in determining the source terms for stockpile storage area sequences. See appendix O4 for igloo inventories.

One important difference between the UMCDF source terms and those associated with the stockpile storage area was the fact that DFs were not considered for stockpile storage area sequences. Because the igloos have vents and agent can leak directly outside, DFs were not applied to reduce releases due to events occurring inside igloos.

10.2.5 Preparation for Consequence Modeling. The source terms are used to create input files for consequence analysis. To prepare for creation of these files, decisions are made regarding the phase of each agent. The explosive events can release liquid agent into the atmosphere. The energy associated with an explosion will quickly convert liquid GB to a vapor phase because of the high volatility of GB. Due to their low volatility, agents VX and HD have the potential to be dispersed as both vapor and aerosol droplets in an explosion. Studies have been performed on the fractions of each agent that will remain as aerosol droplets, drop out of the plume, or evaporate from the droplets (Robbins, 1997). CHEMMACCS does not include a droplet evaporation model, so it was necessary to investigate the agent behavior through sensitivity studies (see appendix O1). These studies have led to the determination that, for munitions containing HD and VX, an initial distribution of 25 percent vapor and 75 percent aerosol upon explosive initiation of the munition will produce conditions at the site boundary reasonably representative of the actual conditions. It was further determined that the same distribution sufficiently models the threat to workers onsite. Simultaneous explosive and non-explosive releases are treated independently. The distribution of agent between vapor and aerosol is considered only for releases from exploding munitions. The agent from the non-exploding munitions is modeled as 100 percent vapor. This assumption is used throughout the analysis except for rocket igloo fires. In this case, the fire within an igloo acts as a furnace, vaporizing all aerosol and burning some vapor.

For CHEMMACCS modeling, each release is treated as a combination of instantaneous (60 seconds) and quasi-continuous plumes. The instantaneous plume is comprised of explosive and short duration (such as pool fire) releases. The instantaneous plume may include aerosol dispersed by the explosion. The quasi-continuous plume is of relatively long duration and is vapor only. The duration of the quasi-continuous plume is input to CHEMMACCS also. Four hundred seconds is used as the threshold for classifying releases as instantaneous or quasi-continuous.

10.3 Overview of Source Term Calculations

Source terms are calculated using a series of source term models coded on Microsoft® Excel worksheets. A number of different models are required to capture all of the possible agent releases associated with accident sequence outcomes. The worksheets make it possible to view all equations and data used in evaluating the source terms. This enables straightforward review of the sometimes complex calculations both by the QRA team, as part of the internal quality assurance process, and by external reviewers. In addition, this method allows testing of the assembly of all portions of the source term for specific accident sequences, a process that was considerably more complex during the TOCDF QRA because then all the calculations were embedded in computer code. It also is very easy to add new models to reflect new circumstances that might be identified as the accident sequences are refined.

The source term worksheets are called automatically by Quantus. The accident progression analysis first solves the event trees in terms of the descriptors and associated accident characteristics that are defined as necessary to the source term estimation. Based on the accident characteristics, the proper source term worksheets are called, calculations are performed in Microsoft® Excel, and the results are stored for each separate unique combination of accident characteristics. The worksheets have a direct communication with the Quantus data repository. Key parameters needed for the calculation are stored in the repository and supplied by Quantus to the spreadsheets. This serves two functions. First, when running in uncertainty mode, random sampling of the data variables is completed within Quantus, and a set of parameter values is provided to worksheets to automate the calculation of results for each sample of an uncertainty evaluation. Second, Quantus will eventually be able to provide information concerning the accident sequence that is dependent on the specific disposal activities. For example, accidents associated with a munition disposal campaign will involve a specific facility configuration in terms of inventories of munitions in various stages of demilitarization in different parts of the facility. Currently, the campaign is provided as an accident sequence descriptor for application worksheets so that accurate inventories can be used in source term calculations.

At the current time, all source term calculations in point-estimate mode are completed using worksheets. To increase the speed of the calculation for the uncertainty analysis the models also are coded in Borland® Delphi™ and run directly in Quantus.

Figure 10-3 illustrates the basic layout of a source term worksheet. As indicated, the first part of the sheet is devoted to an input of the accident sequence in terms of only those descriptors

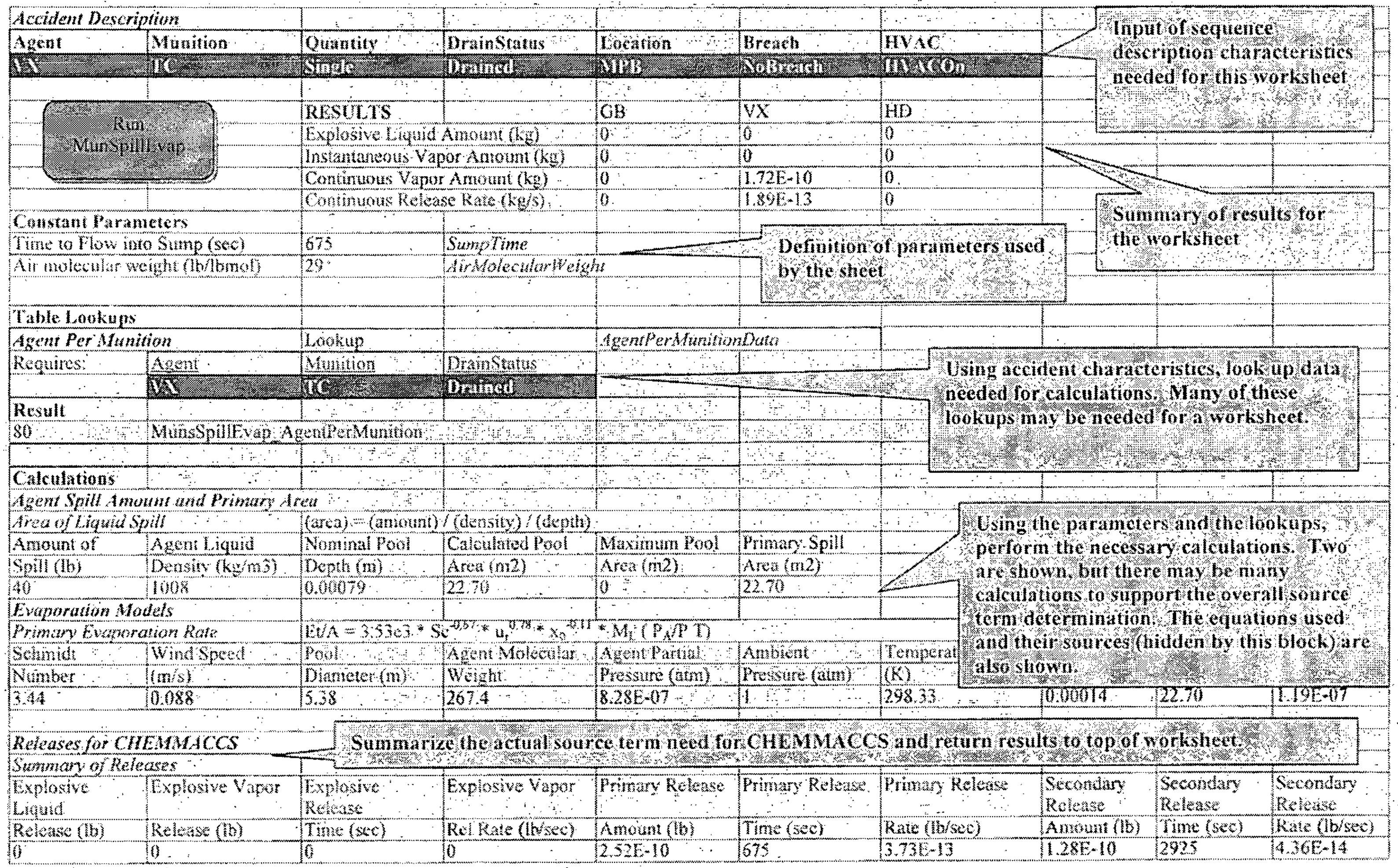


Figure 10-3. Illustration of the Structure of a Source Term Worksheet

needed for the worksheet of interest. The specific set of characteristics is used for the determination of needed information in the *table lookups* portion illustrated in the middle of the sample worksheet. In the example table lookup, the descriptors (Agent, Munition, and DrainStatus) establish the amount of agent in the item. Prior to the table lookups are parameters used in the worksheet. These are labeled *constant parameters* because they do not depend on the accident sequence, although they may be uncertain and therefore be sampled from a parameter distribution during the uncertainty analysis.

Following the lookup tables (many might be required to gather all the needed information for modeling the accident release) is a section of the worksheet devoted to calculation of the result. The calculation may be simple or it may require an entire series of calculations. In the example in figure 10-3, two calculations are shown, one to find a spill area and a second to calculate evaporation. There may be many other calculations included on the worksheet to fully characterize the physical phenomena.

Finally, the calculations are summarized at the end of the worksheet in the format needed for the CHEMMACCS dispersion and consequence code. This creates the link between the source term analysis and the dispersion and consequence analysis. These values also are returned to a summary of results at the top of the worksheet for convenience of the user.

Figure 10-3 includes examples of the various portions of the worksheet analysis. An actual example of an entire worksheet is provided in appendix O1. The source term models are described in detail in appendix O1, and the individual model worksheets are described in appendix O3.

The source term algorithm begins with the characteristics describing the accident, as produced by the accident progression analysis in Quantus. Table 10-1 summarized the accident descriptors for disposal processing. Each unique accident sequence description from an APET run is processed individually. Source term production begins by identifying the primary release mode and selecting the appropriate source term worksheet. For each worksheet, there is a set of required inputs corresponding to a subset of the event attributes. The source term worksheet is capable of determining: 1) the mass of agent available for release; 2) the actual initial release amount based upon the models described in section 10.2 and the parameter values set by default or by the matrix of sampled values; 3) the effectiveness of engineering controls in mitigating the release (DFs) as a function of location, release mode, exterior wall integrity, and HVAC status; and 4) the form of the plume (explosive liquid, instantaneous vapor, quasi-continuous vapor, and quasi-continuous rate) to be modeled by CHEMMACCS.

Primary releases may propagate, causing secondary releases. The secondary release is modeled in the same manner as the primary release, using the same source term worksheets. Global

HVAC failure also will contribute to agent release according to the models described in section 10.2.1.5. A separate source term worksheet is invoked to compute the potential agent release due to global loss of HVAC. Quantus combines the source term contributions from the primary release, secondary release, and global loss of HVAC to determine the overall release for the event.

Once source terms have been determined for all unique accidents, like source terms may be grouped as described in section 10.5. In order for source terms to be grouped together, the time and mode attribute must match, and the mass and rate quantities must be "close enough" to each other according to grouping parameters defined by the Quantus user. Grouping is used when needed to reduce computational time.

10.4 Worksheets Used for Calculation of Source Terms

In these sections, each worksheet used for calculation of source terms is briefly described. For all those events that can happen in the MDB, the capabilities of the building to contain the release and the HVAC to recapture the release are considered to determine the amount of agent that could be released outside the building. The worksheets and their roles are summarized in table 10-7.

10.4.1 AgtVapExp. An agent vapor explosion in the MPF or feed airlock is modeled using this worksheet. If the explosion occurs in the furnace, all agent in the furnace is released subject to the appropriate DF. The furnace is assumed to be hot and ruptured so that all remaining liquid agent quickly evaporates and escapes. If the explosion is in the feed airlock, the contents of the airlock are similarly released. If the airlock explosion causes damage to the furnace, the contents of the furnace are released also.

10.4.2 BLEVE. A BLEVE can result if unpunched munitions are introduced into the MPF. As with the agent vapor explosion, the integrity of the furnace is violated and any remaining agent is quickly evaporated. If the BLEVE occurs in the MPF, other munitions in the furnace also release any remaining agent. The source term is calculated as described in section 10.2.1.4.

10.4.3 BOIL. Due to operational upsets, munitions could be discharged from the MPF while still containing agent. Any remaining agent is assumed to boil off outside the MDB. The release rate is based on MPF vaporization rate tests (Maumee, 1987).

10.4.4 CDFEvap. A seismic event or tornado could cause collapse of a room or rooms in the MDB, crushing the munitions contained therein. This worksheet is used if the event does not result in explosion or fire. The munitions involved are determined from the munitions inventories in the affected rooms of the MDB. The contents of the munitions are spilled and the

Table 10-7. Source Term Worksheets and Their Functions and Inputs

		Inputs																		
Worksheet	Application	Agent	AllUncLevel	Amount	Breach	CHBCollapse	CHB-UPA	Damage	DrainStatus	EnergyLvl	ExplodeLevel	FireLevel	ForkliftDrop	HVAC	Location	Mode	Munition	Quantity	SpillLevel	(StorageUnit Outcomes)
AgtVapExp	Agent vapor explosion at MPF or airlock	x			x			x	x					x	x		x			
BLEVE	BLEVE in MPF	x			x				x					x	x		x	x		
BOIL	Boil off from munition discharged from MPF	x							x								x	x		
CDFEvap	Collapse of MDB room(s), pool evaporation	x													x	x				
CDFExplodeEvap	Collapse of MDB room(s), explosion + evaporation	x	x												x	x				
CDFExplodeFire	Collapse of MDB room(s), explosion + fire	x	x												x	x				
DFSPAS	Release through PAS from DFS	x							x								x	x		
DispSeismic	Combine multiple outcomes due to seismic event at MDB	x			x	x	x						x	x	x	x	x			
ExtFire	Combine multiple outcomes due to fire at MDB	x			x					x		x		x	x	x				
FilterIgloo	Fire in igloo containing spent filter carbon	x														x				
FilterMDB	Fire in MBD HVAC filter unit(s)	x								x					x	x				
HVACExt	Release when HVAC lost – external event	x			x										x		x			
HVACInt	Release when HVAC lost – internal event	x			x										x		x			
IglooFire	Fire engulfing contents of full or partial igloo	x		x											x	x	x			
LICPAS	Release through PAS from LIC	x																		
LICRoomRelease	LIC furnace room release	x												x						
MPFPAS	Release through PAS from MPF	x							x								x			
MPFRoomRelease	MPF furnace room release	x							x					x			x			
MunsExplodeEvap	Burster explosion / pool evaporation, specified quantity of munitions	x			x				x					x	x		x	x		
MunsExplodeFire	Burster explosion / pool fire, specified quantity of munitions	x			x				x					x	x		x	x		
MunsExplodeFurn	Burster explosion of specified quantity of munitions in a furnace	x			x				x					x	x		x	x		
MunsSpillEvap	Agent spill from specified quantity of munitions	x			x				x					x	x		x	x		
MunsSpillFire	Agent pool fire at MDB	x			x				x					x	x		x	x		
NGExpDFS	NG or agent vapor explosion at DFS	x			x									x	x					

Table 10-7. Source Term Worksheets and Their Functions and Inputs (Continued)

Worksheet	Application	Inputs: Agent	AIUncLevel	Amount	Breach	CHBCollapse	CHB-UPA	Damage	DrainStatus	EnergyLvl	ExplodeLevel	FireLevel	ForkliftDrop	HVAC	Location	Mode	Munition	Quantity	SpillLevel	(StorageUnit Outcomes)
NGExpLIC	NG or agent vapor explosion at LIC	x			x									x						
NGExpMPF	NG, agent vapor, or H2 explosion at MPF	x			x				x					x			x			
RHSSpillEvap	Agent spill from RHS piping	x			x									x	x		x			
RoomFire	Explosions and fire consuming contents of specified MDB room	x			x							x		x	x	x				
StgCollapseEvap	Crushing of storage unit contents, explosions and evaporation	x		x											x	x	x			
StgCollapseFire	Crushing of storage unit contents, explosions and pool fire	x		x											x	x	x			
StgExplodeEvap	Munitions explode or spill, evaporation, no fire	x									x				x		x	x	x	
StgSeismic	Combine multiple outcomes due to seismic event at storage yard																			x
TOXSpillEvap	Evaporation of agent spilled from TOX tank or piping	x		x	x									x	x					
TOXSpillFire	Pool fire of agent spilled from TOX tank or piping	x		x	x									x	x					
TransportFilterFire	Filter fire following transportation accident	x																		
UPAFire	Fire engulfs UPA contents	x			x							x		x		x				

release is determined using the pool evaporation model (section 10.2.1.1). The fraction of the room inventory involved depends on the event.

10.4.5 CDFExplodeEvap. This worksheet is similar to ExtEvap, but is used if the event causes burstered munitions to explode but does not cause a fire. Release of agent from the exploded munitions is determined using the explosive RF (section 10.2.1.3). The munitions involved are determined from the munitions inventories in the affected rooms of the MDB. The contents of the remaining munitions are spilled, and the release is determined using the pool evaporation model (section 10.2.1.1). The fraction of the room inventory involved depends on the event.

10.4.6 CDFExplodeFire. This worksheet is similar to ExtExplodeEvap and is used if the event does lead to a fire. Release of agent from the exploded munitions is determined using the explosive RF (section 10.2.1.3). The munitions involved are determined from the munitions inventories in the affected rooms of the MDB. The contents of the remaining munitions are spilled, and the release is determined using the pool fire model (section 10.2.1.2). The fraction of the room inventory involved depends on the event.

10.4.7 DFSPAS. This worksheet determines the amount of agent that could escape to the stack through the DFS PAS and PAS filter based on the contents of the DFS.

10.4.8 DispSeismic. A seismic event during disposal processing can cause multiple types of releases simultaneously. The particular contributory events are determined by the APET. A Microsoft® Visual Basic® macro interprets each input and calls upon the ExtExplodeEvap, ExtExplodeFire, HVACExt, MunsExplodeEvap, MunsSpillEvap, RoomFire, TOXSpillEvap, and TOXSpillFire worksheets to evaluate the contributory source terms. The results for all contributory events are summed to determine the total source term for the event.

10.4.9 ExtFire. An extensive fire in the MDB could cause release of agent both by burning munitions in the building and by heating the MDB filters with hot exhaust, leading to release of agent on the filter carbon. This worksheet calls upon the ExtExplodeFire, UPAFire, or RoomFire worksheet, depending on the extent of the fire in the MDB, to determine agent release from munitions consumed in the fire. ExtFire also calls upon the FilterMDB worksheet to evaluate release of agent from the MDB filter units. The results of the two release contributors are summed to determine the overall release for the event.

10.4.10 FilterIgloo. If an aircraft crashes into the igloo in which spent filter carbon is stored, it could set the carbon on fire. Spent carbon is assumed to be stored separately by agent type. The release rate is determined as described in section 10.2.1.5.

10.4.11 FilterMDB. Agent on the filter carbon in the MDB filter units could be released if the carbon is heated, whether or not the carbon actually catches fire. This worksheet calculates the amount of agent released based on the amount of agent present on the filters and the RF based on the event. The release modes considered include burning of the contents of ruptured filter units, well-ventilated or smoldering fires inside intact units, and desorption without fire. The RFs are determined as described in section 10.2.1.5.

10.4.12 HVACExt. During disposal operations, there are normally punched munitions in the MDB awaiting decontamination in the MPF. Agent vapors evolved from these munitions are recaptured by the HVAC system when the system is operating properly. If there is a global failure of the HVAC system, the normal vacuum relative to the environment is lost and agent can escape the MDB. The HVAC release amount is determined as described in section 10.2.1.5. The duration of the release is the time to evaporate the entire agent heel. The maximum release time following an external event is assumed to be 24 hours.

10.4.13 HVACInt. This worksheet is identical to that for HVACExt except that the maximum release time following an internal event is assumed to be 6 hours.

10.4.14 IglooFire. If rockets are ignited, the explosion could propagate to a fire consuming additional pallets of rockets. This worksheet determines the inventory of munitions in the igloo depending on igloo size and burns the fraction of the igloo determined by the APET. The fire RFs determined as in section 10.2.1.2 are used.

10.4.15 LICPAS. This worksheet determines the amount of agent that could escape to the stack through the LIC PAS and PAS filter based on the agent content in the LIC room piping.

10.4.16 LICRoomRelease. The amount of agent that can be released from the LIC room is determined by this worksheet based on the agent content in the LIC room piping.

10.4.17 MPFPAS. This worksheet determines the amount of agent that could escape to the stack through the MPF PAS and PAS filter based on the contents of the MPF.

10.4.18 MPFRoomRelease. The amount of agent that can be released from the MPF room is determined by this worksheet based on the contents of the MPF.

10.4.19 MunsExplodeEvap. If the release event calls for an explosion in a quantity of munitions, a certain number of those munitions are involved in the explosion and other munitions are spilled. The explosive RF (section 10.2.1.3) is determined for the amount of agent involved in the explosion. The spilled agent is released by pool evaporation (section 10.2.1.1).

10.4.20 MunsExplodeFire. If the release event calls for an explosion in a quantity of munitions, a certain number of those munitions are involved in the explosion and other munitions are spilled. The explosive RF (section 10.2.1.3) is determined for the amount of agent involved in the explosion. Pool fire calculations are employed to determine the release from the spilled agent (section 10.2.1.2).

10.4.21 MunsExplodeFurn. If a burster explosion occurs in the MPF, the RF for the agent depends on the munition type. All agent is released explosively.

10.4.22 MunsSpillEvap. If the release calls for a spill from a quantity (e.g. single, pallet, or transport tray) of munitions, this worksheet determines the number of munitions that spill their contents and calculates the evaporative release from the resultant pool (section 10.2.1.1).

10.4.23 NGExpDFS. A natural gas explosion at the DFS results in agent release from the munitions in the ECR or UPA. About one-quarter of the explosively configured (burstered) munitions explode. All other agent is spilled and involved in a pool fire (section 10.2.1.2).

10.4.24 NGExpLIC. A natural gas explosion at the LIC starts a fire that burns all the agent in the LIC piping according to the pool fire model (section 10.2.1.2).

10.4.25 NGExpMPF. A natural gas explosion at the MPF causes immediate evaporation and release of any agent in the MPF.

10.4.26 PoolFire. The entire amount of agent in the specified quantity of munitions is spilled. The pool fire model (section 10.2.1.2) is used to determine the fraction of the agent actually released.

10.4.27 RHSSpillEvap. If the piping in the UMC ruptures, the agent fill from three munitions could be pumped out onto the floor before the leak is detected and processing stops. The amount of agent spilled is determined from the munition type. The pool evaporation model (section 10.2.1.1) is used to determine release rate and amount.

10.4.28 RoomFire. If a fire engulfs the munitions in an MDB room, this worksheet is used to determine the munitions inventory in that room, model the explosion (section 10.2.1.3) of approximately one-quarter of the burstered munitions (if any), spill all the remaining agent, and apply the pool fire equations (section 10.2.1.2) to determine the agent release. An additional input allows the risk modeler to specify the amount of agent on other things in the room, such as discarded DPE suits.

10.4.29 StgCollapseEvap. A seismic event, sinkhole, or aircraft crash could result in collapse of the igloo. The collapse of the igloo would lead to explosion of approximately one-quarter of the burstered munitions inventoried in the igloo, using the explosive RF (section 10.2.1.3). The agent from the remaining munitions is spilled and released by pool evaporation (section 10.2.1.1). Depending on the size of the aircraft or sinkhole, all or part of the entire igloo could be involved, in which case the fractional involvement of the igloo is applied to the explosive and evaporative releases. A large aircraft might even involve two igloos.

10.4.30 StgCollapseFire. A seismic event, sinkhole, or aircraft crash could result in collapse of the igloo followed by a fire. The collapse of the igloo would lead to explosion of approximately one-quarter of the burstered munitions inventoried in the igloo, using the explosive RF (section 10.2.1.3). The agent from the remaining munitions is spilled and released by a pool fire (section 10.2.1.2). Depending on the size of the aircraft or sinkhole, all or part of the entire igloo could be involved, in which case the fractional involvement of the igloo is applied to the explosive and fire releases. A large aircraft might even involve two igloos.

10.4.31 StgExplodeEvap. A seismic event or a sinkhole could cause stacks of munitions to topple. The falling munitions could explode or spill. The APET determines how many respond in each way. This worksheet calculates the explosive release for the number of munitions that explode in each exploding pallet using the explosive RF (section 10.2.1.3), then calculates the amount of agent spilled by other munitions in the exploding pallets as well as by the munitions in the leaking pallets. The numbers of munitions exploding or leaking in each pallet is the same as used for pallets dropping and exploding or leaking in the MDB. Release of the spilled agent is modeled using the pool evaporation model (section 10.2.1.1).

10.4.32 StgSeismic. When a seismic event strikes the storage yard, there can be releases from many igloos at the same time. The input to this worksheet from the APET provides the level of each various outcome that can happen to each igloo. A Microsoft® Visual Basic® macro interprets each input and calls upon the IglooFire, StgCollapseEvap, StgCollapseFire, and StgExplodeEvap worksheets to evaluate the source terms associated with each storage unit. The results for all storage units are summed to determine the total source terms for the event.

10.4.33 TOXSpillEvap. This worksheet determines the amount of agent spilled if the TOX tank or TOX or LIC piping ruptures, then uses the pool evaporation model (section 10.2.1.1) to determine the agent release.

10.4.34 TOXSpillFire. This worksheet determines the amount of agent spilled if the TOX tank or TOX or LIC piping ruptures, then uses the pool fire model (section 10.2.1.2) to determine the agent release.

10.4.35 TransportFilterFire. If the truck transporting the spent filter carbon to the igloo for storage is involved in an accident and a fire starts, 55 percent of the agent in the carbon is released as described in section 10.2.1.5.

10.4.36 UPAFire. If a fire engulfs the munitions in the UPA, this worksheet is used to determine the munitions inventory in that room, model the explosion (section 10.2.1.3) of approximately one-quarter of the burstered munitions (if any), spill all the remaining agent, and apply the pool fire equations (section 10.2.1.2) to determine the agent release.

10.5 Grouping of Source Terms

After source terms are produced for each unique accident description, it may be necessary to group these source terms. Grouping is necessary because there can be from hundreds (point-estimate calculation) to thousands (uncertainty analysis) of unique accidents for which source terms will be produced. It is not practical or necessary to perform this many consequence calculations. Therefore, similar source terms can be grouped together with respect to agent release mass and duration to produce a reduced number of representative source terms.

The grouping methodology is similar in form to the combining of accident sequences based on their matching descriptions (see tables 10-1 and 10-2). In the grouper, the following four dimensions exist for each agent type (see table 10-8): mass of agent released explosively as

Table 10-8. Summary of Source Term Grouper

Keyword	Title
ExpLiqAmtGB	GB explosive liquid release mass
InstRelAmtGB	GB instantaneous vapor release mass
ContRelAmtGB	GB quasi-continuous release mass
ContRelRateGB	GB quasi-continuous release rate
ExpLiqAmtVX	VX explosive liquid release mass
InstRelAmtVX	VX instantaneous vapor release mass
ContRelAmtVX	VX quasi-continuous release mass
ContRelRateVX	VX quasi-continuous release rate
ExpLiqAmtHD	HD explosive liquid release mass
InstRelAmtHD	HD instantaneous vapor release mass
ContRelAmtHD	HD quasi-continuous release mass
ContRelRateHD	HD quasi-continuous release rate
Time/Mode	Seismic, daytime weather, or 24-hour weather

liquid, other instantaneous release mass (vapor), mass of agent released quasi-continuously as vapor, and the rate of the quasi-continuous release. An additional attribute of the release denotes whether the event can only happen during daylight hours or results from a seismic event. This grouper is described in more detail in appendix O2.

Internal events taking place at the stockpile storage area or during transportation are modeled to occur only during daylight hours, defined as 1 hour after sunrise until 1 hour before sunset. It is assumed that these hours are 7 a.m. to 5 p.m. Sensitivity studies showed that changing these times ±1 hour has no effect on consequences. All other events can occur at any time in a 24-hour period. The time of day is important to the estimation of consequences because of the different weather conditions between day and night. Source terms generated from seismic events must be identified for the consequence analysis, so that a decrease in the likelihood of masking and an increase in the masking delay time can be applied (earthquakes cause disorientation and degradation in human performance).

As the source terms are grouped, a representative source term for each group is calculated using a frequency-weighted average of the source terms that comprise the group.

10.6 Results

The results of the source term evaluation are: 1) information characterizing the source term for each unique accident description generated by the accident progression analysis, and 2) a smaller set of representative source terms derived by grouping the source terms based on similarity of consequence. This information consists of the following:

- The quantities and types of agents released to the environment
- The physical state of each material (vapor or liquid aerosol)
- The rate, timing, and duration of the release (considering mode of release and potential for recovery actions limiting duration in certain cases)
- A range of hours of the day during which the release can occur or whether the release results from a seismic event.

This section has provided a brief summary of the source term analysis. Details of the source term models and parameters, the source term grouper, and the source term model worksheets can be found in appendix O.

(This page intentionally left blank.)

SECTION 11
CONSEQUENCE ANALYSIS

Consequence analysis is the final technical evaluation step in the QRA process, in which the health effects to the population surrounding a facility are estimated for each source term group. Health effects are expressed as the number of acute fatalities and excess cancers that could be associated with a given release. These health effects (consequences) are determined by modeling the transport of agent in the environment, evaluating the population exposures (doses), and then calculating the probable numbers of persons who would sustain the various consequences. By calculating the expected consequences for every source term group and combining this with the frequency of the accident progression sequence, the risk can be estimated as described in section 12.

11.1 Background

The D2PC downwind hazard prediction model has been used to determine agent hazard prediction at each of the stockpile sites. This program models agent transport using a Gaussian plume model and estimates the downwind distances to specified hazard levels: 1 percent fatality, 0 percent fatality (no deaths), and no effects. D2PC uses one weather condition per event and does not contain exposure protection models. The direct use of D2PC in the QRA would have required substantial modifications, including statistical weather sampling, health effect models for agent exposure levels, population distribution handling ability, and exposure protection models. These modifications would have changed the basic structure of the D2PC program.

Another air dispersion program called D2-Puff has been accredited as of June 2000, and will eventually replace D2PC. Installation of the program and training is currently taking place at all the stockpile sites.

A different program capable of handling all the data and generating the statistical results required by the QRA is being used. The MELCOR Accident Consequence Code System (MACCS), a program developed by Sandia National Laboratories and used in the NUREG-1150 studies, models the transport of radionuclides following nuclear accidents and computes doses and health effects in exposed populations. In the MACCS code, population distributions, health effect models, and exposure protection models are combined with a statistical sampling of site-specific meteorological data to yield consequence output in a probabilistic format. While the MACCS program also required modifications to perform the consequence analyses for the QRAs (in particular, for incorporation of chemical agent health effects), these modifications were relatively minor in comparison to the changes required to make D2PC suitable for use in the QRA.

MACCS has been modified by Sandia National Laboratories for use in evaluating public risk associated with chemical agent releases, and this version is now called CHEMMACCS. CHEMMACCS provides the following capabilities: 1) statistical weather sampling of site-specific data, including precipitation; 2) population dose and risk calculations based on site-specific population data; 3) health effect calculations, which include the consideration of potential site-specific protective actions; and 4) modeling of multiple releases.

The CHEMMACCS code has been modified so that it essentially reproduces the results of the D2PC program. The Gaussian plume parameters and the health effect models are the same in both CHEMMACCS and D2PC, and the results have been examined and shown to be comparable. Thus, although a different code is being used in calculation of consequences, the core of the program and the results are essentially the same, and consistency is maintained with other activities using the D2PC program. The CHEMMACCS code is being used because it can produce the results more efficiently in a format consistent with a QRA.

11.2 Overview of Consequence Analysis

As mentioned previously, consequence calculations are performed for each source term group. The calculations model the dispersal of agent from its release point(s), account for the deposition of released agent, compute exposure to individuals, and predict the health effects that could occur. For the QRA, the mode of agent transport in the environment is assumed to be restricted to dispersion of vapor and liquid droplets in the air. For this mode of transport, the meteorological conditions and the population distribution near the release can have a significant impact on the resultant health effects. The health effects calculated in this study are acute fatalities and excess cancers caused by accidental releases of chemical agent. The consequence analysis completes the following actions:

- Performs probabilistic sampling of site-specific historical weather data
- Accounts for the population distribution surrounding the site
- Follows the various exposure pathways [inhalation, percutaneous (through the skin) vapor, and percutaneous liquid]
- Uses dose-response [probability unit (probit)] equations (Finney, 1980) to yield probabilistic estimates of health effects [input parameters such as the Bliss slope (slope of the dose-response curve) and 50 percent dose are provided by the U.S. Army Nuclear and Chemical Agency (USANCA) (1994)]
- Produces the necessary statistical output for the QRA process.

11.3 Description of CHEMMACCS

The CHEMMACCS consequence code calculates the offsite consequences of the accidental atmospheric release of toxicological materials. The CHEMMACCS calculations are based on site-specific data supplied by the user. These input data include site-specific weather, the population distribution surrounding the site, and protective action scenarios. One year of hourly meteorological data may be input to produce a probability distribution of consequences based on the uncertainty in predicting the weather at the time of an accident. CHEMMACCS health-effect calculations are based on probit equations for acute health effects and potency factors for the calculation of latent health effects (excess cancers). The key elements of the code are discussed in the following sections.

11.3.1 Gaussian Plume Model. CHEMMACCS estimates agent dispersion in the atmosphere after accidental releases and determines the doses to which surrounding populations are exposed. PMCD has stipulated that results of air dispersion calculations obtained from CHEMMACCS be essentially the same as results from D2PC for the same input variables.

Like D2PC, CHEMMACCS uses a standard Gaussian plume equation to track the distribution of released material in the air. The rate at which materials disperse in the atmosphere depends strongly on atmospheric turbulence, which varies greatly with stability class. The growth of plume dimensions in the horizontal and vertical directions during downwind transport is expressed in terms of the horizontal and vertical standard deviations of the normal concentration distributions that characterize a Gaussian plume. The horizontal and vertical standard deviations incorporated in the CHEMMACCS model are derived from the D2PC model.

Comparisons have been made between the D2PC and CHEMMACCS Gaussian plume models using several model features. Downwind air concentrations have been compared for variations in stability class and wind speed, deposition velocities, release heights, and mixing layer heights (an atmospheric layer in which effluents can continue to diffuse in the vertical direction). These comparisons show that the CHEMMACCS code used in the UMCDF QRA essentially reproduces the D2PC plume models.

11.3.2 Dispersion Parameters. The CHEMMACCS air dispersion modeling program calculates dispersion parameters using a power-law function shown in equation 11-1. The values of a_i, b_i, c_i, and d_i for each stability class (i) are user-specified in the CHEMMACCS input file (see table 11-1).

$$\sigma_{y_i} = a_i x^{b_i} \qquad \sigma_{z_i} = c_i x^{d_i} \tag{11-1}$$

where:

σ_{y_i} = standard deviation of the normal concentration distribution in the horizontal (crosswind) direction (meters)

σ_{z_i} = standard deviation of the normal concentration distribution in the vertical direction (meters)

x = distance downwind (meters)

a_i, c_i = reference sigma values (meters) at 100 meters

b_i = expansion coefficient in the horizontal direction (dimensionless)

d_i = expansion coefficient in the vertical direction (dimensionless).

Table 11-1. Constants in CHEMMACCS Equations Used to Calculate Dispersion Factors σ_y and σ_z Equivalent to D2PC

Stability Class	Stability Class$_i$	Instantaneous Release $a_{i\,(m)}$	Continuous Release $a_{i\,(m)}$	b_i	$c_{i\,(m)}$	d_i
A	1	0.0900	0.2700	1.0	0.0222	1.40
B	2	0.0633	0.1900	1.0	0.1100	1.00
C	3	0.0480	0.1250	1.0	0.1189	0.90
D	4	0.0634	0.1268	0.9	0.0898	0.85
E	5	0.0754	0.1507	0.8	0.0879	0.80
F	6	0.0796	0.1592	0.7	0.0791	0.75

The CHEMMACCS dispersion parameters, which are calculated using the constants presented in table 11-1, are equivalent to those used in D2PC for continuous and instantaneous releases. The D2PC dispersion parameters were derived from live agent trials in the open atmosphere, primarily at Dugway Proving Ground, but also at Edgewood in the 1970s. These trials were actually munition effectiveness tests, for instance, determining the optimal agent/burster ratio and release height. But the results lend themselves to derivation of dispersion parameters, (i.e, the rate of agent dispersal in the atmosphere). The DDESB created a panel of experts to derive the dispersion parameters based on the hundreds of test trial results. Likewise, the dispersion parameters represent a "best-fit" for a large number of field trials as opposed to any one specific trial.

The Dugway Proving Ground and Edgewood sites are very flat where the trials were conducted. In addition, the vast majority of trials were conducted over distances less than the 1 kilometer range. Therefore, the use of the dispersion parameters in D2PC actually assumes that the plume will disperse at a constant rate as if the plume were over open, flat terrain. So, for most applications, D2PC is expected to be conservative, (i.e., overpredict actual concentrations). This is quite similar to other Gaussian models. D2PC dispersion parameters for neutral and near-neutral stabilities are very similar to other commonly accepted models, including ALOHA and ISC. That is, the predicted concentrations with the Gaussian model are very similar between D2PC and these models for these stabilities. However, D2PC tends to underpredict distances for unstable conditions and overpredict concentrations in stable conditions, at least in comparison to such other models.

Stability refers to the amount of atmospheric turbulence, which can often be measured by the change of temperature with height in the atmosphere. The more the atmosphere cools with increasing height, the less stable the atmosphere is, which allows greater mixing and enhances dispersion. The stability class as identified in column 1 of table 11-1 is a methodology established by Pasquill (1974) for classifying atmospheric stability using information derived from diffusion experiments. Pasquill distinguished seven stability classes from A (highly unstable; absence of stratification) to G (highly stable; stratification). However, the G stability class is treated as F stability; therefore, only 6 stability class categories are used. The criteria for the classification considered the relationship of wind speed, insolation (amount of incoming solar radiation), and cloud cover.

The time of day (e.g., day versus night) also has a significant impact on reducing the concentration of a plume or increasing dispersion, as a plume travels downwind. Nighttime conditions tend to be highly stable with F stability prevalent, whereas daytime conditions tend to be neutral (D stability) to unstable. With this in mind, the QRA accident sequences were categorized as either day-only or 24-hour release. For example, if an accident sequence is associated with onsite transportation activities occurring only during the day, then weather sampling used in the consequence model would only sample from daytime hours, reducing the downwind concentration.

11.3.3 Variables Influencing Atmospheric Dispersion. Within a homogeneous environment, transport and dispersion of an agent plume can be easily modeled using the Gaussian dispersion model and dispersion factors based on Pasquill's methodology for distinguishing the stability of the atmosphere. However, there are a number of variables that will influence the transport and dispersion and likewise, a large number of computational algorithms exist to account for its own specific application. Many of these applications rely on algorithms that will modify, in various ways, the dispersion factors in the vertical and horizontal direction. For example, to account for plume meander during transport of the plume, a linear expansion factor is calculated, which serves to widen the plume in the crosswind direction. The linear expansion factor is applied to the vertical dispersion parameter σ_y.

The modeling of surface roughness over a given area reflecting manmade and natural obstructions, and general surface features are also accounted for by modifying dispersion parameters. These roughness elements affect the horizontal and vertical wind patterns. Differences in the surface roughness over the area of interest can create differences in the wind pattern that may necessitate additional measurement sites. A method of estimating surface roughness length, z_o, is provided in detail in appendix Q. Adjustments to the dispersion parameters in both the vertical and horizontal directions are modified to account for the effects of nearby buildings.

Additional algorithms are used to model plume rise and wet/dry deposition. Plume rise is modeled using equations recommended by Briggs (1975) similar to that used in D2PC. Dry deposition is modeled using Chamberlain's source depletion method (Chanin et al., 1990). With the hourly precipitation data available as input, CHEMMACCS accounts for wet deposition using the model of Brenk and Vogt (Chanin et al., 1990). A detailed analysis supporting each computation is identified in appendix Q.

11.3.4 Source Term: Agent Release Size/Duration. The source term is defined in a user input file to the CHEMMACCS executable. The source term includes the type(s) of agent released, quantity of each type (mass in kilograms), physical state of the released agents (vapor or liquid aerosol), timing (day only or 24-hour), and duration of the release. These input parameters are determined using the source term models described in section 10.

The CHEMMACCS consequence code can handle multiple plume segments of varying size and duration. Releases are defined as either an instantaneous release or semicontinuous release. Instantaneous releases include explosions and splashing, while semicontinuous releases include releases such as spills followed by an evaporative release. A combination of an instantaneous release followed by semicontinuous release(s) can be modeled also.

Two plume durations are used to model accident sequences. The first plume is fixed at 60 seconds, the smallest increment of time allowed by the code to model a release. The second plume varies between 60 seconds and 24 hours, depending on the type of release. The source term models (see section 10) determine the release durations based on type of release (e.g., evaporation of a spill, fire, fuze/burster detonation). Instantaneous releases will be modeled using the first plume, a 60-second release.

11.3.5 Meteorological Data. The atmospheric transport model implemented in CHEMMACCS requires hourly meteorological surface data (i.e., wind speed, wind direction, stability class, precipitation) as input to estimate plume travel following postulated accident sequences. In addition, seasonal averages for morning and afternoon mixing layer heights (height of the capping inversion layer) also are defined.

Surface data other than mixing layer heights were collected from an onsite tower at UMCD. Onsite data were obtained from January 1999 through December 1999, and USEPA regulatory guidance was used to assess the general acceptability of the meteorological data collected. After detailed review of the available data, the onsite data were determined to be the best available and appropriate to support the model. However, the upper air data, namely the mixing layer height data, are not collected onsite. Instead, upper air data from Spokane, Washington, were determined to be the best available data to support the model. Although Spokane may not fully reflect site-specific conditions, a high degree of confidence has been established in the quality of the data set. The upper air data were collected from the nearest NWS station located at Spokane International Airport (approximately 150 miles north-northeast of UMCD).

Upper air data are collected in accordance with NWS requirements for data quality. The specific upper air data needed for the CHEMMACCS model are the daily morning and afternoon mixing height values, which are presented in table 11-2.

Table 11-2. 1999 Seasonal Average Mixing Heights
(Spokane International Airport, NWS Station 24157)

Season	Morning Mixing Height (m)	Afternoon Mixing Height (m)
Winter (21 December – 19 March)	512	753
Spring (20 March – 20 June)	411	2,060
Summer (21 June – 22 September)	249	2,276
Autumn (23 September – 20 December)	397	805

The statistical handling of weather data varies among air dispersion programs. In CHEMMACCS, the air dispersion and consequences of a release are calculated by running hundreds of randomly selected weather sequences (selective start times over 1 complete year of data) to generate a range of results. The CHEMMACCS model only allows 1 year of data to be used as input, and onsite January 1999 through December 1999 data were selected.

11.3.6 Population Data. The population in the region surrounding a facility is mapped onto a radial-polar grid with its origin at the center of the facility and 16 sectors (corresponding to the standard, equally spaced compass directions) with distinct radii ranging from 0 to 100 kilometers.

The larger population centers within 30 kilometers are the communities of Hermiston, Umatilla, and Stanfield located in Umatilla County, and Boardman and Irrigon in Morrow County. The radial rings and some of the major population centers are shown in figure 11-1.

Table 11-3 presents the number of people residing within each of the radial rings around the site. As can be seen, the 8- to 15-kilometer ring contains the first major jump in population. The 8- to 15-kilometer ring to the east of the depot contains the first heavily populated areas, the community of Hermiston, and to the northeast, the community of Umatilla. It is not until the 45- to 60-kilometer distance from UMCD that populations exceed 100,000, including Richland and Kennewick in Washington and Pendleton to the southeast of the site.

The population databases are the most recent U.S. Census bureau population data available (2000 Block Group data) projected for the year 2002. The distinct radii and 16 sectors intersect to form grid elements where the number of persons residing in each grid element is based on the populations of the block groups that intersect each element. When the area of a block group lies entirely within the boundary of the element, the entire population is assigned to the element. When the area of a block group overlaps two or more spatial elements, the population is apportioned to the elements based upon the fraction of the block group area that intersects each element. Adjustments to this distribution are made to account for concentrated population centers (towns and villages).

When a plume traverses the grid, the plume will only overlap portions of population elements, so that only a segment of each element's population will be exposed. One way of handling this problem is to assume that the population is concentrated at the center of the element and include these people in the affected population only if the center of the element lies inside the plume boundary. To refine this method somewhat, the CHEMMACCS program divides the number of people in each grid element into smaller groups and locates them at equal distances apart on an arc through the center of each element.

Worker risk calculations are performed using a grid that provides much more detail on the site and does not extend past the site boundaries. Because the workers are at such a close distance to the release location, two grids are developed: one with the origin located at the center of the chemical igloo storage yard (UMCD) and the other with the origin located at the center of UMCDF. Tables 11-4 and 11-5 present the number of workers residing within each radial ring mapped to the area. Worker estimates are determined based on information used for the TOCDF QRA as reported in the TOCDF Phase 2 QRA (SAIC, 1996b). Other site workers, e.g., administrative and tenant populations have been compiled for Umatilla and are specific to the site. A more detailed analysis is presented in appendix Q.

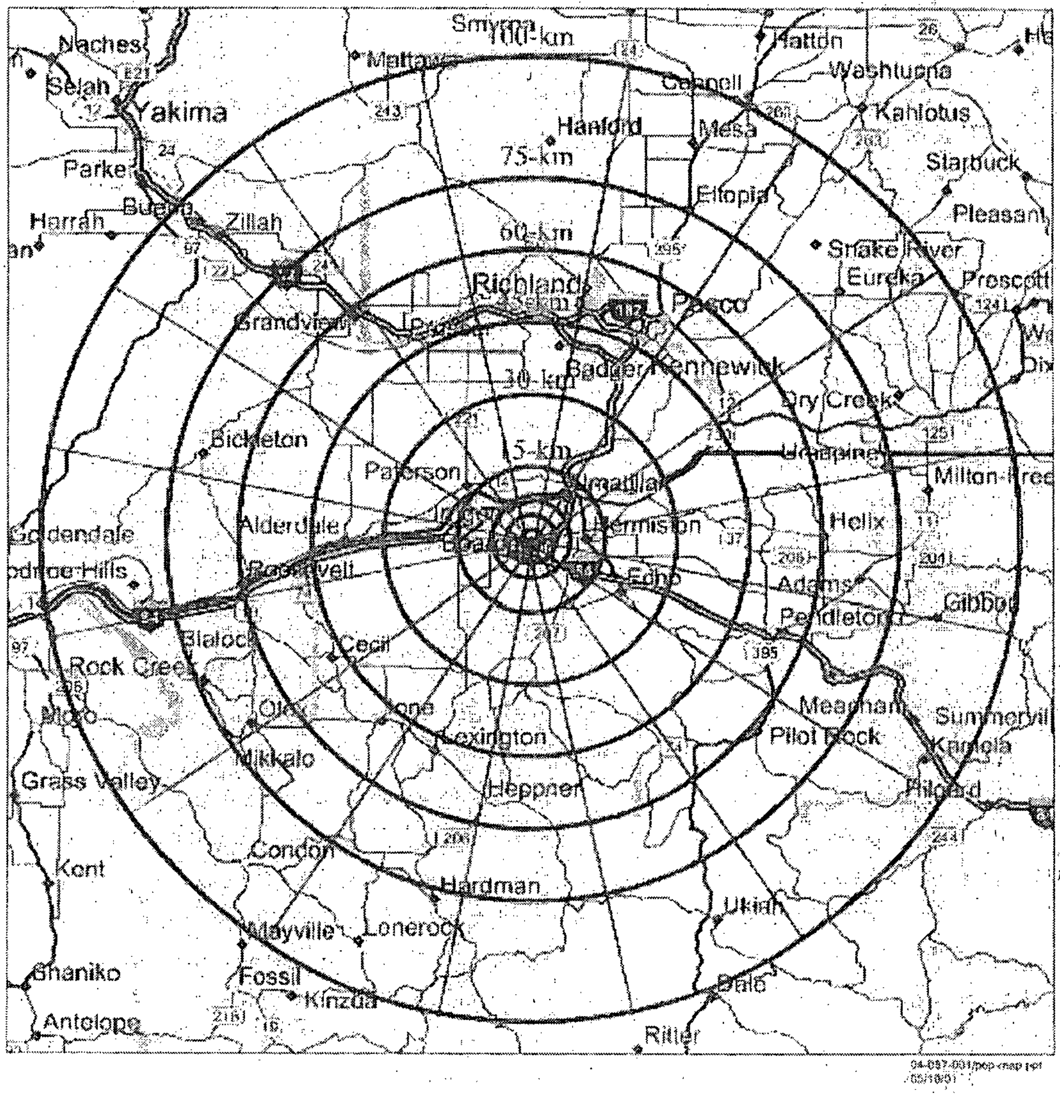


Figure 11-1. Polar Grid of Surrounding Population

Table 11-3. Population Surrounding the Umatilla Chemical Depot

Ring	Distance from UMCDF	Population[a]	Cumulative
1	0 to 2 km	0	0
2	2 to 5 km	46	46
3	5 to 8 km	3,793	3,839
4	8 to 15 km	25,709	29,548
5	15 to 30 km	11,587	41,135
6	30 to 45 km	35,091	76,226
7	45 to 60 km	189,947	266,173
8	60 to 75 km	37,328	303,501
9	75 to 100 km	94,972	398,473

Note:

[a] Source: 1990 U.S. Census data, 2004 Projection.

Table 11-4. Worker Population Within Umatilla Chemical Depot (Release Origin at Center of UMCDF)

Ring	Distance (km)	Population		Area Description
		Daytime	24-hr average	
1	0 – 0.35	305	168	Entire UMCDF area including trailers and process support building just outside the fence
2	0.35 – 2.0	80	37	Chemical igloo storage area (UMCD)
3	2.0 – 4.0	8	8	No significant population centers (site security control)
4	4.0 – 4.5	330	124	Area includes the depot population

Table 11-5. Worker Population Within Umatilla Chemical Depot (Release Origin at Center of the Chemical Igloo Storage Yard)

Ring	Distance (km)	Population		Area Description
		Daytime	24-hr average	
1	0 – 1.0	76	31	Chemical igloo storage area (UMCD)
2	1.0 – 1.25	307	172	UMCDF area including trailers and process support building just outside the fence
3	1.25 – 4.5	10	10	No significant population centers (site security control)
4	4.5 – 5.0	330	124	Area includes depot population

Worker estimates in tables 11-4 and 11-5 include site security control personnel, who are evenly placed on main roads throughout the area. Therefore, comparing worker estimates among a specific area in each of the two tables may not result in the same number of workers.

11.3.7 Exposure Pathways. Following a release, the surrounding population may be exposed to the released material in a variety of ways. Persons can be exposed by inhalation of vapors or aerosols; absorption of vapors or liquids through the skin; ingestion of contaminated food or water; and skin contact with contaminated water, soil, or vegetation. The QRA focuses on acute effects from vapor inhalation and vapor and liquid absorption through the skin.

Exposure pathways depend on the mode of release and the persistence of a chemical in the environment. Explosive releases of agent produce clouds that are mixtures of vapor and liquid droplets. Spills produce an initial vapor/liquid droplet cloud from splashing and a semicontinuous release from evaporation of the liquid pool. Fires produce unburned heated agent vapor, some of which may condense to liquid upon cooling in air.

To model these releases and exposure pathways, the air dispersion modeling segment of the consequence analysis program requires that the source be quantified in terms of its initial size/rate, height above the ground, and distribution between liquid and vapor. These inputs are provided by the source term analysis, as described in section 10. The CHEMMACCS consequence program then calculates the plume/puff rise and the rate at which liquid particles fall out of the plume/puff and are absorbed onto vegetation, soil, or the skin and outer clothing of humans in the plume/puff's path.

The chemical doses that are calculated in CHEMMACCS are associated with the specific effects being analyzed. Doses associated with four different pathways are included: 1) vapor inhalation, 2) percutaneous vapor absorption, 3) percutaneous liquid absorption, and 4) continuous daily dose (CDD) for plume/puff inhalation. CDD is used for determining the latent risk of cancer incidence and refers to the effective mass inhaled per unit mass of a 70-kilogram person divided by a 70-year life span.

11.3.8 Dose Response Equations. The risks of acute health effects due to exposures to toxic chemicals are modeled using dose response (probit) equations. Probit equations have been incorporated into the consequence analysis program to quantify the dose-response relationships for the chemical agents GB, VX, and HD. A probit is a measure of the fraction of the population responding to a dose (Finney, 1980).

The following equations identify the form of the probit equations used in the consequence code CHEMMACCS:

$$\text{probit} = 5 + b \log \left[D/D_{50}\right] \quad (11\text{-}2)$$

$$\text{probit} = a + b \log_{10} \left[D\right] \quad (11\text{-}3)$$

where:

D	=	the biologically effective dose causing the acute effect
D_{50}	=	the dose that would induce the effect in half the exposed population
b	=	Bliss slope (slope of dose-response curve)
a	=	constant, based on the probit and D_{50} values.

With the probit equation, the user specifies the constants for the Bliss slope and D_{50}. The calculated dose D is associated with the specific effects being analyzed. Doses associated with the inhalation and percutaneous vapor absorption pathways are determined by multiplying the downwind air concentration calculated using the Gaussian plume model with the time of exposure. Because downwind air concentrations are only calculated at the plume centerline, off-centerline correction factors are applied to scale the dose accordingly as distance increases from the center of the plume. Bliss slopes and D_{50} values have been provided by USANCA (1994). USANCA D_{50} values for vapor inhalation were modified from a 15-liter per minute to a 25-liter per minute inhalation rate to be equivalent to those used by the D2PC model.

Toxicity data were provided for the following health effects of concern for the QRA: 1) acute fatality following vapor inhalation, 2) acute fatality following percutaneous (through the skin) vapor exposure, and 3) acute fatality following percutaneous liquid exposure. These values are presented in table 11-6.

11.3.9 Latent Health Effects. The consequence code, CHEMMACCS, calculates the additional individual lifetime risk, R, of cancer due to inhalation doses using the following equation:

$$R = Q^* \times CDD \quad (11\text{-}4)$$

where:

Q*	=	"potency factor" [(mg/kg/day) $^{-1}$]
CDD	=	effective CCD expressed as the effective mass inhaled per unit mass of a 70-kilogram person divided by a 70-year life span (mg/kg-day)
R	=	additional lifetime risk of developing cancer as a result of CDD.

Table 11-6. Input Parameters for the Probit Equation

Agent	Hazard	a	b	D_{50}[a]	Threshold[b]
VX	Acute Lethality – Vapor Inhalation	-4.2	7.3	18	2.5
	Acute Lethality – Percutaneous Vapor	-5.2	6	50	0.04
	Acute Lethality – Percutaneous Liquid	0.2	4.8	10	0.04
GB	Acute Lethality – Vapor Inhalation	-6.9	7.3	42	6.0
	Acute Lethality – Percutaneous Vapor	-20.1	6	15,000	2420.6
	Acute Lethality – Percutaneous Liquid	-10.5	4.8	1,700	173.9
HD	Acute Lethality – Vapor Inhalation	-15.3	7.3	600	100.0
	Acute Lethality – Percutaneous Vapor	-19.0	6	10,000	1613.7
	Acute Lethality – Percutaneous Liquid	-6.9	3.1	7,000	205.1

Notes:

[a] Dose units: mg-min/m^3, except for liquid pathway where units are mg/70-kg person.
[b] Probit cutoffs (thresholds) are based on D2PC no-lethality values.

The risk estimate is a measure of potential incidence (i.e., carcinogenicity and not cancer deaths) associated with mustard agents, which are known to be human carcinogens. Methodologies associated with establishing a cancer slope factor, or Q^* value, continue to be reviewed as the values range from less than 10 to 300 milligrams per kilogram per day depending on the research and methods used. Until the Office of the Surgeon General (OTSG) approves a lower value, 300 milligrams per kilogram per day will be used to support the analysis. This value is derived from the Inhalation Unit Risk factor equal to 8.5×10^{-2} per $\mu g/m^3$ endorsed by the OTSG (OTSG, 1996). Q^* is calculated by multiplying the Unit Risk times 70 kilograms (the default adult male body weight) and dividing by the inhalation rate (20 cubic meters per day). The Unit Risk factor = 8.5×10^{-2} per $\mu g/m^3$ is derived from the McNamara studies from the 1970s and is considered one of the most reliable estimates when comparing to the various analyses available (USEPA, 1991).

11.3.10 Emergency Response Actions. The U.S. Army decided that enhanced emergency planning was valuable in reducing the consequences from potential accidental releases of chemical agent during chemical demilitarization activities. In cooperation with FEMA, other federal agencies, and state and local governments, enhanced emergency preparedness capabilities are in the process of being implemented. The CSEPP has established a planning base review group to develop site-specific protective action plans.

Although site-specific emergency preparedness plans have not yet been fully implemented at Umatilla, Umatilla civilian emergency officials favor shelter-in-place (SIP) within the Immediate Response Zone (IRZ) as a best possible protection based on current capabilities. Evacuation may not be feasible given the UMCD's close proximity to at-risk communities in conjunction with response time—time to assess the accident, notify relevant authorities, alert the public, and implement a course of action. The protective action zone (PAZ), which exceeds 15 kilometers, has approximately 1 hour before plume arrival based on wind speeds less than 5 meters per second (which are common in this area). This is assumed sufficient time to employ evacuation of all residents located in the PAZ.

The primary intent of the QRA is not to measure the effectiveness of CSEPP, but to identify the best estimate impact to the general public. The CHEMMACCS consequence model uses a simplistic methodology to simulate protective actions and is not expected to reproduce the results of more sophisticated CSEPP models. It is judged that the model provides a best estimate of risk, although, for any one accident scenario coupled with any one weather condition, the actual strategy to be implemented could be somewhat different and more effective.

Implementing a protective action will reduce the exposure to chemical agent. Of significant importance is the time required to complete a given action. The completion of a protective action involves the time it takes to perform the following:

- Assess accident release and determine appropriate actions
- Notify relevant authorities
- Alert the public
- Public decides on an appropriate course of action
- Implement protective action(s).

Estimates of time allotted for each of these events are presented in table 11-7. More detail can be found in appendix Q. It is assumed that 95 percent of the population will take protective action. This is based on real-life scenarios where taking protective action was necessary (Rogers et al., 1990).

In summary, public receptors in the IRZ SIP after a 37-minute delay. Receptors in the PAZ evacuate after 56 minutes of delay.

11.4 Evaluation of Worker Consequences

This section describes the consequence calculations for close-in Disposal-Related Workers. A Disposal-Related Worker is defined as a person who works within the CDF or security fence, or in offices just outside the fence. Workers moving munitions from the chemical igloo storage

Table 11-7. Response Time Estimates

Response	Time IRZ	Time PAZ	Reference
Assess accident, determine actions, notify authorities	20 min	20 min	(Rogers et al., 1990) Figure 3.2, page 41 (average) based on empirical data
Alert public	5 min	35 min	(Rogers et al., 1990) Figure 3.4, page 49 (average) IRZ notified by sirens/tone alert PAZ notified by media/Emergency Broadcast System
Public decides on course of action	20 min	20 min	(Rogers et al., 1990) Figure 3.5, page 52 (average)
Public implements protective action	3.2 min[1] (SIP)	2.5 hrs[2] (EVAC)	[1](ERDEC, 1995) time estimated to shut doors, windows, and turn off HVAC [2](CSEPP, 1995) based on site specific studies (population, traffic, highways, etc.)
Total delay time	48 min (37)[a]	75 min (56)[a]	
Total evacuation time		3.5 hrs	

Note:

[a] Assumes a state-of-the-art emergency response system; public response can be simulated at a rate that is 25 percent faster than previous disasters (empirically documented). Number in parentheses represents new value, 25 percent faster.

area (UMCD) to the CDF are included in this population. Other Site Workers are all other people within the depot boundaries that are not included in the Disposal-Related Worker category.

Disposal-Related Workers are those who could be directly exposed to an initial release. As such, separate consequence calculations were performed for Disposal-Related Workers to address close-in effects such as splashing following an agent spill. Other Site Workers would be far enough away from the accident to avoid direct exposure, and therefore, not subject to close-in effects.

Workers who would not be impacted by the close-in effects are still subject to the consequences stemming from inhalation of agent vapor and absorption of vapor through the skin. As such, consequences to Disposal-Related Workers also are determined in the same way as public consequences, using the CHEMMACCS consequence code, and are referred to as *remote effects*.

In Quantus, the results from this model are added to the results from CHEMMACCS to calculate the total consequences to Disposal-Related Workers. Disposal-Related Worker consequences include both close-in and remote effects from the agent plume.

Several Microsoft® Excel-based spreadsheets were developed to estimate close-in Disposal-Related Worker consequences. The spreadsheets clearly display the data and calculations used to estimate close-in Disposal-Related Worker health effects. Section 11.4.1 lists the worksheets that were developed. The process of selecting input information from the APET accident progression description is described in section 11.4.2. Section 11.4.3 summarizes key parameters used in estimating close-in Disposal-Related Worker health effects and section 11.4.4 includes an example worksheet.

Close-in worker effects are estimated for fatalities only. As a result, no cancer results are provided for Disposal-Related Workers. No cancer calculations are included in the estimation of close-in effects for a number of reasons. The controlling factor is that cancer risk can occur with very small exposures, with no known lower dose threshold. Other reasons include the following:

- The methods developed for estimating possible close-in fatalities are not designed to calculate very low-level exposures. It would require a substantial enhancement of the current methods to model low-level exposures that might be associated with persons in the general vicinity of an accident but not close enough to be severely exposed.

- The QRA modeling objective is to capture the possibility of accidents that lead to human health threat. It is judged that there is a class of very minor accidents not currently modeled that could be important to estimation of Disposal-Related Worker cancer risk.

- There may be non-accidental exposures that could contribute to cancer risk. The possibility of a person being exposed during routine maintenance activities exists, and the scenario-based QRA models are not detailed enough to capture this type of exposure.

- The calculations might need to be broken down by specific job function because some workers might have much greater likelihood of low-level exposure than others. At the current time, the models are not detailed enough to capture risk to individual subgroups of workers.

- There is a lack of toxicity data, except for vapor inhalation, for cancer health effects. There is no toxicity data for percutaneous pathways, so the calculations would be incomplete.

- It is not known that mustard is the controlling occupational carcinogen. Without study of this issue, any quantification could be misleading, because it may be a partial quantification of the risk.

In addition to the technical issues, there is questionable risk management value to quantification of Disposal-Related Worker cancer risk. The risk management strategy is to minimize any potential for exposure, and it is not obvious how a partial quantification would change any operational activities or management decisions.

11.4.1 Disposal-Related Worker Consequence Spreadsheets. Several spreadsheets were developed to estimate close-in Disposal-Related Worker consequences. Spreadsheets were developed to address all accidents that could result in close-in consequences, including internal and external events. The methodology and spreadsheets were developed along the same framework as those developed to estimate source terms, described in section 10. The spreadsheets use information from the APET accident sequence description to define the accident. Data lookup tables, constant parameters, and equations are used to estimate health effects.

The following lists the spreadsheets developed to estimate close-in Disposal-Related Worker consequences:

- Internal Event Agent Spill Spreadsheet
- Internal Event Explosion Spreadsheet
- Internal Event Natural Gas Explosion Spreadsheet
- Internal Event BLEVE Spreadsheet
- Internal Event Agent Fire Spreadsheet
- Internal Event Agent Vapor Release Spreadsheet
- DFS Chute Jam Clearing Spreadsheet
- Routine Maintenance Entry Spreadsheet
- Special Entry Spreadsheet
- External Event Agent Spill Spreadsheet
- External Event Explosion Spreadsheet
- External Event Agent Fire Spreadsheet.

Similar to the way in which source term spreadsheets were called, the release attribute from the APET accident sequence description was used in most cases to determine which spreadsheet to use. For example, internal event releases that involve explosions call the Internal Event Explosion Spreadsheet. (Appendix L includes tables that correlate each APET release attribute with the associated Disposal-Related Worker consequence spreadsheet.)

In some cases, a special attribute was added to the APET accident sequence description to determine which spreadsheet to call. Special attributes were added for unique cases that required special worker risk models. Special attributes were added to address sequences associated with routine DPE maintenance entries, special DPE entries, and DPE entries to clear DFS chute jams.

11.4.2 Accident Sequence Description Attributes. The first step in estimating close-in Disposal-Related Worker consequences is to determine what information is needed about the accident sequence from the APET accident sequence description. As described in section 6, the accident progression analysis includes the ability to solve APET sequences in terms of specific sets of descriptors and characteristics. As such, each accident is defined by a list of attributes that clearly distinguish key parameters of the sequence.

The attributes for the accident description are carefully selected to yield the information needed to estimate consequences. For each attribute, several answers are generally possible. For example, an attribute descriptor might be location of the accident. The possible outcomes include storage yard igloo, storage yard apron, CHB loading dock, CHB lift, CHB UPA, MDB UPA, ECV, ECR, DFS, MPF, LIC, etc.

These attributes are used in conjunction with data lookup tables to perform calculations to estimate Disposal-Related Worker consequences. Table 11-8 summarizes the attributes that were used in the spreadsheets and provides information on how they were used.

Table 11-8. Accident Sequence Description Attributes Used in Estimating Disposal-Related Worker Consequences

Accident Sequence Description Attribute	How Attribute Is Used in Estimating Disposal-Related Worker Consequences
Release	Determines (in most cases) which close-in Disposal-Related Worker spreadsheet to use to estimate consequences
Propagation Release	Determines if additional workers should be evaluated for accidents that involve additional releases, e.g., igloo fires
Agent	Consequence estimates are based on toxicity data that vary by agent type
Munition	Determines amount of agent that could be involved in the release
Location	Determines number of workers that could be involved
Number of Primary Workers	Determines number of workers who could be affected by the accident
Number of Secondary Workers	Determines number of secondary workers who could be affected if the accident involves a breach or agent migration from one location to another
Campaign Type	This descriptor is used to count additional workers who are involved in complementary or co-processing campaigns
Special	Determines if a special Disposal-Related Worker consequence spreadsheet is needed

11.4.3 Key Parameters Used in the Spreadsheets. There are four key elements used throughout the Disposal-Related Worker consequence spreadsheets: worker population estimates, fatality estimates based on exposure, DPE failure data, and masking considerations. Each element is described in the following sections.

11.4.3.1 Worker Populations. Estimates of worker populations were generated for all locations based on CDF activities. Worker populations were estimated for activities associated with loading munitions at the storage area, transportation, CHB handling, CHB/UPA handling, and MDB operations. Activities for each location and operation were identified and the number of workers involved in each activity was estimated.

Because UMCDF is currently not operating, the number of workers involved in each operation was based on that from TOCDF as reported in the TOCDF Phase 2 QRA (SAIC, 1996b) and discussions with site personnel during site visits (SAF-MC-00-001, 2000; CRC-00-006a, 2000; GJB-00-001, 2000).

To account for the variation (throughout the day and week) in the number of workers associated with each operation, two different estimates of worker populations were made. This was done to account for the aleatory uncertainty associated with changes in the number of workers based on differences that occur over a 24-hour day and a 7-day week. (Aleatory uncertainty is a term used to describe the variability associated with a phenomenon that is random in nature). Worker risk spreadsheets that require information on the number of workers identify two different estimates. The highest number represents the expected peak number of workers who would be in each location (i.e., during peak processing hours). The lowest number represents the expected number of workers who would be in each location during nights or weekends.

11.4.3.2 Probability of Fatality. Following a release, workers can be exposed through a variety of exposure pathways. The two primary ways that were evaluated for workers were inhalation and percutaneous liquid exposure. Health-effect estimates were made for these pathways and used throughout the Disposal-Related Worker consequence spreadsheets. The only health effect considered for close-in Disposal-Related Worker effects was fatality; cancers were not estimated.

Health effects to close-in Disposal-Related Workers from a percutaneous liquid exposure were based on agent toxicity data. Direct contact is possible following an accident that involves a spill and splashing. Agent-specific toxicity data are included in table 11-9. VX was judged to be the most toxic for direct contact and a mean probability of fatality of 0.5 was used because direct contact with VX was judged to be inconclusive (i.e., 50-50). The mean probability of fatality from splashing of GB was judged to be very unlikely (0.01) and HD was judged to be extremely unlikely (0.001).

Table 11-9. Agent Toxicity Values

Agent	Current Human Toxicity Values[a] Vapor Inhalation (LCt_{50})[b] (mg-min/m^3)	Percutaneous Vapor (LD_{50}) (mg-min/m^3)	Percutaneous Liquid (LD_{50}) (mg for a 70-kg man)
GB	42	15,000	1,700
VX	18	50	10
HD	600	10,000	7,000

Notes:

[a] TOCDF QRA (SAIC, 1996b).
[b] Based on a breathing rate of 25 liters per minute.

Calculations were performed to estimate health effects to close-in Disposal-Related Workers from vapor exposures. Vapor releases are possible following spills, fires, and explosions. The calculations, included in a model developed to support the Newport Chemical Agent Disposal Facility (NECDF) analysis (SAIC, 1999b), were used to estimate the buildup of agent vapor as a function of time. The calculations took into consideration agent-specific physical properties such as volitization rates, toxicity values, evaporation rates and associated temperatures, wind or a cascade HVAC system, the duration of exposure, and the size of the release.

For each agent type, two agent quantities were evaluated; the first was used to estimate the effects from a release the size of a bulk item (or several munitions) and the second was used to estimate the effects from a release the size of a single munition. Because of differences in room volumes, temperatures, and factors such as wind and HVAC, both inside and outside releases were evaluated. Table 11-10 includes the mean probabilities of fatalities estimated from the calculations. Results are provided for all agent types and both sizes of releases.

Table 11-10. Mean Probability of Fatality – Inhalation (Workers Close to Spill)

Agent	Amount of Spill	Location	Mean Probability of Fatality From Inhalation
GB	750 pounds	Inside or Outside	0.9
GB	10 pounds	Inside or Outside	0.5
VX	850 pounds	Inside or Outside	0.001
VX	10 pounds	Inside or Outside	0
HD	850 pounds	Inside or Outside	0.01
HD	10 pounds	Inside or Outside	0.0001

The results showed negligible differences for inside versus outside releases. GB was shown to be the most volatile agent; large releases result in a high probability of fatality in less than 1 minute. Smaller releases of GB take only a few minutes to build up to lethal concentrations. Both VX and HD are much less volatile. For evaporative releases, workers have several minutes in which to mask or evacuate before lethal concentrations of VX or HD are reached.

11.4.3.3 Probability of Masking. The reliability of masking during a site emergency was studied to determine the probability of masking and estimate the time it takes to mask. For all scenarios except earthquakes, the mean estimate for the probability of not masking was determined to be 0.01. The expected time to mask, given an alarm, is 30 seconds with the expected time between the onset of the emergency and a site alarm of 30 seconds. Once masked, Disposal-Related Workers are expected to have 100 percent masking efficiency (i.e., dose via vapor inhalation equals 0). Masking was generally credited for workers who were not in the direct vicinity of the release.

11.4.3.4 Probability of Demilitarization Protective Ensemble Failure. For maintenance or special entries into agent or potentially agent-contaminated areas, or accident cleanup activities, workers will be in DPE. Worker consequences are possible during DPE entries if there is a tear or puncture to the DPE.

DPE failure rates were estimated in appendix E14. The probability of DPE failure was estimated to be 1.3×10^{-2} per entry. This was based on the DPE experience at CAMDS, JACADS, and TOCDF. In some models, factors were used to adjust the failure rates of DPE based on the level of hazard of the activity. For example, during cleanup activities following a fire or explosion, a factor of 10 was multiplied by the DPE failure rate to account for increase in the number of sharp objects that could tear or puncture the suit.

The probability of fatality following a DPE tear considered the potential for direct agent contact or inhalation following a loss of life support air. The models previously described for percutaneous liquid and vapor inhalation were used for consequence estimates. A simplified fault tree model was developed to estimate the likelihood of life support air.

11.4.4 Example Spreadsheet. Figure 11-2 illustrates the basic layout of a close-in Disposal-Related Worker consequence spreadsheet. It identifies the attributes needed from the APET accident sequence description, constant parameters used in the calculations, table lookup results, calculations, and results. Each is described in the following section.

The first part of the sheet is devoted to the input needed from the APET. Each attribute needed from the APET accident sequence description is identified. These attributes are used in the table lookups to obtain the information needed to estimate worker health effects. In the example

Accident Description					
Agent	Munition	Location	PriWkrAffect	CampType	Breach
VX	TC	UPACHB	h	single	NoBreach
Run WkrRsk_Spill		RESULTS			
		Fatalities		3.5E-02	
Constant Parameters					
Probability of not masking		0.01			
Probability of DPE failure		1.1E-02			
Table Lookups					
Number of Workers Affected by Splash		Lookup			
Requires:	Location				
	UPACHB				
Result					
1	WorkerAffectedBySplash				
Calculations					
Liquid Exposure					
Number of workers who could be splashed	Probability that workers will be splashed.	Probability of fatality given splash	Number of worker fatalities from splash		
2	0.01	0.001	2.0E-5		
Agent Migration					
Did the accident involve a breach	Number of workers that could be affected	Probability of death from vapor exposure	Number of worker fatalities from agent migration		
1.0	0.45	0.05	2.3E-02		
Total Number of Worker Fatalities from Spill					
Number of worker fatalities from splash	Number of worker fatalities from vapor	Number of worker fatalities from agent migration	Number of worker fatalities from agent cleanup	Total number of worker fatalities from agent spill	
1.0E-04	1.2E-02	2.3E-02	6.7E-05	3.5E-02	

Sequence description attributes needed for this worksheet

Results for the worksheet

Constant parameters used in this spreadsheet

Results of lookup table. Several different lookup tables are used in each spreadsheet.

Constant parameters and data from table lookups are used in the calculations. Although only two are shown, several calculations are performed.

Last line of spreadsheet calculates total number of close-in Disposal-Related Worker fatalities.

Figure 11-2. Illustration of the Close-In Disposal-Related Worker Consequence Worksheet spreadsheet, the attributes of interest include agent type, munition, location of accident, number of primary workers who could be affected, campaign type, and a determination of whether or not the accident involves a breach.

Although several table lookups are generally used in each spreadsheet, only one is included in the example—*number of workers affected by splash*. In the example, only one attribute is used to determine the number of workers who could be affected by the splash—*location*. Other lookup tables use several attributes in combination to provide an answer.

Prior to the table lookups is a section that identifies the constant parameters used in the spreadsheet. These are labeled constant parameters because they do not depend on the accident sequence. In the example, two constant parameters are identified; the probability of not masking and the probability of a DPE tear.

All of the calculations are summarized in the worksheet. In this example, two calculations are included—the number of fatalities due to a liquid exposure and the number of fatalities associated with agent migration. The calculations use data from the list of constant parameters and table lookups. The final calculation in each spreadsheet lists all the interim results, which are summed together to give the final result. In the example spreadsheet, the final answer is the total number of fatalities associated with an agent spill. This answer also is included in the results box toward the top of the page.

Additional information on close-in Disposal-Related Worker consequence calculations is included in appendix Q. Appendix Q also includes all the spreadsheets and data tables used to calculate close-in Disposal-Related Worker consequences.

11.5 Summary of Consequence Analysis Results

The output from the CHEMMACCS consequence analysis program includes mean values for societal response, individual response, and complementary cumulative distribution functions (CCDFs) for each health effect of concern. CCDFs give the probability (y-axis) that *x* or more persons exhibit a particular health effect for each source term.

Mean values, based on site-specific data, represent the average number of health effect cases that will occur within a range of distances. Individual risk also is output in the same format. Individual risk is obtained by calculating the cases of a health effect in a certain region and then dividing by the total population in the region.

The CCDF is an estimate of the distribution of consequence magnitudes (the probability that *x* or more persons will exhibit a particular health effect). The variability of consequence values in

CHEMMACCS CCDFs is due solely to the uncertainty of the weather conditions at the time of the chemical agent release. The CCDF probabilities then can be multiplied by the estimated frequency of the source term group, and the product becomes known as exceedance frequencies for a given health effect. Then, a graph is created that plots the probability that more than *n* people will be affected. The risk results are presented in sections 13, 15, and 16.

11.6 Quantus Risk Management Workstation Overview

The dispersion analysis continues the characterization of the accident sequence consequences. Because this involves the application of an entirely new model, it is accessed as a separate dispersion editor in Quantus, rather than as a sequence function. The user can change aspects of the dispersion model regarding transport, e.g., the selection of weather and deposition parameters, directly in the dispersion editor. Figure 11-3 illustrates an example of the transport model screen found within the dispersion editor in Quantus.

Public and worker protective actions, as well as other key elements, can be changed directly in the dispersion editor by the user. Figure 11-4 illustrates an example of the public protective actions screen and figure 11-5 illustrates an example of the worker protective actions screen, both found within the dispersion editor in Quantus. Figures 11-3, 11-4, and 11-5 are only examples and do not represent parameters used in the Umatilla model.

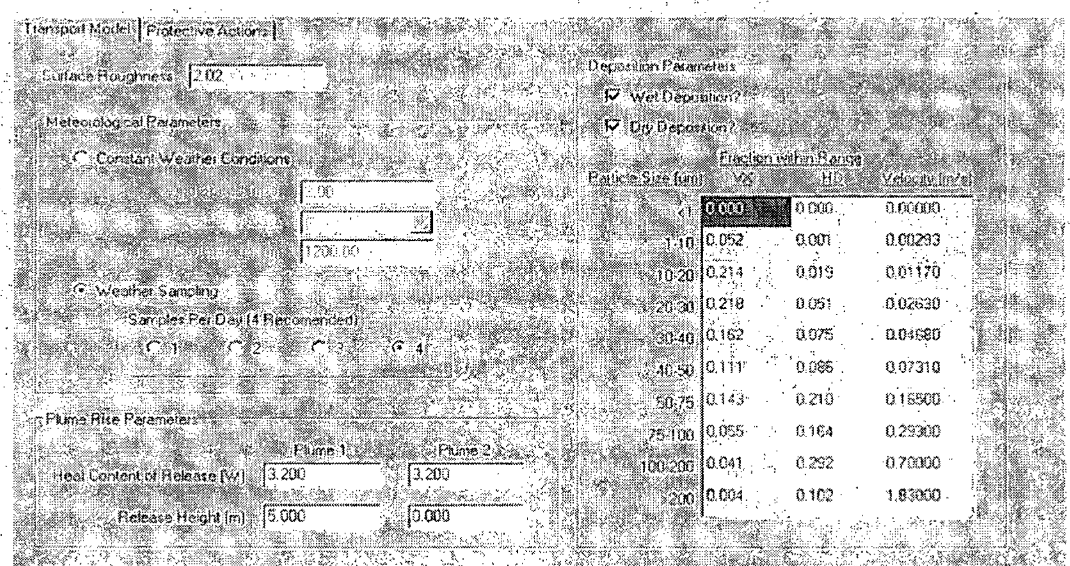


Figure 11-3. Transport Model Screen in Quantus

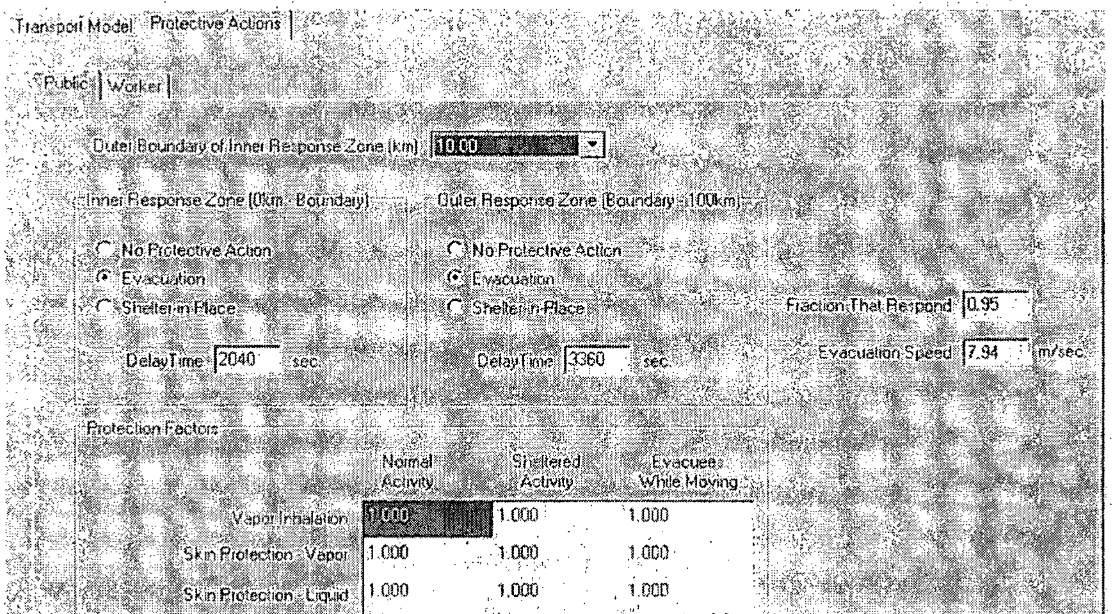


Figure 11-4. Public Protective Actions Screen in Quantus

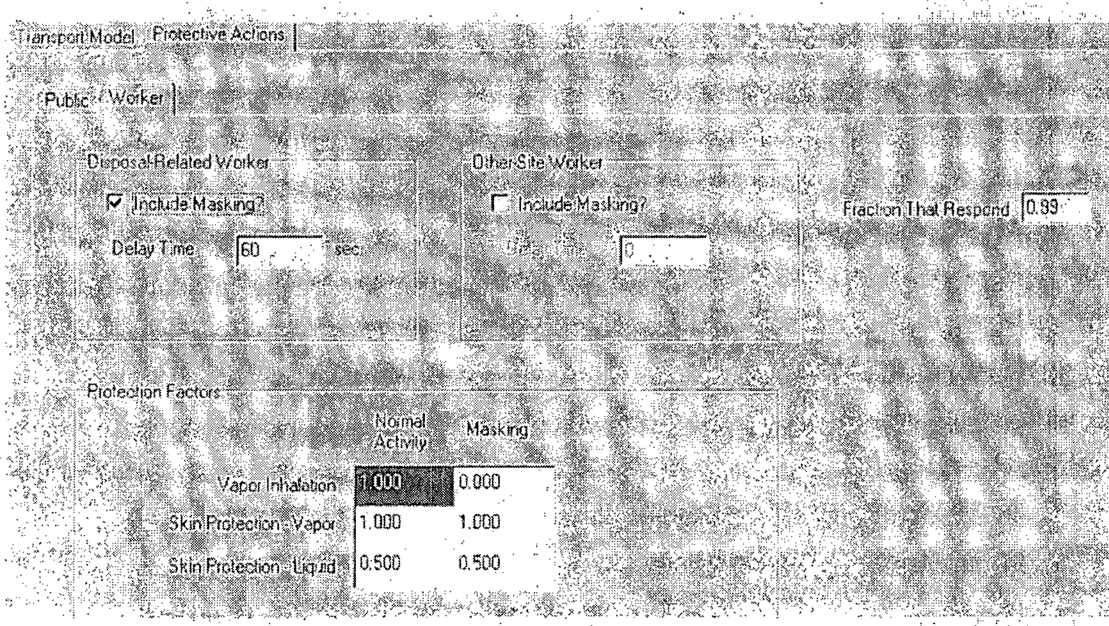


Figure 11-5. Worker Protective Actions Screen in Quantus

11.7 Summary of Potential Issues

Several issues have been identified by the expert panel regarding the margins of CHEMMACCS. Sensitivity analyses have been performed to address each issue and are summarized in the following section. Additional details regarding the dense gas and complex terrain sensitivity studies can be found in appendix Q.

11.7.1 Agent Degradation. Chemical agents (GB, VX, and HD) decompose as a result of reaction with hydroxyl ions that are created by photolysis of water molecules by sunlight in the atmosphere (Howard et al., 1991). The concentration of hydroxyl ions in the atmosphere produced by sunlight ranges from zero during nighttime to 3,000,000 radicals for a cubic centimeter with bright sunlight (Howard et al., 1991). The concentration also depends on the cloud density and humidity. Agent destruction by hydrolysis under low temperature liquid phase at temperatures and atmospheric conditions ranging from 20°C to 100°C also is reported (NRC, 1993).

To include agent degradation in the consequence analysis, a degradation fraction must be created for each weather sample, and multiplied by release concentration of that sample. Two other parameters, cloud density and humidity, must be sampled also.

A decision was made to not include atmospheric degradation of the GB, VX, and HD in the CHEMMACCS consequence analysis code at this time. In reviewing a study on agent degradation rates (NRC, 1993), it was found that:

- The analysis was based on degradation at low temperature in the liquid phase under atmospheric pressure conditions. Degradation in the atmosphere occurs in the vapor phase. No data on vapor phase degradation were cited. There is no doubt that agent degradation happens in the atmosphere, but experimental data would be needed to support development of an agent degradation model during atmospheric transport.

- Including agent degradation into the consequence analysis without real test data might lead to underestimating the amount of agent released, which could lead to underestimating the overall risk in the case of accidental release of agent in the atmosphere.

- The degradation products also may have health effects. Because these have not been studied, it is prudent to calculate health effects based on the original agent.

11.7.2 Dense Gas. GB, VX, and HD all have a vapor density and molecular weight greater than air and, therefore, all are considered as dense gases. However, it has been the assumption in previous QRAs and within the D2PC methodology that the rapid mixing with air would cause an agent plume to almost immediately have the characteristics of a neutrally buoyant plume. This assumption is based on determining the density of an agent-air mixture versus pure agent densities. It is more accurate to compute the agent-air mixture density obtained through a release and compare that value with the density of pure air. Gaussian models such as CHEMMACCS and D2PC are effective in predicting the behavior of neutrally buoyant plumes.

In determining whether an agent release will be negatively, neutrally, or positively buoyant in air, it is necessary to consider the circumstances under which the substance enters the environment. CDFs include accident sequences where agent could be released by a spill/evaporative release, release from a fire, and release caused by an explosion. A vapor-air mixture exposed to the heat of a fire will become positively buoyant and rise into the air until it cools. Postulated accident sequences associated with explosive releases are modeled as a combination of aerosol and vapor. Aerosol droplets in an agent plume can cause the agent-air mixture to initially behave as negatively buoyant. Once the aerosol evaporates or leaves the mixture by contact with a surface, the mixture becomes neutrally buoyant again.

If the relative density of a vapor-air mixture is close to 1.0, it will quickly mix with additional air as it drifts away from the source and behave as a neutrally buoyant plume. As a general rule, if the relative vapor-air density ratio of a substance under prevailing conditions exceeds 1.5, then the mixture may behave as a negatively buoyant plume for some distance close to the source. A series of hand calculations, including a comparison to the Richardson number describing the release to a selected value, was used to determine whether a release should be considered denser than air. The results of these calculations justify the assumption of neutral buoyancy for accident scenarios model within the QRA and are presented in appendix Q.

The issue of dense gas behavior is most critical for exposure close to the point of release. As described in section 11.4, the close-in effects consider the impact of the potential releases on people in the vicinity. These calculations consider all exposure pathways. The possibility of splashing and direct inhalation and the impact of HVAC and masking are more critical than the dense gas behavior.

11.7.3 Toxicity Sensitivity. Upon request from the expert panel, a set of sensitivity studies has been developed to cover a range of toxicity values. The intent of these sensitivities was to ascertain if other risk drivers are present that were not identified as a result of using baseline toxicity values. The baseline toxicity values (LD_{50} and slope) used to calculate consequences in the baseline QRA were supplied to SAIC in a June 1994 memorandum from the U.S. Army Nuclear and Chemical Agency (USANCA, 1994). These values were used to quantify baseline risk. Since then, additional work has been performed concerning toxicity values and probit slopes to be used to analyze consequences of chemical agent exposure to healthy soldiers (Grotte and Yang, 1998; NRC, 1997b). The intent is to use the more recent data to find toxicity values for analyzing consequences to the general population, including sensitive subgroups. Because there are no published studies documenting LD_{50} and probit slopes for the general population, these sensitivity parameters are based on expert judgment. It is the intent of the sensitivity studies to span the range of possible values that might be proposed if this issue were posed to the whole toxicological community. Information was drawn from experts and from publicly available reports (including draft reports). While it is not typical to reference draft reports when trying to establish the range of uncertainty across a highly uncertain issue with limited available data, draft reports are used over a complete data vacuum. No classified information was used.

A meeting was held between SAIC and toxicologists to discuss the issue of which toxicity values to consider in the QRAs as sensitivity studies. Sensitivity consequence analyses were performed using values decided upon at the meeting for the three agents: VX, GB, and HD.

The logic behind the values selected at the meeting was that LD_{50} values 1/3 (factor of 3) and 1/10 (factor of 10) of the alternative values referenced in previous reports (Grotte and Yang, 1998; NRC, 1997b) would be appropriate. In the meeting, however, there was one exception, in that the VX LD_{50} was based on GB and was selected as a factor of 10 greater (smaller dose for the same effect) than the GB value. To make the situation more straightforward, a new sensitivity case was added in which all LD_{50} values are a factor of 10 greater from the alternative values. The issue of the VX LD_{50} being a factor of 10 greater than the GB LD_{50} then is considered in a separate case (case 5). Table 11-11 lists the LD_{50} and probit slope values used in the sensitivity studies.

As stated previously, baseline toxicities have not changed from the U.S. Army's currently accepted values, but to meet the goal of having a comprehensive QRA including uncertainty, alternative toxicities were used in sensitivity studies. Results from the sensitivities are used primarily to identify any new risk scenarios needing risk management attention. This approach will ensure that the entire range of risk drivers is identified and addressed as part of the QRA process. The results of the toxicity sensitivities are presented in sections 13 and 15.

11.7.4 Complex Terrain. The extent to which a dispersion model is suitable for the analysis depends upon several factors. These include: 1) the meteorological and topographic complexities of the area, 2) the level of detail and accuracy needed for the analysis, 3) resources available, and 4) the detail and accuracy of the input data (i.e., meteorological data, population data, etc.). Terrain elevation differences can have significant control over dispersion and, particularly in coastal and mountainous areas, the effect of terrain may include terrain-induced atmospheric circulation as well as physical limitations on boundary-layer advection. Areas

Table 11-11. Sensitivity Study Case Definitions

	Toxicities LD_{50}[a]/Probit Slope				
	Baseline (case 1)	Sensitivity (case 2)	Sensitivity (case 3)	Sensitivity (case 4)	Sensitivity (case 5)[b]
Pathway	Current Values (USANCA)[c]	Alternate Values[d]	Alternative Values (~factor of 3)	Alternative Values (~factor of 10 across for VX VI)	Upper Bound (~factor of 10)
GB Vapor Inhalation[e]	42/7.3	21/12	7/7.3	2.1/7.3	2.1/7.3
VX Vapor Inhalation[e]	18/7.3	9/6	2.3/6	0.9/6	0.21/6
HD Vapor Inhalation[e]	600/7.3	600/6	200/6	60/6	60/6
GB Percutaneous Vapor	15,000/6	10,000/5	3,333/5/1	1,000/5/1	1,000/5/1
VX Percutaneous Vapor	50/6	150/6	50/6/1	15/6/1	15/6/1
HD Percutaneous Vapor	10,000/6	5,000/6	1,667/6/1	500/6/1	500/6/1
VX Percutaneous Liquid	10/4.8	5/6	1.67/4.8/1	0.5/4.8/1	0.5/4.8/1
HD Percutaneous Liquid	7,000/3.1	1,400/7	467/3.1/1	140/3.1/1	140/3.1/1

Notes:

a LD_{50} dose units: mg-min/m^3, except for liquid pathway where units are mg/70-kg person.
b Same as case 4 but VX LD_{50} is 1/10 (factor of 10 greater) of GB for inhalation.
c USANCA, 1994.
d Values based on these reports: Grotte and Yang (1998) and NRC (1997b).
e Vapor Inhalation (VI) based on 25 liters per minute.

subject to major topographic influences such as these experience meteorological complexities that are extremely difficult to simulate. Capturing and accurately modeling the topographic complexities of the area is important. However, the level of effort required to depict the infinite details of the input data most likely will be counterproductive and may actually cause the overall risk to be underestimated.

Placement of receptors requires very careful attention when modeling in complex terrain. Often the highest concentrations are predicted to occur under very stable conditions, when the plume is near or impinges on the terrain. The plume under such conditions may be quite narrow in the vertical, so that even relatively small changes in a receptor's location may substantially affect the predicted concentration. Receptors closer in are even more sensitive to location. The population surrounding the depot is based on U.S. Census data at the census block aggregate level of detail and superimposed onto a radial polar grid. The population at best is represented as an approximation in distance and direction from the source. Even the summation of population within a census block could span an area of several square kilometers with multiple terrain effects and elevations within each. At this level of detail, it is nearly impossible not to move persons outside of their geographic complexity. For example, the population extracted from the census block group is mapped to a radial polar grid. Each grid element may cover several square kilometers. The population that falls within that grid element is distributed evenly across the center of that grid element.

Quality meteorological data from the point of release are readily available as the CSEPP and PMCD have implemented four towers to collect data. Likewise, the PMCD has implemented a strong and supportive quality assurance program for the collection of data. However, beyond the collection of data from onsite towers and possibly one first order NWS station, no additional reliable data are available. Therefore, it is necessary to assume the same meteorological conditions are occurring the entire distance of travel for the plume. Unfortunately, meteorological conditions at locations 10 kilometers apart are seldom the same at the same time. Light winds tend to be very unstable in speed and direction, especially in daytime conditions. The uncertainty of results from dispersion observations over low altitudes and over flat terrain at distances of a few meters to 10 kilometers are present based on using meteorological conditions only at the source. Likewise, this can lead to cascading effects on the uncertainty of plume travel through potential terrain complexity further from the source.

More recently, the CSEPP community has modified the D2PC model with the addition of terrain parameterization (e.g., the D2-Puff model). A sensitivity study has been completed comparing the CHEMMACCS code to D2-Puff with and without modeling for complex terrain. Downwind plume concentrations are compared, not fatalities or risk. The assessment is a high level look at the effects of using the D2-Puff model and wind processing options. The assessment identifies the effects of terrain and potential wind shifts that would not be picked up by a Gaussian model modeled over flat terrain. However, the assessment identifies that the more sophisticated modeling approach would most likely not differ to a great extent from the result from the Gaussian model in distances approximate to the IRZ. Details of the study are presented in appendix Q.

SECTION 12
DISCUSSION OF RISK ASSEMBLY AND UNCERTAINTY ANALYSIS

The goal of this section is to aid in understanding how the QRA arrives at its risk answers. This section is a description of the methods for assembling the overall risk analysis and the uncertainty analysis that is an integral part of this risk assembly. Details concerning the individual pieces that make up the assessment have been presented in previous sections and will not be repeated here.

12.1 Basic Elements of Risk Assembly

Previous sections of this document have discussed a variety of different tasks that compose the QRA, as well as the interrelationships among the tasks. Section 2 provides an overview discussion of the entire process and includes high-level diagrams of the risk assembly process. This section discusses some of the more technical elements associated with the risk assembly process.

As noted in section 2, the most generalized form for estimating risk is as a product of frequency and consequence:

$$R = F \times C \tag{12-1}$$

where:

R = Risk, measured in consequences per unit time
F = Frequency, events per unit time
C = Consequence, fatalities or cancers per event.

This risk formulation has been used by PMCD and in other industries to determine operational and storage risks. Because the activities being undertaken by PMCD are of specific durations, it also is useful to calculate the integrated risk for the entire operation. Thus, the frequency in the equation is multiplied by the appropriate duration to calculate the total risk. This still can be thought of as a frequency, such as events per the entire disposal period, or it can be understood to be a probability over the disposal period. No matter how it is considered, some of the risk calculations to support PMCD decision making actually involve somewhat more complex formulations than shown in equation 12-1.

To understand the risk assembly steps, it is necessary to consider the facility operation. The disposal facilities will perform specific operations to dispose of a type of munition (commonly called a campaign). The QRA models are developed for these specific operations to determine the frequency and consequences for individual accident sequences that are defined by the QRA model. By summing these accident sequences, the total risk can be calculated for that munition campaign, and the risk will be in the form of equation 12-1, with a result of fatalities or cancers per hour of operation. (Traditionally, most risks are calculated per year, but because campaigns are often less than a year, frequencies are calculated per hour in this QRA). This risk calculation is useful for understanding the risk of the operation, but it is not a complete story. While it is useful to understand how the risk of one campaign compares to another on a per-hour basis, it is very important for PMCD to understand the integrated risks of the entire campaign. This way, the total risk of a campaign can be compared to another, leading to potentially different risk insights.

The risk of a campaign, therefore, can be developed according to the relationship:

$$\text{Risk}_{\text{Campaign}} = \sum_{\text{Seq}_i}^{N} \text{Risk of Sequence}_i \qquad (12\text{-}2)$$

or,

$$\text{Risk}_{\text{Campaign}} = \sum_{\text{Seq}_i}^{N} F_i \times C_i \times T \qquad (12\text{-}3)$$

where:

F_i	=	frequency of release sequence *i*
C_i	=	consequence from release sequence *i*
T	=	total duration of the campaign
N	=	number of accident sequences in the model for the campaign
Risk	=	sum of the product of release sequence frequency, consequence, and duration over all release sequences in the campaign.

While the risk of the campaign is one useful risk result, it also is useful to know the risk for the entire disposal operation. This involves an extension of equation 12-3 across all campaigns:

$$\text{Risk}_{\text{disposal}} = \sum_{\text{Camp}_j}^{M} \sum_{\text{Seq}_i}^{N_j} F_{ij} \times C_{ij} \times T_j \qquad (12\text{-}4)$$

where:

F_{ij}	=	frequency of release sequence *i* in campaign *j*
C_{ij}	=	consequence from release sequence *i* in campaign *j*
T_j	=	total duration of campaign *j*
N_j	=	number of accident sequences in the model for campaign *j*
M	=	number of campaigns for the facility
Risk	=	sum of the product of release sequence frequency, consequence, and duration over all release sequences in the campaign, and summed over all campaigns.

Thus, risk has units of the consequence measure such as fatalities or cancers either per unit time, such as hour or year if calculated using equation 12-1, or over a specific operation, as in equation 12-4. Equation 12-4 is a conceptual representation of the risk assembly process. The characterization of the accident sequence frequencies and consequences is composed of multiple steps, and the inclusion of uncertainty in the process requires multiple evaluations of the risk. This section will discuss how the individual tasks in the analysis fit together to generate a risk estimate. The actual risk assembly process is carried out in the Quantus Risk Management Workstation. The use of Quantus is documented in the *Quantus User's Manual* (SAIC, 2002a). For example, the Quantus scheduler function provides an easy-to-use interface to ensure all appropriate campaign time elements (T_j) in equation 12-4 are accounted for in the risk assembly process.

12.2 Risk Assembly Without Uncertainty Calculations

It is understood that nearly every parameter in the QRA model is uncertain in some regard. The risk solution process outlined by equation 12-4 can be carried out using single parameter estimates for every variable in the model. This is known as a point-estimate evaluation. Because of the size of the risk model, it often is useful to evaluate it using point estimates to determine the risk results and contributors without the additional complexity and time involved in evaluating the risk with full consideration of uncertainty. Although the results of such an evaluation are not parameters of statistical distribution, an appropriately selected set of point-estimate inputs can provide useful results. Point-estimate evaluations are routinely used by decision makers as an input to their decision process. For many audiences, point estimates provide useful insights because they can be explained straightforwardly without understanding of the statistical nuances involved in uncertainty analysis. This also can be a problem, because comprehension of these nuances and other uncertainties is needed for a full understanding of the meaning of the results.

The QRA is performed using both point estimates and a full uncertainty evaluation. The Quantus Risk Management Workstation allows the user to select the type of evaluation to be performed. When point-estimate evaluations are done in the QRA using Quantus, the point estimates provided for each input are the mean values of the attendant uncertainty distributions for those inputs. While a point-estimate risk result using these values is not a mean value of risk that is statistically determined, it does typically come close to the mean value of the risk uncertainty distribution obtained by propagating all the uncertainty distributions for the entire risk model. The risk models can be run with and without uncertainty to determine how well the point estimate approximates the mean value of the full uncertainty distribution.

In practice, the point-estimate solution does include the uncertainty in some part of the risk formulation. Aleatory uncertainty (due to randomness) is built into the structure of the model in the APET and in the evaluation of consequences. In the event tree, additional sequences are generated to model some of the uncertainty due to random events, such as the number of workers near an accident when it occurs. In the consequence evaluation, the impact of the variation in weather always is included in the risk formulation. As described later in section 12.4.3, a distribution of consequences called a CCDF is produced for each accident sequence to capture the large variability in health effects associated with the random weather variation. From these CCDFs, it is possible to calculate a mean consequence, and this is used in the point-estimate risk result. The decision maker also can combine the point estimate in sequence frequency with an entire CCDF to arrive at solutions that consider the range of possible consequences.

12.3 Overview of Uncertainty in Risk Calculations

Very few of the probabilities, frequencies, or physical parameters used in this QRA are known with certainty. Some of them, such as quantities of agent in the munitions, are known reasonably well, while others, such as the recurrence frequencies of earthquakes, are very uncertain. This uncertainty should be recognized when using the QRA results for risk management activities, because significant uncertainty in scenarios may affect decisions about how to approach facility equipment or operational changes to most effectively achieve risk minimization. Thus, the goal of the uncertainty analysis in this QRA is to propagate the effects of uncertainty in the basic models and parameters and then calculate the influence of these uncertainties on the QRA results. There is also an issue of completeness when considering potential uses of these models and results. Completeness is discussed in section 16.5.

12.3.1 Types of Uncertainty. Two types of uncertainty are currently discussed in the literature: epistemic uncertainty and aleatory variability (Mosleh et al., 1993). The term epistemic uncertainty is used to refer to uncertainties in the model that are due to a lack of perfect knowledge. Thus, the term is generally applied to uncertainties in the model parameter values, such as physical parameter values, failure frequencies, etc. Aleatory variability is a term used to describe the variability associated with a phenomenon that is random in nature (i.e., the wind speed at any arbitrary point in time is generally considered to be random in nature). The basic difference between the two types of uncertainty is whether increased knowledge about the subject could reduce the imprecision in the model used in the QRA. Even if hundreds of years of data were taken on the wind speed during the year at a specific location, accuracy in the prediction of the wind speed at a specific (future) time would benefit very little due to the inherent randomness of the phenomenon. Thus, wind speed has aleatory variability. Values for the failure rates of specific components used at the plant, however, could be improved significantly by observing many years of failures of those components. Theoretically, the uncertainty on the failure rate value for failures of identical components could be reduced to zero (i.e., the failure rate could be known exactly). In practice, this is unachievable. Note also that as modeled in the QRA, the actual failure time of a component is random because it is assumed to be governed by a Poisson process. Thus, the failure rate has epistemic uncertainty, while the failure time has aleatory variability.

These two types of uncertainties are included in the QRA in different ways: Aleatory variability is included in the basic structure of the models and in assumptions such as the Poisson nature of the failure processes. Epistemic uncertainty, however, is treated as unknown parameters that are sampled using probability distributions and a Monte Carlo process.

12.3.2 Distributions. Only four types of uncertainty distributions are currently being used in the QRA: lognormal, maximum entropy, discrete, and empirical distributions. The use of each type will be briefly described here, with more detail provided in section 12.4. Figure 12-1 shows examples of the four types used in the QRA.

12.3.2.1 Lognormal Distributions. Lognormal distributions often have been used to characterize component failure frequencies and human failure probabilities. The general shape of the distribution, left skewed with a long upper tail, often fits observed data. Other distributions might be used with similar results to the lognormal; however, no better information exists to indicate other distributions are more appropriate choices. Thus, the lognormal distribution is used extensively in this analysis for component failure frequencies, HFEs, and in a few other instances.

12.3.2.2 Maximum Entropy Distributions. The maximum entropy technique was derived from information theory in an attempt to generate Bayesian prior distributions that introduced minimal amounts of extraneous information due to distribution shape (Cook and Unwin, 1986). A computer code (IMPAGE) was written to allow easy derivation of numerical maximum entropy distributions (Unwin, 1987). This code allows for a number of different options that have significant impact on the resulting distributions. The code allows percentiles of a distribution, moments of a distribution, or both to be defined by the user. Then, an appropriate discretized maximum entropy distribution is generated. For this QRA, only percentiles are defined for variables to be characterized with maximum entropy distributions (no moments such as the mean or variance). This has the effect of generating piecewise continuous uniform distributions for maximum entropy-defined variables. The distributions are piecewise continuous between each defined percentile (an upper and lower bound, along with the median and two other percentiles, may be defined in this QRA). Maximum entropy distributions are typically used in this QRA for APET branch probabilities that model the probability of mechanistic events and for source term parameters.

12.3.2.3 Discrete Distributions. Discrete distributions are available for use in the Quantus program to allow consideration of cases where a small number of discrete outcomes are the only possible results. Simply, the discrete distribution defines a set of possible variable outcomes and

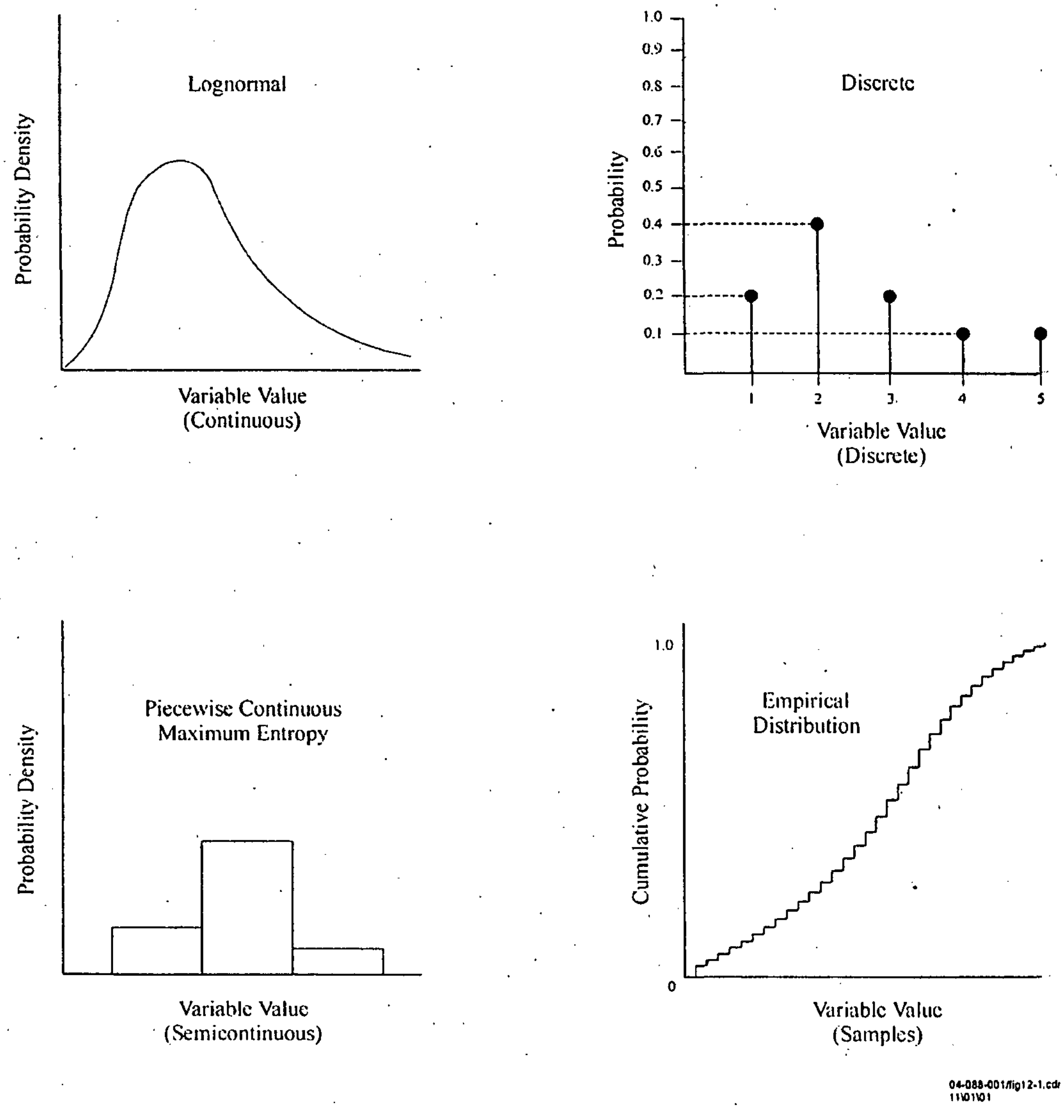


Figure 12-1. Examples of Probability Distributions Used in the QRA

assigns probabilities to each outcome (the sum of the probabilities over the entire set of outcomes for a single variable must equal unity). In the current model the discrete distribution is not used. The APET model itself is discrete, and functions with discrete outcomes have been explicitly modeled, which also better characterizes the aleatory uncertainty.

12.3.2.4 Empirical Distributions. An empirical distribution function is generally used to model a set of experimentally derived data. Empirical distributions are used in the QRA to characterize the munition explosion probability distributions generated as described in section 9 and appendix M, and to incorporate the uncertainty in fault tree results. The munition explosion probability distributions are generated outside the formal uncertainty quantification by considering uncertainties in the calculations leading to the generation of the munition explosion probability. The numerical distributions generated by the explosion probability calculations are highly skewed and cannot be fitted to a lognormal or maximum entropy distribution. Instead, a sample of 500 points is taken from each munition explosion distribution, and this sample is treated as an empirical sample from the distribution. Each of the 500 sample members is assumed to be equally probable, and a cumulative distribution function is constructed from a sorted list of the 500 points. This sample also could be thought of as a discrete distribution with 500 potential outcomes with equal probability, but they are more appropriately thought of in distribution function terms because they are developed as continuous distributions.

The empirical distribution function also can be used to simulate other distributions not currently included in the solution process in Quantus. For some variables, it was determined that a normal distribution better reflected the uncertainty distribution than a lognormal distribution. In this case, a point distribution simulating a normal distribution was used.

12.3.3 Sampling Method. The QRA can be thought of as a very large and complex function of many variables, as indicated in equation 12-5, where the x_i values are parameters in the risk model, and R is the risk result being calculated.

$$R(x_i) = \text{Function}(x_1, x_2, \ldots x_n) \tag{12-5}$$

Because it is not analytically possible to derive the uncertainty function for this expression, a numerical technique must be used to estimate the distribution of R given the distributions on the x_i parameters. Monte Carlo analysis is a typical method for estimating the distribution of R. In Monte Carlo analysis, a sample of independent variable values is assembled from the variable distributions using a random number generator. Equation 12-5 then is used to calculate R. This process is repeated many times and an empirical sample of the distribution of R is formed. Typically, many thousands of samples are required to be run to generate a reasonable estimate of the distribution of R, especially if skewed distributions such as the lognormal are used for some of the independent variables. Because each sample taken requires a quantification of all the fault tree cutsets, the APET, and the source term algorithm, a straightforward application of Monte Carlo analysis could be prohibitive in terms of analytical effort and time. Instead, a technique called Latin Hypercube Sampling (Iman and Shortencarrier, 1984) has been developed to restrict the number of necessary QRA quantifications to a few hundred, depending on the number of parameters being sampled. This technique was used in previous QRAs, including the TOCDF QRA (SAIC, 1996b), and is used in this QRA.

Figure 12-2 provides an overview of the Latin Hypercube Sampling process for a single variable distribution. This figure shows a typical cumulative distribution function for a continuous variable in the analysis (e.g., a lognormal distribution). The QRA currently uses between 200 and 500 Latin Hypercube Sampling sample members in the analysis. (Sampling analysis suggests that the number of samples be 25 percent greater than the number of variables.) In Latin Hypercube Sampling for 500 samples, each distribution is separated into 500 equally probable intervals by dividing the probability axis in figure 12-2 into 500 equally probable sections (figure 12-2 shows only 5 sections for clarity). Within each section, a value from the distribution is chosen using a random number generator only over that interval. Thus, in the example shown in figure 12-2, five values will be chosen, one randomly selected from each of the five intervals. The values shown in figure 12-2 are for example only and could have been any other set of values, restricted of course to being one from each of the five intervals.

Figure 12-3 shows an idealization of the main Latin Hypercube Sampling matrix that is produced to characterize the distributions of all sampled variables in the analysis. (In the example, there are 600 variables and 500 Latin Hypercube Sampling sample members.) As can be seen from the figure and as discussed in the following sections, the variables that have samples in this matrix can be grouped in several sets for discussion purposes. There is no reason for grouping the variables other than for tracking and clarity; they also could be in a random order within the matrix.

This Latin Hypercube Sampling matrix is formed to ensure a self-consistent overall sample of variables that has the correct correlation structure between variables. If all the sampled variables were considered independently of each other, it would be possible to generate samples for the variables within each individual part of the analysis, one sample member at a time, instead of making a large matrix of values all at once. It sometimes is desired to correlate two variable samples due to a perceived relationship between the variables. To do this, all the sample members for the two variables must be produced at once so that a correlation may be introduced between the samples. Conversely, if two variables are believed to be completely independent, then it is undesirable to have a correlation between the variables.

When generating a small random sample, it is possible that a spurious correlation may be formed between two or more variables, due to chance and the way the sample members were picked.

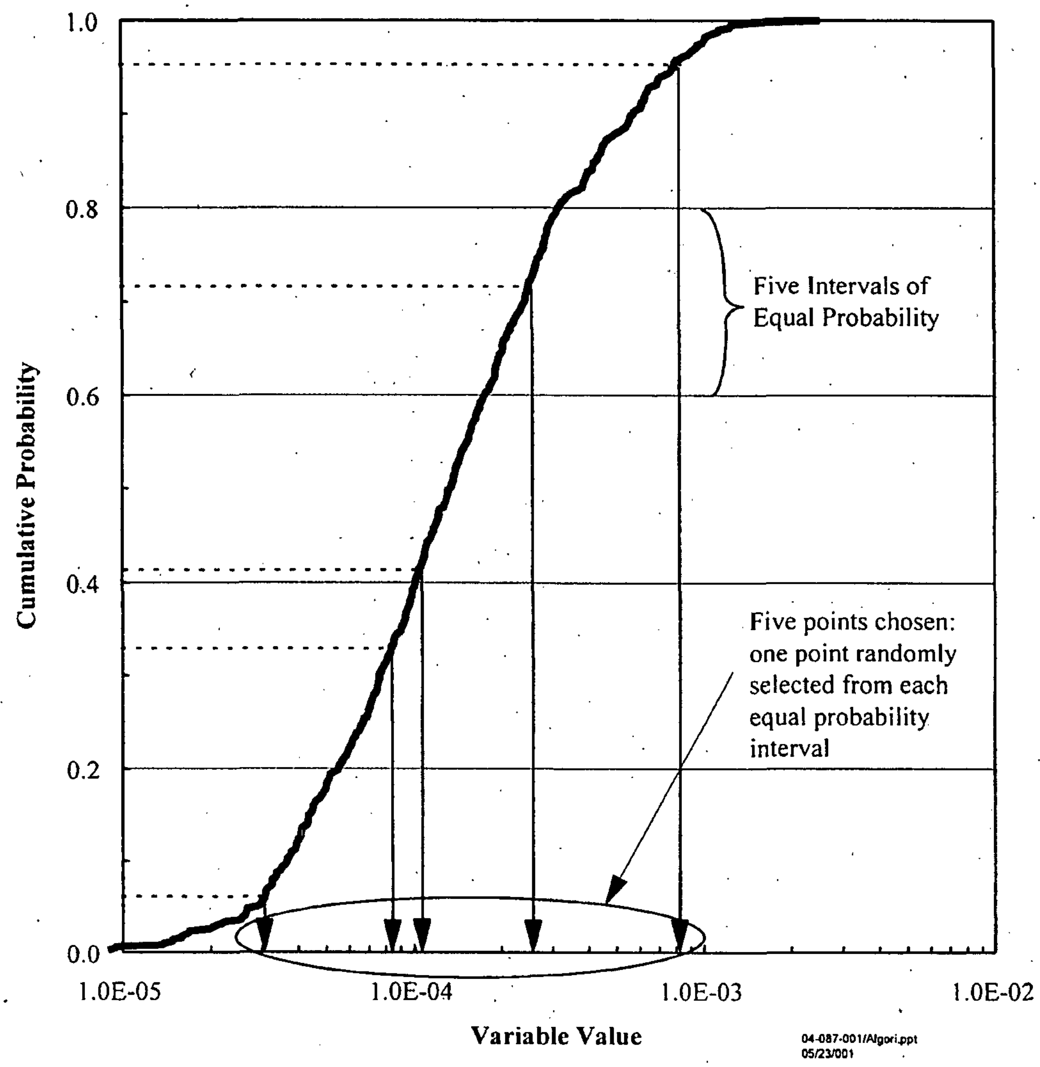


Figure 12-2. Latin Hypercube Sampling Algorithm

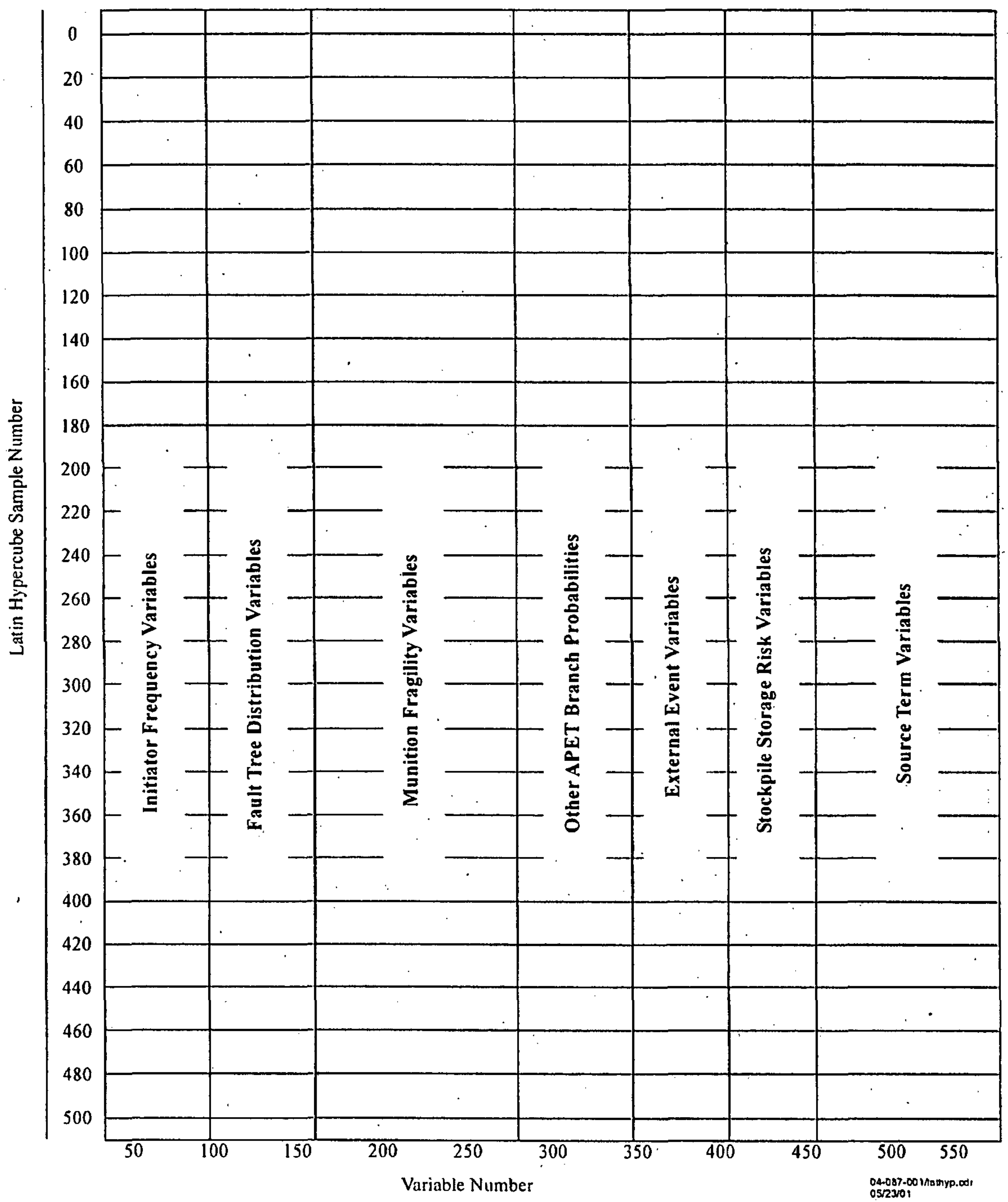


Figure 12-3. Structure of the Main Latin Hypercube Sampling Matrix

The Latin Hypercube Sampling computer code has been written to accomplish both the job of inducing a desired correlation between variables, and to ensure that no spurious correlations are formed between independent variables (Iman and Shortencarrier, 1984). Producing the large matrix of all sample members at once is a necessary part of the process of inducing correlations and ensuring the lack of spurious correlations.

There are thousands of variables in the accident sequence and source term portions of the QRA. Theoretically, it would be optimal to assign an uncertainty distribution to every variable that is not perfectly known, and then propagate these distributions through the risk model to include their effects on the risk result. However, computational and resource restrictions prohibit this. Computationally, the Latin Hypercube Sampling matrix would become extremely large. Further, a general rule for generating a matrix of this type is that the number of sample members in the sample should be equal to or greater than the number of variables in the matrix, preferably more than 25 percent greater (Iman and Conover, 1982). Thus, if 3,000 variables were to be modeled, then 4,000 sample members would need to be used. Because computational time for the QRA grows more than linearly with the number of sample members (computer memory becomes a problem as the QRA grows), the time for solving the QRA would be prohibitive. Thus, it is desirable to restrict the number of variables in the matrix.

The goal of the variable selection process is to include only those variables that have a significant impact on the QRA results. There are many criteria on which this selection could be made (contributions to accident frequency, source term size, risk, etc.), but this QRA has selected a top-down approach that chooses variables based on their contributions to mean risk. This technique requires that a full point-estimate quantification of the QRA be available before choosing variables for the uncertainty analysis. This point estimate uses variable values that are as close as possible to the means of the distributions that would be assigned to them. Given that a full point-estimate quantification is available, the variable selection process begins by reviewing the accident sequences in the QRA model that contribute the top 99 percent or more to risk over all campaigns, both to the public or workers. The scenarios that generate these accident sequences then become the initial focus for the uncertainty analysis.

Overall risk is not the only focus for the QRA. Risk results of each campaign are also of interest. Thus, the point-estimate results also are quantified for each campaign, and the accident sequences that contribute the majority (often, but not always greater than 99 percent) of the risk for each campaign are analyzed, again for both public and worker risks. The list of sequences from these two levels is the starting point for selecting variables for the uncertainty analysis. Appendix P has a detailed discussion of potential variables and their reasons for inclusion or exclusion.

12.4 Uncertainty in Each Part of the Assessment

A discussion is provided in this section on the series of variables included in the main Latin Hypercube Sampling matrix. However, fully detailed descriptions of all the variables are not provided here. Sampled variables, as well as their distributions, correlations, and statistics, are described in the detailed appendices discussing the model inputs, and additional summaries are provided in appendix P.

12.4.1 Accident Sequence Frequency Uncertainty. The variables that contribute to the accident sequence frequency uncertainty may be divided into five different groups:

1. Initiator events
2. Munition fragility events
3. Other APET variables
4. External event APET variables
5. Stockpile APET variables.

The initiators identified during the point-estimate evaluation as requiring uncertainty characterization may be individual event values, such as an HFE causing a munition drop, or they may be the result of a system failure fault tree quantification. If they are derived from a fault tree solution, then the uncertainty in the initiator is quantified from a solution of the fault tree with inclusion of the uncertainty in all the fault tree basic events.

Uncertainty distributions are assigned to all the fault tree basic events. These events are associated with the fault trees described in appendix D. The uncertainty for all fault tree events is characterized with lognormal distributions as described in sections 7 and 8. The lognormal distribution is judged to adequately reflect the epistemic uncertainty and has been used routinely to represent equipment failure rates in published and reviewed risk assessments.

There are over 100 different APET variables sampled in the Latin Hypercube Sampling matrix for the internal events APET. These variables model everything from initiating events to leak probabilities given drops to conditional probabilities of barrier failures during explosions. Appendix P describes which variables were sampled and their assigned distributions. A general discussion of the different types of variables sampled in the APET is provided in this section.

One class of parameters in the APET is the conditional probabilities of munition spill or explosion on drop or impact. Many boundary conditions are assessed for these probabilities [i.e., munitions in EONCs or out, in pallets or out, dropped from different heights, and dropped onto either flat surfaces or probes (protrusions or other edges that may puncture a munition)].

Section 9 and appendix M1 describe in detail the derivation of the uncertainty distributions on these variables.

The methodology chosen for characterization of these probabilities uses the Monte Carlo propagation of uncertainties to arrive at a numerical estimate of the distribution of the munition spill or explosion probabilities for variables internal to the munition analyses. This propagation is performed outside of the main Latin Hypercube Sampling performed for the QRA quantification, and the resulting distributions are used as if the independent variables from which they are generated were completely independent of other variables in the QRA (which it is believed they are).

All the actual numerical distributions are input to the Latin Hypercube Sampling analysis as empirical distribution functions, as discussed in section 12.2.2. The variables for which this technique has been used are all instances of explosions or leaks given drop or impact and have been separated out in the Latin Hypercube Sampling. Most of these munition fragility variables are quite skewed and have a very broad range, reflecting significant uncertainty in some of the variables used in the models.

The miscellaneous variables included in the APET uncertainty analysis include a number of probabilities assigned to phenomena or outcomes of events. Some of these probabilities describe complex events (such as the probability of an MPF agent vapor explosion). These events are often associated with both aleatory and epistemic uncertainties. In the QRA, the aleatory uncertainties in these events are generally modeled with a multibranch (most often binary) APET question that delineates the possible outcomes of the process being modeled. The epistemic uncertainty then is modeled as variation in the probability that each state is realized. Thus, for an event such as *the MPF room walls fail during a furnace explosion*, the aleatory model is Bernoulli: the walls either fail or not, and the epistemic uncertainty is a distribution on the probability of failure. This type of modeling implies that the analyst believes that there is a random component to the phenomenon under study (or there would be no aleatory model). For the MPF explosion, the analyst's belief is conditions in the furnace, timings of explosions, variations in combustion efficiency, etc., would cause variability in explosion yields and MPF room wall responses even for basically identical scenarios. Thus, the possibility of either failure or nonfailure of the walls results. The inability to precisely model the explosion and resulting wall response leads to uncertainty in the probability that the wall will fail.

Some of the probabilities can be estimated from data or equipment failure rates. The rest rely on analyst judgment based on knowledge gained during investigation of the phenomenon involved in the process. To assist analysts in assigning probabilities to events that rely on physical evidence and analyst judgment for their quantifications, a set of guidelines was used. These guidelines are based on those used during the NUREG-1150 studies (USNRC, 1990), as well as during other later work, such as for the U.S. DOE K-reactor (Brandyberry et al., 1992). These guidelines provide a consistent framework for assigning probabilities to events based on the weight of evidence available to support the occurrence of the events. In most cases, probabilities concerning physical phenomena are specified by the analyst(s) based on the strength and depth of the evidence provided by the supporting mechanistic analyses. The assignment process is a structured one in which the analyst(s) examines the calculations and data associated with the particular event in question. The event outcome then is placed into one of the following categories using the guidance listed:

- *Impossible.* The outcome is either logically excluded by prior events in the sequence; impossible based on physical laws; or ruled out by overwhelming, well-documented evidence that is, to the best of knowledge, unrefuted (P = 0.0).

- *Extremely Unlikely.* The outcome is refuted by a detailed analysis (analytical or based on experimental data) that considers all relevant phenomena and their uncertainties in detail. This analysis has been subjected to independent review and is supported by a significant body of independent evidence from published, referential sources (P = 0.001).

- *Very Unlikely.* The outcome is refuted by an analysis (analytical or based on experimental data) that considers the relevant phenomena and their uncertainties. This analysis has been subjected to independent review that confirms the results. Alternative views are obviously flawed and not supported by analysis or experimental data (P = 0.01).

- *Unlikely.* The outcome is refuted by an analysis (analytical or based on experimental data) that considers the relevant phenomena. There is general agreement among the analysts involved in the quantification process. Alternative views are apparently flawed, but they do have a technical basis supporting their position (P = 0.1).

- *Even Odds.* Existing analyses are lacking and/or inconclusive and the outcome is not clearly indicated by experimental data (P = 0.5).

- *Likely.* The outcome is supported by an analysis (analytical or based on experimental data) that considers the relevant phenomena. There is general agreement among the analysts involved in the quantification process. Alternative views are apparently flawed, but they do have a technical basis supporting their position (P = 0.9).

- *Very Likely.* The outcome is supported by an analysis (analytical or based on experimental data) that considers the relevant phenomena and their uncertainties. This analysis has been subjected to independent review that confirms the results. Alternative views are obviously flawed and not supported by analysis or experimental data (P = 0.99).

- *Extremely Likely.* The outcome is supported by a detailed analysis (analytical or based on experimental data) that considers all relevant phenomena and their uncertainties in detail. This analysis has been subjected to independent review and is supported by a significant body of independent evidence from published, referential sources (P = 0.999).

- *Certain.* The outcome is either logically indicated by prior events in the sequence; inevitable based on physical laws; or supported by overwhelming, well-documented evidence that is, to the best of knowledge, unrefuted (P = 1.0).

The primary purpose of this methodology is to act as a common framework for assigning probabilities of mechanistic event outcomes that allows for the relative weighting of event likelihoods. The methodology encourages the structured and thorough evaluation of supporting data relative to established criteria. This approach controls some of the subjectivity from the process of assigning probabilities and allows insights to be drawn based on relative rankings.

These guidelines are used in the QRA when it is necessary to use judgment to assess the probability of an event. Generally, the analyst will select a median at the point believed to be just as likely that the "true" value will lie above as below. Then, the highest and lowest probability values believed possible (upper and lower bounds) are assigned, based on the strength of evidence available. These three points then will be used to describe a maximum entropy distribution on the variable. If the analyst believes that the evidence can support more detail on the shape of the distribution, up to two other percentiles may be assigned as well (but this has rarely been done in this QRA). A lognormal distribution also may be used if the skewed shape fits the evidence that the analyst has about the variable. Only two parameters, such as the mean and an upper bound (used as the 99.9 percentile) need to be assessed in this case. When using the lognormal, the lower bound needs to be checked to ensure that the forced shape of the distribution does not cause the lower bound to generate values for the variable that are unrealistic compared to the knowledge held by the analyst.

There are also external event APET variables in the main Latin Hypercube Sampling matrix for which uncertainty distributions are assigned. Some of these variables describe the distributions of the median seismic fragilities of key structures. The lognormal distributions on these variables are one dimension of the seismic uncertainty. They characterize the uncertainty in the median value of the fragilities of each structure or component, using the β_u value as the logarithmic standard deviation (see section 5.1). Thus, these distributions describe the epistemic uncertainty in the seismic fragility variables. The aleatory uncertainty in the fragility variables, described by the β_r parameter and a second lognormal distribution, is calculated internally by the APET. For every median fragility sample for each component, the APET calculates the fragility value at each of the 10 different g-levels used in the UMCDF external event seismic analysis. Thus, for each of the 500 Latin Hypercube Sampling sample members, there are actually 10 fragility values for each structure/component input into the seismic uncertainty analysis.

As described in section 5.1, multiple discrete hazard curves are used in the characterization of the uncertainty in the seismic hazard. A variable in the Latin Hypercube Sampling matrix is used to choose 500 sample members from this set of hazard curves, based on the probabilities of each separate curve. The Latin Hypercube Sampling matrix contains a vector of 500 "hazard curve pointers," each of which represents an entire hazard curve to be used in one sample member of the uncertainty analysis.

Variables also are assigned probability distributions in the uncertainty analysis for the stockpile APET. These variables include seismic fragilities. The distributions assigned in the matrix are the median value epistemic distributions of the fragilities, and the aleatory variability is calculated by the APET user function in the same manner as the UMCDF external event APET fragilities.

Other initiating event variables have been defined in the stockpile portion of the Latin Hypercube Sampling matrix to model aircraft crashes. A set of lightning-related variables also is included.

12.4.2 Source Term Uncertainty. After the frequency of each accident sequence has been determined, an analysis must be made of the potential effects of the accident; i.e., how the accident releases agent. The most important parameters characterizing the release from an accident are: 1) type(s) of agent released, 2) release duration and quantity of each agent, 3) physical state of the released agents (vapor, liquid, or aerosol), 4) location of the release, 5) time of day during which the release occurs, and 6) any special characteristics that affect mitigative measures or relevant meteorology. Details of the source term analysis are provided in section 10, but the basic result is for each accident sequence, a source term is produced that characterizes the release from the accident.

There are over 100 separate variables associated with source term estimation that are assigned uncertainty distributions in the QRA. Two general classes of variables may be defined as follows:

- Physical parameters, such as evaporation rates, decontamination factors, burning rates, or pool depths

- Modeling fractions, such as the percentage of a munition that actually spills during a drop, or agent destruction fractions in a fire.

Uncertainties in the class of physical parameters are generally epistemic uncertainty, because they describe material properties, effects, or behaviors. Uncertainty distributions assigned to these variables are derived by considering the scenarios modeled, conditions under which the variables are used, and maximum and minimum possible values for these variables. These bounds often require the use of analyst judgment, after considering whatever information is available.

The second set of variables, the modeling fractions, is assessed after considering the applicable scenarios. For fractions such as the percentage of agent actually spilled from a breached munition, the types of drops and resulting breaches, along with the possible geometries, are considered. In some cases, fractions may be calculated, and in others, analyst judgment must be used again to estimate the fractions based on the scenario. For fractions such as the agent destruction fraction in a pool fire, limited experimental evidence is available for agent fires, and a large amount of literature is available for other combustible liquid fires. This information is reviewed to assign distributions to the variables. The uncertainties in these variables are assumed to be dominated by epistemic uncertainty, although some of them may have an aleatory component (e.g., the geometry in which a munition ends up after a drop and breach may be considered to be somewhat random). The interpretation and use of the previous two classes of variables is discussed in section 10 and appendix O.

12.4.3 Consequence Uncertainty. Uncertainty in the consequence analysis is generated by two very separate models. These are the uncertainty in remote-agent consequences associated with dispersion in the atmosphere that vary due to CHEMMACCS weather sampling, and the uncertainty in the close-in Disposal-Related Worker risk effects.

The CHEMMACCS computer code uses many input variables (e.g., probit equation parameters, deposition velocities, and Gaussian plume dispersion parameters) that can be very uncertain. In the current state-of-the-art full-scope QRAs, however, there is no mechanism to consistently include the uncertainties in these parameters in the QRA results, due to computational restrictions. In theory, uncertainties in these parameters may be addressed using Latin

Hypercube Sampling in the same manner as for other variables. However, this would generate thousands of consequence runs, which could not be solved in a reasonable amount of time. The only variability that is modeled in the CHEMMACCS calculation is variation in the area weather during the time of the event. This weather variation causes a large range of consequences to be generated for any single source term. The greatest uncertainty in the consequence evaluation is related to the dose-response relationships describing the health effects of the agents. Instead of uncertainty analyses, these have been addressed with sensitivity studies of entirely different hypotheses, as discussed in section 16.

For each source term, a consequence calculation is performed for each of the three populations at risk that are modeled in the QRA (offsite public, Disposal-Related Workers, and Other Site Workers). Each consequence run calculates the release effects in terms of one or more risk measures (i.e., societal or individual acute fatalities or cancer occurrences). The result for each consequence calculation is a single CCDF for each risk measure. The CCDF is a curve that relates numbers of potential consequences from the release to the probability of exceeding those numbers.

The CCDF is a result of variations in the weather during the consequence calculation. Site-specific weather data are used to generate weather scenarios for the analysis. To more accurately account for the effects of the variability in weather, the source term groups are generated in two forms: groups that are applicable any time during a 24-hour period, and groups that are only appropriate during the daytime. The latter groups are generated, for the most part, by accidents occurring during munition removal from the igloo or by transportation accidents, because these activities can only occur during the daytime. Thus, the CHEMMACCS code generates many potential weather scenarios during a single run [generating start times either over a 24-hour period or over a 10-hour daytime period (7 a.m. to 5 p.m.) as appropriate] and calculates the consequences that would result from the selected source term group with each of these weather conditions. A variation in the consequences results from this variation in the weather (a weather pattern with wind toward population centers will cause higher consequences than a pattern with the wind away from them), and the code calculates the CCDF from this variation. Section 11 and appendix Q provide the details on the consequence analysis. These CCDFs are the basic result of the consequence analysis for agent-related risks. A CCDF is developed for every release group, so that the *C* in equation 12-4 can be replaced by a function describing the probability of different consequences for the same release, as determined by the variability in weather.

CCDFs provide a good description of the overall numerical risk from facility operation, but are somewhat difficult to work with (because they are curves and not individual numbers) when attempting to investigate contributions to risk from various portions of the risk model. A single value may be derived from the CCDF by taking the area under the curve, as shown in equation 12-6:

$$E(R) = \int_{0}^{\infty} CCDF(x)dx \qquad (12\text{-}6)$$

where:

x = the level of consequence in terms of fatalities or cancer incidences
E(R) = the statistically expected number, or mean number of fatalities or cancer incidences, i.e., the expected risk.

The result in equation 12-6 is not intuitively obvious, so now the derivation will be provided. Consider a probability density function on consequence, called *g(C')*, for which it is desired to calculate the mean value of risk, *E(C)*. The probability that *C'* is greater than any specific value *C* (i.e., the CCDF) is given by:

$$P(C' > C) = \int_{C}^{C_{max}} g(C')dC' \qquad (12\text{-}7)$$

where C_{max} is the maximum possible consequence. The following also can be written from this equation:

$$dP(C' > C) = -g(C)dC \qquad (12\text{-}8)$$

Using these definitions and integration by parts, the integral of the CCDF over the entire consequence range may be expressed as:

$$\int_{0}^{C_{max}} P(C' > C)dC = [C \times P(C' > C)]_{0}^{C_{max}} - \int_{0}^{C_{max}} C \times P(C' > C) = 0 + \int_{0}^{C_{max}} C \times g(C)dC \qquad (12\text{-}9)$$

The last term of this equation is the definition of the expected value of *C*, which is the mean risk.

If generation of a single number to characterize a risk measure for the QRA is desired, this expected value is the logical choice. This integration also may be performed for each CCDF produced for each source term to provide the mean number of fatalities estimated for each source term. The CHEMMACCS model provides this mean value from each of its calculated CCDFs. The Quantus computer code assembles these mean consequence values, along with the frequency and duration information for the accident sequences and campaigns, and produces importance measure information on the contribution of various portions of the risk model to the risk result.

Close-in Disposal-Related Worker consequence effects are modeled with individual estimates of worker consequences by accident area. There are also close-in worker consequence variables included in the Latin Hypercube Sampling matrix. These variables model the estimated number of close-in fatalities that would be generated by a variety of accidents, generally separated by accident class (spill, explosion, etc.) and accident location (UPA, outside the MPF, stockpile, etc.). The values of, and distributions for, these close-in effect probabilities are assessed by considering the uncertainties in the effects of the accidents. The aleatory variability in the number of workers potentially exposed has been addressed by adding branches to the APET to describe the possibility that these accidents could occur when the population of a given area was high or low. It was judged that this classification of populations by facility areas was sufficient to capture the variability. Section 11 and appendix Q discuss the use of these variables.

For Disposal-Related Workers, two potential consequences have now been defined: the close-in effects of accidents and the potential effects at a distance from the agent release (calculated by the CHEMMACCS code). These effects are combined to predict overall Disposal-Related Worker consequences. Other Site Workers and the public are only affected by releases that are dispersed in the atmosphere.

12.5 Risk Assembly with Uncertainty Calculations

In theory, the assembly of the risk models during an uncertainty quantification is no different than running the QRA 500 times with 500 different sets of variable input values and then assessing the results. In practice, however, there are several subtleties in the analysis that should be recognized. The following sections discuss those factors that are unique to the quantification of risk with uncertainty.

12.5.1 Variable Correlations. Appendix P contains a description of variables in the Latin Hypercube Sampling matrix that have been defined to be correlated to each other. In the QRA, all variables are either defined as completely independent (correlation as close to zero as possible), or completely dependent (correlation as close to 1.0 as possible). There is generally no reason or rationale for defining correlations other than these values.

Correlations are defined among variables in the QRA if the variables are believed to have the same knowledge base used in the definition of their distributions. This means that if two identical pieces of equipment are being modeled in the fault tree analysis, and they use the same data to generate their uncertainty distributions, then it is not reasonable to allow any sample member in the QRA to model the failure rate of one of these items to be low, and the other high. For that sample member, this situation would be inconsistent. Thus, the two distributions are defined to be completely correlated and they then vary together; they would either both be high, or both be low.

A similar situation exists for APET branch probabilities and source term variables. Appendix P shows that all the conditional probabilities of munition spill or explosion are correlated together in the QRA. This is due to the fact they all use the same modeling techniques, same basic distributions on the input parameters, and same basic assumptions. Thus, again, if for any one sample member the explosion probability of a rocket in a 3-foot drop in one area were allowed to be radically different than the explosion probability of a 3-foot drop in another area, then that sample member would be internally inconsistent. Thus, all munition drop failure probability values are correlated. There are many other sets of variables in the analysis that are correlated due to common background models, assumptions, or data. The correlations assigned between these distributions are documented in appendix P.

12.5.2 Derived Distributions. The main Latin Hypercube Sampling matrix previously described has one variable from which other distributions are calculated: the seismic hazard pointer is used to generate the seismic hazard frequency samples for both the UMCDF and stockpile analyses. The distributions of the seismic hazard curve samples are assembled into a second Latin Hypercube Sampling matrix (termed the seismic hazard matrix), which is directly related to the main matrix through the samples of the seismic hazard pointer variable.

Section 5.1.1 presents the discrete seismic hazard curve. The weighted curves presented in that section are in terms of frequencies of exceedance of a series of g-levels. For the QRA quantification, the values that must be used are frequencies of recurrence of different g-level ranges and not the frequencies of exceedance. Thus, a set of g-levels has been defined for the QRA that is designed to model the g-levels that occur in the failure ranges of the major components and structures, and recurrence frequencies have been derived for these.

To generate the actual seismic hazard frequency samples using the seismic hazard pointer variable and the seismicity information, the value of the seismic hazard pointer is used to select a hazard frequency curve from each table for each Latin Hypercube Sampling sample member. As an example, if the first sample member in the hazard pointer sample is equal to the integer 5, then the fifth hazard frequency curve is selected, and the hazard values are used to form the first sample member of different variables in the Latin Hypercube Sampling frequency matrix. These variables represent the seismic frequency values needed to characterize the seismic hazard for all g-levels for both the UMCDF and stockpile trees. Subsequently, for each seismic hazard pointer variable sample member, the value of the pointer chooses which seismic frequency curve is used for the seismic recurrence frequency variables. Because the pointer values were weighted by the weights of each seismic hazard curve, each curve will be chosen an appropriate number of times for its weight. The result of this derivation will be a set of variables with 500 sample members each that describes the different hazard frequency values necessary for the analysis.

12.5.3 Production of Complementary Cumulative Distribution Functions with Uncertainty. Combining accident sequence and resultant source term frequency distributions with the consequence CCDFs distributions generates a space of risk curves. This space of curves is produced by applying equation 12-4 to the combination of source term frequency and consequence CCDFs for each of the 500 Latin Hypercube Sampling sample members in the analysis. Thus, 500 separate CCDFs are produced.

At any point along the consequence axis for the CCDFs, a vertical slice across the 500 curves in the space would generate 500 estimates of the frequency of exceedance of that level of consequence. If this is thought of as the frequency of exceedance distribution at that consequence level, then statistics may be calculated from the sample of 500 points describing this distribution. For presentation in this QRA, the mean, median, 5th percentile, and 95th percentile values will be used. If these percentiles are calculated at vertical cuts at each point along the consequence axis, a set of four curves is generated. Curves such as these are used throughout this QRA to represent the space of 500 curves. These curves can be shown to be similar to CCDFs in that they are non-increasing functions that approach unity at zero consequence and go to zero at high consequence. They do not, however, represent any specific sample quantification of the QRA.

SECTION 13
UMCDF QRA RESULTS FOR DISPOSAL PROCESSING

The UMCDF QRA characterizes risk to the public surrounding the UMCDF site, as well as to Disposal-Related Workers and Other Site Workers (see box 13-1). Separate discussions of risk for each of these populations are provided in this section. There are many ways to present risk and several methods of display have been selected with a goal of optimizing the risk management information that can be derived from the QRA models. As each new type of display is introduced, a discussion is provided about the interpretation of the results. Additional explanations are provided in the imbedded boxes that accompany this narrative. The boxes include information that will be useful for repeated reference as the risk results are examined.

Box 13-1. Populations Studied in the QRA

Public	Census-based population residing up to 63 miles outside the UMCD fence.
Disposal-Related Workers	People working within or just outside the UMCDF and storage area security fences. Also includes those workers responsible for retrieving the munitions from storage.
Other Site Workers	People working within the UMCD fence, but not included in the Disposal-Related Worker category.

In risk studies of most industries (e.g., nuclear power), risk is provided on a per-year basis. Per-year results also are provided in the UMCDF QRA, but the main emphasis is "risk over the facility or campaign lifetime." This allows an integrated examination of risk on a campaign-by-campaign basis, and also allows calculation of risk for the entire disposal effort.

The potential accidents contributing to the different risk measures for the various populations of interest are presented in several ways. First, results are shown in terms of important contributors to each population and risk measure over the entire UMCDF operational duration. This provides a focus for identification of the areas accounting for the overall risk at the facility. Results also are presented on a campaign basis. (A campaign is defined here as an operation period devoted to disposal of a single agent-munition, or single agent-coprocessed munition, combination.) Thus, the dominant risk contributors are identified even for campaigns that do not contribute significantly to the overall risk.

Public risk is discussed first, in sections 13.1 through 13.4. A summary of results is provided in section 13.1 with a detailed discussion of significant risk contributors in section 13.2. A summary of public risk contributors to each campaign is provided in section 13.3, and public cancer risk is summarized in section 13.4.

The risk to UMCD workers who are involved in activities other than chemical demilitarization (Other Site Workers) is described in section 13.5. Disposal-Related Worker risk is discussed in sections 13.6 through 13.8. The last discussion, in section 13.9, is devoted to sensitivity studies performed to provide additional insight.

All the results include a presentation of uncertainty in the calculated estimates. The range of uncertainty and important contributors to uncertainty are detailed in the text. In addition, section 16 discusses uncertainties that were not explicitly considered in the model, as well as model limitations.

The results summarized here are focused on the risk results as well as the risk contributors to overall risk and individual munition campaigns. This is appropriate given the risk-based scope of the QRA. As described in section 2, there are other uses of the model that are expected to provide useful insights. It is anticipated that the model will be exercised to study proposed changes or provide insights for specific safety issues.

13.1 Public Risk

The following sections describe the agent-related risks to the public within a 100-kilometer (63-mile) radius surrounding UMCDF. This 100-kilometer limit was chosen based on calculations that show the risk from any modeled accident would be negligible beyond this distance from UMCDF, as discussed in section 13.1.1.2. Two consequence measures are presented: acute fatalities and latent cancers (cancers are discussed in section 13.4). The risk results include the impact of emergency protective actions within the community. The sensitivity of the results to protective action is examined in section 13.9.

13.1.1 Acute Fatality Risk (All Campaigns). The acute fatality risk measure discussed in these sections represents the risk of agent-related fatalities that would occur very soon after exposure. This risk will be presented as *societal risk* (the probability of some number of fatalities in the population at risk) and *individual risk* (the probability of fatality to an individual in the population at risk). Box 13-2 provides these definitions for reference.

Box 13-2. Societal and Individual Risk

Societal	Risk to society, the total impact. For example, there are about 40,000 people killed in U.S. car accidents each year.
Individual	Per-person risk, the chance that an individual is affected. For example, typical citizens have a 1 in 6,000 chance of being killed in a car accident each year.

13.1.1.1 Public Societal Acute Fatality Risk (All Campaigns). Figure 13-1 shows the most complete depiction of the risk of acute fatality to the surrounding population. The results depicted in this figure are a combination of all identified potential accidents associated with disposal processing. This type of figure is called a CCDF. The vertical axis is the probability of exceeding a given number of fatalities during UMCDF operation, and the horizontal axis is the number of fatalities. Each CCDF curve

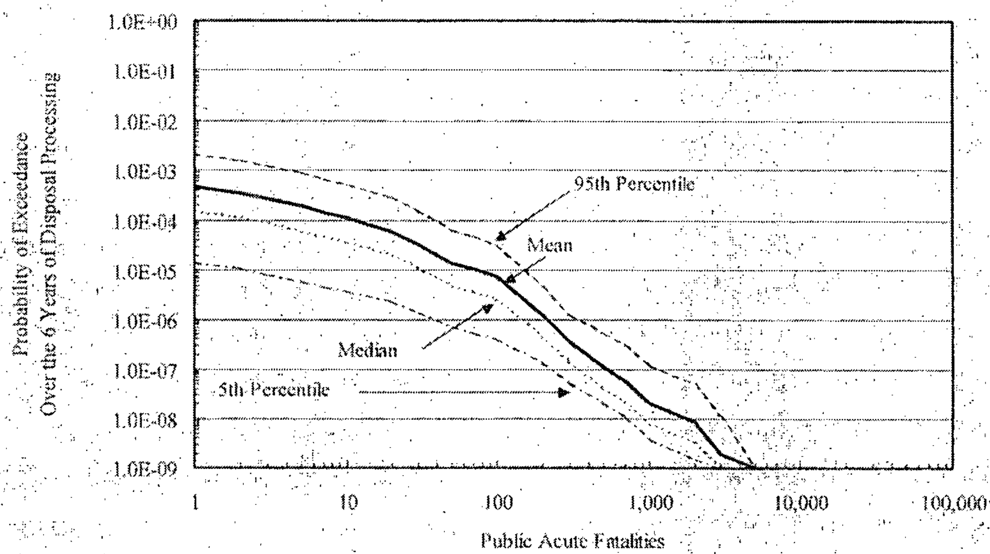
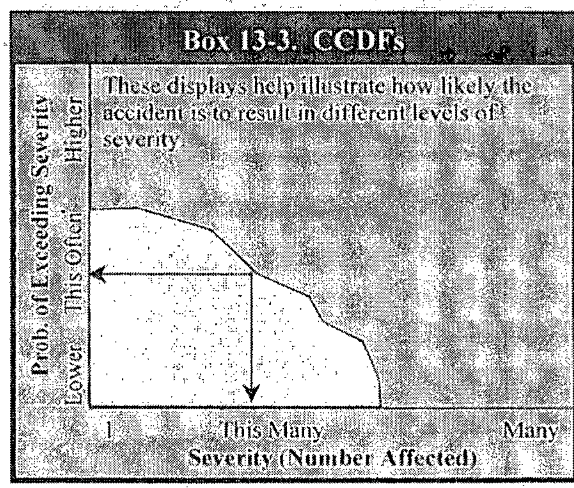


Figure 13-1. Public Societal Acute Fatality Risk for All Campaigns (UMCDF Disposal Processing)

represents the impact of variability in weather. Therefore, the mean CCDF curve is over many weather conditions. A substantial number of these events show that less than one fatality occurs from the accident. Wind speed and direction, as well as the "stability" of the atmosphere at the time of the accident, have a major effect on the potential consequences. This analysis uses a probabilistic description of site-specific weather conditions to characterize the variability in weather that may occur at the time of a potential accident. This type of display is useful because it illustrates how potential accidents of different severity and likelihood affect the population (see box 13-3).



The area under the mean curve in figure 13-1 is the value most often quoted as the "average expected fatality risk" of the facility. This value is 5.3×10^{-3} and represents the mean number of societal acute fatalities over UMCDF's entire operational duration. Figure 13-1 illustrates that the probability of exceeding a given level of fatalities drops substantially as the number of potential fatalities increases. The probability of one or more fatalities is approximately 4.7×10^{-4}. There is a one in one million (1×10^{-6}) chance that approximately 200 or more people could be affected. The probability of 5,000 or more fatalities is one in one billion, or 1×10^{-9}. (Box 13-4 summarizes some of the number formats used in this report).

Box 13-4. Numbers Used in Presenting Risk Values

Scientific	Decimal	Scientific Used in Graphs	Numeric Description if it is a Probability	Word Description if the Number is a Probability
1.0×10^{-1}	0.1	1.0E-01	1 in 10	1 in ten chance
1.0×10^{-2}	0.01	1.0E-02	1 in 100	1 in one hundred chance
1.0×10^{-3}	0.001	1.0E-03	1 in 1,000	1 in one thousand chance
1.0×10^{-4}	0.0001	1.0E-04	1 in 10,000	1 in ten thousand chance
1.0×10^{-5}	0.00001	1.0E-05	1 in 100,000	1 in one hundred thousand chance
1.0×10^{-6}	0.000001	1.0E-06	1 in 1,000,000	1 in one million chance
1.0×10^{-7}	0.0000001	1.0E-07	1 in 10,000,000	1 in ten million chance
1.0×10^{-8}	0.00000001	1.0E-08	1 in 100,000,000	1 in one hundred million chance
1.0×10^{-9}	0.000000001	1.0E-09	1 in 1,000,000,000	1 in one billion chance

There are four curves depicted in figure 13-1 that illustrate the estimated uncertainty in the risk results. As described in section 12, these curves represent the uncertainty in all of the sampled parameters in the model, coupled with the uncertainty in the weather that is captured in the CCDF. The upper and lower 5 percentiles are shown, along with the mean and median curves. As indicated, there is substantial uncertainty in the results, ranging from a factor of 100 at the lower consequences to a factor of 2 at the upper range.

The mean expected fatality risk is the value referenced most often for the risk of the facility. Therefore, it is useful to understand the confidence in this value. Figure 13-2 is a plot of the mean expected fatality risk for all the Latin Hypercube Sampling observations in the uncertainty analysis. The upper and lower percentiles, median, and mean are shown. As indicated, there is approximately a factor of 100 between the 5th and 95th percentiles.

The sequences contributing in greatest measure to the public acute fatality risk are provided in summary tables in this report, in a format described in box 13-5. In the analysis, thousands of accident sequences are developed that represent all the ways a given accident could progress. These sequences have been categorized into larger groups for display purposes. Shown in the tables for each sequence group are short descriptions, the mean societal acute fatality risk, and the mean consequence (number of fatalities). These consequence and risk values are derived from the CCDFs calculated for each individual accident. The tables have been provided for mean risk. The uncertainty in the risk and the contributors to risk also have been examined and are discussed as appropriate in this section.

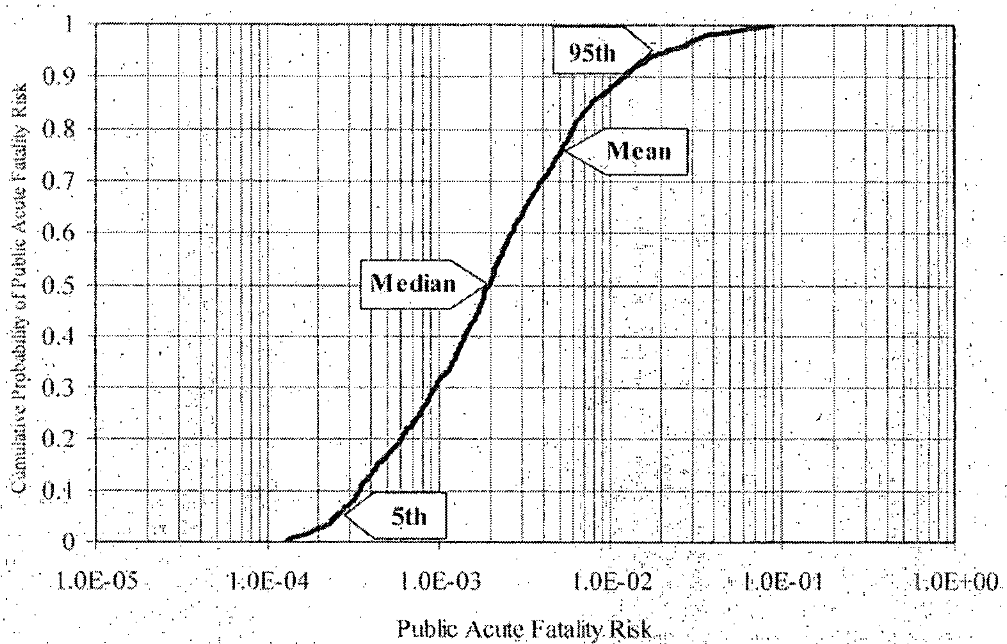


Figure 13-2. Distribution of the Mean Public Societal Acute Fatality Risk for UMCDF Disposal Processing

Box 13-5. Overview of Results Tables

Campaign #: Munition	Accident Sequence Category	Mean Recurrence Interval	Mean Consequence (Fatalities)	Mean Fatality Risk	Contribution to Mean Risk
Campaign number and munition based on the evaluated schedule. (Column not needed if table applies to one campaign only.)	A summary description of the accidents included in a generalized category. For ease of presentation, similar accidents are grouped into a sequence category. This does not have all the details of the accident. The text describes the contributors further. Appendix R provides results in more detail.	Average number of times the entire process could be repeated before the accident would be expected to occur. This gives insight into how likely the accident is.	Average consequence of all sampled weather conditions. Some weather conditions may cause no fatalities, others may cause several; this is the average over the entire sequence category.	Release sequence frequency times consequence, as described in section 12. The duration of interest is also included. For tables presenting risk across all campaigns, this is the risk over the 6 years of disposal processing. For tables presenting risk for only one campaign, this is the risk over the entire campaign of interest.	Percent of the total mean risk that is a result of this sequence. This may be total facility mean risk, or total campaign mean risk, depending on the table.

For some sequences, the consequences are very low (i.e., less than one fatality). For example, if the mean consequence for a sequence is 0.1 fatalities, one person would be expected to die if this scenario occurred 10 times and no deaths would be expected the other 9 times. The scenario is not expected to occur 10 times; however, any time it occurs there would still be a 1-in-10 probability of a fatality. The variability in consequence is a function of many factors affecting the size of the agent release as well as its dispersion in the surrounding environment (e.g., weather conditions). Furthermore, because the consequences presented reflect the mean, greater or lesser consequences could actually occur.

Also included in the summary table are the mean recurrence intervals for each accident (i.e., a return period associated with each accident if the activities of UMCDF were carried out over and over many times). This measure provides a perspective on how often an accident may be expected to occur if that particular campaign was repeated continuously. For example, one dominant sequence would occur, on average, once every 190 times that the GB rocket and MC-1 bomb disposal campaign was carried out. Of course, the process only needs to be done once, so there is a 1 in 190 chance that the accident would occur during that one time.

The summary table for public risk across all disposal campaigns is provided in table 13-1. The results indicate that fires that originate in the MDB and spread to wider portions of the facility dominate risk. Sequences involving seismic events and M55 rocket handling at the igloos also contribute. These accidents will be described in more detail in section 13.2. As shown in the table, the mean of the total public societal acute fatality risk is 5.3×10^{-3} over the lifetime of the facility (almost 6 years), which is the same as the area under the mean curve in figure 13-1.

Table 13-2 provides the fractional contribution of accidents in each campaign to the mean public acute fatality risk. As seen in table 13-2, the GB rocket campaigns account for half the total disposal risk. The VX M55 rocket and VX spray tank campaign alone contributes another 30 percent to total risk (the remaining VX M55 rocket campaigns contribute another 3 percent). The VX 8-inch and 155mm projectile campaigns contribute 6 percent to total risk. The GB 8-inch and 155mm projectile campaigns contribute 10 percent to total risk. HD processing contributes only a very small fraction of the overall risk. The changeovers after completion of GB campaigns also contribute to risk due to the possibility of a building fire that could involve the GB agent on the HVAC filters.

13.1.1.2 Societal and Individual Acute Fatality Risk by Distance from UMCDF. The risk results described in the previous section are termed *societal risk* because they apply to the public as a whole. This societal risk also may be calculated for subpopulations surrounding the facility to provide a clearer picture of how risk varies within different surrounding regions. The risk of acute fatality thus has been estimated for each population ring surrounding UMCDF. Individual risks also have been calculated to indicate the risks to individuals within these population rings.

Table 13-1. Dominant Public Societal Acute Fatality Risk Scenarios for All Campaigns for UMCDF Disposal Processing

Campaign #: Munition	Accident Sequence Category (Associated with Processing)	Mean Recurrence Interval	Mean Consequence (Fatalities)	Mean Fatality Risk Over Entire Processing Duration	Contribution to Mean Risk
1b: GB Rocket + MC-1 Bombs	MDB Fire that Spreads Beyond the Room of Origin and Involves Agent and/or HVAC Filters	190	0.3	1.8×10^{-3}	33%
2b: VX Rockets + Spray Tanks	MDB Fire that Spreads Beyond the Room of Origin and Involves Agent and/or HVAC Filters	870	1.1	1.3×10^{-3}	24%
1d: GB Rockets (2)	MDB Fire that Spreads Beyond the Room of Origin and Involves Agent and/or HVAC Filters	450	0.2	5.0×10^{-4}	9%
6: GB 155mm Projectiles	MDB Fire that Spreads Beyond the Room of Origin and Involves Agent and/or HVAC Filters	610	0.2	2.4×10^{-4}	5%
7: GB 8-inch Projectiles	MDB Fire that Spreads Beyond the Room of Origin and Involves Agent and/or HVAC Filters	1000	0.2	2.3×10^{-4}	4%
2b: VX Rockets + Spray Tanks	Seismic Event that Leads to a Fire in the MDB	240,000	48	2.0×10^{-4}	4%
1a: GB Rockets (1)	MDB Fire that Spreads Beyond the Room of Origin and Involves Agent and/or HVAC Filters	800	0.2	1.9×10^{-4}	4%
4: VX 155mm Projectiles	MDB Fire that Spreads Beyond the Room of Origin and Involves Agent and/or HVAC Filters	850	0.1	1.7×10^{-4}	3%
3: VX 8-inch Projectiles	MDB Fire that Spreads Beyond the Room of Origin and Involves Agent and/or HVAC Filters	1,700	0.3	1.5×10^{-4}	3%
2a: VX Rockets (1)	Igloo Handling Accident that Results in an Igloo Fire	31,000	1.9	6.3×10^{-5}	1%
1b: GB Rocket + MC-1 Bombs	Seismic Event that Leads to a Fire in the MDB	46,000	2.6	5.7×10^{-5}	1%
1b: GB Rocket + MC-1 Bombs	Igloo Handling Accident that Results in an Igloo Fire	5,000	0.2	4.8×10^{-5}	1%
2b: VX Rockets + Spray Tanks	Igloo Handling Accident that Results in an Igloo Fire	44,000	1.9	4.4×10^{-5}	1%
1d: GB Rockets (2)	Igloo Handling Accident that Results in an Igloo Fire	5,400	0.2	4.3×10^{-5}	1%
2b: VX Rockets + Spray Tanks	Seismic Event that Leads to a Collapse in the CHB/UPA	51,000	2.1	4.2×10^{-5}	1%

Table 13-1. Dominant Public Societal Acute Fatality Risk Scenarios for All Campaigns for UMCDF Disposal Processing (Continued)

Campaign #: Munition	Accident Sequence Category (Associated with Processing)	Mean Recurrence Interval	Mean Consequence (Fatalities)	Mean Fatality Risk Over Entire Processing Duration	Contribution to Mean Risk
2a: VX Rockets (1)	MDB Fire that Spreads Beyond the Room of Origin and Involves Agent and/or HVAC Filters	1,900	0.07	3.7×10^{-5}	1%
2c: VX Rockets (2)	Igloo Handling Accident that Results in an Igloo Fire	49,000	2.0	3.9×10^{-5}	1%
1b: GB Rocket + MC-1 Bombs	Seismic Event that Leads to a Collapse in the CHB/UPA	23,000	0.6	2.6×10^{-5}	<1%
	All Other Scenarios Combined			1.8×10^{-4}	3%
	Total Mean Public Societal Acute Fatality Risk			5.3×10^{-3}	100%

Table 13-3 provides the results of calculations for societal acute fatality risk by ring, where *ring* refers to the radial rings shown in figure 11-1 in section 11. The societal risk is highest (57 percent) in the 8- to 15-kilometer ring. The 2- to 5-kilometer and the 5- to 8-kilometer rings are closer to the site but contribute less to total risk, 10 percent 33 percent respectively. This is due to the lower population within those rings, which are approximately 46 and 3,793 persons respectively (compared to over 25,000 in the 8- to 15-kilometer ring). Nearly 100 percent of the public acute facility risk is associated with the first three populated rings (population living between 2 and 15 kilometers from the site). Beyond 15-kilometers the risk drops off significantly. Workers in this first ring are discussed in sections 13.6 and 13.7.

Building fire initiators dominate public disposal risk up to approximately 15 kilometers. Very unlikely but catastrophic events, including accidental aircraft crashes and seismic events, dominate the population rings beyond 15 kilometers.

Figure 13-3 shows the CCDFs for each distance ring plotted on the same graph for comparison. As seen from this figure, societal public risk is dominated by the 5- to 15-kilometer ring. The probability of exceeding one or more fatalities in the 5- to 8-kilometer ring is 2.6×10^{-4} and in the 8- to 15-kilometer ring the probability of exceeding one or more fatalities is 1.8×10^{-4} (over UMCDF's operational period, almost 6 years). For the closest ring (2 to 5 kilometers), the probability of exceeding one or more fatalities is 1.3×10^{-5}. The risk drops considerably after 15 kilometers. Due to the limited population in the 2- to 5-kilometer ring (46 people), this ring curve crosses all but the 5- to 15-kilometer ring beyond 46 fatalities, illustrating the low probability accidents that cause more fatalities in the farther rings.

Table 13-2. Percent Contribution to Total Mean Public Societal Acute Fatality Risk by Campaign for UMCDF Disposal Processing

Campaign #	Campaign	Duration (Weeks)	Contribution to Total Mean Public Acute Fatality Risk
1a	GB M55 Rockets (1)	18.0	4%
1b	GB M55 Rockets + GB MC-1 Bombs	35.1	36%
1c	GB M55 Rockets + GB MK-94 Bombs	0.1	<1%
1d	GB M55 Rockets (2)	32.0	11%
	Changeover	27.1	<1%
2a	VX M55 Rockets (1)	8.4	2%
2b	VX M55 Rockets + VX Spray Tanks	5.9	30%
2c	VX M55 Rockets (2)	5.3	1%
	Changeover	9.1	Negligible[a]
3	VX 8-inch Projectiles	4.7	3%
	Changeover	6.0	Negligible[a]
4	VX 155mm Projectiles	9.1	3%
	Changeover	7.0	Negligible[a]
5	VX Land Mines	8.7	<1%
	Changeover	27.1	Negligible[a]
6	GB 155mm Projectiles	12.4	5%
	Changeover	6.0	Negligible[a]
7	GB 8-inch Projectiles	7.9	5%
	Changeover	27.1	Negligible[a]
8	HD Ton Containers	42.0	<1%
	Closure	52.1	N/A
	Total	351.1	100%

Note:

[a] Negligible contributions are 0.0001 or less.

Table 13-4 lists the individual risk of acute fatality, calculated by distance from the facility. This table is provided on a per-year basis as an average risk rate over the 6 years of disposal processing. As described in box 13-2, individual risk is an important display because it provides a point of comparison to other risks to which individuals might be subjected. As described in box 13-6, the risks are actually calculated for each of the 16 sectors in each ring. The individual

Table 13-3. Public Societal Acute Fatality Risk for Disposal Processing by Distance from UMCDF

	0-2 km[a]	2-5 km	5-8 km	8-15 km	15-30 km	30-45 km	45-60 km	60-75 km	75-100 km
Mean Societal Acute Fatality Risk	–	5.0×10^{-4}	1.8×10^{-3}	3.0×10^{-3}	1.7×10^{-5}	2.9×10^{-6}	5.6×10^{-7}	6.9×10^{-9}	4.1×10^{-9}
Fraction of Total Mean Risk from Each Ring	–	10%	33%	57%	<1%	<1%	<1%	<<1%	<<1%

Note:

[a] Within facility boundaries; no public population.

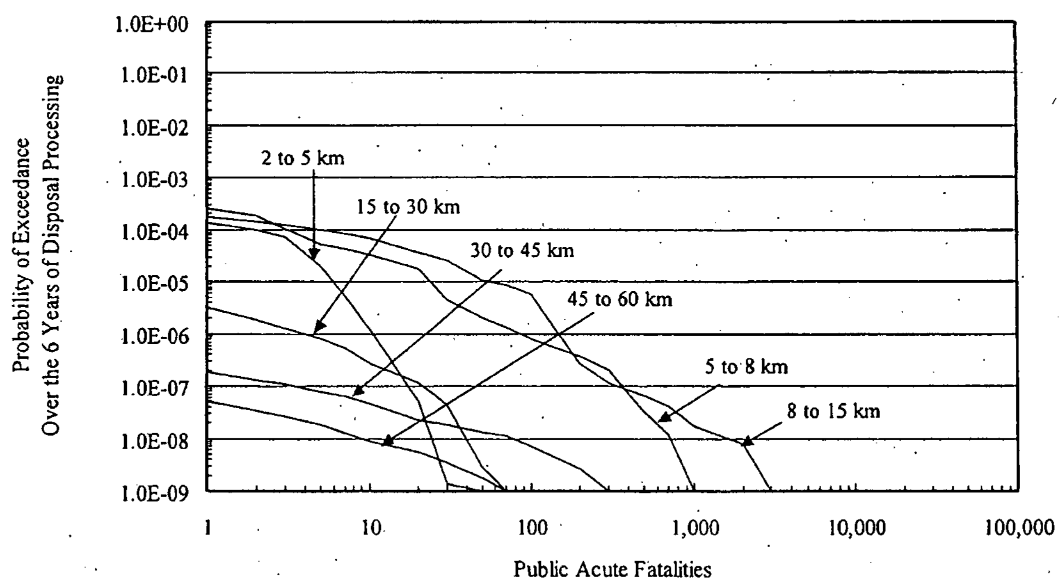


Figure 13-3. Mean Public Acute Fatality Risk for UMCDF Disposal Processing by Distance from UMCDF

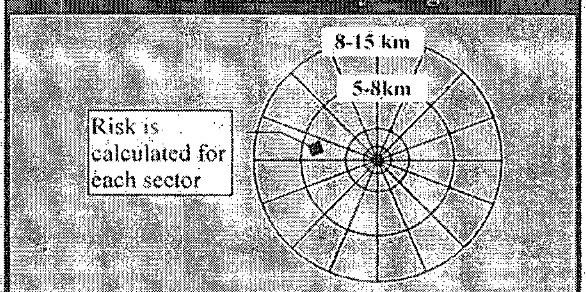
Table 13-4. Public Individual Acute Fatality Risk (per Year) for Disposal Processing by Distance from UMCDF

	0-2 km[a]	2-5 km	5-8 km	8-15 km	15-30 km	30-45 km	45-60 km	60-75 km	75-100 km
Average Individual Fatality Risk	–	1.9×10^{-6}	8.3×10^{-8}	2.1×10^{-8}	2.6×10^{-10}	1.5×10^{-11}	$<10^{-12}$	$<10^{-12}$	$<10^{-12}$

Note:

[a] Within facility boundaries; no public population

Box 13-6. Risk by Ring



The individual risks are calculated for each of 16 sectors in a ring. This allows more accurate consideration of both weather and population in developing average individual risk values. For societal risk by distance, the mean of all 16 sectors is presented.

risk is highest near the site and drops rapidly with increasing distance. The societal risk was highest in the 8- to 15-kilometer ring because of the large population in that ring. Individual risk divides out the impact of population; therefore, risk is highest nearest the facility.

The risk varies across the 16 sectors of a ring as a function of population and weather (the wind is more likely to move toward some sectors than others). The Quantus Risk Management Workstation can be used to examine the risks in each sector if needed.

13.2 Discussion of Contributors to Public Acute Fatality Risk

Figure 13-4 illustrates the key classes of accidents that contribute to the total UMCDF mean public acute fatality risk. As illustrated, fires within the facility account for most of the public risk of processing. Fires have higher frequencies than most other events with potentially widespread effects and they can involve multiple agent sources. Seismic events can also cause fires in the facility and cause the collapse of the CHB/UPA. There is also a small contribution from rocket handling accidents that could occur as the rockets are removed from the igloos at the storage area. Other accidents have very small or negligible contributions to disposal risk. The significant risk contributors are shown in figure 13-4 and described in more detail in the sections that follow.

13.2.1 Facility Fires. Facility fires are the dominant contributor at UMCDF, accounting for approximately 87 percent of the total mean acute fatality risk. Fire accident sequences have been

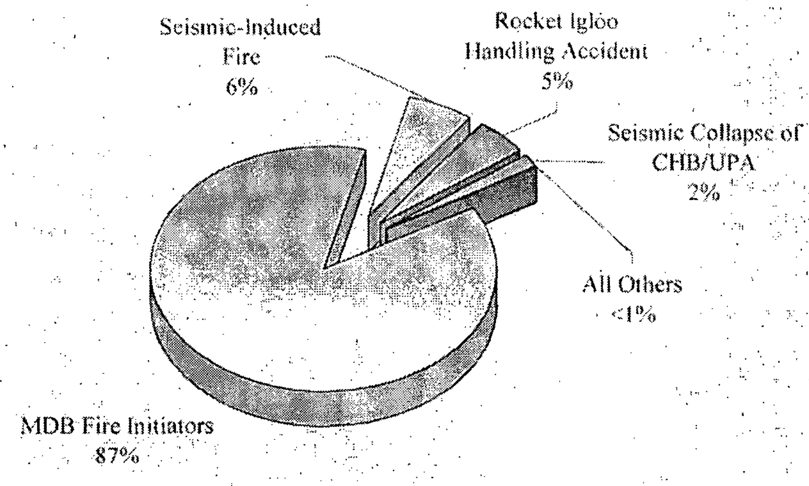


Figure 13-4. Contributors to Mean Public Societal Acute Fatality Risk for UMCDF Disposal Processing

included in the QRA based on the fire initiation frequency, the possibility of the fire propagating to other areas, and the potential for agent release either directly or as a result of HVAC filter involvement. Four specific rooms were identified as most important to risk of agent release and have been studied in detail: TOX, UMC, UPA, and MPB. Three large propagating fires also have been modeled: a second-floor MDB fire, a first-floor MDB fire, and an MDB-wide fire. In addition, a fire in a room not containing agent but potentially leading to filter involvement was included. The fire analysis is summarized in section 5 and detailed in appendix K2. A high-level summary of the fire analysis is provided here as an aid to understanding the risk results..

A method for estimating the frequencies of severe fires has been developed for this QRA. This is primarily new methodology, because very little precedent exists for the type of fire analysis needed here. Fire methods have been used extensively in nuclear-generating station QRAs, and while this QRA draws on those methods and lessons learned, new methods were still required. The methods were first applied to ANCDF in a preliminary draft, refined further and applied to UMCDF as reported in a preliminary draft Phase 2 QRA, and additional refinements have been incorporated in this QRA since the UMCDF preliminary draft in response to comments and as planned improvements.

The frequency of fire initiation was obtained through a structured process of applying appropriate industrial fire experience data. This method was chosen because it was deemed impossible to identify all the precise combustible loads, mechanisms, and paths that would cause a fire to initiate and spread. In other words, it is difficult to be specifically predictive about fires, yet past experience has shown that large fires do occur in industrial facilities.

Data from 1988 to 1997 were obtained from the NFPA. The data were from industrial chemical, plastics, and hazardous chemical facilities with facility construction similar to the CDF. This data source was judged to be the most representative of a CDF. Although the analogy to industrial facilities is not perfect, UMCDF has furnaces, natural gas, hydrogen, and combustibles that move through the facility. The CDF also contains explosives, which are not in many of the industrial facilities but are contained in a subset of those in the NFPA database. Further, UMCDF has equipment common to all industrial facilities, such as electrical, control, and HVAC equipment. The frequency of potentially significant fires in these facilities is 8×10^{-6} per hour, or about one fire every 14 facility years. Smaller fires, quickly extinguished, occur much more frequently. As described in appendix K2, sensitivity studies have shown that the frequency of fires is fairly constant across the industry and that this part of the risk estimate is not the dominant area of uncertainty.

Through a systematic process, the facility frequency has been partitioned to estimate fire frequencies in each CDF fire zone. In order to develop accident sequences with agent-related consequences, the possibility of fire propagation within a fire zone was studied, also with industrial data. This resulted in a frequency for fires that could threaten agent sources within the room or zone. Through a consideration of frequencies and potential agent involvement, accident sequences were developed in the APET for five areas: TOX, UMC, UPA, MPB, and a generalized room that has no agent sources but that considered the possible impact on carbon filters.

The next consideration is the probability that a fire will spread beyond the fire zone where it started. A large fire can be initiated anywhere within the facility. What makes it a large fire is that through some mechanism and path, it propagates from combustible to combustible and grows sufficiently such that it spreads throughout a portion of the facility, or most of the facility in the case of the MDB-wide fire. Industrial fire data limited to comparable facilities were used to evaluate the propagation of fires. The consideration of building construction is addressed by limiting the data set to buildings of non-combustible construction. The most important aspect here is that the building itself does not contribute to the spread of a fire, and in fact, generally suffers very little actual structural damage. The spread of fires in such buildings is through the combustion of its contents. It was not possible to separate out the age of the facilities, but the limitation to non-combustible construction and only the most recent 10 years of fire data is thought to focus the data used on more modern facilities representative of the CDF. From these data it is possible to estimate the probability that a fire spreads based on the type of room and the fire suppression available. The possibility of propagation was considered for every fire zone and then three propagating fire scenarios were defined and included in accident sequences:

1) second-floor MDB fire, 2) first-floor MDB fire, and 3) MDB-wide fire. (In some of the documentation in this report, these are referred to as the upper level, lower level, and building-wide fires.)

Table 13-5 lists the fire initiator frequencies specifically examined in the APET. As described in appendix K2, other fire initiating event frequencies were developed, but a representative set of scenarios was selected to model the agent-related risk from fires. The room fire frequencies are for fires that are large enough to threaten agent sources in the room, but do not propagate. The floor and building fires account for initiation anywhere, with propagation to a large portion of the facility. It is assumed that fires will not be fought if they approach agent sources.

Table 13-5. Fire Initiating Event Mean Frequencies

Initiator	Mean Frequency[a] (per Year)
TOX	5.6×10^{-4}
UMC	5.8×10^{-4}
UPA	5.8×10^{-4}
MPB	3.3×10^{-3}
Room Fire (non-agent)	3.8×10^{-3}
First Floor	3.0×10^{-3}
Second Floor	3.7×10^{-3}
MDB-Wide	1.8×10^{-3}

Note:

[a] Frequencies are listed for the specific fires studied in the QRA model. These are not the frequencies of fire ignition. Rather, they include the probability that a fire threatens an agent source. In addition, the floor and facility fires include the probability of a fire starting and spreading to a large area.

Given a fire, there are two considerations for agent release: 1) release from agent-containing items in the MDB and 2) possible release of agent previously adsorbed on the HVAC carbon filters. Methods for estimating potential agent releases involve extensive modeling and calculations that are detailed in appendix K2 and only summarized here.

A fire may or may not involve agent sources depending on the type, location, and intensity of the fire and the specifics of the agent configuration nearby. To model these variations, a study was performed of the possible heatup and involvement of agent sources. Two failure mechanisms were examined: 1) hydraulic container failure due to expansion of the agent in a closed volume, and 2) the initiation of energetics due to heating. The effects of automatic fire suppression also were modeled. It is assumed that fires will not be fought manually if they approach agent sources. The controlling failure mechanism was determined for each agent source. For each munition, ton container, or tank in combination with the different agents, a calculation of heatup to the point of failure was performed with the time to failure being recorded. This was completed using a Monte Carlo uncertainty analysis to vary all the critical inputs, including the intensity of the fire and the uncertainty in the failure threshold. The result of these calculations was a probability distribution for failure as a function of the fire duration. Then these curves were convoluted (i.e., mathematically combined) with curves representing the probability distribution of the fire duration as a function of type of fire and the availability of automatic suppression. The result of these calculations is the probability that the agent sources in different locations will be involved in a fire that moves through the location. This was modeled for different disposal campaigns to capture all the specific aspects of the susceptibility of the items being processed to fire involvement. The mean values for agent involvement are provided in table 13-6. As illustrated in the table, the probabilities of failure and involvement in a fire are a function of the availability of fire suppression and the susceptibility of the munition to failure. For rockets and land mines, autoignition of the energetic components controls the failure probability. Hydraulic failure due to pressurization controls the probabilistic result for the other items.

Table 13-6. Mean Failure Probability for Agent-Containing Items Resulting from the Combination of a Probability Distribution of Time to Failure and the Probability Distribution of Fire Duration

	Mean Failure Probability	
Item	With Suppression	Without Suppression
M55 Rockets (GB and VX)	0.6	0.7
VX 8-inch Projectiles	0.02	0.4
GB 8-inch Projectiles	0.02	0.4
GB 155mm Projectiles	0.03	0.5
VX 155mm Projectiles	0.03	0.5
GB MC-1 Bomb	0.009	0.3
GB MK-94 Bomb	0.02	0.4
VX Land Mines	0.1	0.8
HD Ton Containers	0.0005	0.07
VX Spray Tank	0.005	0.3
TOX Tank (GB)	0.0005	–
TOX Tank (VX)	0.0005	–
TOX Tank (HD)	0.0005	–

Some risk-significant fire sequences involve the HVAC filters. The filters can be a major source of agent during the GB campaigns. The expected average agent inventories on the MDB HVAC filters during processing campaigns are summarized in table 13-7. Because of the importance of this potential source of agent, detailed models were developed for estimating these agent loads and are detailed in appendix M4.

Table 13-7. Average Agent Loading on HVAC Filters During All Campaigns and Changeovers

Campaign Number: Munition	Average Inventory on the MDB HVAC Filters Used in QRA Analysis[a]
1a: GB M55 Rockets	1,558 lbs. GB
1b: GB M55 Rockets and MC-1 750-lb Bombs	2,217 lbs. GB
1c: GB M55 Rockets and MK-94 500-lb Bombs	2,471 lbs. GB
1d: GB M55 Rockets	2,212 lbs. GB
Changeover[b]	918 lbs. GB
2a: VX M55 Rockets	3 lbs. VX
2b: VX M55 Rockets and Spray Tanks	7 lbs. VX
2c: VX M55 Rockets	11 lbs. VX
Changeover[b]	13 lbs. VX
3: VX 8-inch Projectiles	14 lbs. VX
Changeover[b]	15 lbs. VX
4: VX 155mm Projectiles	16 lbs. VX
Changeover[b]	18 lbs. VX
5: VX M23 Landmines	19 lbs. VX
Changeover[b]	21 lbs. VX
6: GB 155mm Projectiles	650 lbs. GB
Changeover[b]	900 lbs. GB
7: GB 8-inch Projectiles	987 lbs. GB
Changeover[b]	533 lbs. GB
8: HD Ton Containers	783 lbs. HD
Closure[b]	1,253 lbs. HD

[a] Substantially more agent is deposited on the filters, but the QRA models account for decomposition of the agent into less hazardous products.

[b] The filters are assumed to remain in place during most of the changeover period before eventual filter changeout at the end of the changeover.

First, data for agent going to the filters were collected. For GB, TOCDF data were gathered from 1 July to 31 December 2000. Agent readings in the exhaust flow taken approximately every 3 minutes over the 6-month period were analyzed to derive an agent loading profile for GB. Enough information was available to discern the variation in agent concentration with plant status: rocket processing, ton container and projectile processing, and no processing. Supplemental data for VX and HD processing also were obtained from more recent JACADS operations. The agent concentrations going to the filters therefore have been derived from actual operational data. It is recognized that some initiatives are under investigation to reduce agent loadings to the filters, especially for rocket processing. When specific information is available, those initiatives can be credited as appropriate in the QRA models.

There also is agent degradation within the carbon filter units. This is an important consideration for estimating the actual agent load on the filters. Tests of JACADS filter carbon in 1996 found there was essentially no GB left on the filters. Test data from the Edgewood Chemical Biological Center (ECBC) indicate that hydrolysis is taking place on the filters. Reaction rates and decomposition products have been reported for GB and HD. Tests also are planned for TOCDF spent carbon, but have not been completed yet. The QRA models account for the hydrolysis of agent on the filters. Based on the laboratory tests, an agent decay rate is known, although there is substantial uncertainty in the GB results depending on the amount of water in the air to the filters. The QRA models currently use a conservative reaction rate. The inclusion of agent decomposition is a major influence. The average agent inventories on the filters would be approximately a factor of 5 or greater if decomposition were not included. The details of the agent loading calculations are provided in appendix M4.

Large fires can create a substantial amount of heat (and hot gases) that may reach the HVAC filters and cause entrained agent to desorb or burn off. The amount of heat is dependent on the status of the HVAC exhaust fans as well as the dampers that may be used to isolate the fire. For room fires, the filter involvement is less likely because: 1) there is a greater chance the fire dampers or isolation dampers will be closed and 2) there is less heat from the room and more dilution flow from other areas of the facility than in larger fires. For the floor and MDB-wide fires, it is more difficult to isolate the fire. Even if dampers are closed, there are other flow paths and the possibility of leakage paths due to building damage caused by HVAC imbalances. Because a large fire could affect the power and control systems for HVAC, it is considered most likely that the exhaust fans will be off for large fires, but there remains a possibility that they will be on.

There are many possibilities for filter involvement considered in the accident progression analysis. If heat reaches the filters, there are a number of possibilities for agent release, or the event may be benign and there will be no agent release. Four types of release mechanisms were considered for the agent deposited on the HVAC filters during a fire.

Well-Ventilated Filter Fire. The filters catch fire due to heat carried over from the MDB and HVAC continues running. A probability of ignition has been developed based on the filter temperatures and the specific properties of the carbon. In this case, the HVAC airflow feeds the fire and the filters continue burning. This will result in most of the agent embedded in the filters being burned, although the possibility of some initial desorption was included.

Well-Ventilated Agent Desorption from the Filters. The filters do not catch fire and HVAC continues running. In this case, the HVAC airflow feeds hot air to the filters and the HVAC model considers both the heat input from a fire and the dilution flows from other areas. The temperature is high enough to cause the filters to desorb their agent load but is insufficient to break down or burn the agent. The response of the filters was evaluated based on ECBC models of filter desorption. Temperature-dependent RFs were applied. At lower temperatures such as 200°F, there is very little agent released, but at temperatures such as 500°F, a very large agent release would be expected.

Underventilated Filter Fire. The filters catch fire from the heat carried over but the HVAC is secured or fails to run. Loss of HVAC results in depriving the fire of oxygen. In this case, the fire continues at a moderate heat level (i.e., smolders), which results in sufficient heat to cause agent desorption but insufficient heat to burn or otherwise destroy the agent. The elevated temperatures could damage the filter housing and ductwork, leaving gaps through which agent could escape.

Underventilated Desorption. The filters do not catch fire and the HVAC is secured or fails to run. The temperature may increase, but there is very little flow, even considering natural circulation. Agent desorption may occur, but there is no driving force and the agent release from the filter bank is very small.

Using the results of these ventilation studies, the APET logic was developed to capture the status of the HVAC dampers and exhaust fans and to break out the possibilities of different temperature regimes in the exhaust flow. Thus, the potential for filter involvement was considered for every fire.

The risk-significant scenarios were summarized in figure 13-4. As shown in that figure, facility fires dominate disposal risk (87 percent). Figure 13-5 shows the initiating area contribution to total fire risk. As shown, the largest contributor to fire risk is from second-floor fires (58 percent). MDB-wide fires, though more catastrophic, contribute 37 percent to total fire risk. First floor fires contribute only 5 percent to total fire risk and single-room fires are negligible contributors to total fire risk. The second floor fires are most significant because these fires have a higher frequency than the first floor or MDB-wide fires and involve significant agent. The filters were a significant contribution to the fire in about 27 percent of the total fires.

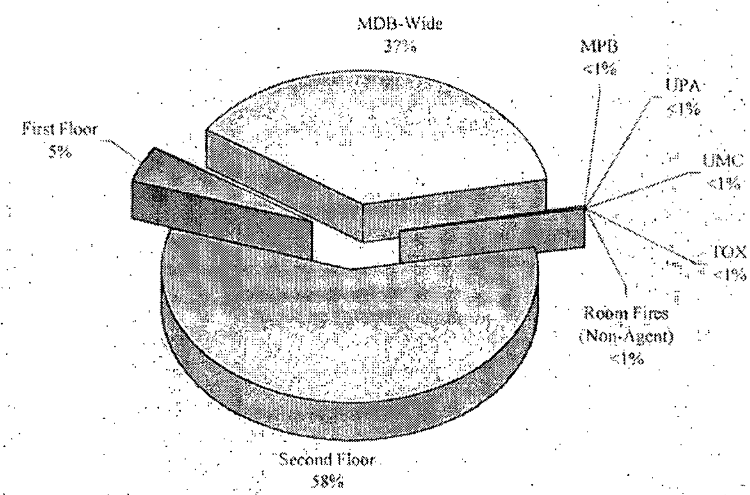


Figure 13-5. Fire Initiator Contribution to Total Fire Risk

Fires are clearly the dominant risk as evaluated in this QRA. The probabilistic evaluation of fires is a fairly involved process that is described in detail in appendix K2. Included in appendix K2 is a discussion of the application of the model and answers to questions that have frequently arisen during the review of this work.

Fires were not identified as being critical to risk in previous Phase 1 QRAs. Two things have changed in this QRA. First, the previous QRAs were based on observations of pre-operational facilities. Now that actual operations have been observed, more information is available on the transient combustible loading of trash, dunnage, and other processing by-products in several locations in the facility. Given that there is no UMCDF experience, it is necessary to assume for the time being that UMCDF will have a combustible distribution similar to TOCDF. The second change is in methodology. The fire methodology was re-examined in light of previous TOCDF QRA Expert Panel discussions that the overall results were not reflective of the fact that industrial facilities burn down despite fire-resistive construction. The previous nuclear facility-based fire analysis methodology used for TOCDF and the Phase 1 QRAs was supplemented here with industrial data. The ANCDF/UMCDF Expert Panel has reviewed the specifics of the analysis and has endorsed the methods now used for fire analysis.

13.2.2 Seismic Event. Seismic-induced fires contribute about 6 percent of the public risk. This accident sequence is referred to in QRA nomenclature as the seismic surrogate sequence and reflects very improbable but very damaging earthquakes. It is called the surrogate because it is defined to capture all the earthquake risk not specifically analyzed in other sequences. In this study, the key components and structures were studied to determine the potential for failures in earthquakes. Due to the resources required for detailed seismic analysis, not every system and component could be studied, and in some cases, the analysis just identified that a component was capable of withstanding earthquakes up to a certain ground motion, with motions greater than that not being analyzed in detail. To account for the fact that risk could be associated with these large earthquakes from items not specifically modeled, the surrogate sequence is defined, which assumed failure of all structures and components not known to withstand above a 1 g ground motion. The accident is examined with and without a post-earthquake fire, with fires being the most important outcome. The resultant model is likely conservative (overstating the risk) but the analysis can be presented as being complete.

The seismic collapse of the CHB/UPA was individually evaluated and found to contribute about 2 percent of the public risk. In the Phase 1 UMCDF QRA, earthquakes were found to be very important to disposal risk. Earthquake-initiated collapse of the CHB/UPA was identified as the dominant sequence in the TOCDF Phase 2 QRA (SAIC, 1996b) because the CHB/UPA was one of the weaker portions of the facility and had one of the largest agent inventories. This was a major finding and subsequent facilities were constructed with an improved design to reduce the seismic vulnerability of this component and thereby reduce the facility risk. A seismic evaluation of the UMCDF CHB/UPA showed that the capacity of this room had increased by a factor of 2 over the TOCDF design. With the improvement in design, collapse of the CHB/UPA now contributes much less to the overall risk than reported in the Phase 1 UMCDF QRA. (This much lower contribution to total risk, however, is due in part to a much higher overall contribution from facility fires, which were not dominant in the previous assessments.) Other rooms of the MDB have seismic capacities that are much higher and were not vulnerable to most earthquakes.

13.2.3 Handling Accidents. Handling accidents modeled in the QRA involve munition handling by forklift, truck, crane, conveyor, elevator, and hand. Handling accidents are modeled during removal from storage, CHB movements, and UPA handling. Each movement during the process has been analyzed for potential initiating events.

The dominant handling accidents are those that involve M55 rockets at the igloo storage area, which contribute 5 percent to the total mean disposal risk. Although the rockets are in the storage area, this is a processing risk because the rockets are being moved at the initiation of the disposal process. The fractional contribution to mean acute fatality risk of an accident involving an entire rocket igloo is approximately 1.2 percent for VX rocket igloos and 1.0 percent for GB rocket igloos.

During removal of rocket pallets from their storage igloos, it is postulated that a forklift-related accident may occur that would cause either a rocket burster to explode or rocket propellant to ignite. Either event may propagate to other rockets in the igloo, ultimately involving the entire igloo inventory of rockets. In such instances, a substantial fraction of the agent would be consumed in the resulting fire, but because the available quantity is large, the amount of agent that could potentially be released is still significant. The probability of impact or drop per rocket pallet movement is approximately 1×10^{-5}. This probability is substantially lower than industrial forklift load-drop probabilities and is consistent with chemical weapons handling experience to date. Forklift drops of rocket pallets may occur from different heights, up to 10 feet for pallets on the top of stacks. The mean probability of ignition or explosion of a rocket in a pallet given a drop from 10 feet has been estimated to be approximately 5.5×10^{-3}. Pallets falling from lower distances have lower probabilities of failure. For example, a 3-foot fall has only a 1.3×10^{-3} likelihood of ignition.

Forklift impacts or punctures of rockets also are possible, but the rockets are protected to some degree with wooden 2x4-inch boards along their sides. Rockets are not completely protected from forklift punctures, and energy calculations have been performed to estimate the likelihood that a puncture will lead to a leak or ignition. Calculations indicate that the forklift would have to be traveling approximately 2 mph or more when impacting the rocket pallet to have a significant chance of puncturing a rocket. This is greater than the normal speed when approaching a pallet stack, but it cannot be ruled out. Thus, the potential puncture or impact is a low frequency scenario that has a high source term and resulting consequence. The mean probability of ignition or explosion of a rocket is 2.2×10^{-3} for forklift impact in the igloos.

There are a number of factors applied in the derivation of these probabilities, including a geometry factor for the forklift impacting the rocket instead of the pallet or space between rockets. The possibility of a falling pallet hitting edges or corners of objects in the igloo (other pallets or the forklift itself) is considered also. The model includes an evaluation of uncertainty in the initiation of explosive and propellant given impact.

The final factor in this scenario is a 50 percent probability that the first exploding rocket propagates to the other rockets and involves the entire igloo. This fraction is based on several tests performed in the late 1960s with rockets at the Black Hills Army Depot. Storage yard M55 rocket handling accidents that occur outside of the igloo have a much smaller chance of involving the entire rocket igloo.

VX rocket igloo fires have a larger contribution to overall risk than GB rocket igloo fires because the fire RFs are different for the two chemical agents and VX has a greater toxicity. For VX igloo fires, nearly 12 percent of the agent is released (i.e., 88 percent is consumed in the fire). GB igloo fires, on the other hand, release only 7 percent of the agent (i.e., 93 percent is consumed in the fire). An 80-foot VX rocket igloo fire is estimated to result in 1.9 fatalities, while an 80-foot GB rocket igloo fire is estimated to have a consequence of 0.24 fatalities.

Because igloo-handling activities can only occur during the daylight hours, only daytime weather was sampled in the consequence analysis.

Igloo fires that can occur at any time (day or night) result in far greater consequences because nighttime releases would more likely occur in conjunction with stable weather. This allows the agent plume to travel farther and remain concentrated for a longer period of time. The differences in VX and GB fire RFs are very pronounced in storage yard accidents that lead to igloo fires.

Other handling accidents that can occur during UMCDF munition processing take place within the UPA. Handling accidents that occur in the UPA contribute much less than 1 percent to total risk. Handling accidents in the UPA are less important than those in the storage area for two reasons. First, fewer munitions are involved, usually no more than a few pallets. Second, agent releases are minimized by the operation of the HVAC and carbon filtration system.

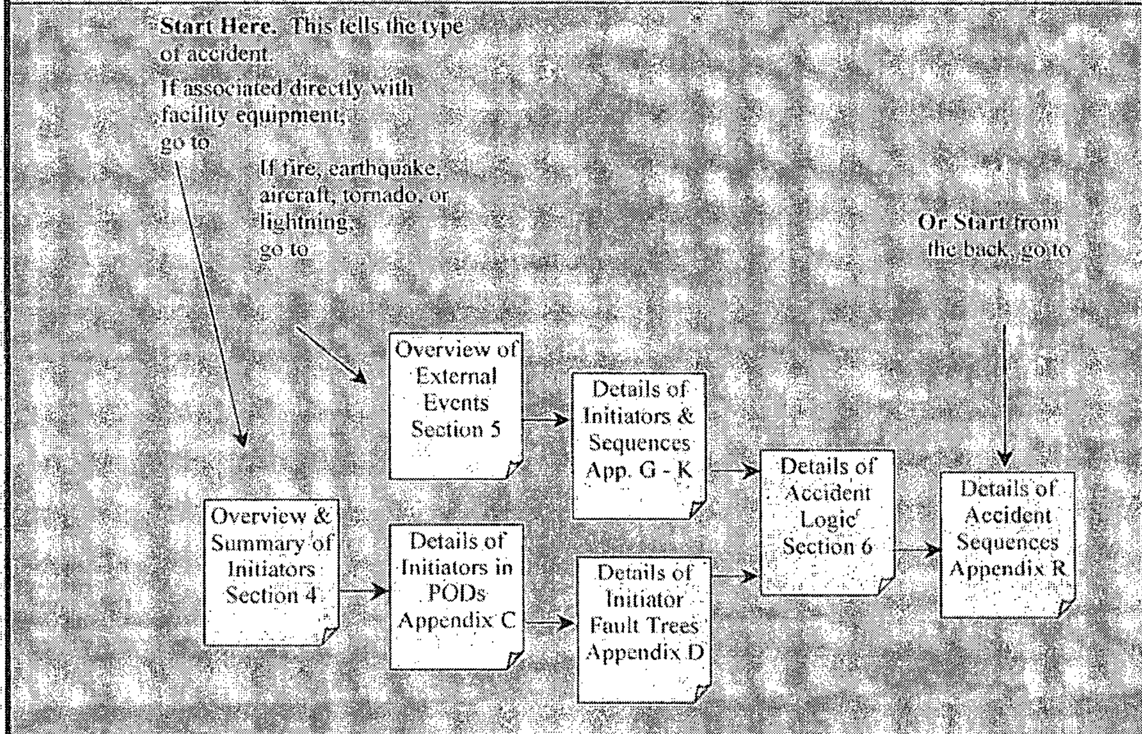
13.2.4 Other Accidents. Many other accident sequences are considered, but are not detailed here because they do not contribute significantly to public risk. Additional accident sequences also are described for the campaign-by-campaign risk presentations in subsequent sections. These scenarios can be investigated using the Quantus Risk Management Workstation and supplemental spreadsheets. The detailed accident sequences also are provided in appendix R. Box 13-7 describes how the information in this report can be used to investigate the details of accident sequences.

13.3 Public Acute Fatality Risk by Campaign

The results discussed in section 13.1 provide an overall perspective on the public acute fatality risk from disposal operations at UMCDF. Risk contribution by campaign is summarized in figures 13-6 (as a pie chart) and 13-7 (as a bar graph). As shown in these figures, campaign 1b, which coprocesses GB M55 rockets with MC-1 bombs is the largest single contributor to disposal risk (36 percent). The second largest contributor to disposal risk is campaign 2b which processes VX M55 rockets and spray tanks (30 percent). The third largest contributor to disposal risk is campaign 1d, which processes GB M55 rockets (11 percent). All remaining campaigns each contribute 5 percent or less; these are: GB 155mm projectiles (5 percent), GB 8-inch projectiles (5 percent), the first GB M55 rockets campaign (4 percent), VX 155mm projectiles (3 percent), VX 8-inch projectiles (3 percent), the first VX M55 rockets campaign (2 percent), and the second VX M55 rockets campaign (1 percent). The VX land mines, HD ton containers, and the campaign that coprocesses GB M55 rockets with MK-94 bombs each contribute less than 1 percent of the total disposal risk. Changeover periods contribute negligible risk.

Box 13-7. How to Learn More About Accident Sequences

Campaign #: Munition	Accident Sequence Category	Recurrence Interval	Mean Consequence (Fatalities)	Mean Fatality Risk	Contribution to Mean Risk



The accident sequence results are the assembly of all the models described in the report using the Quantus Risk Management Workstation. All the models are provided in this report, but a computer is required to assemble the results, so it is not realistically possible to recreate every sequence just on paper.

- An overview of the risk assembly process is provided in **section 2**.
- A more detailed risk assembly discussion is provided in **section 12**.
- **Appendix R** contains a guide to understanding the computer output used to generate the result tables and includes a discussion of the detailed anatomy of an accident sequence.

Figure 13-8 provides a slightly different perspective of the UMCDF risk. This figure presents the rate of risk during each campaign in units of fatalities per year of operation. Thus, while each campaign occurs, it has a "risk rate," which is shown in figure 13-8. The relative risks among the campaigns are somewhat different when considered with this measure. As seen in figure 13-8, the risk rate is highest for the campaign that coprocesses VX M55 rockets and spray tanks. The risk rate also is shown using a logarithmic scale (figure 13-9). From this figure it is easier to see the contributions of the low risk campaigns and the filters during changeover following initial GB campaigns. Note that the risk during closure has not been fully quantified at this time because disposal of the HVAC carbon filters has not been modeled.

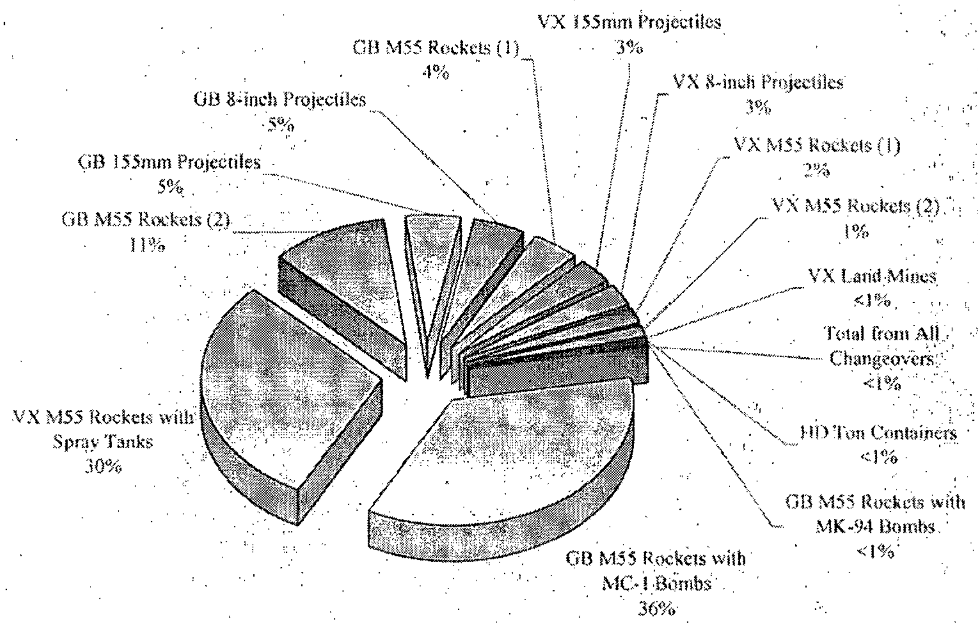


Figure 13-6. Mean Public Societal Acute Fatality Risk by Campaign for UMCDF Disposal Processing (Pie Chart)

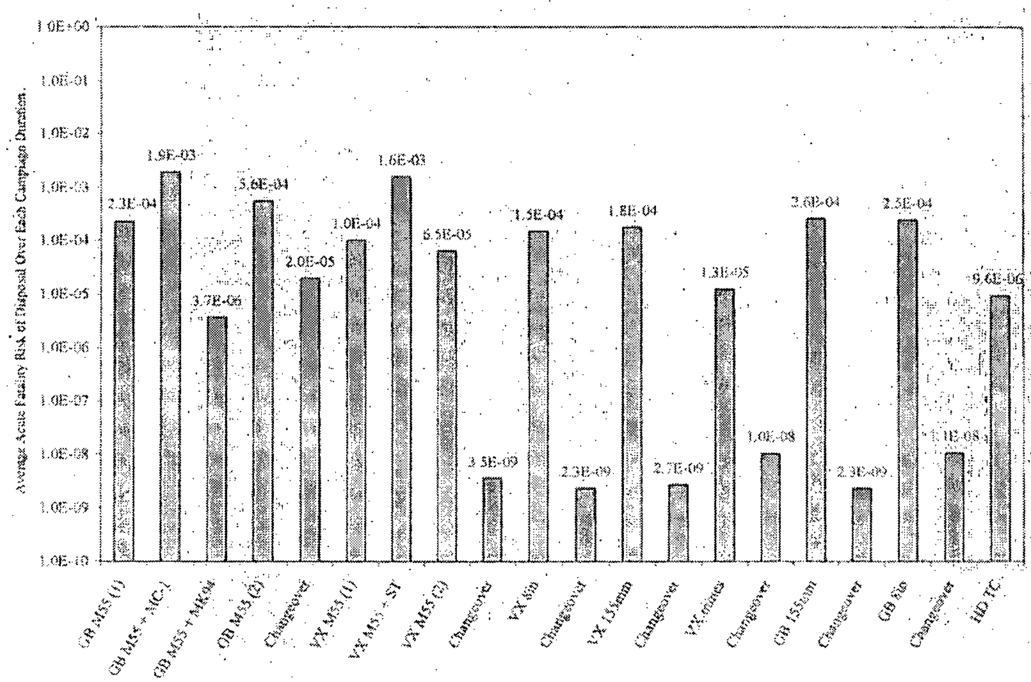


Figure 13-7. Mean Public Societal Acute Fatality Risk by Campaign for UMCDF Disposal Processing (Bar Graph)

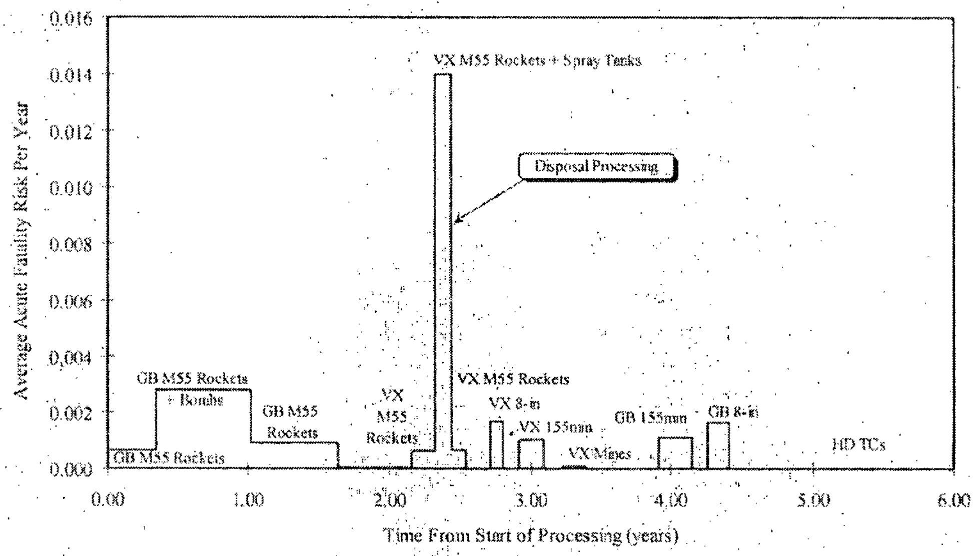


Figure 13-8. Mean Public Societal Acute Fatality Risk per Year by Campaign for UMCDF Disposal Processing (Linear Scale)

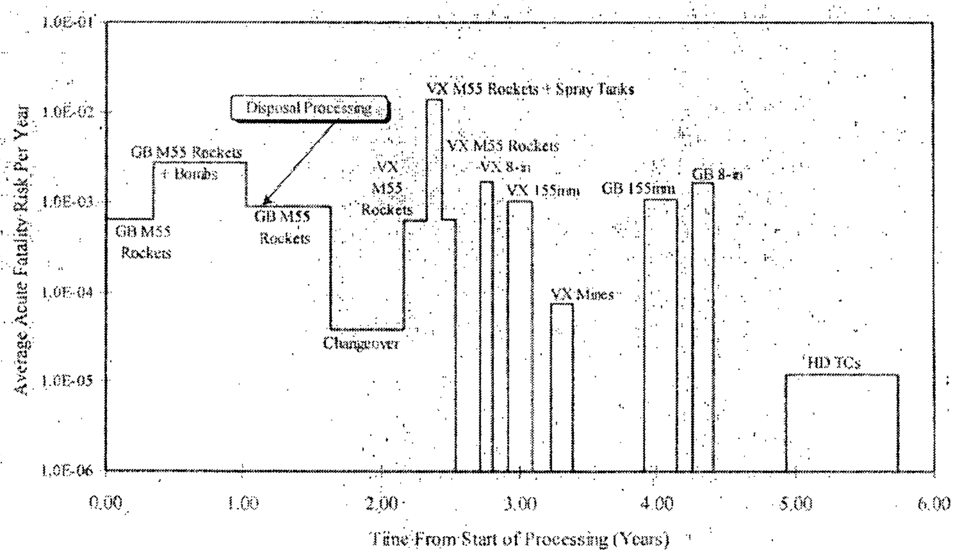


Figure 13-9. Mean Public Societal Acute Fatality Risk per Year by Campaign for UMCDF Disposal Processing (Logarithmic Scale)

Figure 13-10 shows the uncertainty in mean risk for each campaign. The upper and lower percentiles, median, and mean are shown for each campaign and compared to the total public risk. There is about a factor of 100 between the 5th and 95th percentiles of most campaigns. Also, there is very little uncertainty associated with changeovers following VX and HD campaigns. This is because the risk is negligible due to the limited availability of agent on the filters.

In the following sections, discussion is provided on the dominant contributors from each campaign, notwithstanding the campaign's overall contribution to the risk profile. This allows a more in-depth look at the activities that contribute to risk at each point in time during UMCDF operation.

13.3.1 GB M55 Rockets (1). Campaign 1a involves the processing of 19,299 GB M55 rockets (approximately 206,499 pounds of GB) and is scheduled to last 18 weeks. Contributions to campaign 1a risk are shown in figure 13-11 with the dominant scenarios summarized in table 13-8.

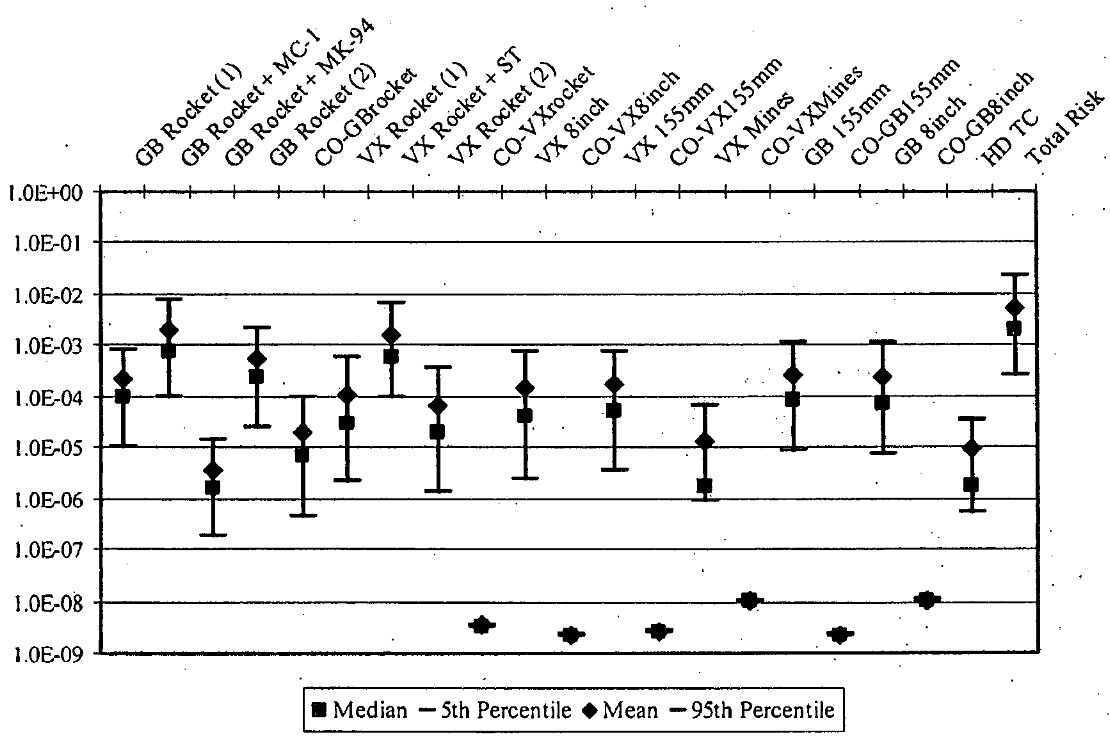


Figure 13-10. Uncertainty in Public Societal Acute Fatality Risk by Campaign for UMCDF Disposal Processing

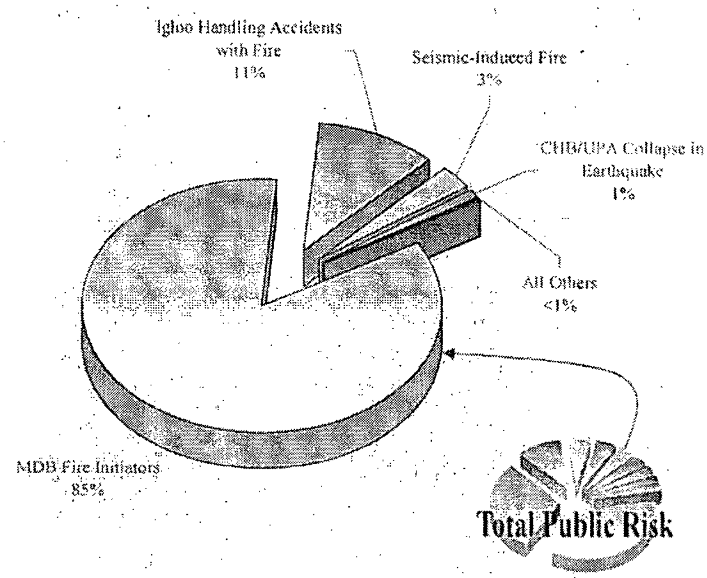


Figure 13-11. Contributors to Mean Public Societal Acute Fatality Risk for Campaign 1a [GB M55 Rockets (1)]

Table 13-8. Public Societal Acute Fatality Risk Scenarios for Campaign 1a [GB M55 Rockets (1)] for UMCDF Disposal Processing

Accident Sequence Category	Mean Recurrence Interval	Mean Consequence (Fatalities)	Mean Acute Fatality Risk Over Entire Campaign	Contribution to Campaign 1a Mean Risk
Second Floor Fire with Filter Desorption	12,000	0.7	6.0×10^{-5}	27%
Second Floor Fire with No Filter Involvement	1,600	0.1	5.2×10^{-5}	23%
MDB-Wide Fire with Filter Desorption	23,000	0.8	3.4×10^{-5}	15%
MDB-Wide Fire with No Filter Involvement	3,200	0.1	2.6×10^{-5}	12%
Igloo Handling Accident with Resultant Igloo Fire	9,700	0.2	2.4×10^{-5}	11%
First Floor Fire with Filter Desorption[a]	23,000	0.4	1.7×10^{-5}	8%
Seismic-Induced Fire	130,000	0.9	6.8×10^{-6}	3%
CHB/UPA Collapse in an Earthquake	45,000	0.1	2.6×10^{-6}	1%
All Other Scenarios			2.7×10^{-6}	<1%
Total Mean Public Societal Acute Fatality Risk	—	—	2.3×10^{-4}	100%

Note:

[a] This sequence includes mostly the filters, without the building inventory and TOX.

Building fire initiators dominate the public disposal risk during campaign 1a, contributing roughly 85 percent to the risk of this campaign. Fires that result in agent desorption from the MDB filters are the most important and contribute roughly 59 percent to fire risk during this campaign. About 41 percent of the fire sequences do not involve the filters. Igloo handling accidents are the next largest contributor and account for about 11 percent of the risk of this campaign. Seismic-induced fires contribute 3 percent and involve large seismic events that cause both small and large fires to occur within the facility. Seismic collapse of the CHB/UPA contributes 1 percent of the risk of this campaign. All other sequences combined account for less than 1 percent of the total campaign risk.

13.3.2 GB M55 Rockets with GB MC-1 Bombs. Campaign 1b involves the processing of 37,680 GB M55 rockets (approximately 403,176 pounds of GB) and 2,418 GB MC-1 bombs (approximately 531,960 pounds of GB) and is scheduled to last approximately 35 weeks. Contributions to campaign 1b risk are shown in figure 13-12 with the dominant scenarios summarized in table 13-9.

Building fire initiators dominate the public disposal risk during campaign 1b, contributing roughly 92 percent of the risk of this campaign. Fires that do not involve the filters are the most important and contribute roughly 62 percent to fire risk during this campaign. Fires that result in agent desorption from the MDB filters contribute roughly 38 percent of the fire risk during this campaign. Seismic-induced fires are the next largest contributor and account for about 3 percent of the risk of this campaign and involve large seismic events that cause both small and large fires to occur within the facility. Igloo handling accidents also contribute about 3 percent of the risk of this campaign. Seismic collapse of the CHB/UPA contributes 1 percent of the risk of this campaign. All other sequences combined account for about 1 percent of the total campaign risk.

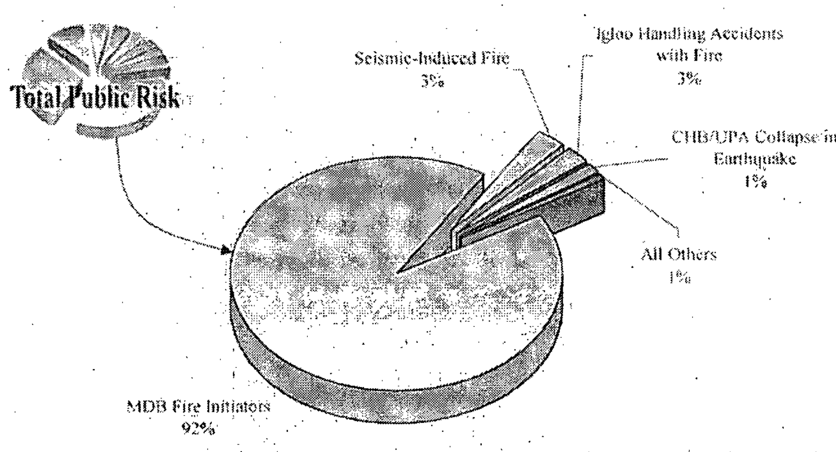


Figure 13-12. Contributors to Mean Public Societal Acute Fatality Risk for Campaign 1b (GB M55 Rockets with GB MC-1 Bombs)

Table 13-9. Public Societal Acute Fatality Risk Scenarios for Campaign 1b (GB M55 Rockets with GB MC-1 Bombs) for UMCDF Disposal Processing

Accident Sequence Category	Mean Recurrence Interval	Mean Consequence (Fatalities)	Mean Acute Fatality Risk Over Entire Campaign	Contribution to Campaign 1b Mean Risk
Second Floor Fire with No Filter Involvement	770	0.5	6.8×10^{-4}	36%
MDB-Wide Fire with No Filter Involvement	680	0.3	3.9×10^{-4}	21%
Second Floor Fire with Filter Desorption	4,500	1.6	3.6×10^{-4}	19%
MDB-Wide Fire with Filter Desorption	8,800	1.7	1.9×10^{-4}	10%
First Floor Fire with Filter Desorption[a]	7,800	0.9	1.1×10^{-4}	6%
Seismic-Induced Fire	46,000	2.6	5.7×10^{-5}	3%
Igloo Handling Accident with Resultant Igloo Fire	5,000	0.2	4.8×10^{-5}	3%
CHB/UPA Collapse in an Earthquake	23,000	0.6	2.6×10^{-5}	1%
All Other Scenarios			2.2×10^{-5}	1%
Total Mean Public Societal Acute Fatality Risk	–	–	1.9×10^{-3}	100%

Note:

[a] This sequence includes mostly the filters, without the building inventory and TOX.

13.3.3 GB M55 Rockets with GB MK-94 Bombs. Campaign 1c involves the processing of 153 GB M55 rockets (approximately 1,637 pounds of GB) and 27 GB MK-94 bombs (approximately 2,916 pounds of GB) and is scheduled to last less than 1 week. Contributions to campaign 1c risk are shown in figure 13-13 with the dominant scenarios summarized in table 13-10.

Building fire initiators dominate the public disposal risk during campaign 1c, contributing roughly 90 percent of the risk of this campaign. Fires that result in agent desorption from the MDB filters are the most important and contribute roughly 77 percent to fire risk during this campaign. About 23 percent of the fire sequences do not involve the filters. Igloo handling accidents are the next largest contributor and account for about 5 percent of the risk of this campaign. Seismic-induced fires contribute 3 percent and involve large seismic events that cause both small and large fires to occur within the facility. All other sequences combined account for about two percent of the total campaign risk.

13.3.4 GB M55 Rockets (2). Campaign 1d involves the processing of 34,310 GB M55 rockets (approximately 367,117 pounds of GB) and is scheduled to last 32 weeks. Contributions to campaign 1d risk are shown in figure 13-14 with the dominant scenarios summarized in table 13-11.

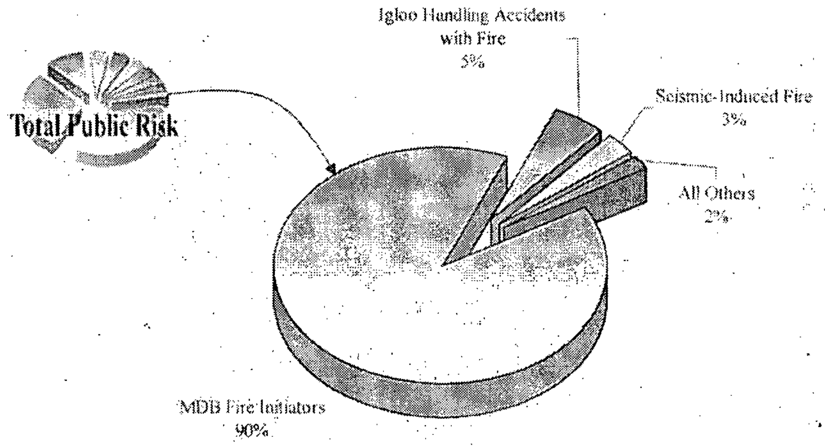


Figure 13-13. Contributors to Mean Public Societal Acute Fatality Risk for Campaign 1c (GB M55 Rockets with GB MK-94 Bombs)

Table 13-10. Public Societal Acute Fatality Risk Scenarios for Campaign 1c (GB M55 Rockets with GB MK-94 Bombs) for UMCDF Disposal Processing

Accident Sequence Category	Mean Recurrence Interval	Mean Consequence (Fatalities)	Mean Acute Fatality Risk Over Entire Campaign	Contribution to Campaign 1c Mean Risk
Second Floor Fire with Filter Desorption	1 million	1.4	1.3×10^{-6}	36%
MDB-Wide Fire with Filter Desorption	2 million	1.4	6.7×10^{-7}	18%
First Floor Fire with Filter Desorption[a]	2 million	1.0	5.5×10^{-7}	15%
Second Floor Fire with No Filter Involvement	170,000	0.1	5.2×10^{-7}	14%
MDB-Wide Fire with No Filter Involvement	340,000	0.1	2.6×10^{-7}	7%
Igloo Handling Accident with Resultant Igloo Fire	1 million	0.2	1.9×10^{-7}	5%
Seismic-Induced Fire	11 million	1.3	1.1×10^{-7}	3%
All Other Scenarios			5.2×10^{-8}	2%
Total Mean Public Societal Acute Fatality Risk	–	–	3.7×10^{-6}	100%

Note:

[a] This sequence includes mostly the filters, without the building inventory and TOX.

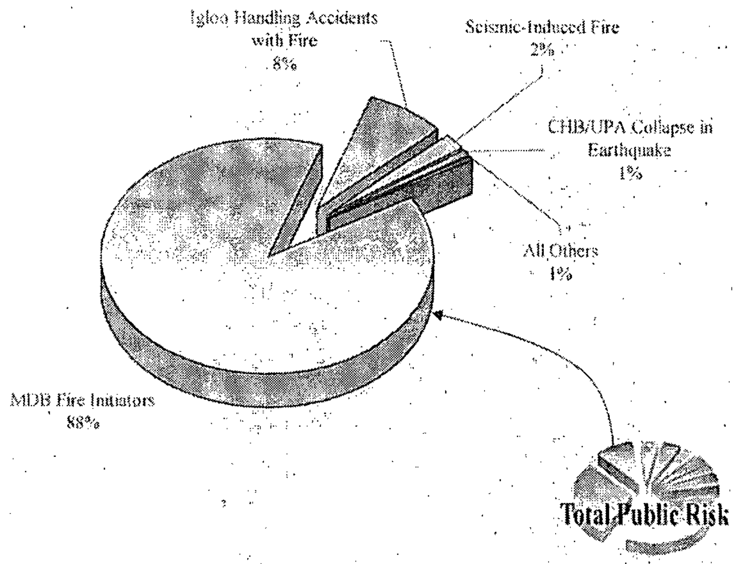


Figure 13-14. Contributors to Mean Public Societal Acute Fatality Risk for Campaign 1d [GB M55 Rockets (2)]

Table 13-11. Public Societal Acute Fatality Risk Scenarios for Campaign 1d [GB M55 Rockets (2)] for UMCDF Disposal Processing

Accident Sequence Category	Mean Recurrence Interval	Mean Consequence (Fatalities)	Mean Acute Fatality Risk Over Entire Campaign	Contribution to Campaign 1d Mean Risk
Second Floor Fire with Filter Desorption	6,500	1.2	1.9×10^{-4}	33%
MDB-Wide Fire with Filter Desorption	13,000	1.3	1.0×10^{-4}	18%
Second Floor Fire with No Filter Involvement	890	0.1	7.3×10^{-5}	13%
MDB-Wide Fire with No Filter Involvement	1,800	0.1	6.6×10^{-5}	12%
First Floor Fire with Filter Desorption[a]	13,000	0.8	6.5×10^{-5}	12%
Igloo Handling Accident with Resultant Igloo Fire	5,400	0.2	4.3×10^{-5}	8%
Seismic-Induced Fire	73,000	0.9	1.2×10^{-5}	2%
CHB/UPA Collapse in an Earthquake	26,000	0.1	4.7×10^{-6}	1%
All Other Scenarios			6.7×10^{-6}	1%
Total Mean Public Societal Acute Fatality Risk	—	—	5.6×10^{-4}	100%

Note:

[a] This sequence includes mostly the filters, without the building inventory and TOX.

Building fire initiators dominate the public disposal risk during campaign 1d, contributing roughly 88 percent of the risk of this campaign. Fires that result in agent desorption from the MDB filters are the most important and contribute roughly 72 percent to fire risk during this campaign. About 28 percent of the fire sequences do not involve the filters. Igloo handling accidents are the next largest contributor and account for about 8 percent of the risk of this campaign. Seismic-induced fires contribute 2 percent and involve large seismic events that cause both small and large fires to occur within the facility. Seismic collapse of the CHB/UPA contributes 1 percent of the risk of this campaign. All other sequences combined account for about 1 percent of the total campaign risk.

13.3.5 VX M55 Rockets (1). Campaign 2a involves the processing of 6,253 VX M55 rockets (approximately 62,530 pounds of VX) and is scheduled to take about 8 weeks. Contributions to campaign 2a mean risk are shown in figure 13-15 with the dominant scenarios summarized in table 13-12. As shown in figure 13-15, this campaign is dominated (61 percent) by handling accidents in the storage yard. Building fire initiators are also important; however, they are only approximately 35 percent of the total campaign risk. This is primarily due to the fact that only agent within the facility is contributing to the release because there is only a small amount of agent available on the filters (due to the low volatility of VX). As a result, nearly 91 percent of the fire risk does not involve the filters at all. Seismic-induced fires are a small portion of the overall risk (approximately 3 percent). All other sequences combined account for about 1 percent of the total campaign risk.

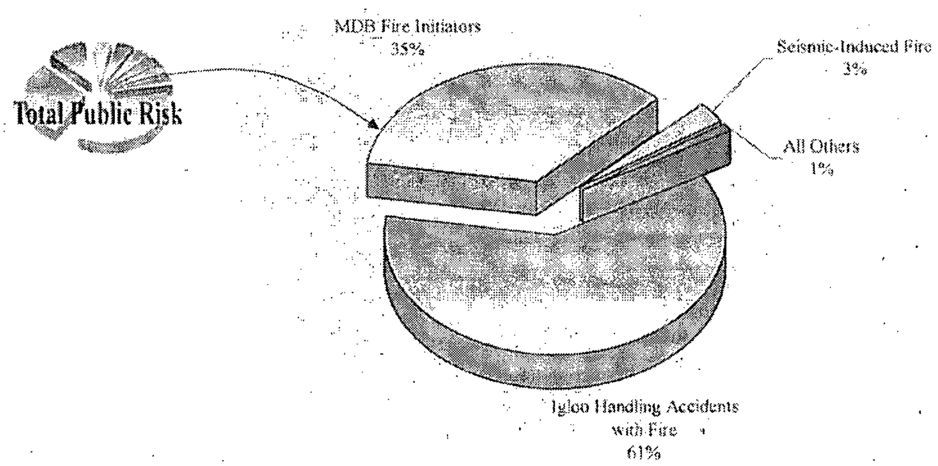


Figure 13-15. Contributors to Mean Public Societal Acute Fatality Risk for Campaign 2a [VX M55 Rockets (1)]

Table 13-12. Public Societal Acute Fatality Risk Scenarios for Campaign 2a [VX M55 Rockets (1)] for UMCDF Disposal Processing

Accident Sequence Category	Mean Recurrence Interval	Mean Consequence (Fatalities)	Mean Acute Fatality Risk Over Entire Campaign	Contribution to Campaign 2a Mean Risk
Igloo Handling Accident with Resultant Igloo Fire	31,000	1.9	6.3×10^{-5}	61%
Second Floor Fire with No Filter Involvement	3,400	0.1	1.7×10^{-5}	17%
MDB-Wide Fire with No Filter Involvement	6,800	0.1	1.6×10^{-5}	15%
Seismic-Induced Fire	280,000	0.8	2.9×10^{-6}	3%
Second Floor Fire with Filter Desorption	35,000	0.1	2.0×10^{-6}	2%
MDB-Wide Fire with Filter Desorption	70,000	0.1	1.5×10^{-6}	1%
All Other Scenarios			6.9×10^{-7}	1%
Total Mean Public Societal Acute Fatality Risk	–	–	1.0×10^{-4}	100%

13.3.6 VX M55 Rockets with VX Spray Tanks. Campaign 2b involves the processing of 4,345 VX M55 rockets (approximately 43,450 pounds of VX) and 156 VX spray tanks (approximately 211,536 pounds of VX) and is scheduled to take about 6 weeks. Contributions to campaign 2b mean risk are shown in figure 13-16 with the dominant scenarios summarized in table 13-13. As shown in figure 13-16, this campaign is dominated by building fire initiators,

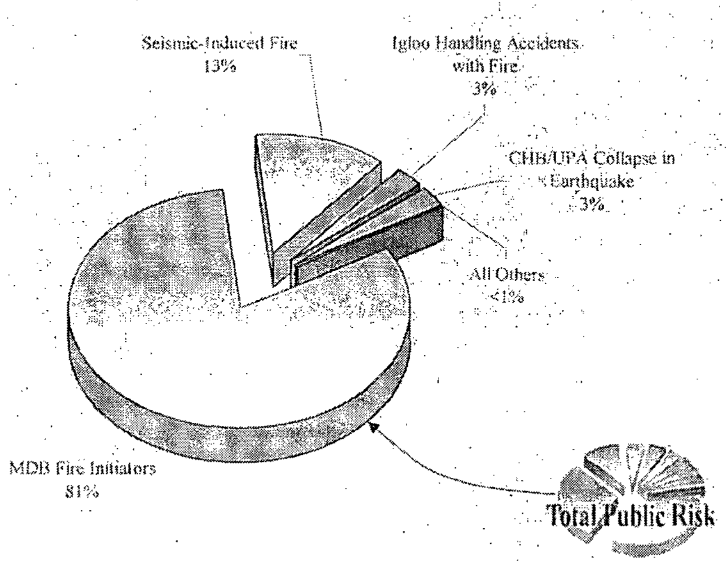


Figure 13-16. Contributors to Mean Public Societal Acute Fatality Risk for Campaign 2b (VX M55 Rockets with VX Spray Tanks)

Table 13-13. Public Societal Acute Fatality Risk Scenarios for Campaign 2b (VX M55 Rockets with VX Spray Tanks) for UMCDF Disposal Processing

Accident Sequence Category	Mean Recurrence Interval	Mean Consequence (Fatalities)	Mean Acute Fatality Risk Over Entire Campaign	Contribution to Campaign 2b Mean Risk
Second Floor Fire with No Filter Involvement	2,000	1.4	7.0×10^{-4}	45%
MDB-Wide Fire with No Filter Involvement	4,100	1.8	4.5×10^{-4}	29%
Seismic-Induced Fire	230,000	47	2.0×10^{-4}	13%
Second Floor Fire with Filter Desorption	31,000	2.1	6.9×10^{-5}	4%
MDB-Wide Fire with Filter Desorption	61,000	2.7	4.4×10^{-5}	3%
Igloo Handling Accident with Resultant Igloo Fire	44,000	1.9	4.4×10^{-5}	3%
CHB/UPA Collapse in an Earthquake	51,000	2.2	4.2×10^{-5}	3%
All Other Scenarios			1.7×10^{-5}	<1%
Total Mean Public Societal Acute Fatality Risk	–	–	1.6×10^{-3}	100%

which account for 81 percent of the campaign risk. Only agent within the facility is contributing to the release because there is only a small amount of agent available on the filters (due to the low volatility of VX). As a result, nearly 91 percent of the fire risk does not involve the filters.

Seismic-induced fires contribute 13 percent and involve large seismic events that cause both small and large fires to occur within the facility. Igloo handling accidents account for about 3 percent of the risk of this campaign. Seismic collapse of the CHB/UPA contributes 3 percent of the risk of this campaign. All other sequences combined account for less than 1 percent of the total campaign risk.

13.3.7 VX M55 Rockets (2). Campaign 2c involves the processing of 3,921 VX M55 rockets (approximately 39,210 pounds of VX) and is scheduled to take about 5 weeks. Contributions to campaign 2c mean risk are shown in figure 13-17 with the dominant scenarios summarized in table 13-14. As shown in figure 13-17, this campaign is dominated (61 percent) by handling accidents in the storage yard. Building fire initiators are also important; however, they are only approximately 36 percent of the total campaign risk. This is primarily due to the fact that only agent within the facility is contributing to the release because there is only a small amount of agent available on the filters (due to the low volatility of VX). As a result, nearly 92 percent of the fire risk does not involve the filters at all. Seismic-induced fires are a small portion of the overall risk (approximately 3 percent). All other sequences combined account for less than 1 percent of the total campaign risk.

13.3.8 VX 8-inch Projectiles. Campaign 3 involves the processing of 3,752 VX 8-inch projectiles (approximately 54,404 pounds of VX). This is scheduled to take approximately

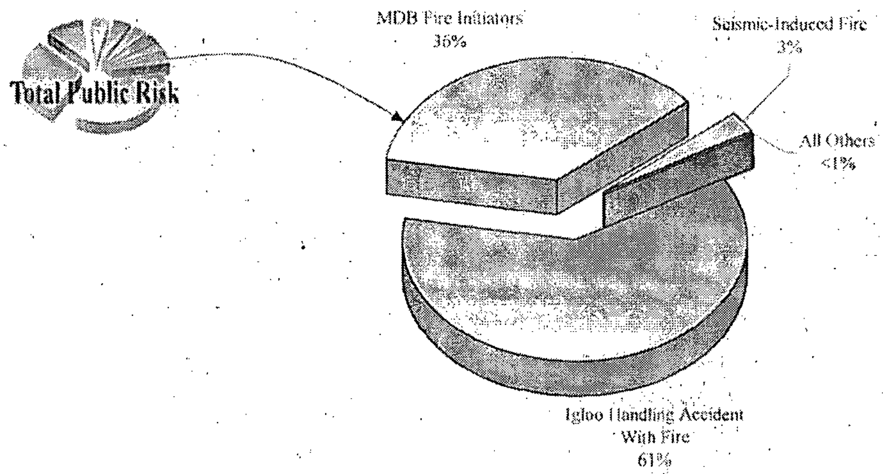


Figure 13-17. Contributors to Mean Public Societal Acute Fatality Risk for Campaign 2c [VX M55 Rockets (2)]

Table 13-14. Public Societal Acute Fatality Risk Scenarios for Campaign 2c [VX M55 Rockets (2)] for UMCDF Disposal Processing

Accident Sequence Category	Mean Recurrence Interval	Mean Consequence (Fatalities)	Mean Acute Fatality Risk Over Entire Campaign	Contribution to Campaign 2c Mean Risk
Igloo Handling Accident with Resultant Igloo Fire	49,000	1.9	3.9×10^{-5}	61%
Second Floor Fire with No Filter Involvement	5,400	0.1	1.1×10^{-5}	17%
MDB-Wide Fire with No Filter Involvement	11,000	0.1	1.0×10^{-5}	16%
Seismic-Induced Fire	440,000	0.8	1.8×10^{-6}	3%
Second Floor Fire with Filter Desorption	52,000	0.1	1.1×10^{-6}	2%
MDB-Wide Fire with Filter Desorption	100,000	0.1	9.6×10^{-7}	1%
All Other Scenarios			4.3×10^{-7}	<1%
Total Mean Public Societal Acute Fatality Risk	—	—	6.5×10^{-5}	100%

5 weeks. Contributions to campaign 3 risk are shown in figure 13-18 with the dominant scenarios summarized in table 13-15. Facility fires dominate risk during this campaign, accounting for 96 percent of the campaign risk. Only agent within the facility is contributing to the release because there is only a small amount of agent available on the filters (due to the low volatility of VX). As a result, nearly 91 percent of the fire risk does not involve the filters. Seismic-induced fires contribute 4 percent and involve large seismic events that cause both small

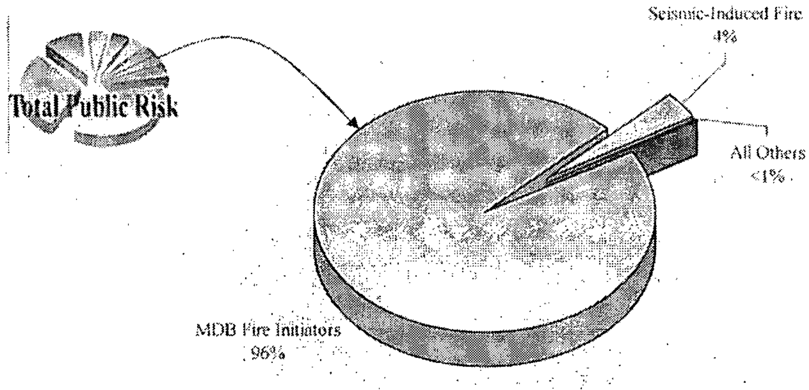


Figure 13-18. Contributors to Mean Public Societal Acute Fatality Risk for Campaign 3 (VX 8-inch Projectiles)

Table 13-15. Public Societal Acute Fatality Risk Scenarios for Campaign 3 (VX 8-inch Projectiles) for UMCDF Disposal Processing

Accident Sequence Category	Mean Recurrence Interval	Mean Consequence (Fatalities)	Mean Acute Fatality Risk Over Entire Campaign	Contribution to Campaign 3 Mean Risk
Second Floor Fire with No Filter Involvement	8,300	0.6	7.1×10^{-5}	47%
MDB-Wide Fire with No Filter Involvement	6,400	0.4	6.0×10^{-5}	40%
Second Floor Fire with Filter Desorption	66,000	0.5	7.2×10^{-6}	5%
MDB-Wide Fire with Filter Desorption	97,000	0.6	6.0×10^{-6}	4%
Seismic-Induced Fire	490,000	2.8	5.6×10^{-6}	4%
All Other Scenarios			1.6×10^{-6}	<1%
Total Mean Public Societal Acute Fatality Risk	–	–	1.5×10^{-4}	100%

and large fires to occur within the facility. All other sequences combined account for less than 1 percent of the total campaign risk.

13.3.9 VX 155mm Projectiles. Campaign 4 involves the processing of 32,313 VX 155mm projectiles (approximately 203,572 pounds of VX) in a campaign scheduled to last about 9 weeks. Contributions to campaign 4 risk are shown in figure 13-19 with the dominant scenarios summarized in table 13-16. Facility fires dominate risk during this campaign, accounting for 95 percent of the campaign risk. Only agent within the facility is contributing to the release because there is only a small amount of agent available on the filters (due to the low volatility of VX). As a result, nearly 90 percent of the fire risk does not involve the filters.

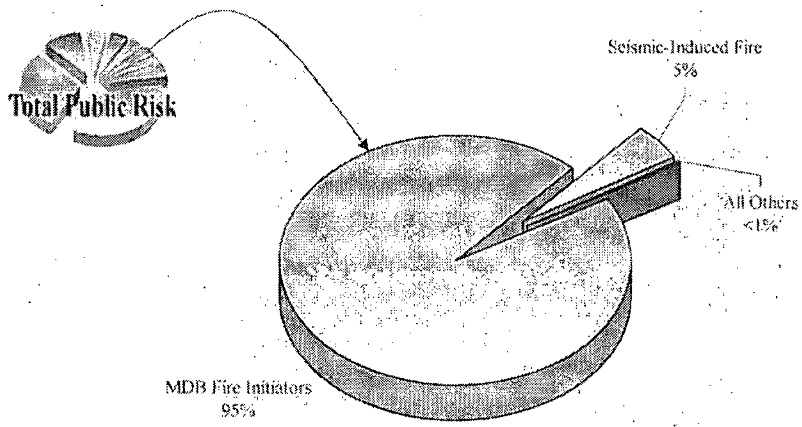


Figure 13-19. Contributors to Mean Public Societal Acute Fatality Risk for Campaign 4 (VX 155mm Projectiles)

Table 13-16. Public Societal Acute Fatality Risk Scenarios for Campaign 4 (VX 155mm Projectiles) for UMCDF Disposal Processing

Accident Sequence Category	Mean Recurrence Interval	Mean Consequence (Fatalities)	Mean Acute Fatality Risk Over Entire Campaign	Contribution to Campaign 4 Mean Risk
Second Floor Fire with No Filter Involvement	3,600	0.3	8.2×10^{-5}	46%
MDB-Wide Fire with No Filter Involvement	3,300	0.2	7.1×10^{-5}	40%
Seismic-Induced Fire	250,000	2.1	8.4×10^{-6}	5%
Second Floor Fire with Filter Desorption	28,000	0.2	8.2×10^{-6}	5%
MDB-Wide Fire with Filter Desorption	48,000	0.3	7.2×10^{-6}	4%
All Other Scenarios			1.9×10^{-6}	<1%
Total Mean Public Societal Acute Fatality Risk	–	–	1.8×10^{-4}	100%

Seismic-induced fires contribute 5 percent and involve large seismic events that cause both small and large fires to occur within the facility. All other sequences combined account for less than 1 percent of the total campaign risk.

13.3.10 VX Land Mines. The 11,685 VX land mines (approximately 122,693 pounds of VX) are scheduled for disposal over an approximately 9-week period in campaign 5. Contributions to campaign 5 risk are shown in figure 13-20 with the dominant scenarios summarized in table 13-17. Facility fires dominate risk during this campaign, accounting for 72 percent of the campaign risk. Only agent within the facility is contributing to the release because there is only

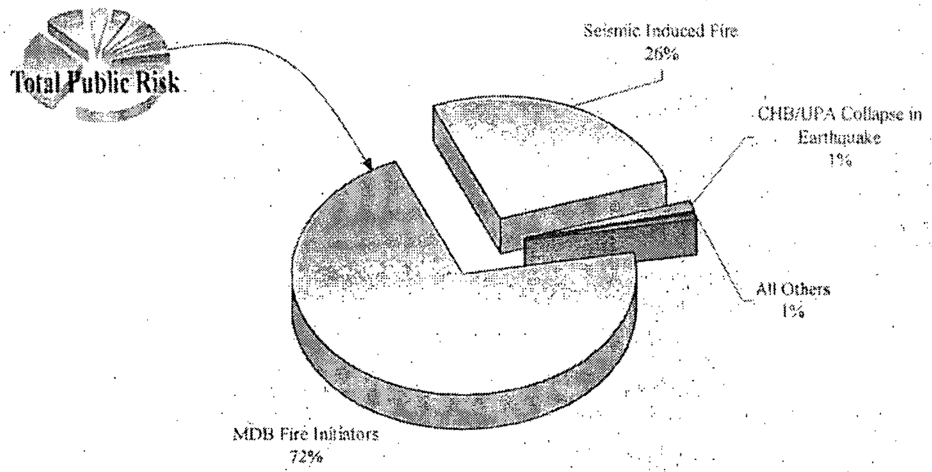


Figure 13-20. Contributors to Mean Public Societal Acute Fatality Risk for Campaign 5 (VX Land Mines)

Table 13-17. Public Societal Acute Fatality Risk Scenarios for Campaign 5 (VX Land Mines) for UMCDF Disposal Processing

Accident Sequence Category	Mean Recurrence Interval	Mean Consequence (Fatalities)	Mean Acute Fatality Risk Over Entire Campaign	Contribution to Campaign 5 Mean Risk
Second Floor Fire with No Filter Involvement	22,000	0.1	4.2×10^{-6}	33%
MDB-Wide Fire with No Filter Involvement	43,000	0.2	3.8×10^{-6}	30%
Seismic-Induced Fire	270,000	0.9	3.3×10^{-6}	26%
Second Floor Fire with Filter Desorption	69,000	0.04	5.7×10^{-7}	5%
MDB-Wide Fire with Filter Desorption	140,000	0.1	3.8×10^{-7}	3%
CHB/UPA Collapse in an Earthquake	94,000	0.02	1.7×10^{-7}	1%
UPA Fire with No Filter Involvement	130,000	0.01	7.0×10^{-8}	1%
All Other Scenarios			1.7×10^{-7}	1%
Total Mean Public Societal Acute Fatality Risk	–	–	1.3×10^{-5}	100%

a small amount of agent available on the filters (due to the low volatility of VX). As a result, nearly 86 percent of the fire risk does not involve the filters. Seismic-induced fires are also a significant contributor of risk to this campaign, accounting for 26 percent of the total risk. Seismic collapse of the CHB/UPA adds another 1 percent to the campaign risk. All other sequences combined account for about 1 percent of the total campaign risk.

13.3.11 GB 155mm Projectiles. Campaign 6 involves the processing of 47,406 GB 155mm projectiles (approximately 308,139 pounds of GB) and is scheduled to last approximately 12 weeks. Contributions to campaign 6 risk are shown in figure 13-21 with the dominant scenarios summarized in table 13-18. Facility fires dominate risk during this campaign, accounting for 93 percent of the campaign risk. Nearly 82 percent of the fire risk does not involve the filters. Seismic-induced fires are also a contributor of risk to this campaign, accounting for 5 percent of the total risk. Seismic collapse of the CHB/UPA adds another 2 percent to the campaign risk. All other sequences combined account for less than 1 percent of the total campaign risk.

13.3.12 GB 8-inch Projectiles. Campaign 7 accounts for the processing of 14,246 GB 8-inch projectiles (approximately 206,567 pounds of GB). This is scheduled to take approximately 8 weeks. Contributions to campaign 7 risk are shown in figure 13-22 with the dominant scenarios summarized in table 13-19. Facility fires dominate risk during this campaign, accounting for 93 percent of the campaign risk. Nearly 81 percent of the fire risk does not involve the filters. Seismic-induced fires are also a contributor of risk to this campaign, accounting for 4 percent of the total risk. Seismic collapse of the CHB/UPA adds another 2 percent to the campaign risk. All other sequences combined account for about 1 percent of the total campaign risk.

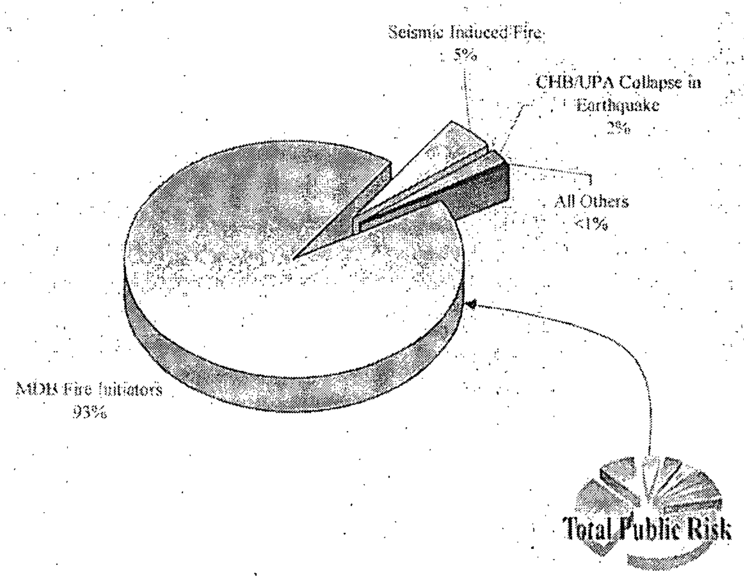


Figure 13-21. Contributors to Mean Public Societal Acute Fatality Risk for Campaign 6 (GB 155mm Projectiles)

Table 13-18. Public Societal Acute Fatality Risk Scenarios for Campaign 6 (GB 155mm Projectiles) for UMCDF Disposal Processing

Accident Sequence Category	Mean Recurrence Interval	Mean Consequence (Fatalities)	Mean Acute Fatality Risk Over Entire Campaign	Contribution to Campaign 6 Mean Risk
Second Floor Fire with No Filter Involvement	2,600	0.3	1.0×10^{-4}	39%
MDB-Wide Fire with No Filter Involvement	2,400	0.2	9.7×10^{-5}	37%
Second Floor Fire with Filter Desorption	19,000	0.4	2.3×10^{-5}	9%
MDB-Wide Fire with Filter Desorption	34,000	0.6	1.8×10^{-5}	7%
Seismic-Induced Fire	190,000	2.3	1.2×10^{-5}	5%
CHB/UPA Collapse in an Earthquake	66,000	0.4	5.4×10^{-6}	2%
First Floor Fire with Filter Desorption[a]	33,000	0.1	1.6×10^{-6}	1%
All Other Scenarios			2.9×10^{-6}	<1%
Total Mean Public Societal Acute Fatality Risk	—	—	2.6×10^{-4}	100%

Note:

[a] This sequence includes mostly the filters, without the building inventory and TOX.

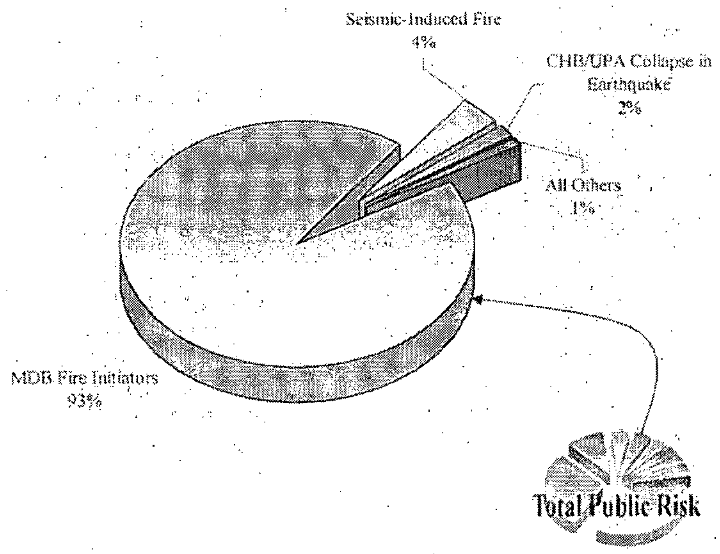


Figure 13-22. Contributors to Mean Public Societal Acute Fatality Risk for Campaign 7 (GB 8-inch Projectiles)

Table 13-19. Public Societal Acute Fatality Risk Scenarios for Campaign 7 (GB 8-inch Projectiles) for UMCDF Disposal Processing

Accident Sequence Category	Mean Recurrence Interval	Mean Consequence (Fatalities)	Mean Acute Fatality Risk Over Entire Campaign	Contribution to Campaign 7 Mean Risk
Second Floor Fire with No Filter Involvement	4,700	0.5	9.4×10^{-5}	39%
MDB-Wide Fire with No Filter Involvement	3,800	0.3	8.9×10^{-5}	36%
Second Floor Fire with Filter Desorption	29,000	0.7	2.5×10^{-5}	10%
MDB-Wide Fire with Filter Desorption	57,000	1.0	1.8×10^{-5}	7%
Seismic-Induced Fire	300,000	2.8	9.6×10^{-6}	4%
CHB/UPA Collapse in an Earthquake	100,000	0.5	4.3×10^{-6}	2%
First Floor Fire with Filter Desorption[a]	52,000	0.2	2.9×10^{-6}	1%
All Other Scenarios			2.6×10^{-6}	1%
Total Mean Public Societal Acute Fatality Risk	—	—	2.5×10^{-4}	100%

Note:

[a] This sequence includes mostly the filters, without the building inventory and TOX.

13.3.13 HD Ton Containers. The 2,635 HD ton containers (approximately 4,479,500 pounds of HD) are scheduled for disposal in campaign 8. This campaign is scheduled to last 42 weeks. Contributions to campaign 8 risk are shown in figure 13-23 with the dominant scenarios summarized in table 13-20. Facility fires dominate risk during this campaign, accounting for

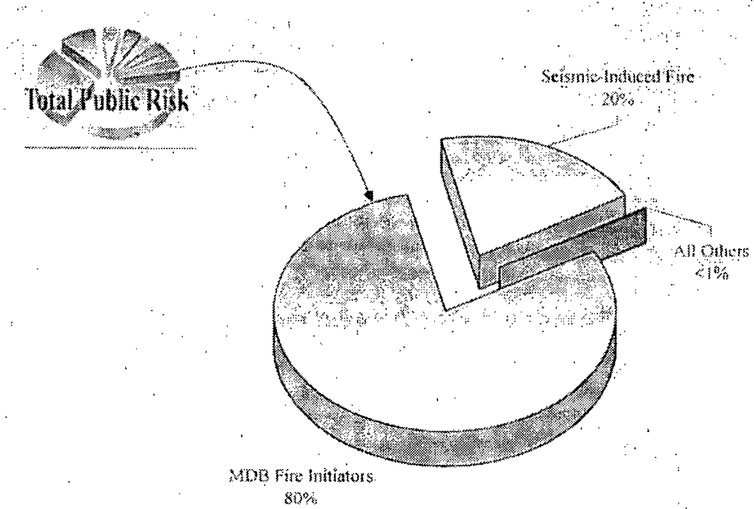


Figure 13-23. Contributors to Mean Public Societal Acute Fatality Risk for Campaign 8 (HD Ton Containers)

Table 13-20. Public Societal Acute Fatality Risk Scenarios for Campaign 8 (HD Ton Containers) for UMCDF Disposal Processing

Accident Sequence Category	Mean Recurrence Interval	Mean Consequence (Fatalities)	Mean Acute Fatality Risk Over Entire Campaign	Contribution to Campaign 8 Mean Risk
Second Floor Fire with No Filter Involvement	6,500	0.03	4.4×10^{-6}	46%
MDB-Wide Fire with No Filter Involvement	700	0.002	2.3×10^{-6}	24%
Seismic-Induced Fire	57,000	0.1	1.9×10^{-6}	20%
Second Floor Fire with Filter Desorption	11,000	0.01	5.5×10^{-7}	6%
MDB-Wide Fire with Filter Desorption	14,000	0.004	3.0×10^{-7}	3%
Second Floor Fire with Underventilated Filter Fire	730,000	0.04	4.9×10^{-8}	1%
All Other Scenarios			7.2×10^{-8}	<1%
Total Mean Public Societal Acute Fatality Risk	–	–	9.6×10^{-6}	100%

80 percent of the campaign risk. Nearly 88 percent of the fire risk does not involve the filters. Seismic-induced fires are also a significant contributor of risk to this campaign, accounting for 20 percent of the total risk. All other sequences combined account for less than 1 percent of the total campaign risk.

13.3.14 Campaign Changeovers. Following each campaign, there is a changeover period as the facility is prepared for the next campaign. As shown in table 13-21, almost all of the risk during changeovers is associated with building fires that lead to agent desorption from the HVAC filters. Because of the high volatility of GB, the amount of GB on the filters following GB campaigns is much greater than the amounts of VX and HD following those campaigns. Therefore, almost 100 percent of the risk during all changeovers is associated with changeovers following GB campaigns.

13.4 Public Cancer Risk

The second risk measure assessed in the QRA is the risk of cancers caused by one-time agent exposure. [Cancer risk due to long-term exposures to non-agent facility emissions is considered in other studies such as the Health Risk Assessment (Kearney, 1996).] Of the three agents considered in this analysis, HD is the only one that has shown any carcinogenic potential. The results of the analysis show that the risk of cancer is low (1.7×10^{-5} over UMCDF processing lifetime).

Table 13-21. Public Societal Acute Fatality Risk Scenarios for Campaign Changeovers for UMCDF Disposal Processing

Accident Sequence Category	Mean Recurrence Interval	Mean Consequence (Fatalities)	Mean Acute Fatality Risk Over All Campaign Changeovers	Contribution to Campaign Changeover Mean Risk
Second Floor Fire with Filter Desorption	9,600	0.1	8.5×10^{-6}	43%
First Floor Fire (without TOX) with Filter Desorption	12,000	0.1	6.7×10^{-6}	34%
MDB-Wide Fire with Filter Desorption	19,000	0.1	4.3×10^{-6}	22%
MPB Room Fire with Filter Desorption	850,000	0.1	1.5×10^{-7}	1%
Accidental Aircraft Crash into Filter Storage Igloo	60 million	6.0	9.5×10^{-8}	<1%
All Other Scenarios			1.0×10^{-7}	<1%
Total Mean Public Societal Acute Fatality Risk	–	–	2.0×10^{-5}	100%

13.4.1 Public Societal Cancer Risk (All Campaigns). As shown in table 13-22, the public cancer risk is dominated (88 percent) by the building fire initiators. Seismic-induced fires contribute another 4 percent to risk. BLEVE in the MPF, CHB/UPA collapse in an earthquake, LIC natural gas explosions, and agent-vapor explosion in the MPF each contribute 2 percent. All other contributors amount to approximately 1 percent. All contributors to public societal latent cancer risk are shown in figure 13-24.

13.4.2 Societal and Individual Cancer Risk by Distance from UMCDF. Tables 13-23 and 13-24 show the cancer risk by ring for accidental HD release from UMCDF. As with the public acute fatality risk, the first populated ring (2 to 5 kilometers) has a small contribution to total risk due to the low population. The largest public societal risk is in the 8- to 15-kilometer ring (68 percent). Societal cancer risk does not diminish as rapidly beyond 30 kilometers as individual risk does. This behavior is purely a function of the increasing population coupled with the linear non-threshold cancer model. Thus, the population is increasing more quickly than the dose and linear effects are decreasing. The individual risk profile reflects the actual risk weighted by population and shows the largest risk closest to the site. The risk values, however, are all very low, and are negligible in comparison to the acute fatality measures for similar accidents.

Table 13-22. Dominant Public Societal Cancer Risk Scenarios for All Campaigns for UMCDF Disposal Processing

Campaign #: Munition	Accident Sequence Category (Associated with Processing)	Mean Recurrence Interval	Mean Consequence (Latent Cancers)	Latent Cancer Risk Over Entire Processing Duration	Contribution to Mean Risk
8: HD Ton Container	MDB Fire that Spreads Beyond the Room of Origin and Involves Agent and/or HVAC Filters	110	1.6×10^{-3}	1.5×10^{-5}	87%
8: HD Ton Container	Seismic-Induced Fire	49,000	3.2×10^{-2}	6.6×10^{-7}	4%
8: HD Ton Container	BLEVE in the MPF	7,800	3.1×10^{-3}	3.9×10^{-7}	2%
8: HD Ton Container	CHB/UPA Collapse in an Earthquake	20,000	6.8×10^{-3}	3.5×10^{-7}	2%
8: HD Ton Container	LIC Natural Gas Explosion	240	6.3×10^{-5}	2.6×10^{-7}	2%
8: HD Ton Container	Agent Vapor Explosion in the MPF	310	7.8×10^{-5}	2.6×10^{-7}	2%
	All Other Scenarios			1.5×10^{-7}	1%
	Total Mean Public Societal Latent Cancer Risk			1.7×10^{-5}	100%

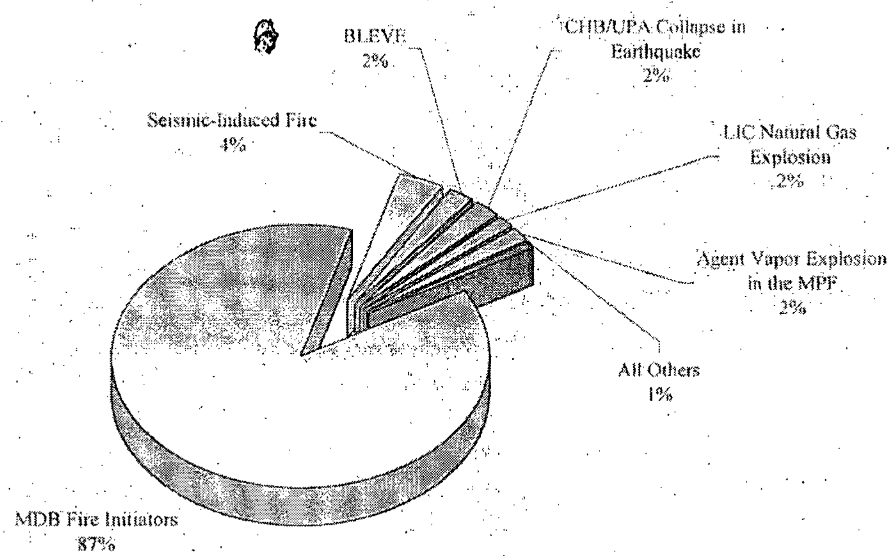


Figure 13-24. Contributors to Mean Public Societal Latent Cancer Risk for UMCDF Disposal Processing

Table 13-23. Public Societal Cancer Risk for Disposal Processing by Distance from UMCDF

	0-2 km[a]	2-5 km	5-8 km	8-15 km	15-30 km	30-45 km	45-60 km	60-75 km	75-100 km
Mean Societal Cancer Risk	–	1.7×10^{-7}	2.5×10^{-6}	1.1×10^{-5}	6.6×10^{-7}	6.2×10^{-7}	9.6×10^{-7}	8.5×10^{-8}	3.8×10^{-7}
Percent of Total Mean Risk from Each Ring	–	1%	15%	68%	4%	4%	6%	1%	1%

Note:

[a] Within facility boundaries; no public population.

Table 13-24. Public Individual Cancer Risk for Disposal Processing by Distance from UMCDF

	0-2 km[a]	2-5 km	5-8 km	8-15 km	15-30 km	30-45 km	45-60 km	60-75 km	75-100 km
Average Individual Latent Cancer Risk	–	3.6×10^{-9}	6.5×10^{-10}	4.5×10^{-10}	5.7×10^{-11}	1.8×10^{-11}	5.1×10^{-12}	2.3×10^{-12}	4.0×10^{-12}

Note:

[a] Within facility boundaries; no public population.

13.5 Other Site Worker Risk

For the purposes of this analysis, two worker populations have been defined. The first population is all persons working inside the UMCDF and chemical storage area fences, or just outside these fences in support buildings. These workers are termed *Disposal-Related Workers*. Their risks will be discussed in section 13.6. This section describes the risks from UMCDF operation to all other persons on the UMCD site (e.g., those working in the site administration areas) (box 13-8). These workers are termed *Other Site Workers*.

Box 13-8. Other Site Workers

As described in appendix Q2, the Other Site Worker populations are based on estimates of activities at areas of UMCD away from UMCDF.

Day	344 workers
Night	35 workers
Average	138 workers

Figure 13-25 shows the overall contributions for Other Site Worker risk over the entire UMCDF operational schedule. As with the public risk, Other Site Worker risk is dominated by MDB-wide fires, as shown in this figure. The important sequences for Other Site Worker risk are summarized in table 13-25 and the top events in the table are in roughly the same order of importance as the sequences in table 13-1, the public risk summary. Because the Other Site Worker population is much smaller than the surrounding public, these sequences result in far fewer fatalities.

Table 13-26 shows the contributions of the different campaigns to the Other Site Worker acute fatality risk. Again, the order of importance of contributions shown in this table is somewhat similar to that for public risk.

The accidents contributing to Other Site Worker risk are similar to public risk and are discussed in detail in section 13.2. There are no new insights generated by the Other Site Worker risk results that were not uncovered by the public risk answers. As indicated in table 13-25, these accidents have very low mean consequences, typically less than 10^{-2} fatalities, due to the small population of Other Site Workers (except for the VX M55 rocket and spray tank co-processing campaign, which is 2.0×10^{-1}).

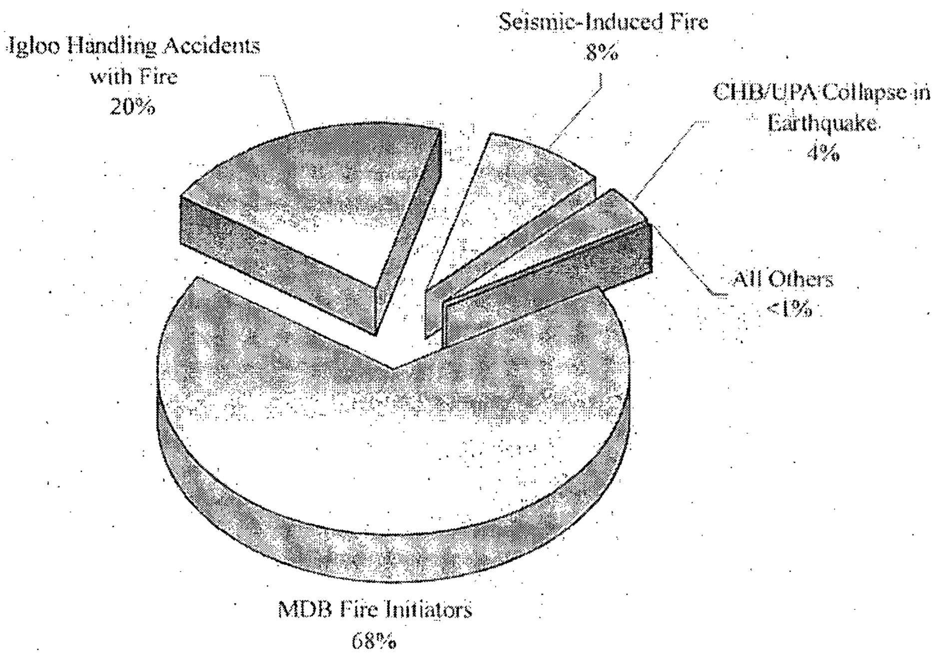


Figure 13-25. Contributors to Mean Other Site Worker Acute Fatality Risk for UMCDF Processing

Table 13-25. Dominant Other Site Worker Acute Fatality Risk Scenarios for All Campaigns for UMCDF Disposal Processing

Campaign #: Munition	Accident Sequence Category (Associated with Processing)	Mean Recurrence Interval	Mean Consequence (Fatalities)	Mean Fatality Risk Over Entire Disposal Duration	Contribution to Mean Risk
1b: GB M55 Rockets and MC-1 Bombs	MDB Fire that Spreads Beyond the Room of Origin and Involves Agent and/or HVAC Filters	190	0.001	3.7×10^{-6}	19%
2b: VX M55 Rockets and Spray Tanks	MDB Fire that Spreads Beyond the Room of Origin and Involves Agent and/or HVAC Filters	870	0.003	3.5×10^{-6}	18%
1d: GB M55 Rockets (2)	MDB Fire that Spreads Beyond the Room of Origin and Involves Agent and/or HVAC Filters	450	0.001	1.8×10^{-6}	9%
2a: VX M55 Rockets (1)	Igloo Handling Accident that Results in an Igloo Fire	31,000	0.04	1.3×10^{-6}	7%
2b: VX M55 Rockets and Spray Tanks	Seismic-Induced Fire	230,000	0.2	1.0×10^{-6}	5%
1a: GB M55 Rockets (1)	MDB Fire that Spreads Beyond the Room of Origin and Involves Agent and/or HVAC Filters	800	0.001	9.8×10^{-7}	5%
6: GB 155mm Projectiles	MDB Fire that Spreads Beyond the Room of Origin and Involves Agent and/or HVAC Filters	610	0.001	9.0×10^{-7}	5%
2b: VX M55 Rockets and Spray Tanks	Igloo Handling Accident that Results in an Igloo Fire	44,000	0.04	8.9×10^{-7}	5%
2c: VX M55 Rockets (2)	Igloo Handling Accident that Results in an Igloo Fire	49,000	0.04	8.1×10^{-7}	4%
4: VX 155mm Projectiles	MDB Fire that Spreads Beyond the Room of Origin and Involves Agent and/or HVAC Filters	850	0.001	6.1×10^{-7}	3%
5: GB 8-inch Projectiles	MDB Fire that Spreads Beyond the Room of Origin and Involves Agent and/or HVAC Filters	1,000	0.001	5.9×10^{-7}	3%
1b: GB M55 Rockets and MC-1 Bombs	Igloo Handling Accident that Results in an Igloo Fire	5,000	0.002	3.9×10^{-7}	2%
1c: GB M55 Rockets (2)	Igloo Handling Accident that Results in an Igloo Fire	5,400	0.002	3.5×10^{-7}	2%
3: VX 8-inch Projectiles	MDB Fire that Spreads Beyond the Room of Origin and Involves Agent and/or HVAC Filters	1,700	0.001	3.5×10^{-7}	2%

Table 13-25. Dominant Other Site Worker Acute Fatality Risk Scenarios for All Campaigns for UMCDF Disposal Processing (Continued)

Campaign #: Munition	Accident Sequence Category (Associated with Processing)	Mean Recurrence Interval	Mean Consequence (Fatalities)	Mean Fatality Risk Over Entire Disposal Duration	Contribution to Mean Risk
2a: VX M55 Rockets (1)	MDB Fire that Spreads Beyond the Room of Origin and Involves Agent and/or HVAC Filters	1,900	0.001	3.2×10^{-7}	2%
2b: VX M55 Rockets and Spray Tanks	CHB/UPA Collapse Due to a Seismic Event	51,000	0.015	2.8×10^{-7}	1%
1b: GB M55 Rockets and MC-1 Bombs	Seismic-Induced Fire	46,000	0.01	2.1×10^{-7}	1%
2c: VX M55 Rockets (2)	MDB Fire that Spreads Beyond the Room of Origin and Involves Agent and/or HVAC Filters	2,900	0.001	2.0×10^{-7}	1%
1a: GB M55 Rockets (1)	Igloo Handling Accident that Results in an Igloo Fire	9,700	0.002	2.0×10^{-7}	1%
1b: GB M55 Rockets and MC-1 Bombs	CHB/UPA Collapse Due to a Seismic Event	23,000	0.004	1.7×10^{-7}	1%
8: HD Ton Containers	MDB Fire that Spreads Beyond the Room of Origin and Involves Agent and/or HVAC Filters	240	3.3×10^{-5}	1.3×10^{-7}	<1%
	All Other Scenarios Combined			8.8×10^{-7}	4%
	Total Mean Other Site Worker Societal Acute Fatality Risk			2.0×10^{-5}	100%

13.6 Disposal-Related Worker Acute Fatality Risk (All Campaigns)

For the purposes of this QRA, Disposal-Related Workers (as opposed to the Other Site Workers discussed in section 13.5) are defined as those personnel working within or just outside the UMCDF fence, or within or just outside the storage area fence (see box 13-9). All other UMCD personnel are accounted for in the Other Site Worker calculations. This analysis considers only acute fatality agent-related risk. It does not include risks from non-agent sources, such as common industrial accidents. Disposal-Related Worker risk is more complicated than public risk, because there are different elements contributing to the total risk. Three different Disposal-Related Worker vulnerabilities are assessed: 1) close-in effects of accidents due to workers being in close proximity to the accident, 2) agent-related effects at a distance from the

Table 13-26. Percent Contribution to Total Mean Other Site Worker Acute Fatality Risk by Campaign for UMCDF Disposal Processing

Campaign #	Campaign	Duration (Weeks)	Contribution to Total Mean Public Acute Fatality Risk
1a	GB M55 Rockets (1)	18.0	6%
1b	GB M55 Rockets + GB MC-1 Bombs	35.1	23%
1c	GB M55 Rockets + GB MK-94 Bombs	0.1	1%
1d	GB M55 Rockets (2)	32.0	12%
	Changeover	27.1	1%
2a	VX M55 Rockets (1)	8.4	8%
2b	VX M55 Rockets + VX Spray Tanks	5.9	29%
2c	VX M55 Rockets (2)	5.3	5%
	Changeover	9.1	Negligible [a]
3	VX 8-inch Projectiles	4.7	2%
	Changeover	6.0	Negligible [a]
4	VX 155mm Projectiles	9.1	3%
	Changeover	7.0	Negligible [a]
5	VX Land Mines	8.7	1%
	Changeover	27.1	Negligible [a]
6	GB 155mm Projectiles	12.4	5%
	Changeover	6.0	Negligible [a]
7	GB 8-inch Projectiles	7.9	3%
	Changeover	27.1	Negligible [a]
8	HD Ton Containers	42.0	1%
	Closure	52.1	N/A
	Total	351.1	100%

Note:

[a] Negligible contributions are 0.0001 or less.

Box 13-9. Disposal-Related Workers

As described in appendix Q2, the Disposal-Related Worker populations are based on estimates currently derived from TOCDF.

	UMCDF	Storage Operations
Day	305	74 workers
Night	103	10 workers
Average	168	31 workers

accident (remote effects), similar to public risk, and 3) agent exposure during performance of normal duties.

Quantitative worker risk assessment is still a relatively new endeavor. The methods include uncertainties and limitations that should be considered when reviewing the results. The main purpose is to help further the understanding of the relative importance of different types of accident scenarios to risk. This understanding can be used in conjunction with all the other worker risk management activities to make continued improvements in safety.

The mean expected Disposal-Related Worker fatality risk for the facility lifetime is 0.50. This mean is shown in figure 13-26, which is a plot of the expected fatality risk for all the Latin Hypercube Sampling observations in the uncertainty analysis. As indicated, there is over a factor of 10 between the 5th and 95th percentiles.

The effects on Disposal-Related Workers have been calculated assuming two different masking models. For all accidents except earthquakes, it is assumed that 99 percent of the Disposal-Related Worker personnel mask, and that masking takes place 60 seconds after the initial release (note that this 60-second period contains time for both notification and masking; the actual process of masking only takes a few seconds once notification has been given). For earthquakes, it is assumed that 97 percent of the personnel mask, and that the masking time is 150 seconds after the accident. The lower masking percentage and longer masking times are due to the potential disorientation and/or incapacitation of personnel after the occurrence of an earthquake.

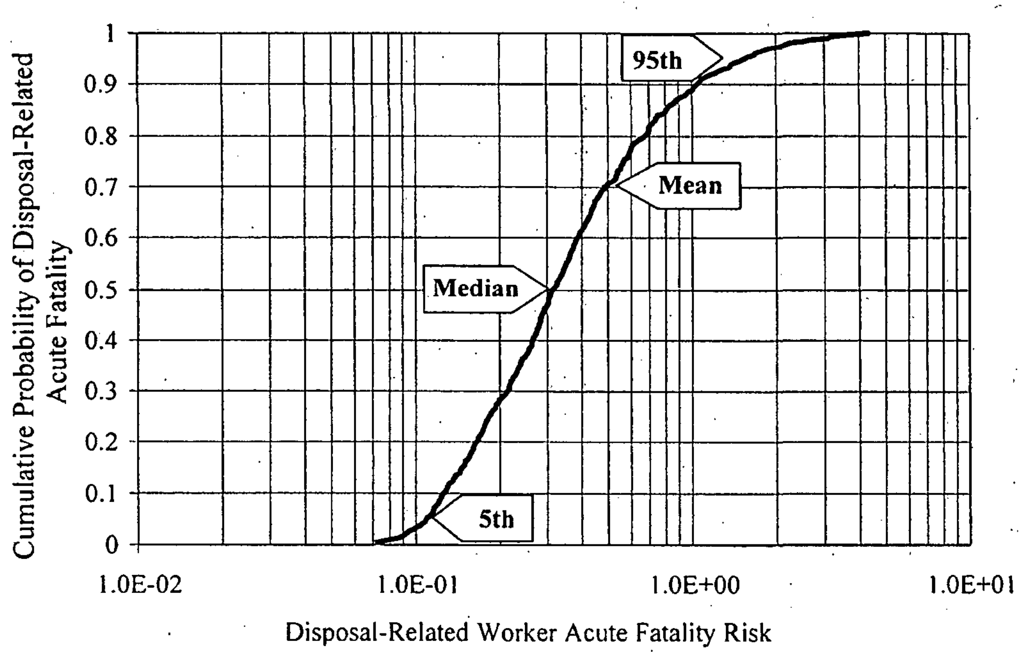


Figure 13-26. Distribution of the Mean Disposal-Related Worker Acute Fatality Risk for UMCDF Disposal Processing

Cancer risk for Disposal-Related Workers is not reported. Cancer risk from accident releases could only be partially quantified using the QRA models. Close-in worker effects are estimated for fatalities only. As a result, no cancer results are provided for Disposal-Related Workers. No cancer calculations are included in the estimation of close-in effects for a number of reasons.

The controlling factor is that cancer risk can occur with very small exposures, with no known lower dose threshold, and a dose-response has only been estimated for inhalation. The methods developed for estimating possible close-in fatalities are not designed to calculate very low level exposures, including those associated with maintenance activities. In addition, the QRA modeling objective is to capture the possibility of accidents that lead to human health threat. It is judged that there is a class of very minor events not currently within scope of the QRA that could be important to estimation of Disposal-Related Worker cancer risk, so any quantification would be a partial assessment of risk. Finally, it is not known that HD is the controlling occupational carcinogen.

In addition to the technical issues, there is questionable risk management value to quantification of Disposal-Related Worker cancer risk. The risk management strategy is to minimize any potential for exposure, and it is not obvious how a partial quantification would change any operational activities or management decisions.

In a few instances, it is difficult to define the exact boundary for the worker risk evaluation. The scope of this study is limited to risks from chemical agents and munition energetics. A tornado could cause fatalities that would be independent of agent, but it also could cause an agent release. An attempt has been made here to limit the Disposal-Related Worker risk to those workers that would be affected by energetics and agents. For example, no risk is calculated for tornadoes that cause structural damage but no agent release.

The risk of fatalities to workers is summarized here in section 13.6. Then the dominant contributors to the risk are discussed (section 13.7), followed by risk by campaign (section 13.8), and the effects of sensitivity studies to both public and Disposal-Related Worker risk (section 13.9).

The Disposal-Related Worker risk results are summarized in table 13-27 and figure 13-27. As noted previously, the acute fatalities for accidental releases are calculated separately for the close-in effects to workers in the vicinity of the accidents and the possible remote effects on other Disposal-Related Workers who would be evacuating the facility. The consequences shown in the table are the sum of both effects.

Energetic events resulting from operations staff intervention to clear DFS chute jams are the largest contributors to Disposal-Related Worker risk. A number of other events are important

Table 13-27. Dominant Disposal-Related Worker Acute Fatality Risk Scenarios for All Campaigns for UMCDF Disposal Processing

Accident Sequence Category	Mean Recurrence Interval	Mean Consequence (Fatalities)	Mean Fatality Risk Over Entire Disposal Duration	Contribution to Mean Risk
Energetic Initiation During Manual Chute Jam Clearing Operation (GB Rocket + MC-1 Bomb Campaign)	9.3	1.0	0.11	22%
Energetic Initiation During Manual Chute Jam Clearing Operation (GB M55 Rocket (2) Campaign)	10	1.0	0.10	20%
MDB Fire Initiators (All Campaigns)	30	1.9	6.4×10^{-2}	13%
Energetic Initiation During Manual Chute Jam Clearing Operation (GB M55 Rocket (1) Campaign)	18	1.0	5.6×10^{-2}	11%
UPA Handling Accident Resulting in Explosion (All Campaigns)[a]	130	3.5	2.6×10^{-2}	5%
Maintenance-Related Exposure (All Campaigns)	1.9	0.05	2.5×10^{-2}	5%
Energetic Initiation During Manual Chute Jam Clearing Operation (VX M55 Rocket (1) Campaign)	56	1.0	1.8×10^{-2}	4%
UPA Handling Accident Resulting in Agent Spill (All Campaigns)	5.8	0.1	1.8×10^{-2}	4%
Leaker Handling Accident Resulting in Explosion in the ECV (All Campaigns)[a]	150	2.2	1.4×10^{-2}	3%
Handling Accident in Storage Yard Resulting in Fire (All Campaigns)[a]	450	6.3	1.4×10^{-2}	3%
Energetic Initiation During Manual Chute Jam Clearing Operation (VX M55 Rocket + Spray Tank Campaign)	80	1.0	1.3×10^{-2}	2%
Energetic Initiation During Manual Chute Jam Clearing Operation (VX M55 Rocket (2) Campaign)	90	1.0	1.1×10^{-2}	2%
LIC Natural Gas Explosion (All Campaigns)	54	0.5	8.5×10^{-3}	2%
Storage Yard Handling Accident Resulting in Agent Spill (All Campaigns)	18	0.1	5.5×10^{-3}	1%
Furnace Munition Explosion (All Campaigns)[a]	56	0.2	4.4×10^{-3}	<1%
All Other Scenarios			1.4×10^{-2}	3%
Total Mean Disposal-Related Worker Societal Acute Fatality Risk	–	–	0.50	100%

Notes:

[a] These sequences specifically involve munitions with energetics.

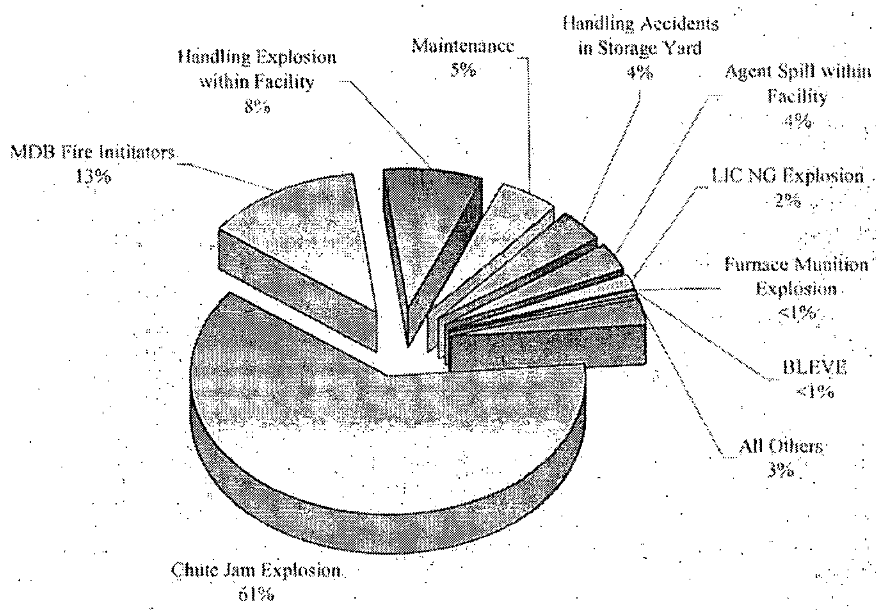


Figure 13-27. Contributors to Mean Disposal-Related Worker Acute Fatality Risk for UMCDF Processing

contributors, specifically building fires, explosions following handling accidents or improper operations, maintenance activities, and LIC natural gas explosions. With the exception of building fires, these sequences are mostly different from those that dominate public risk. This is because many of the accidents contributing to the Disposal-Related Worker risk profile involve munition explosions with serious close-in effects. Single munition accidents are not generally important to public risk because of the limited agent associated with individual munitions. All the contributors are discussed in the next section.

Table 13-28 provides the contribution of accidents in each campaign to the Disposal-Related Worker acute fatality risk measure. Detailed discussions of the risks by campaign will be presented in section 13.8.

13.7 Discussion of Contributors to Disposal-Related Worker Risk

The dominant worker risk is associated with DFS feed chute jams. Most of the Disposal-Related Worker risk is associated with operational events, as opposed to external events such as earthquakes (though building fires are important). The most important worker risk scenarios are summarized in these sections.

Table 13-28. Percent Contribution to Total Mean Disposal-Related Worker Acute Fatality Risk by Campaign for UMCDF Disposal Processing

Campaign #	Campaign	Duration (Weeks)	Contribution to Total Mean Public Acute Fatality Risk
1a	GB M55 Rockets (1)	18.0	14%
1b	GB M55 Rockets + GB MC-1 Bombs	35.1	29%
1c	GB M55 Rockets + GB MK-94 Bombs	0.1	<1%
1d	GB M55 Rockets (2)	32.0	25%
	Changeover	27.1	1%
2a	VX M55 Rockets (1)	8.4	6%
2b	VX M55 Rockets + VX Spray Tanks	5.9	5%
2c	VX M55 Rockets (2)	5.3	4%
	Changeover	9.1	<1%
3	VX 8-inch Projectiles	4.7	1%
	Changeover	6.0	<1%
4	VX 155mm Projectiles	9.1	2%
	Changeover	7.0	<1%
5	VX Land Mines	8.7	8%
	Changeover	27.1	<1%
6	GB 155mm Projectiles	12.4	2%
	Changeover	6.0	<1%
7	GB 8-inch Projectiles	7.9	1%
	Changeover	27.1	<1%
8	HD Ton Containers	42.0	2%
	Closure	52.1	N/A
	Total	351.1	100%

13.7.1 Deactivation Furnace System Feed Chute Jam. Experience at TOCDF and JACADS has shown that the DFS chute can become jammed with pieces of munitions that have been dropped into the chute but that did not slide fully down and into the DFS. DFS feed chute jams can result in workers being required to physically assist in clearing the blockage. This jam clearing operation creates an opportunity for exposure to both agent and energetics hazards.

As noted previously, worker risk is dominated by rocket chute jam scenarios. Although jams also can occur with projectile bursters and mines, the probabilities of the jam and of energetic events are much lower, and they do not contribute significantly to overall risk, although they are important to those campaigns. Section D6.3.1 includes a detailed explanation of the DFS chute jam scenario evaluation.

Based on TOCDF and JACADS experience, an entry is required to clear a jam approximately every 1,500 rockets (much less frequently for projectiles and mines). Draft versions of the ANCDF QRA pointed out the potential risks of DFS chute jams, and as a result, PMCD undertook a study of the chute to determine what changes could reduce the probability of a jam. A chute was assembled at the Chemical Demilitarization Training Facility and a study was undertaken to determine chute jam causes and possible changes to reduce the likelihood. These efforts resulted in some design changes to the chutes being incorporated into the UMCDF design. The transition between sections of the chute has been redesigned and an additional set of water sprays has been added to wet the chute surface. The impact of these changes in the field is not yet known. The changes are based upon testing with an actual chute, but the chute did not have all of the characteristics associated with the operating demilitarization system. From discussions with the sites, it is clear that this is a complex problem and details associated with the operating system could be important. In draft versions, the frequency of this event was based solely on the JACADS and TOCDF experience. In this final report, credit has been given to the changes being implemented, although the effect is somewhat limited because no data with the new system are available yet. For rockets, the mean value of the uncertainty distribution suggests one rocket feed chute jam for every 3,000 rockets processed at UMCDF. This value should be compared to experience and updated as rocket processing is undertaken.

The probability of a chute jam energetic event is very uncertain. Due to the randomness, it is difficult to create a mechanistic model. The available information for friction initiation of the energetic components was examined, with a conclusion that energetic initiation was possible. Explosive ordnance disposal personnel were contacted for their viewpoints, which centered on the possibility for a fuze initiation with subsequent involvement of other components. The likelihood has been considered from several perspectives, which have been used to develop an uncertainty distribution. After the draft ANCDF QRA publication, there was another change concerning chute jams that has affected the model. The Risk Management and Quality Assurance Office at PMCD issued a memorandum on 9 April 2001 recommending that TOCDF discontinue manual clearing of chute jams. The letter recommends use of personnel expert in these matters, such as explosive ordnance disposal personnel. The UMCDF staff is aware of this recommendation and will follow this recommendation. It is noted, however, that TOCDF personnel cleared two jams after receipt of this recommendation, so it does not seem prudent to rule out the possibility that the recommendation would not be fully followed at other sites. In the quantification of this event, credit is given for the UMCDF assurance that the chute jam clearance would be done by appropriately trained individuals. PMCD also is continuing to examine remote ways of clearing the jams but no system has been developed to a sufficient level of detail for study in the QRA.

Determining the likelihood of an explosion is difficult for a number of reasons. The most important is the randomness associated with the nature of the jam and the nature of the response.

The jam can include pieces of various flights of rockets, and the potential for localized pockets of propellant, bursters, and fuzes to exist. This could exist in a matrix of rocket pieces including aluminum and steel wire, igniter squibs, and various other parts. The manner in which these parts jam would be random. Before intervention, it is the intent to both wet and heat the materials such that energetics would be melted or degraded. However, heating will not eliminate the explosives unless done to a very high temperature for an extended period, and partial heating could sensitize the energetics. Wetting is good, but is not an assurance that friction will be eliminated, particularly in the lower levels of the jam. It is difficult in the QRA model to credit any absolute clearing method because it is impossible to ensure that no pockets of explosives remain, especially given the fact that each blockage can have different characteristics.

The probability of explosion or fire during a clearing operation was considered from a number of different perspectives. First, the successful experience in manually clearing jams to date allows an understanding of the upper bound probability and an estimate of the mean probability. Consideration of the number of jams cleared to date successfully without incident generates an estimate of about a 1-in-100 probability of explosion during these physical activities to clear a rocket jam. This is based on a review of available information concerning prior chute jams as well as discussions with TOCDF staff.

A second method of quantification is to use the QRA method for quantifying uncertain phenomena, as outlined in section 12. Use of this method generates a value for the probability of an explosion or fire no lower than 0.01, or 1 in 100. This evaluation was supplemented by discussions with explosive ordnance disposal personnel who concluded that the manual intervention posed undue risk from their perspective. The uncertainty distribution also reflects the possibility that an explosion has a very low probability, reflecting the viewpoints of some TOCDF personnel.

The uncertainty distribution used in the draft UMCDF QRA was updated for the final to reflect the likelihood that explosive ordnance disposal personnel would be involved. Due to the wide uncertainty and the lack of clear data, the uncertainty distribution yields a mean conditional probability of explosion or fire for rocket jams of 0.008.

This accident, which accounts for 61 percent of the acute worker fatality risk, results in an average of one fatality per explosion. This is the result of a model in which the two workers are evaluated to have a 50 percent fatality rate for the range of energetic events that could occur.

13.7.2 Munitions Demilitarization Building Fire Initiators. The fires that dominate public risk also contribute to Disposal-Related Worker risk, with all fires accounting for roughly 13 percent of the total. The fire analysis was discussed in section 13.2.1. The worker fatalities for fires are primarily associated with the agent plume from the fire that might impact workers as they evacuate the facility, even considering the availability of masking. The agent sources include munitions and bulk containers as well as the agent from the HVAC filters for GB campaigns. The consequences are calculated with CHEMMACCS and include the probability of failure to mask properly, as well as vapor deposition on the skin, which is another path of exposure. It is assumed that fires will not be fought if they approach agent sources and that the fire would allow time for evacuation such that close-in worker effects are not critical. As noted in table 13-27, the mean consequence for these large fire scenarios is approximately two worker fatalities.

13.7.3 Unpack Area Accidents Resulting in Explosions. Munition explosion events in the UPA contribute 5 percent of the worker acute fatality risk. The largest contributor is associated with dropping a mine when it is transported by crane from the drum to the conveyor. While relatively unlikely, explosions would have significant consequences (an average of 3.5 fatalities) because the UPA is an area of relatively high occupancy and there is a good chance that many in the area would be affected.

13.7.4 Maintenance-Related Exposures. Maintenance activities contribute 5 percent of the worker acute fatality risk. This risk is dominated by maintenance activities on equipment in the TOX, MPB, and ECR.

This part of the model includes an exception to the standard methodology in that the POD event accounts for just the frequency of maintenance, while the close-in worker consequence model accounts for both the probability of exposure and the probability of fatality. In order to provide more useful risk insights in the tables of recurrence intervals and consequences, the recurrence intervals for maintenance events have been recalculated as the frequency of maintenance multiplied by the probability of DPE failure. The mean consequence also was provided. Maintenance considers the possibility of DPE plus support air failure leading to an inhalation dose, as well as DPE failure (e.g., a puncture) leading to a direct dermal contact dose. The probabilities of fatalities for these cases are adjusted depending on agent type. The details of the worker risk model are provided in appendix Q3.

Although they are not important to overall risk, the risks of some campaigns include special maintenance events. A number of maintenance activities were identified on the PODs that were judged to represent unique hazards not adequately captured by the normal maintenance events. These special DPE entries include recovery events, such as manual intervention if a tray gets stuck during transfer on to or off of a charge car.

13.7.5 Unpack Area Handling Accidents Resulting in Agent Spills. Agent spills associated with handling activities in the UPA account for 4 percent of the Disposal-Related Worker risk. The dominant contributor is the possibility that the movement of an empty EONC could impact

GB-filled items on the scissor lift. Other handling accidents also contribute, including the drop of an EONC tray of rockets during loading or unloading from the scissor lift. Due to the volatility of GB, GB campaigns contribute almost all of this type of worker risk. These accidents on average result in less than a 1 in 10 chance of fatality, but occur more frequently than other, more serious events such as explosions.

13.7.6 Explosive Containment Vestibule Accidents Resulting in Explosions. ECV explosions contribute about 3 percent to risk. These are primarily associated with a gate catching on a rocket tube or a mine explosion. While relatively unlikely, explosions would have significant consequences (over 2 fatalities) because there is a good chance that many in the area would be affected.

13.7.7 Handling Accidents in the Storage Area Resulting in Fire. The QRA scope includes the entire disposal process, starting with the removal of items from the storage area. Handling activities contribute to worker risk primarily when there is a subsequent explosion because many workers could be potentially exposed. While not frequent, these accidents do contribute to the worker risk (3 percent), especially for individual campaigns; and these accidents on average result in over six fatalities. The handling risk includes the possibility of a forklift impact or drop of a munition load. Given the resultant impact, there is a chance of explosion. Explosion probabilities, as discussed in section 9, vary with the severity of the impact and the type of munition involved, and are in the range of 1 in 100 to 1 in 1,000 for these accidents when rockets are involved. Other munitions do not contribute because energetic initiation is more unlikely.

13.7.8 Liquid Incinerator Natural Gas Explosions. All fuel gas fired furnaces and incinerators carry an inherent risk of explosion due to fuel gas explosions. While modern facilities have many systems to prevent this type of event, it cannot be ruled out. These events are infrequent but do contribute to the overall worker risks, especially for some individual campaigns. For these events, determining the impact of the event to count only agent-related fatalities is rather difficult; however, effects were considered for workers in the immediate vicinity of the explosion. The potential for natural gas explosions is considered for all the furnaces, but the LIC has the highest estimated risk. The LIC natural gas explosion accounts for 2 percent of worker risk.

13.7.9 Handling Accidents at the Storage Area Resulting in Spills. Handling activities would be more likely to result in spills than explosions, but the consequences would be less severe. These are essentially all forklift accidents including drop of a pallet and puncture of a munition or bulk container and account for about 1 percent of worker risk.

13.7.10 Furnace Munition Explosion. As indicated in table 13-27, the risk associated with a furnace munition explosion is less than 1 percent of the total Disposal-Related Worker risk. This includes munitions inadvertently left in overpacks that are sent to the MPF.

Leaker processing involves the handling of rockets in steel overpacks. Overpacked leakers from the stockpile must be unpacked in the ECV by personnel in DPE and loaded by hand onto the input conveyors to the appropriate demilitarization line. The overpacks then are sent to the MPF for decontamination. Space limitations in the ECV could give rise to temporary placement of items in areas that could lead to a later misidentification, or an item could be skipped and inadvertently sent to the furnace. The overpack processing performed to date has been well controlled and monitored, but the possibility for this type of error exists. The probability of occurrence that an operator could inadvertently send an overpack that still contains a munition to the MPF is 6.5×10^{-5} (1 in 15,000 chance) per overpacked item processed.

If a rocket or mine were placed into the MPF, it would explode and is predicted to cause large-scale damage to the MPF. The overpressure in the MPF room itself, however, is such that the explosion may or may not fail the room boundary. It also is predicted that most of the agent from the munition will be destroyed in an explosion in the MPF. Thus, agent releases are small. However, there may be someone near the outer walls of the MPF enclosure during this scenario. There is a chance of personnel being outside the MPF or attending to the MPF output conveyor, the LIC slag removal system, or the treaty compliance systems. The average consequence for these scenarios is approximately 0.2 fatalities.

13.8 UMCDF Worker Acute Fatality Risk by Campaign

The results discussed in section 13.7 provide an overall perspective on the Disposal-Related Worker acute fatality risk from disposal operations at UMCDF. In this section, discussion is provided on the dominant contributors from each campaign, notwithstanding the campaign's overall contribution to the risk profile. This allows a more in-depth look at the activities that contribute to risk at each point in time during UMCDF operation.

Figure 13-28 shows the contribution of each campaign to the total acute worker fatality risk. As seen in the figure, the two GB M55 rocket campaigns (campaigns 1a and 1d) and the GB M55 rocket and MC-1 bomb coprocessing campaign (1b) dominate the risk profile over the UMCDF campaign schedule, accounting for 68 percent of the total acute worker fatality risk. VX land mines (campaign 5) contribute 8 percent. The first VX M55 rocket campaign contributes 6 percent, the VX M55 rocket and spray tank coprocessing campaign accounts for another 5 percent of the risk, and the second VX M55 rocket campaign contributes another 4 percent. All other campaigns each contribute 2 percent or less to total acute worker fatality risk; VX 155mm projectiles (2 percent), GB 155mm projectiles (2 percent), HD ton containers (2 percent),

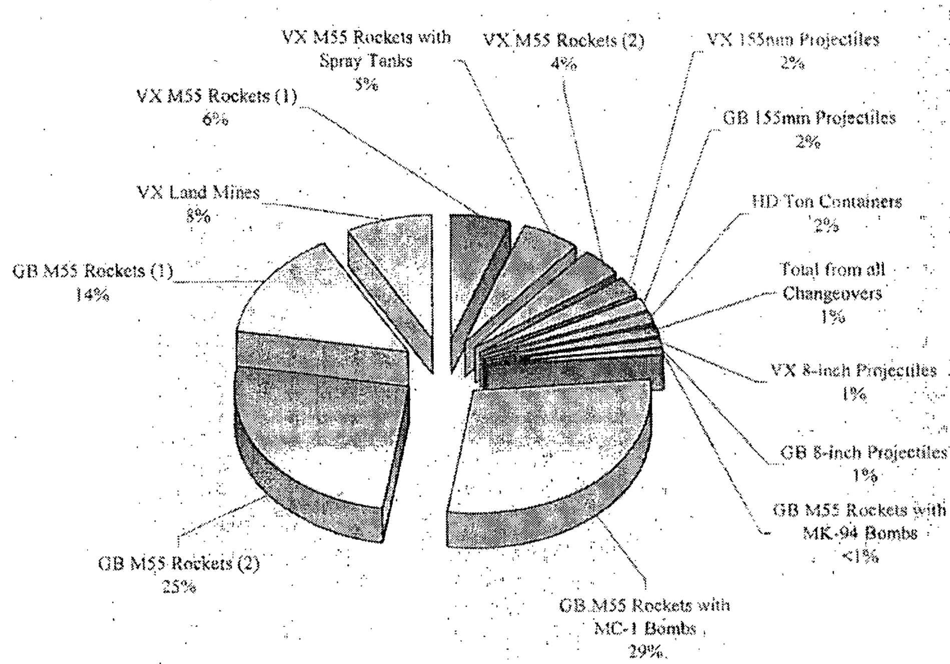


Figure 13-28. Mean Disposal-Related Worker Acute Fatality Risk by Campaign for UMCDF Disposal Processing (Pie Chart)

VX 8-inch projectiles (1 percent), and the GB 8-inch projectiles (1 percent). The GB M55 rocket and MK-94 bomb coprocessing campaign (1c) contributes less than 1 percent to total risk, but this is because this campaign lasts a single day. All changeovers account for about 1 percent of total acute worker fatality risk.

Figures 13-29 and 13-30 each provide a display of the relationships between the various campaign risks. Figure 13-29 shows the risk over the duration of each campaign. Thus, not only are the accidents that may occur within each campaign considered, but the number of munitions of each type also is considered (the number of munitions to be processed is related to the campaign duration). Refer to box 13-10 for further information on comparing campaigns.

Figure 13-30 provides a slightly different perspective, however. This figure presents the rate of risk during each campaign in units of fatalities per year of operation. Thus, while each campaign is occurring, it has a risk rate. The relative importance of each campaign is somewhat different when considered with this measure. The campaign with the highest risk rate is the VX land mine campaign. The GB and VX rocket campaigns (including coprocessing campaigns) also have significant risk rates. The other campaigns all have lower risk rates. Campaigns that have similar risk rates often have similar risk contributors, and this is shown in the risk scenario tables

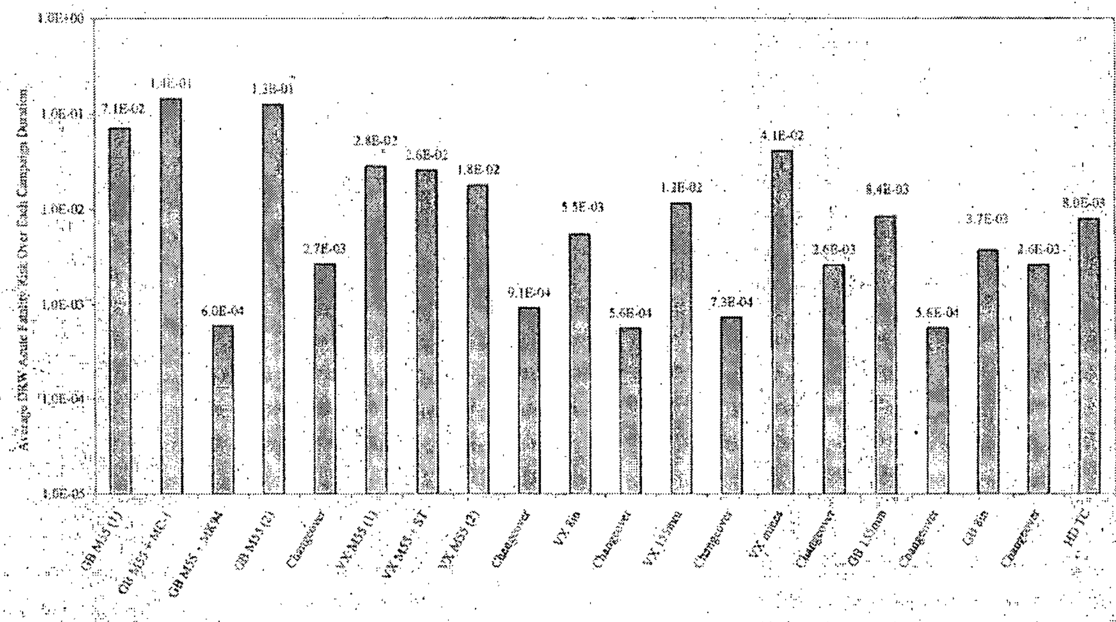


Figure 13-29. Mean Disposal-Related Worker Acute Fatality Risk by Campaign for UMCDF Disposal Processing (Bar Graph)

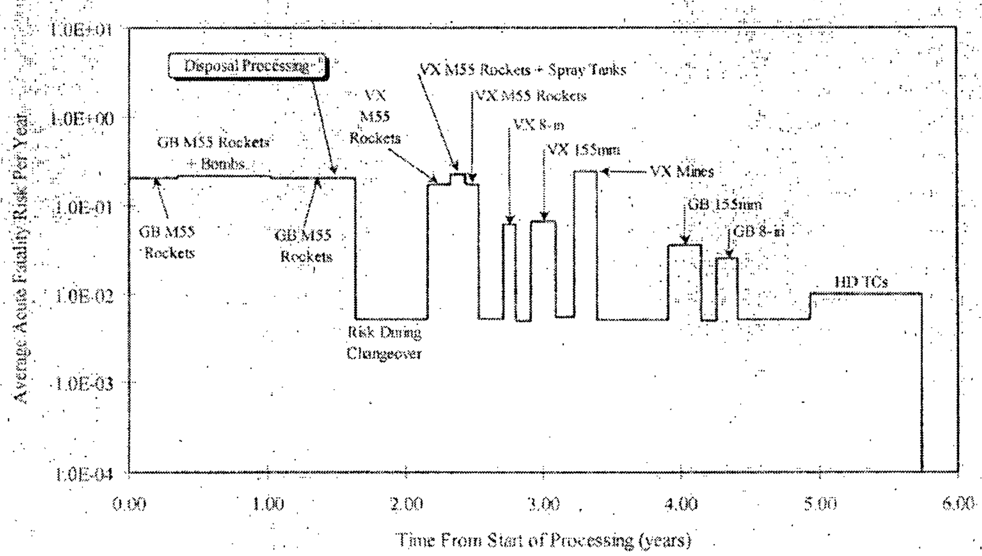


Figure 13-30. Mean Disposal-Related Worker Acute Fatality Risk Rate (per Year) by Campaign for UMCDF Disposal Processing

Box 13-10. Comparing Campaigns

When examining contributors to risk for each campaign, comparisons may be more complex than they would appear on the surface. Two seemingly similar campaigns can have differing recurrence intervals for similar accidents:

1. Some accident frequencies, such as earthquakes and gas explosions, are a function of time; thus, recurrence intervals vary with campaign durations.
2. Some accident frequencies, such as chute jams, are a function of the number of munitions, so recurrence intervals vary with quantities.
3. Consequences are a function of agent type, amount of release, and release type (e.g., explosion, spill), and therefore will vary across campaigns.

for each campaign. The campaigns with the highest risk rates have events that are either unique or more frequent.

Figure 13-31 displays the uncertainty associated with Disposal-Related Worker acute fatality risk for each campaign. As shown in the figure, there is considerable uncertainty associated with most processing campaigns. Conversely, there is little uncertainty (and low risk) associated with campaign changeovers. Because this graph is based on the entire campaign, rather than a risk

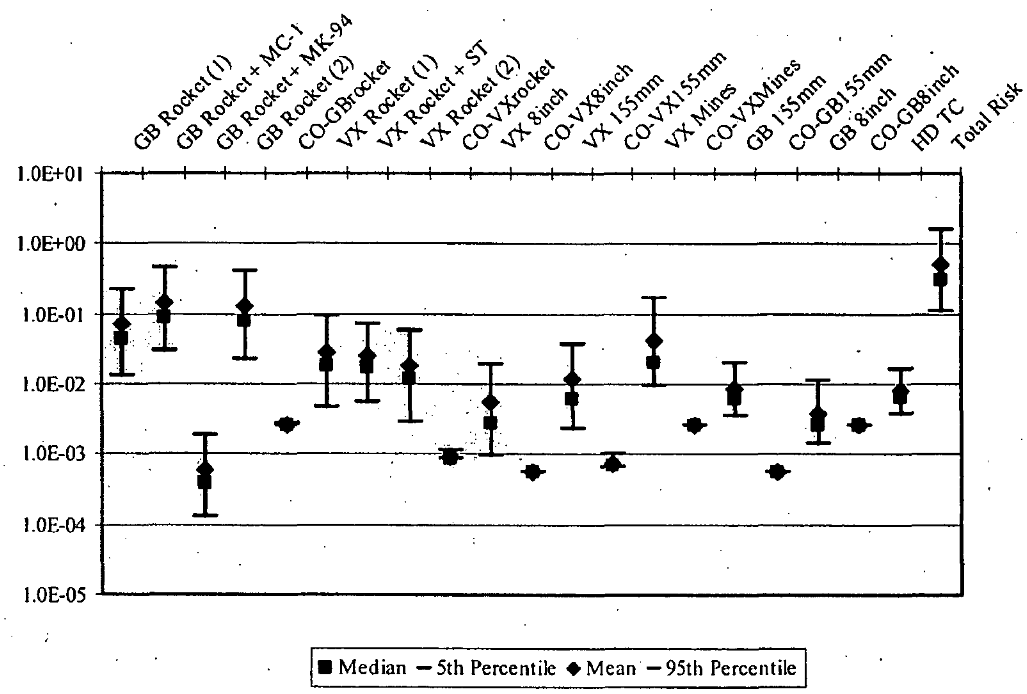


Figure 13-31. Uncertainty in Disposal-Related Worker Acute Fatality Risk by Campaign for UMCDF Disposal Processing

rate per year, differences in risk among campaigns are affected by the number of munitions processed in those campaigns.

13.8.1 GB M55 Rockets (1). Campaign 1a involves the processing of 19,299 GB M55 rockets (approximately 206,499 pounds of GB) and is scheduled to last 18 weeks. The most significant contributor to risk for this campaign is the DFS feed chute jam clearance explosion, which accounts for about 79 percent of the risk. As shown in table 13-29, the remaining risk is due to a variety of possible accidents with contributions of 7 percent or less each. The types of accidents were summarized in section 13.7.

Table 13-29. Disposal-Related Worker Acute Fatality Risk Scenarios for Campaign 1a [GB M55 Rockets (1)] for UMCDF Disposal Processing

Accident Sequence Category	Mean Recurrence Interval	Mean Consequence (Fatalities)	Mean Acute Fatality Risk Over Entire Campaign	Contribution to Campaign 1a Mean Risk
Energetic Initiation During Manual Chute Jam Clearing Operation	18	1.0	5.6×10^{-2}	79%
Building Fire Initiators	800	3.9	4.9×10^{-3}	7%
UPA Handling Accident Resulting in Agent Spill	39	0.1	3.1×10^{-3}	4%
Storage Area Handling Accident Resulting in Fire	2,900	5.9	2.0×10^{-3}	3%
Maintenance-Related Exposure	720	0.9	1.3×10^{-3}	2%
UPA Handling Accident Resulting in Explosion	2,000	2.1	1.0×10^{-3}	2%
Storage Area Handling Accident Resulting in Spill	150	0.1	8.0×10^{-4}	1%
LIC Natural Gas Explosion	570	0.4	7.2×10^{-4}	1%
All Other Scenarios			9.5×10^{-4}	1%
Total Mean Disposal-Related Worker Societal Acute Fatality Risk	–	–	7.1×10^{-2}	100%

13.8.2 GB M55 Rockets with MC-1 Bombs. Campaign 1b involves the co-processing of 37,680 GB M55 rockets (approximately 403,176 pounds of GB) and 2,418 GB MC-1 bombs (approximately 531,960 pounds of GB) and is scheduled to last approximately 35 weeks. As with the previous GB rocket campaign, the most significant contributor to risk for this campaign is the DFS feed chute jam clearance explosion, which accounts for about 77 percent of the risk. As shown in table 13-30, the remaining risk is due to a variety of possible accidents with contributions of 7 percent or less each.

Table 13-30. Disposal-Related Worker Acute Fatality Risk Scenarios for Campaign 1b (GB M55 Rockets and MC-1 Bombs) for UMCDF Disposal Processing

Accident Sequence Category	Mean Recurrence Interval	Mean Consequence (Fatalities)	Mean Acute Fatality Risk Over Entire Campaign	Contribution to Campaign 1b Mean Risk
Energetic Initiation During Manual Chute Jam Clearing Operation	9.3	1.0	0.11	77%
Building Fire Initiators	110	1.2	1.1×10^{-2}	7%
UPA Handling Accident Resulting in Agent Spill	16	0.1	7.5×10^{-3}	5%
Storage Area Handling Accident Resulting in Fire	1,500	5.9	4.0×10^{-3}	3%
Maintenance-Related Exposure	310	0.9	3.0×10^{-3}	2%
UPA Handling Accident Resulting in Explosion	1,000	2.1	2.0×10^{-3}	1%
Storage Area Handling Accident Resulting in Spill	66	0.1	1.9×10^{-3}	1%
LIC Natural Gas Explosion	290	0.4	1.4×10^{-3}	1%
BLEVE	3,700	4.7	1.2×10^{-3}	1%
All Other Scenarios			2.1×10^{-3}	2%
Total Mean Disposal-Related Worker Societal Acute Fatality Risk	–	–	0.14	100%

13.8.3 GB M55 Rockets with GB MK-94 Bombs. Campaign 1c involves the co-processing of 153 GB M55 rockets (approximately 1,637 pounds of GB) and 27 GB MK-94 bombs (approximately 2,916 pounds of GB) and is scheduled to last less than 1 week. As with the previous GB rocket campaigns, the most significant contributor to risk for this campaign is the DFS feed chute jam clearance explosion, which accounts for about 75 percent of the risk. As shown in table 13-31, the remaining risk is due to a variety of possible accidents with contributions of 6 percent or less each.

13.8.4 GB M55 Rockets (2). Campaign 1d involves the processing of 34,310 GB M55 rockets (approximately 367,117 pounds of GB) and is scheduled to last 32 weeks. As with the previous GB rocket campaigns, the most significant contributor to risk for this campaign is the DFS feed chute jam clearance explosion, which accounts for about 79 percent of the risk. As shown in table 13-32, the remaining risk is due to a variety of possible accidents with contributions of 7 percent or less each.

13.8.5 VX M55 Rockets (1). Campaign 2a involves the processing of 6,253 VX M55 rockets (approximately 62,530 pounds of VX) and is scheduled to take about 8 weeks. This campaign

Table 13-31. Disposal-Related Worker Acute Fatality Risk Scenarios for Campaign 1c (GB M55 Rockets and MK-94 Bombs) for UMCDF Disposal Processing

Accident Sequence Category	Mean Recurrence Interval	Mean Consequence (Fatalities)	Mean Acute Fatality Risk Over Entire Campaign	Contribution to Campaign 1c Mean Risk
Energetic Initiation During Manual Chute Jam Clearing Operation	2,300	1.0	4.5×10^{-4}	75%
Building Fire Initiators	28,000	1.0	3.6×10^{-5}	6%
UPA Handling Accident Resulting in Agent Spill	4,000	0.1	3.1×10^{-5}	5%
BLEVE	180,000	3.8	2.2×10^{-5}	4%
Storage Area Handling Accident Resulting in Fire	370,000	5.9	1.6×10^{-5}	3%
Maintenance-Related Exposure	74,000	0.9	1.2×10^{-5}	2%
UPA Handling Accident Resulting in Explosion	250,000	2.1	8.2×10^{-6}	1%
Storage Area Handling Accident Resulting in Spill	16,000	0.1	8.0×10^{-6}	1%
LIC Natural Gas Explosion	72,000	0.4	5.7×10^{-6}	1%
All Other Scenarios			9.8×10^{-6}	2%
Total Mean Disposal-Related Worker Societal Acute Fatality Risk	–	–	6.0×10^{-4}	100%

Table 13-32. Disposal-Related Worker Acute Fatality Risk Scenarios for Campaign 1d [GB M55 Rockets (2)] for UMCDF Disposal Processing

Accident Sequence Category	Mean Recurrence Interval	Mean Consequence (Fatalities)	Mean Acute Fatality Risk Over Entire Campaign	Contribution to Campaign 1d Mean Risk
Energetic Initiation During Manual Chute Jam Clearing Operation	10	1.0	0.10	79%
Building Fire Initiators	450	3.7	8.3×10^{-3}	7%
UPA Handling Accident Resulting in Agent Spill	22	0.1	5.5×10^{-3}	4%
Storage Area Handling Accident Resulting in Fire	1,600	5.9	3.6×10^{-3}	3%
Maintenance-Related Exposure	410	0.9	2.2×10^{-3}	2%
UPA Handling Accident Resulting in Explosion	1,100	2.1	1.9×10^{-3}	2%
Storage Area Handling Accident Resulting in Spill	87	0.1	1.4×10^{-3}	1%
LIC Natural Gas Explosion	320	0.4	1.3×10^{-3}	1%
All Other Scenarios			1.7×10^{-3}	1%
Total Mean Disposal-Related Worker Societal Acute Fatality Risk	–	–	0.13	100%

also is dominated by chute jam explosions (65 percent), but building fire initiators also contribute significantly to risk (22 percent) because of the toxicity of VX compared to GB. Other contributors are similar to the GB rocket campaigns but have slightly higher consequences due to VX toxicity. The dominant sequences are shown in table 13-33. Maintenance-related exposure mean consequences, however, are higher for GB because in the event of a DPE failure, vapor exposure is more likely than contact exposure. In addition, spills of VX are less risk-significant than GB due to the lower volatility of VX.

Table 13-33. Disposal-Related Worker Acute Fatality Risk Scenarios for Campaign 2a [VX M55 Rockets (1)] for UMCDF Disposal Processing

Accident Sequence Category	Mean Recurrence Interval	Mean Consequence (Fatalities)	Mean Acute Fatality Risk Over Entire Campaign	Contribution to Campaign 2a Mean Risk
Energetic Initiation During Manual Chute Jam Clearing Operation	56	1.0	1.8×10^{-2}	65%
Building Fire Initiators	1,700	11	6.2×10^{-3}	22%
Storage Area Handling Accident Resulting in Fire	9,400	10	1.1×10^{-3}	4%
UPA Handling Accident Resulting in Explosion	6,300	5.4	8.6×10^{-4}	3%
LIC Natural Gas Explosion	1,200	0.7	6.0×10^{-4}	2%
Maintenance-Related Exposure	850	0.5	5.9×10^{-4}	2%
ECV Gate Accident Resulting in Explosion	3,800	1.6	4.3×10^{-4}	2%
All Other Scenarios			2.4×10^{-4}	1%
Total Mean Disposal-Related Worker Societal Acute Fatality Risk	–	–	2.8×10^{-2}	100%

13.8.6 VX M55 Rockets with VX Spray Tanks. Campaign 2b involves the co-processing of 4,345 VX M55 rockets (approximately 43,450 pounds of VX) and 156 VX Spray Tanks (approximately 211,536 pounds of VX) and is scheduled to take about 6 weeks. Like the previous VX rocket campaign, this campaign also is dominated by chute jam explosions (49 percent), and building fire initiators also contribute significantly to risk (35 percent) because of the toxicity of VX compared to GB. In this campaign the chute jam risk has dropped slightly and the building fire risk has gone up slightly (on a percentage basis) due to the presence of the spray tanks in this campaign. Other contributors are similar to the GB rocket campaigns but have slightly higher consequences due to VX toxicity. The dominant sequences are shown in table 13-34. Maintenance-related exposure mean consequences, however, are higher for GB because in the event of a DPE failure, vapor exposure is more likely than contact exposure. In addition, spills of VX are less risk-significant than GB due to the lower volatility of VX.

Table 13-34. Disposal-Related Worker Acute Fatality Risk Scenarios for Campaign 2b (VX M55 Rockets and Spray Tanks) for UMCDF Disposal Processing

Accident Sequence Category	Mean Recurrence Interval	Mean Consequence (Fatalities)	Mean Acute Fatality Risk Over Entire Campaign	Contribution to Campaign 2b Mean Risk
Energetic Initiation During Manual Chute Jam Clearing Operation	81	1.0	1.3×10^{-2}	49%
Building Fire Initiators	680	6.0	8.9×10^{-3}	35%
Storage Area Handling Accident Resulting in Fire	13,000	10	7.6×10^{-4}	3%
UPA Handling Accident Resulting in Explosion	9,100	5.2	5.8×10^{-4}	2%
Agent Vapor Explosion in the MPF	1,900	1.0	5.1×10^{-4}	2%
Maintenance-Related Exposure	1,000	0.5	5.0×10^{-4}	2%
UPA Handling Accident Resulting in Spill	100	0.04	4.2×10^{-4}	2%
LIC Natural Gas Explosion	1,700	0.7	4.2×10^{-4}	2%
ECV Gate Accident Resulting in Explosion	5,400	1.6	2.9×10^{-4}	1%
All Other Scenarios			5.8×10^{-4}	2%
Total Mean Disposal-Related Worker Societal Acute Fatality Risk	–	–	2.6×10^{-2}	100%

13.8.7 VX M55 Rockets (2). Campaign 2c involves the processing of 3,921 VX M55 rockets (approximately 39,210 pounds of VX) and is scheduled to take about 5 weeks. Like the first VX rocket campaign, this campaign also is dominated by chute jam explosions (64 percent) and building fire initiators (22 percent). The dominant sequences are shown in table 13-35.

13.8.8 VX 8-inch Projectiles. Campaign 3 involves the processing of 3,752 VX 8-inch projectiles (approximately 54,404 pounds of VX). This is scheduled to take approximately 5 weeks. The most significant contributor to risk for this campaign is building fires, which account for about 79 percent of the risk. As shown in table 13-36, the remaining risk is due to a variety of possible accidents with contributions of 7 percent or less each. The types of accidents were summarized in section 13.7. Chute jam explosions do not appear in table 13-36 because jams resulting from projectile energetics are much less likely to occur than rockets and have lower probabilities of energetic initiation. Because chute jams are less important, other contributors are more evident, such as furnace explosions and collapse of the CHB/UPA due to an earthquake.

13.8.9 VX 155mm Projectiles. Campaign 4 involves the processing of 32,313 VX 155mm projectiles (approximately 203,572 pounds of VX) in a campaign scheduled to last about 9 weeks. The most significant contributor to risk for this campaign are building fires, which

Table 13-35. Disposal-Related Worker Acute Fatality Risk Scenarios for Campaign 2c [VX M55 Rockets (2)] for UMCDF Disposal Processing

Accident Sequence Category	Mean Recurrence Interval	Mean Consequence (Fatalities)	Mean Acute Fatality Risk Over Entire Campaign	Contribution to Campaign 2c Mean Risk
Energetic Initiation During Manual Chute Jam Clearing Operation	90	1.0	1.1×10^{-2}	64%
Building Fire Initiators	2,700	11	4.0×10^{-3}	22%
Storage Area Handling Accident Resulting in Fire	15,000	10	6.8×10^{-4}	4%
UPA Handling Accident Resulting in Explosion	10,000	5.4	5.4×10^{-4}	3%
LIC Natural Gas Explosion	1,900	0.7	3.8×10^{-4}	2%
Maintenance-Related Exposure	1,300	0.5	3.7×10^{-4}	2%
ECV Gate Accident Resulting in Explosion	6,000	1.6	2.7×10^{-4}	2%
All Other Scenarios			1.5×10^{-4}	1%
Total Mean Disposal-Related Worker Societal Acute Fatality Risk	–	–	1.8×10^{-2}	100%

Table 13-36. Disposal-Related Worker Acute Fatality Risk Scenarios for Campaign 3 (VX 8-inch Projectiles) for UMCDF Disposal Processing

Accident Sequence Category	Mean Recurrence Interval	Mean Consequence (Fatalities)	Mean Acute Fatality Risk Over Entire Campaign	Contribution to Campaign 3 Mean Risk
Building Fire Initiators	960	4.2	4.3×10^{-3}	79%
Maintenance-Related Exposure	1,200	0.5	4.1×10^{-4}	7%
LIC Natural Gas Explosion	2,200	0.7	3.4×10^{-4}	6%
Furnace Munition Explosion	1,400	0.4	2.5×10^{-4}	5%
Collapse of the CHB/UPA due to Seismic Event	150,000	12.2	8.0×10^{-4}	2%
All Other Scenarios			7.5×10^{-5}	1%
Total Mean Disposal-Related Worker Societal Acute Fatality Risk	–	–	5.5×10^{-3}	100%

account for about 74 percent of the risk. As shown in table 13-37, the remaining risk is due to a variety of possible accidents with contributions of 6 percent or less each. Chute jam explosions are smaller contributors to Disposal-Related Worker risk compared to the rockets, because jams resulting from projectile energetics are much less likely to occur and have lower probabilities of

Table 13-37. Disposal-Related Worker Acute Fatality Risk Scenarios for Campaign 4 (VX 155mm Projectiles) for UMCDF Disposal Processing

Accident Sequence Category	Mean Recurrence Interval	Mean Consequence (Fatalities)	Mean Acute Fatality Risk Over Entire Campaign	Contribution to Campaign 4 Mean Risk
Building Fire Initiators	500	4.2	8.5×10^{-3}	74%
Furnace Munition Explosion	430	0.3	7.1×10^{-4}	6%
LIC Natural Gas Explosion	1,100	0.7	6.6×10^{-4}	6%
Maintenance-Related Exposure	720	0.5	7.0×10^{-4}	6%
Storage Area Handling Accident Resulting in Fire	15,000	5.7	3.8×10^{-4}	3%
Energetic Initiation During Manual Chute Jam Clearing Operation	4,400	1.0	2.3×10^{-4}	2%
Collapse of the CHB/UPA due to Seismic Event	79,000	12.2	1.6×10^{-4}	1%
Special DPE Entry Leads to Exposure	7,100	0.5	7.0×10^{-5}	1%
All Other Scenarios			1.7×10^{-4}	1%
Total Mean Disposal-Related Worker Societal Acute Fatality Risk	–	–	1.2×10^{-2}	100%

energetic initiation. Because chute jams are less important, a new contributor, special DPE entry leads to exposure, is evident.

13.8.10 VX Land Mines. The 11,685 VX land mines (approximately 122,693 pounds of VX) are scheduled for disposal over an approximately 9-week period in campaign 5. The dominant events of this campaign, shown in table 13-38, are handling accidents that lead to explosions (47 percent and 34 percent). As shown in table 13-38, the remaining risk is due to a variety of possible accidents with contributions of 6 percent or less each.

13.8.11 GB 155mm Projectiles. Campaign 6 involves the processing of 47,406 GB 155mm projectiles (approximately 308,139 pounds of GB) and is scheduled to last approximately 12 weeks. The dominant events of this campaign, shown in table 13-39, are building fires (38 percent), storage area handling accidents that result in spill (14 percent), maintenance-related exposures (11 percent), and UPA handling accident that results in spill (10 percent). As shown in table 13-39, the remaining risk is due to a variety of possible accidents with contributions of 6 percent or less each. New sequences that appear involve HVAC agent migration (3 percent), HVAC failure (1 percent), and seismic-induced fire (1 percent).

13.8.12 GB 8-inch Projectiles. Campaign 7 accounts for the processing of 14,246 GB 8-inch projectiles (approximately 206,567 pounds of GB). This is scheduled to take approximately

Table 13-38. Disposal-Related Worker Acute Fatality Risk Scenarios for Campaign 5 (VX Mines) for UMCDF Disposal Processing

Accident Sequence Category	Mean Recurrence Interval	Mean Consequence (Fatalities)	Mean Acute Fatality Risk Over Entire Campaign	Contribution to Campaign 5 Mean Risk
UPA Handling Accident Resulting in Explosion	210	4.0	1.9×10^{-2}	47%
Leaker Handling Accident Resulting in Explosion in ECV	150	2.2	1.4×10^{-2}	34%
Furnace Munition Explosion	82	0.2	2.5×10^{-3}	6%
Building Fire Initiators	6,700	7.1	1.1×10^{-3}	3%
Storage Area Handling Accident Resulting in Fire	5,600	5.7	1.0×10^{-3}	3%
EONC Handling Accident Resulting in Explosion in CHB/UPA	12,000	12	1.0×10^{-3}	3%
LIC Natural Gas Explosion	1,200	0.7	6.3×10^{-4}	2%
Maintenance-Related Exposure	820	0.5	6.1×10^{-4}	1%
ECR Gate Accident Resulting in Explosion	0.29	0.0001	5.1×10^{-4}	1%
All Other Scenarios			3.3×10^{-4}	<1%
Total Mean Disposal-Related Worker Societal Acute Fatality Risk	–	–	4.1×10^{-2}	100%

8 weeks. The dominant events of this campaign, shown in table 13-40, are building fires (48 percent), maintenance-related exposures (18 percent), and furnace and LIC explosions (9 percent and 8 percent, respectively). As shown in table 13-40, the remaining risk is due to a variety of possible accidents with contributions of 3 percent or less each.

13.8.13 HD Ton Containers. The 2,635 HD ton containers (approximately 4,479,500 pounds of HD) are scheduled for disposal in campaign 8. The dominant events of this campaign, shown in table 13-41, are maintenance-related exposures (37 percent), building fires (26 percent), and LIC explosions (16 percent). As shown in table 13-31, the remaining risk is due to a variety of possible accidents with contributions of 6 percent or less each.

13.9 Sensitivity Studies

13.9.1 Effects of Emergency Protective Actions on Public Fatality Risk Estimates. The results presented in previous sections represent the base case risk and credit emergency planning for protective actions. See section 11 for details on protective actions used in the QRA. This protective action model is applied consistently for all accidents in the QRA. As a sensitivity

Table 13-39. Disposal-Related Worker Acute Fatality Risk Scenarios for Campaign 6 (GB 155mm Projectiles) for UMCDF Disposal Processing

Accident Sequence Category	Mean Recurrence Interval	Mean Consequence (Fatalities)	Mean Acute Fatality Risk Over Entire Campaign	Contribution to Campaign 6 Mean Risk
Building Fire Initiators	360	1.2	3.2×10^{-3}	38%
Storage Area Handling Accident Resulting in Spill	110	0.1	1.2×10^{-3}	14%
Maintenance-Related Exposure	960	0.9	9.5×10^{-4}	11%
UPA Handling Accident Resulting in Spill	150	0.1	8.3×10^{-4}	10%
LIC Natural Gas Explosion	820	0.4	5.0×10^{-4}	6%
Storage Area Handling Accident Resulting in Fire	10,000	4.9	4.8×10^{-4}	6%
Energetic Initiation During Manual Chute Jam Clearing Operation	3,000	1.0	3.4×10^{-4}	4%
Furnace Munition Explosion	1,200	0.3	2.5×10^{-4}	3%
HVAC Agent Migration	170	0.03	1.8×10^{-4}	3%
Collapse of the CHB/UPA due to Seismic Event	66,000	9.8	1.5×10^{-4}	2%
Special DPE Entry Leads to Exposure	8,700	0.9	1.0×10^{-4}	1%
HVAC Failure	47	0.004	8.6×10^{-5}	1%
Seismic-Induced Fire	170,000	12.7	7.7×10^{-5}	1%
All Other Scenarios			1.1×10^{-4}	1%
Total Mean Disposal-Related Worker Societal Acute Fatality Risk	–	–	8.4×10^{-3}	100%

study, the QRA was quantified assuming no protective action of the surrounding population, and a continuation of normal activity by the public.

Figure 13-32 presents the basic results for the no protective action calculations. The plot in figure 13-32 contains the distribution of the public acute fatality societal risk for the no protective action case, as well as the mean curve from figure 13-1 (for the protective action case) reproduced for comparison. As can be seen from the comparison, protective action causes significant decrease in the risks to the public from accidents at UMCDF. Without protective action, the mean probability of one or more fatalities increases from 4.7×10^{-4} to 1.1×10^{-3} (a factor of 2 increase). The area under the "no protective action" curve is 8.5×10^{-2} compared with 5.3×10^{-3} of the baseline case, indicating that protective action reduces public acute fatality risk during disposal processing by a factor of 16.

13.9.2 Toxicity Sensitivity Study Results for Disposal Processing. At the request of the expert panel, a set of sensitivity studies has been developed to cover a range of toxicity values.

Table 13-40. Disposal-Related Worker Acute Fatality Risk Scenarios for Campaign 7 (GB 8-inch Projectiles) for UMCDF Disposal Processing

Accident Sequence Category	Mean Recurrence Interval	Mean Consequence (Fatalities)	Mean Acute Fatality Risk Over Entire Campaign	Contribution to Campaign 7 Mean Risk
Building Fire Initiators	580	1.0	1.8×10^{-3}	48%
Maintenance-Related Exposure	1,300	0.9	6.9×10^{-4}	18%
Furnace Munition Explosion	1,100	0.4	3.3×10^{-4}	9%
LIC Natural Gas Explosion	1,300	0.4	3.1×10^{-4}	8%
HVAC Agent Migration	220	0.03	1.1×10^{-4}	3%
Storage Area Handling Accident Resulting in Spill	1,100	0.1	1.1×10^{-4}	3%
Collapse of the CHB/UPA due to Seismic Event	91,000	10	1.1×10^{-4}	3%
UPA Handling Accident Resulting in Spill	2,000	0.1	6.2×10^{-5}	2%
Energetic Initiation During Manual Chute Jam Clearing Operation	17,000	1.0	5.7×10^{-5}	2%
Special DPE Entry Leads to Exposure	16,000	0.9	5.5×10^{-5}	1%
HVAC Failure	74	0.004	5.4×10^{-5}	1%
Seismic-Induced Fire	620,000	16	2.6×10^{-5}	1%
All Other Scenarios			4.5×10^{-5}	1%
Total Mean Disposal-Related Worker Societal Acute Fatality Risk	–	–	3.7×10^{-3}	100%

The toxicity values are used as input to the dispersion model. The intent of these sensitivities was to ascertain if other risk drivers are present that were not identified as a result of using baseline toxicity values. For more information regarding the sensitivity study case inputs, see section 11.7.3.

As stated previously, baseline toxicities have not changed from the U.S. Army's currently accepted values, but to meet the goal of having a comprehensive QRA including uncertainty, alternative toxicities were used in sensitivity studies. Results from the sensitivities are used primarily to identify any new risk scenarios needing risk management attention. This approach will ensure that the entire range of risk drivers is identified and addressed as part of the QRA process. Table 13-42 presents the risk results of the toxicity sensitivities for disposal processing. Figure 13-33 illustrates the CCDFs for the sensitivity cases. As with the results in the table, the numerical estimates of risk are quite sensitive to the uncertainty in the toxicology.

It is obvious from this sensitivity study that the toxicity values have a tremendous impact on the numerical estimate of risk; however, it does not change the contributors to risk. The risk

Table 13-41. Disposal-Related Worker Acute Fatality Risk Scenarios for Campaign 8 (HD Ton Containers) for UMCDF Disposal Processing

Accident Sequence Category	Mean Recurrence Interval	Mean Consequence (Fatalities)	Mean Acute Fatality Risk Over Entire Campaign	Contribution to Campaign 8 Mean Risk
Maintenance-Related Exposure	3.7	0.01	3.0×10^{-3}	37%
Building Fire Initiators	110	0.2	2.0×10^{-3}	26%
LIC Natural Gas Explosion	240	0.3	1.3×10^{-3}	16%
BLEVE	7,800	3.9	5.1×10^{-4}	6%
Special DPE Entry Leads to Exposure	48	0.01	2.3×10^{-4}	3%
Collapse of the CHB/UPA due to Seismic Event	20,000	4.3	2.2×10^{-4}	3%
Agent Vapor Explosion	310	0.1	2.0×10^{-4}	2%
Seismic-Induced Fire	49,000	9.0	1.8×10^{-4}	2%
Natural Gas Explosion in the MPF	7,400	1.1	1.5×10^{-4}	2%
Natural Gas Explosion in the MPF Afterburner	8,500	1.1	1.3×10^{-4}	2%
All Other Scenarios			4.2×10^{-5}	1%
Total Mean Disposal-Related Worker Societal Acute Fatality Risk	–	–	8.0×10^{-3}	100%

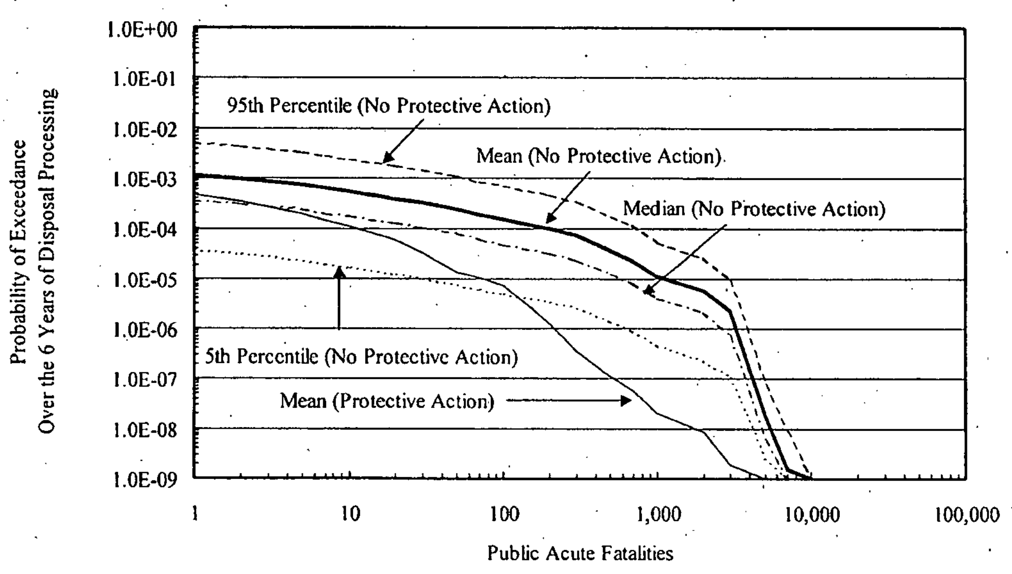


Figure 13-32. Comparison of Public Acute Fatality Risk With and Without Protective Actions for UMCDF Disposal Processing

Table 13-42. Total Public Societal Acute Fatality Mean Risk of Disposal Processing for Varying Toxicity Values

	Risk Results (per lifetime of the facility)				
	Baseline (case 1)[a]	Sensitivity (case 2)[a]	Sensitivity (case 3)[a]	Sensitivity (case 4)[a]	Sensitivity (case 5)[a]
Disposal Processing	5×10^{-3}	2×10^{-2}	2×10^{-1}	1	2

Note:

[a] Toxicity sensitivity cases are defined in detail in section 11.7.3.

contributors resulting from the sensitivity studies are the same as the baseline contributors. However, the sensitivity results do show the large amount of uncertainty associated with toxicity values.

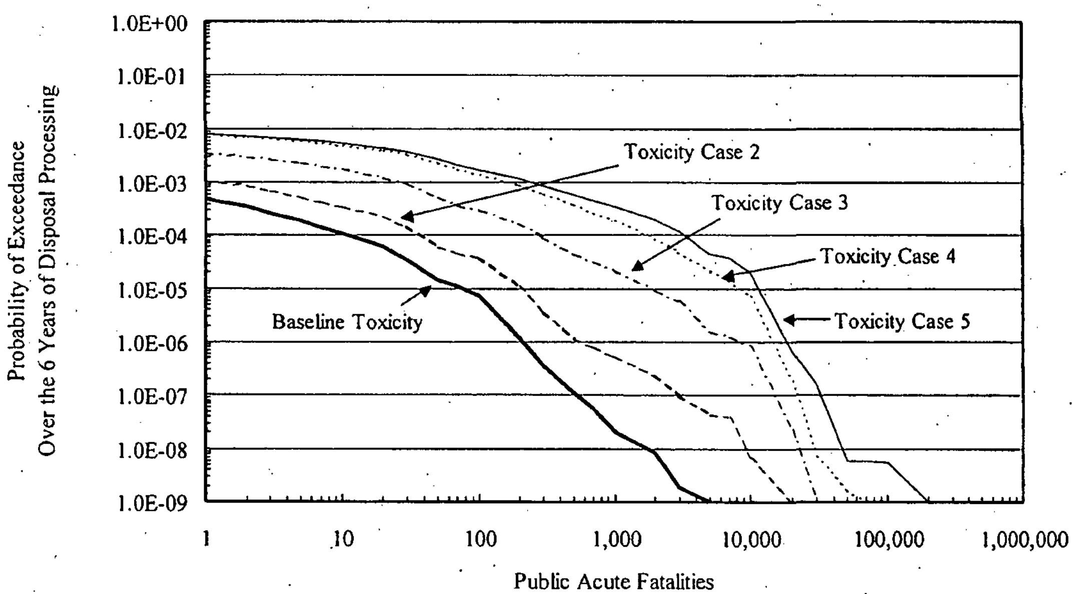


Figure 13-33. Risk Results with Varying Toxicity Values for Disposal Processing

SECTION 14
ANALYSIS OF THE RISK OF THE STOCKPILE STORAGE AREA

This section describes the accident analysis performed to evaluate the public risk of the chemical munition storage at UMCD. Two principal contributions to storage risk were evaluated in this study: 1) external events (primarily earthquake, severe weather, and aircraft crash) and 2) internal events (primarily rocket autoignition and routine maintenance and handling). Routine maintenance and handling includes activities performed in the stockpile storage area, such as surveillance monitoring and containerization of leaking munitions. Reconfiguration of cartridges, as well as complete consideration of the effects of future aging of the munitions, was not within the scope of this analysis.

14.1 Umatilla Chemical Depot Stockpile

Section 3 provides information on the general location of the UMCD stockpile, the characteristics of the munitions considered in this study, and a description of how the munitions are stored in igloos. This section will provide more detail on the arrangement of the stockpile and the igloos located there.

Figure 14-1 shows the locations of the igloos in the UMCD stockpile. Figures 14-2 and 14-3 show the two igloo storage areas, K-Block and I-Block. The rockets, projectiles, mines, and spray tanks are stored in K-Block. The ton containers are stored in I-Block. Within the stockpile area at Umatilla, all munitions are stored in earth-covered 80-foot long concrete igloos (figure 14-4). There are 113 igloos at Umatilla used to store chemical munitions. An igloo is an arched-ceiling storage building covered by several feet of earth. The igloos are constructed of reinforced concrete and have steel doors. The storage igloos also have a lightning protection system. There is passive ventilation in the form of both louvered vents in the front concrete face or in the door, as well as a single ventilation stack penetrating the earthen cover at the rear of the igloos. The igloos are designed to prevent water entry but include drain lines to the outside.

Chemical munitions are stored in configurations generally suitable for transport. These configurations include boxes, protective tubes, metal overpacks, and pallets. The pallet configurations are specific to the individual munition types. Aisles are maintained in the igloos so that units in each stack can be inspected, inventoried, and removed for shipment or maintenance as necessary.

Routine activities associated with chemical agent storage consist of inspection and annual inventory of the munitions. When inspected, both the munitions and the storage structure

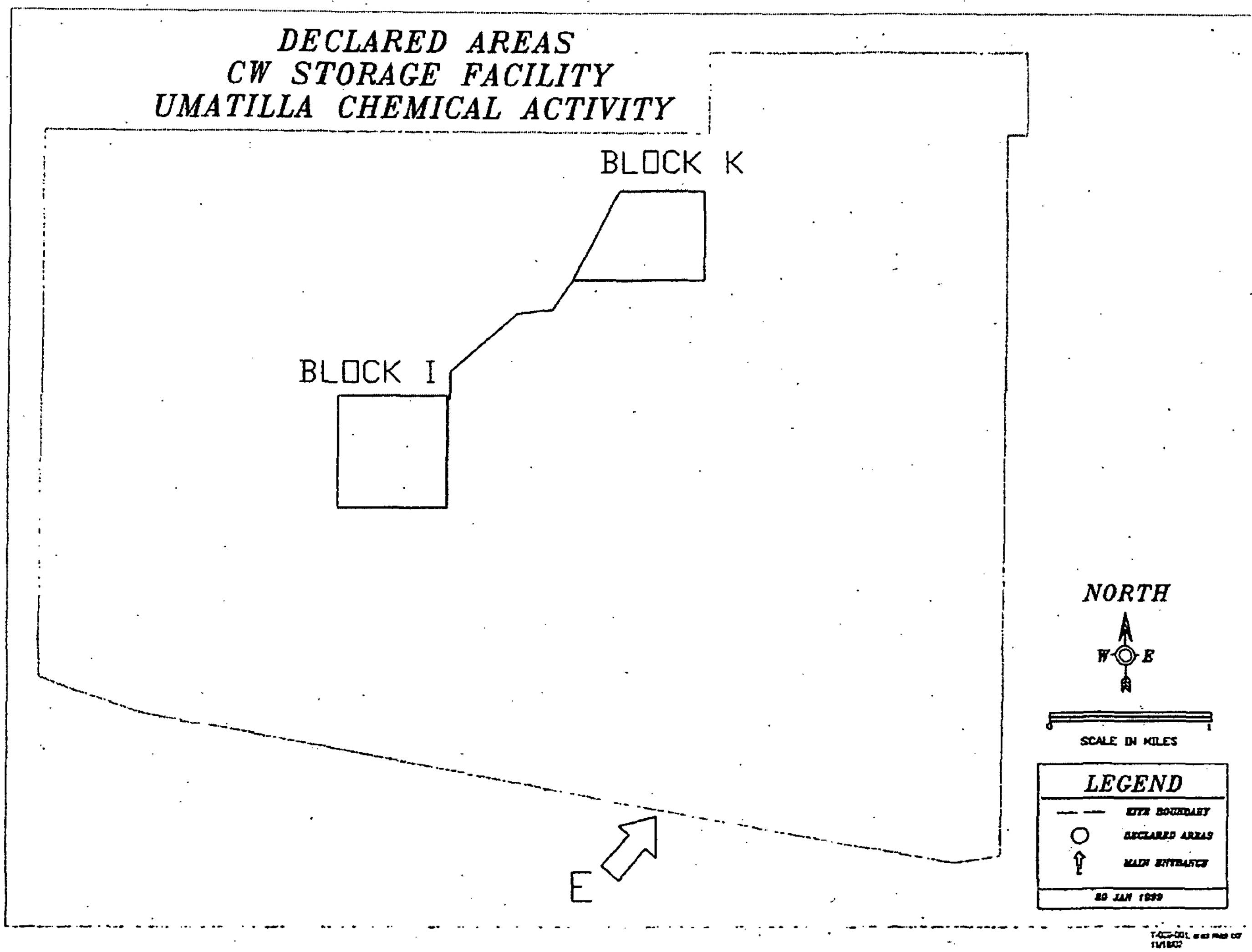


Figure 14-1. Umatilla Igloo Storage Areas

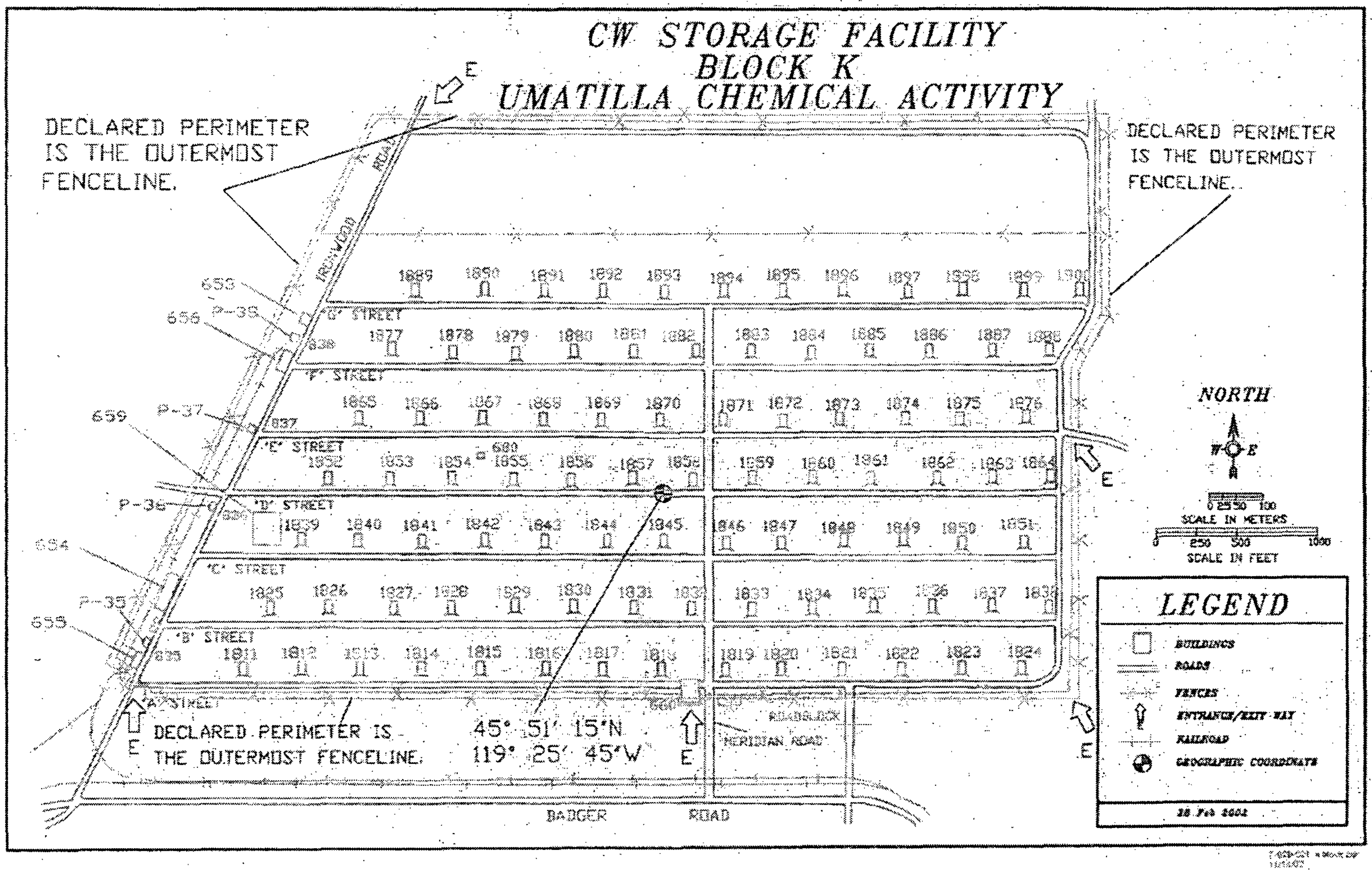


Figure 14-2. Umatilla K-Block Storage Area

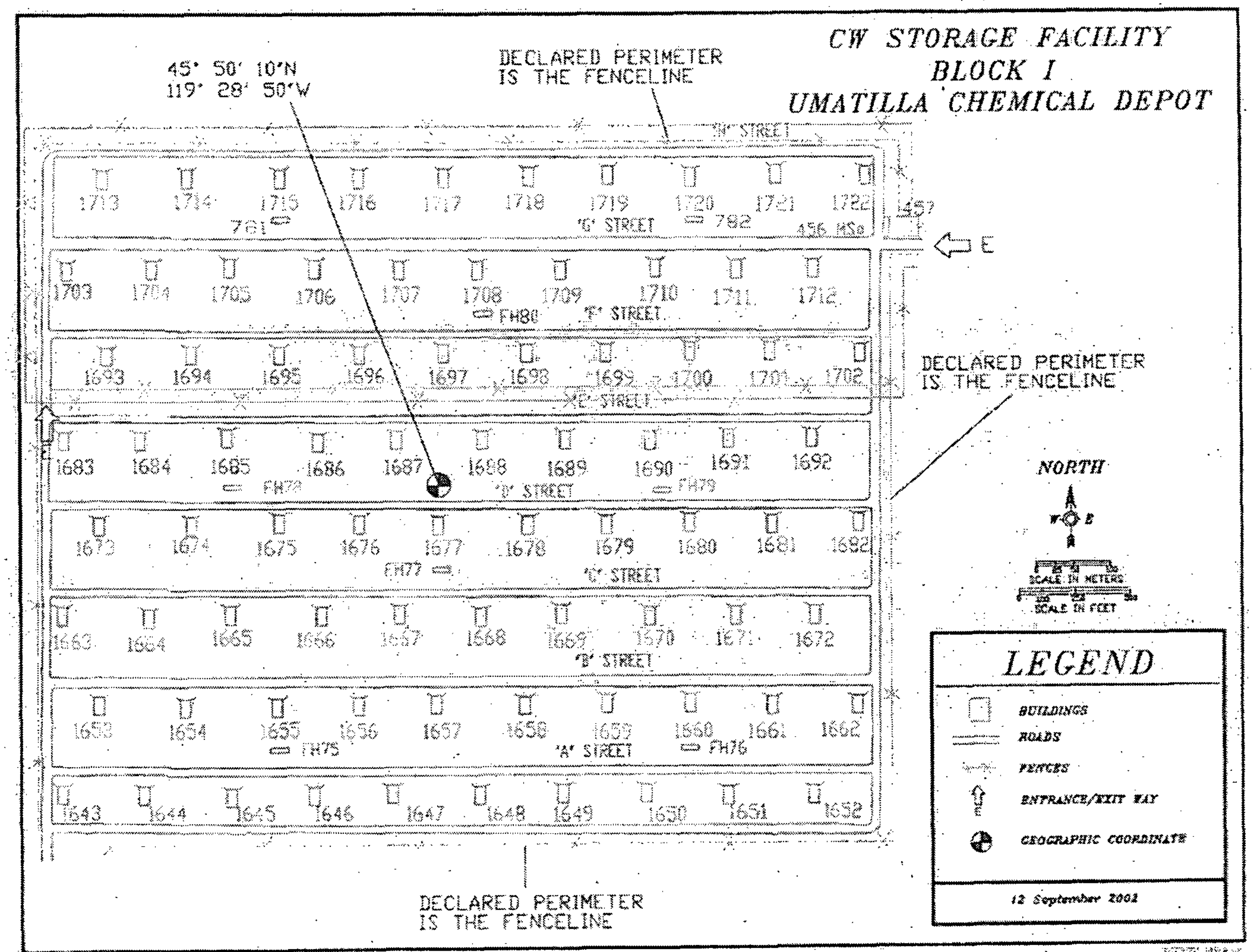


Figure 14-3. Umatilla I-Block Storage Area.

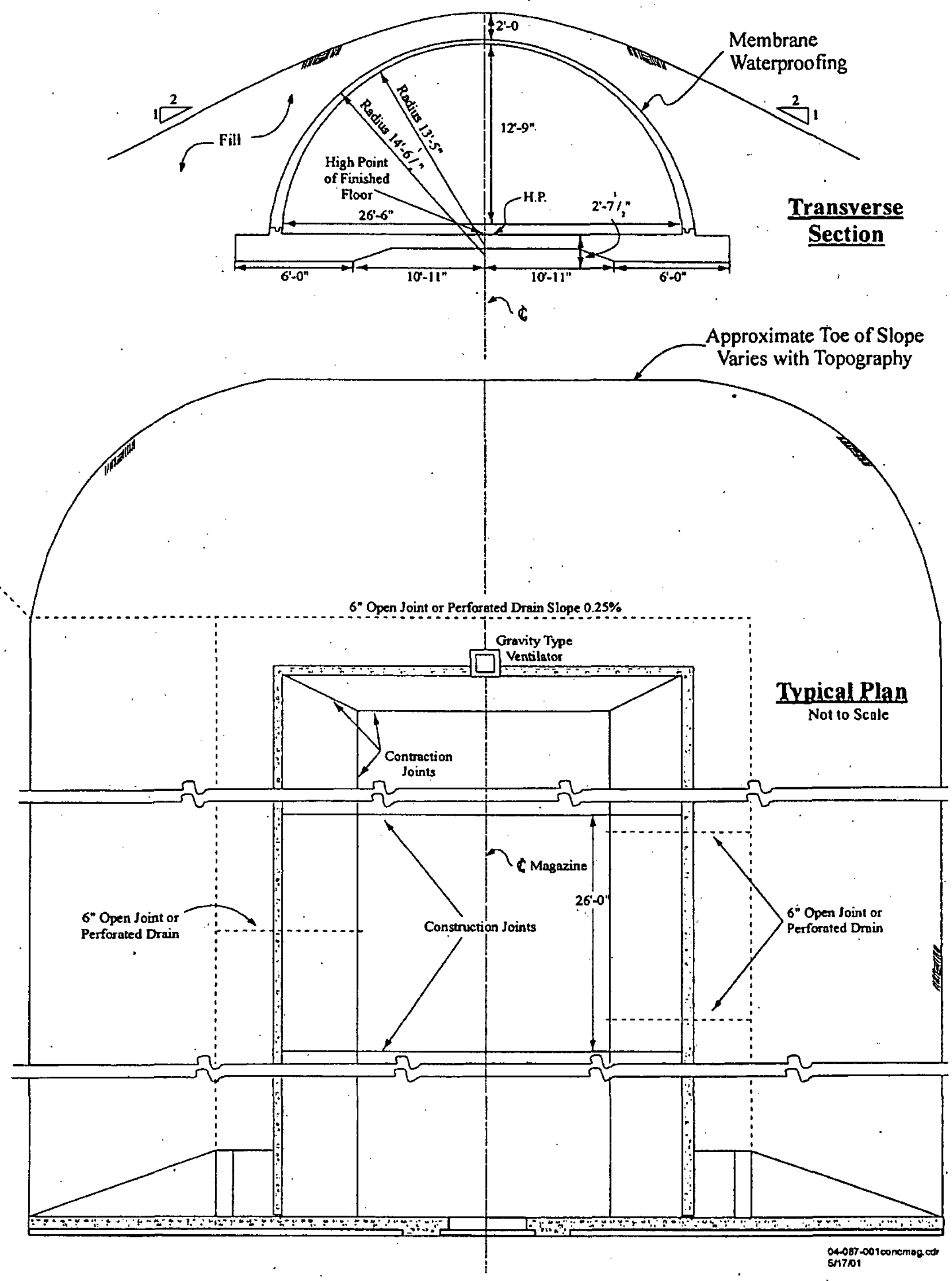


Figure 14-4. Concrete 80-foot Igloo

are visually examined, and the air inside is monitored for the presence of agent. When agent is detected in an igloo, special procedures are followed. These procedures involve identification of the specific munitions that are leaking, removal of those munitions from the pallets or boxes in which they are stored, and simultaneous decontamination of the individual munition, adjacent munitions, and other contaminated areas. The munition is placed into a steel overpack designed to provide vapor and liquid containment (even if the munition continues to leak) and is stored in a separate storage igloo.

Section 5.1 discusses the potential for stacks of munitions to topple in seismic events, potentially causing leaks or explosions of munitions. The seismic fragilities of these stacks vary by the type of munition, configuration of the stacks and pallets, and igloo size because the igloos are packed differently (stacking configurations are discussed in section 3, section 14.4, and appendix H). The fragilities for toppling stacks and collapsing structures are used in unique ways in this analysis, as will be discussed in section 14.2.1.

The following sections will describe the analyses of initiating events that may impact the structures within the storage area and the munitions that they contain. External events such as seismic events and lightning strikes are more important to the storage area risk (as will be discussed in section 15), so they are discussed first. Then, accidents initiated by internal events, such as autoignition and handling accidents, will be presented.

14.2 Stockpile Storage Area External Events

As described in section 5, the analysis of external events requires the use of specialized methods to address important factors not usually encountered in the analysis of internal events. The lists of external events evaluated for applicability to UMCDF were also evaluated for applicability to stockpile storage. In addition, the methodology and criteria used to screen external events at UMCDF, also were used for stockpile storage. For each external event that was not screened, the following subtasks were performed: 1) characterization of the hazard in terms of frequency of occurrence and intensity level, 2) identification of vulnerabilities of structures to the external hazard, 3) development of models to identify and assess various accident sequences that may result from the external event, and 4) quantification of the models to determine risk due to the external event.

External events are potentially significant contributors to the risk associated with munition storage. The external events considered for the storage operation included seismic events, lightning, tornadoes and high winds, and aircraft crashes. Other external events, such as external fires, hail and ice storms, landslides, and high and low temperatures (as listed in table 5-1), would have no effect on storage inside the igloos. The following sections discuss the methods used for performing these analyses for the external events considered applicable to the UMCD stockpile storage area.

14.2.1 Seismic Initiating Events. This section describes the seismic analysis performed for the stockpile storage area. The seismic hazard for UMCD is described in section 5.1.1. An overview of the structural and equipment fragility analysis performed for UMCDF is described in section 5.1.2. In addition to components and structures at the UMCDF, fragilities were evaluated for munitions and igloos in the stockpile storage area. Munitions falling from storage configurations were considered the primary event to be caused by a seismic event in the storage yard.

Seismic fragilities were developed for the oval-arch concrete igloo structure and for tipping or sliding of stacked munitions in storage (S&A, 2000y). The purpose of the seismic fragility analysis was to estimate the capacity of structures and equipment at UMCDF and the igloo storage area in terms of PGA. As described in section 5.2, the seismic fragility of an individual component (structure or equipment item) is defined as the conditional probability of failure for given levels of ground motion normalized to a PGA value. The assessment of the seismic fragility of a component is based on its seismic design basis, if any, the factors of safety incorporated in the design process, the variability in earthquake ground motion, and factors that influence structure response.

Stevenson and Associates (S&A) assessed the design and construction of the igloos at Umatilla based on drawings provided by UMCD. The UMCD igloos are constructed of reinforced concrete, which yields a relatively strong median capacity. S&A calculated cracking of these igloos at a median ground acceleration (g)-level of 1.41 g. Although S&A did not continue their calculations to complete igloo collapse, based on their past experience with similar structures, they estimated that igloo collapse would occur at 20 to 30 percent higher earthquake intensity. For that reason, a median igloo collapse fragility of 1.69 g was assumed.

The stability of munition pallets in igloos also was assessed. Stack height and the typical configuration of the different munitions in storage were taken from U.S. Army storage drawings (USAMC, 1976a, b, 1992). Because the pallets may slide on the concrete floor, the fragility of the munition stacks was controlled by the friction between wood on concrete or wood on wood, whichever was smaller. The static coefficient of friction between wood and wood was found to be smaller. The median capacity for the pallets sliding in storage was calculated to be 0.6 g for rockets, 0.24 g for 155mm projectiles, 0.44 g for 8-inch projectiles, 0.76 g for all bombs and mines, and 0.6 g for ton containers.

Seismic sequences for the stockpile storage area were evaluated similarly to the evaluation for UMCDF. Earthquake sizes were categorized into levels representing the seismic hazard at the site (as defined in section 5) and ensuring coverage of the median capacity g-levels for the stability of the munitions in the stockpile.

In seismic risk assessments for facilities such as commercial nuclear power plants (and, in fact, for the analysis of UMCDF), the analyst is often faced with modeling a situation where only one of a group of components located in a room is required to provide a particular safety function. Typically these components are the same in all respects, have been anchored to the floor or foundation slab in the same manner, and are close spatially, but still physically separated (i.e., they do not interact) throughout the room. As discussed in appendix H, this is very different from the circumstances involving the performance of stacks of pallets.

In a typical component-based seismic systems analysis, the responses of multiple identical components in a single area are assumed to be completely coupled (i.e., if an earthquake would cause one of the components to fail, then all the identical components in the same area were assumed to fail). This interpretation is generally believed to be a reasonable, but conservative, assumption. In this case, the seismic fragility analyst simply estimates the fragility of one component, because the response of the other components is expected to be the same as the analyzed component. This is reasonable because these components are built of the same materials, are anchored the same, experience the same seismic motion, and respond to this motion identically (assuming that they do not interact with each other).

In the analysis of the stockpile, however, there are hundreds or thousands of individual "identical" igloos and munition stacks spread out over more than 1 square mile of land area. The standard approach to fragility analysis would model stacks of the same munition type as being completely dependent in their failure. This would mean that if there were 10 igloos filled with a specific type of munition stack, and 100 stacks in each igloo, then the fragility of the stacks at a g-level would predict that either none of the stacks would fall (with some probability), or that all of the stacks would fall (all 1,000 of them) with one minus the none-fall probability. It is believed, however, that this approach would be unrealistic. Thus, the conservative assumption of complete dependence used in most previous QRAs for small numbers of like components was judged to be overly conservative for this particular analysis.

Before proceeding further, it is worthwhile to consider what the prototypic condition is. In an igloo there is a matrix (rows and columns) of munition stacks. With the exception of the border stacks (around the perimeter of the matrix), a prototypic stack is one surrounded by other stacks. Due to variations in stacking of pallets one on top of the other, and in the placement of stacks next to each other, the physical arrangement of a given stack to its neighbors varies (i.e., is somewhat independent). Note, they are not totally independent because they may have the same number of pallets in a stack, pallets are made of the same material, etc. When earthquake ground motion occurs, stacks will interact as their response displacements increase (i.e., they knock into each other), and this interaction will increase as the level of motion increases. This interaction produces a physical interference, limiting the range of stack movement. The stacks most likely to topple are those along the free borders of the matrix (i.e., those on aisles).

In the current QRA model, fragilities are used as percentages of the pallet stacks that fall in an igloo, or of igloos of a specific condition that fail. Thus, for an earthquake of an acceleration equal to the median capacity of some type of munition stack in an igloo, 50 percent of the stacks of munitions in that igloo are assumed to topple. For an earthquake with an acceleration equal to the 5th-percentile capacity of a particular type of munition stack in an igloo, 5 percent of the stacks of munitions in that igloo are modeled to topple. If there are two or more igloos with the same type of munitions and same stacking configuration, then the results for each igloo are assumed to be completely coupled (i.e., if 50 percent of the stacks in one igloo of rockets fall, then 50 percent of the stacks in all rocket igloos fall).

There is also a further consideration in the analysis. For each igloo/stack configuration, the arrangement was examined to determine how many of the pallets in the stacks could physically fall, given that the volume in the igloo is fixed. In other words, after a certain number of stacks fall, there is no room for any additional toppling (the former aisleways are now filled with toppled pallets).

The munition stack fragilities for this analysis are derived assuming a single stack of each type of munition is individually placed in the center of the igloo and subjected to earthquake motion. Both rocking and sliding responses of the stacks are considered, but sliding is dominated by rocking at UMCD. In this idealized model, interaction of the stack with igloo walls or other stacks is not considered. Thus, the model is obviously very simplified relative to the actual configurations in the igloos. However, considering the detailed response of a hundred or more stacks and their interactions is not possible.

The TOCDF and UMCDF QRA Expert Panels expressed concern that this modeling approach was: 1) different from what has been used in QRAs in the past; and 2) potentially inconsistent with the theory behind the development of the fragility methodology. The reasons for the difference from past interpretations have been discussed. With regard to the theory, the seismic analysts, who have been involved with the development and refinement of probabilistic seismic analysis, have judged that the approach used is reasonable.

During discussions with the seismic analysts responsible for the seismic hazard and fragility analyses, thought experiments were typically used to describe the problem as applied to the situations in the stockpile. One example using a subdivision of similar houses with similar brick chimneys is instructional. Typically, if an earthquake occurred and affected this hypothetical subdivision, all or nothing failure of the chimneys in the subdivision would be unexpected.

Either extreme is possible, given a very small or very large earthquake, but in between these extremes, one would expect some fraction of the chimneys to fall.

One particular concern of the expert panel was the use of this model in the lower ranges of munition stack or igloo fragilities, where only small percentages of the stacks or igloos would be predicted to fail. Discussions were held with the seismic analysts concerning these lower fragility ranges. Another type of thought experiment was used in this case concerning expectations of damage in an igloo given historical patterns of damage. It was discussed what one would expect to find if standing outside an igloo when an earthquake occurred, and then opened the igloo door. At lower accelerations, when the door is opened, it would be quite unexpected to find stacks all over the floor. Conversely, at high accelerations, one would expect to find many fallen pallets. The analysts found it unreasonable to expect that after each earthquake (large and small), one would find that either all the stacks had fallen, or that none had fallen.

The fragility model as used in the QRA has limitations based on the assumptions discussed previously. In the QRA, an estimate of the fragility of a single pallet stack is used to estimate the fragility of a matrix of pallet stacks. The current model of seismic performance of the pallet stacks assumes complete independence. The fact is that the stacks would actually be interacting with each other, and the igloo walls would tend to make the response of the stacks more complex than the assumption of independence. Also, all stacks will not be identically stacked (small variations in placement of the pallets as they are stacked by the forklifts will occur).

This issue of fragility usage also was examined from another viewpoint. The goal of the analysis is to generate a reasonable, best-estimate of risk. In the interpretation used in this study, all earthquakes of a given magnitude would result in 50 percent of the stacks falling at the median fragility. In the other interpretation, 50 percent of the earthquakes of that level would result in all stacks falling, and the other 50 percent would result in none falling. The estimate of risk is a function of frequency and consequences. The frequency would be calculated differently in these two examples; the example with all or none falling would incorporate the 0.5 probability of all stacks falling into the frequency, and thus be a factor of two lower. The consequences are a function of the amount of agent released, and the releases here also differ by a factor of two (assuming all agent evaporates before cleanup). Thus, if consequences are approximately a linear function of release size, the calculated risk will be approximately the same for both interpretations of seismic fragility.

To investigate this issue, additional risk calculations were performed in which the seismic failure of the M55 rocket igloos was assumed to be perfectly correlated. This assumption can be explained by considering the example of a rocket igloo subjected to an earthquake with a peak gravitational acceleration equal to the median igloo collapse fragility. In the seismic sensitivity study, 100 percent of the igloos were assumed to fail half of the time, while the other half of the time it was assumed that no igloos would fail. This compares to the treatment in the baseline risk calculation, in which it was assumed that 50 percent of the igloos would fail 100 percent of the time. Only the M55 rocket igloos were considered in this sensitivity study because their failure dominates risk. Failures due to both rocket igloo collapse and rocket igloo fires were considered in the sensitivity study.

The sensitivity calculations show that the risk per year of continued storage increases by only about 20 percent if seismic failure of the rocket igloos is assumed to be perfectly correlated. This increase is well within the uncertainty of the analysis (see discussion in section 15.2). Although it would be conservative to assume a perfect correlation, the current treatment of seismic fragilities is believed to be a more reasonable interpretation of what might happen in the UMCD storage yard during an earthquake.

14.2.2 Weather-Related Initiating Events. Severe weather and weather-related initiating events have the potential to impact munitions in the stockpile storage area. The same weather-related external events analyzed for UMCDF were considered for the storage yard. Events analyzed include tornado and heavy wind hazards, lightning strikes, heavy precipitation, and floods. The following sections describe these analyses as they apply to UMCD.

14.2.2.1 Tornado/High Wind Events. As described in section 5.4.1, the primary effects of tornadoes are pressure loading and missile generation due to high-speed winds. At UMCD, storage igloos have been built to resist the effects of tornadoes and high winds. Tornado fragility studies for these storage igloos determined that, due to low profiles, tornadoes and/or direct winds would not result in any significant lateral load (S&A, 1994). The only concern is uplifting of the roof due to wind pressure or tornado pressure drop. From the concrete igloo seismic calculation, the overload on top of the igloo is 702 pounds per square foot. Based on information contained in *Design Basis Tornado for Nuclear Power Plants* (USNRC, 1974), this corresponds to a maximum tornado wind velocity of 460 miles per hour (mph), which governs the median maximum wind speed estimate. Therefore, the median tornado wind capacity for the igloos is estimated as 460 mph. The median capacity is the wind speed at which there is a 0.5 probability that the component will fail. Based on the UMCDF tornado hazard curve (described in section 5.4.1), failure of the igloos has been screened because wind speeds greater than 319 mph have a strike frequency less than the external event screening value.

When modeling igloo compromise due to tornado-generated missiles, the only vulnerable part of the igloo was judged to be its exposed headwall and its steel door (the rest is covered with at least 2 feet of earth). For igloo penetration, the compressive strength of concrete was estimated to be 3,000 pounds per square inch (psi) (GA, 1987b). The velocity of the missile required to pass through the steel igloo doors was calculated by GA Technologies. The thickness of the igloo door was taken conservatively by ignoring the effects of the supports between steel panels. This report judged that the required wind velocity sufficient to breach the steel door and any munitions inside was in excess of 250 mph (GA, 1987b). The probability that an airborne missile would have this velocity was shown by Stringfield and Holderness (2000) to be negligible (much less than 1×10^{-8} per year). Combining this value with the missile strike frequency results in an igloo breach frequency that can be screened from further consideration.

Based on these analyses, all direct and indirect tornado effects for munition storage at UMCD were eliminated as potential release scenarios. These analyses are discussed in detail in appendix J1.

14.2.2.2 Lightning Events. Hazards associated with lightning also are discussed in section 5.4.2 and appendix J2. These sections discuss the assessment of M55 rocket vulnerability to lightning when in storage. Of all the weapons currently in the U.S. chemical stockpile, the M55 rocket is considered to be the most vulnerable to lightning because of its firing circuit. Additionally, both the motor and warhead are combined within the rocket body, such that explosions and/or fires initiated by the motor also will involve the chemical agent fill inside the warhead. Since approximately 165 pallets of M55 rockets can be stored together inside one igloo, single-unit ignitions can have the potential to cause other rockets to ignite as well. In a worst case scenario, the entire igloo's worth of rockets (up to approximately 2,500) may become involved.

The M55 rockets were constructed in the early 1960s using the M67 rocket motor assembly, which employed an M62 igniter, two M2 squibs, and the M28 propellant grain. These components contain all of the energetic materials within the rocket motor. The warhead itself contains energetic material (a fuze and burster); however, these components are not considered susceptible to lightning.

All other munitions are considered safe from the effects of lightning because they are encased in metal bodies and contain no exposed propellant nor have electro-explosive igniters.

The assessment of M55 rocket vulnerability to lightning while in storage was broken up into the following four main areas of analysis:

1. *Frequency of Lightning Attachment to Igloos:* This analysis requires determining the probability of lightning strikes on or near rocket storage igloos.

2. *Characterization of Lightning Environment Within the Igloo:* This analysis determines how much of the lightning energy is coupled into the structure in the form of electromagnetic energy.

3. *Characterization of Coupling Energy to the M55 Rocket and M62 Ignition Circuitry:* This analysis determines how much of the ambient electric and magnetic field energy is coupled to the M55 rocket and M62 igniter circuit inside the structure. This study also considers the effects of side-flash arcs.

4. *Characterization of Sensitivity of M2 Squib, M62 Igniter, and M28 Propellant Grain:* This analysis determines the sensitivity of the M2 squibs from induced currents and/or voltages, including arcing and corona effects.

Each analysis is discussed in detail in appendix J2.

14.2.3 Aircraft. The frequencies for a potential aircraft crash into a storage area igloo were estimated, as described in section 5.3 and appendix I.

The scenarios were further developed in the APET by considering the potential for a post-crash fire. The ability of a firefighting team to respond to and extinguish a post-crash fire was assessed as part of the FPEIS analysis. This analysis suggests that a firefighting team would not be able to extinguish the fire in time. Therefore, no credit was taken for potential fire mitigation in the Phase 2 QRA. The probability of striking an igloo containing a particular munition type was assessed based on the fraction of igloos in which that munition is stored. For large aircraft crashes, there is also a small probability that two igloos may become involved.

14.2.4 Screening Analysis for Storage External Events. The screening of events for both disposal processing and continued storage was conducted in one investigation. A discussion of the screening analysis of storage yard external events is included in the screening analysis description in section 5.6.

14.3 Stockpile Storage Internal Events

The methodology employed for identification of internal initiating events at the CDF also was applied to the stockpile storage area. A step-by-step examination of the handling activities at the stockpile storage area was performed through the development of PODs, as described in section 4 and detailed in appendix C. Once PODs were developed and the initiators identified, fault tree models were constructed for munition handling activities at the stockpile storage area. Fault tree models are located in appendix D1.

Internal events considered for the stockpile storage area include those associated with maintaining the munitions while in storage and autoignition of overpacked or non-overpacked rockets. These events are discussed in the following sections.

14.3.1 Rocket Autoignition. M55 rockets use a double-base propellant containing both nitroglycerin and nitrocellulose. Under normal storage conditions, the nitroglycerin and nitrocellulose in the propellant degrade slowly in a series of reactions that generate heat and release nitrogen oxides (NO_x) that subsequently form nitric or nitrous acids due to reactions with water in the propellant. Both heat and acids accelerate the degradation process. If the degradation rate and heat generation rate increase sufficiently, the propellant may ignite—a phenomenon known as autoignition.

Chemical compounds referred to as stabilizers are added to the propellant to prevent autoignition by absorbing the NO_x species as they are released. The stabilizer used in the M28 propellant, 2-nitrodiphenylamine (2-NDPA; CAS No. 119-75-5), can absorb as many as six NO_x molecules through a series of reactions that produce progressively more nitrated stabilizer daughter products. Each subsequent nitration reaction yields a daughter product that is a less effective stabilizer than the 2-NDPA. As stabilizer effectiveness decreases, the propellant becomes less stable and may eventually autoignite.

In 1994, the National Research Council and the General Accounting Office expressed concerns regarding the stability of the M28 propellant and the existing level of uncertainty in the safe storage life of the rockets. In order to address the uncertainty in the stability of the stored M55 rockets, the U.S. Army undertook an extensive research program to investigate propellant stability and the potential for rocket autoignition. Initially, the focus of this program was the stability of uncontaminated propellant and the effectiveness of stabilizer daughter products. However, tests involving propellant contamination by agent and agent simulants showed that agent may significantly accelerate depletion of the stabilizer. For that reason, the focus of the U.S. Army's program switched to investigation of the effects of chemical agent on M28 propellant.

The U.S. Army's program involved extensive laboratory testing to investigate all aspects of propellant behavior following agent contamination, as well as testing to assess the magnitude of heat losses from rockets stored in the field. It also included development of an analytical model of propellant thermal behavior. The model was used to apply the results from the laboratory test program to the prediction of propellant behavior under field storage conditions.

The following discussion summarizes the results from the analysis of autoignition probability. Leaking and nonleaking rockets are discussed separately because leaking rockets may have agent-contaminated propellant and therefore may be undergoing more rapid stabilizer depletion. Note that the focus of this discussion is GB contamination because GB rockets are much more likely to leak than VX rockets.

14.3.1.1 Autoignition of Nonleaking GB Rockets. Periodic chemical analyses of uncontaminated propellant samples from the field have shown that the concentration of 2-NDPA stabilizer in the propellant is depleted very slowly over time. Slow depletion of the 2-NDPA stabilizer also has been confirmed in accelerated aging tests of the propellant performed at elevated temperatures. An analysis of the autoignition probability was completed based on this information. The results from this analysis indicated that autoignition probability is extremely small, and is, in fact, below the cutoff frequency for inclusion in the QRAs. Moreover, the autoignition probability was well below the probabilities of other rocket ignition events, e.g., those resulting from rocket handling in the storage yard or from external events such as a lightning strike or earthquake.

14.3.1.2 Autoignition of Leaking GB Rockets. The results from the agent-propellant testing program showed that GB accelerates stabilizer depletion even at moderate concentrations. A threshold concentration of approximately 6 to 8 weight percent GB was observed. Stabilizer depletion is greatly accelerated at or above this concentration, while below this concentration, stabilizer depletion is much slower (although it is still faster than uncontaminated propellant).

The nitroglycerin and nitrocellulose in the propellant were observed to deplete along with the stabilizer. As the nitrate esters and stabilizers deplete, the heat generation in the propellant increases to a peak value and then decreases as the nitrate ester concentration falls further. The time of the peak heat generation rate is the critical time for propellant autoignition.

The time and magnitude of the peak heat generation rate in the propellant were found to be sensitive to buildup of NO_x gases inside the propellant container. The peak heat generation rate was considerably higher when the NO_x pressure was allowed to build. If the NO_x pressure was not allowed to build, the peak heat generation rate was lower and the peak generally occurred much later. This observation is important because the overpack containers used to confine leaking M55 rockets may allow NO_x pressure to build.

A series of tests was performed to evaluate heat losses from the M55 rockets under realistic storage conditions and storage configurations. These tests used simulated M55 rockets that were internally heated and instrumented with thermocouples. Both overpacked and normally stored rockets were tested in a variety of storage configurations and at two different temperatures. The magnitude of the heat loss from the propellant was higher than had been expected based on literature correlations for free convection. This is believed to be due to heat conduction within the propellant casing and within the walls of the steel overpack. Heat conduction distributes heat more uniformly across the surface of the casing or overpack, effectively increasing the surface available for heat transfer to the surroundings. It also was found that the steel overpack reduced heat losses from the rocket by providing another barrier to heat transfer.

The time after agent contamination at which the heat generation peak would occur was determined based on data from the agent propellant test program. The mean time to peak heat generation in the propellant was calculated to be on the order of 15 to 22 years.

When the peak heat generation rate is reached, autoignition may occur if heat generation in the propellant exceeds heat losses from the propellant to the surroundings. Calculations were performed to estimate the autoignition probability as a function of time for both overpacked and non-overpacked[4] rockets (PMCD, 2001). These calculations have shown that autoignition of non-overpacked rockets is extremely unlikely, with an estimated frequency of approximately 6.0×10^{-7} per year (7.0×10^{-11} per hour) during the next 5 years of storage.[5] Autoignition of overpacked rockets was calculated to be more likely, occurring with a frequency of 1.0×10^{-5} per year (1.0×10^{-9} per hour) during the next 5 years.

If a rocket ignites, it may cause adjacent rockets to ignite, potentially involving all munitions in the igloo. The probability of propagation to the entire rocket igloo has been estimated to be 0.5 for normally stored rockets, based on data from tests at Dugway Proving Ground and Black Hills Army Depot. The propagation probability for overpacked rockets has recently been assessed by considering the Dugway Proving Ground and Black Hills Army Depot data along with heat transfer analyses to evaluate the response of an overpacked rocket to a fire within the igloo (Bailey and Bradley, 2000a,b; Bradley, 2000). Based on this assessment, it was concluded that the probability of propagation to the other munitions in the leaker igloo is approximately 0.1.

14.3.2 Storage Yard Maintenance. The primary activity associated with munition storage is monitoring for possible agent leakage. If agent leakage is detected, the leaking munition is identified, isolated, and overpacked. For most munitions, the leak itself is not a public risk concern because the amount of agent leakage is small. Therefore, the concerns for most leaking munitions are potential impacts and drops while handling the leaking munitions.

To date, most of the munition leakage of concern has been associated with M55 rockets. Hundreds of rockets have been isolated as leakers and placed in overpacks. Isolation of leaking munitions involves moving munitions to access the leaker, thereby creating the potential for handling accidents. Although accidents were considered for all burstered munitions, accidents involving munitions with propellant have the most significant potential for propagation to other munitions. Because the rockets are the only munitions with propellant (cartridges have their propellant removed during reconfiguration), they have the most significant potential for propagation and involvement of a large inventory of chemical agent.

---

4 Non-overpacked leaking rockets are rockets that are leaking but have not yet been detected and overpacked.
5 The autoignition probability increases with time as an increasing number of leaking rockets reach a depleted stabilizer condition.

When agent is detected within an igloo, the leaking munition is identified, removed from its pallet configuration, decontaminated, and placed in an overpack. The overpack performs the function of containing the leak. Rockets are overpacked in either steel single round containers or PIGs. Projectiles are overpacked in steel single round containers. Mine drums are overpacked in 75-gallon plastic containers. The overpacks are designed to provide a high level of assurance of agent vapor and liquid containment even if the munitions continue to leak. Munitions placed in overpacks are transferred to separate storage igloos.

A forklift moves pallets within an igloo to gain access to the leaking munition. The initiators considered during this operation include both forklift impacts and drops. Once a munition is overpacked, it is transferred to a separate igloo designated for overpacked munitions. The heavy steel overpacks provide both agent containment and protection from further damage. To perform these steps, operators in personal protective equipment manually disassemble the pallet and overpack the leaking munition. The potential for the operators to drop one of the munitions during removal and overpacking also was considered. The remaining munitions that are not leaking are re-palletized and restacked in the igloo. Drops during re-palletizing, as well as impacts and drops during restacking with the forklift, are considered.

The internal events modeled for stockpile storage are described in table 14-1.

14.4 Storage Accident Progression Event Tree

Two separate APETs were developed to analyze the UMCDF QRA continued storage risk: one for internal events and one for external events, which are discussed in the following sections. Two more trees were developed to analyze internal and external events associated with processing and they are described in section 6.

This section includes a brief description of the APET logic associated with internal events during munitions storage. A more detailed description of the APET logic for both internal and external events is included in appendix L.

14.4.1 Development of UMCDF Continued Storage Internal Event Accident Progression Event Tree. The logic in the continued storage internal event APET is divided into two sections. Section 1 of the APET treats rocket autoignition and section 2 considers leaker munition handling.

Because there are no other activities associated with continued storage, no other initiators are postulated.

Table 14-1. Initiators and Frequencies for Stockpile Storage Internal Events

Event	Description	Frequency[a] or Conditional Probability[b]
	Frequency Events	
Autoignite Overpacked	GB Overpacked Rocket Autoignition	1.1×10^{-9}
Autoignite Unoverpacked	GB Non-Overpacked Rocket Autoignition	6.8×10^{-11}
LkRktGB	GB Rocket Leaks	1.1×10^{-8}
LkRktVX	VX Rocket Leaks	8.7×10^{-11}
Lk8inGB	GB 8-inch Projectile Leaks	8.0×10^{-10}
Lk8inVX	VX 8-inch Projectile Leaks	1.0×10^{-9}
Lk1555GB	GB 155mm Projectile Leaks	6.9×10^{-9}
Lk155Vx	VX 155mm Projectile Leaks	2.4×10^{-10}
Lk500GB	GB 500-lb Bomb Leaks	4.2×10^{-7}
Lk750GB	GB 750-lb Bomb Leaks	3.3×10^{-8}
	Conditional Probability Events	
U###LKRFRKIM1	Pallet Impact During Forklift Operation to Isolate Leaker	
	M55 Rocket	1.1×10^{-4}
	8-inch Projectile	2.7×10^{-4}
	155mm Projectile	2.0×10^{-4}
	500-lb Bomb	8.0×10^{-4}
	750-lb Bomb	8.0×10^{-4}
U###LKRFRKDP1	Pallet Dropped During Forklift Operation to Isolate Leaker	
	M55 Rocket	1.1×10^{-4}
	8-inch Projectile	2.7×10^{-4}
	155mm Projectile	2.0×10^{-4}
	500-lb Bomb	8.0×10^{-4}
	750-lb Bomb	8.0×10^{-4}
U###LKRMANDP1	Munition Dropped During Pallet Disassembly to Isolate Leaker	
	M55 Rocket	1.4×10^{-1}
U###LKRMANDP2	Munition Dropped During Decon and Overpacking	
	M55 Rocket	7.1×10^{-3}
U###LKRFRKIM2	Pallet Impact During Forklift Operation During Restacking	
	M55 Rocket	1.1×10^{-4}

Table 14-1. Initiators and Frequencies for
Stockpile Storage Internal Events (Continued)

Event	Description	Frequency[a] or Conditional Probability[b]
	8-inch Projectile	2.7×10^{-4}
	155mm Projectile	2.0×10^{-4}
	500-lb Bomb	8.0×10^{-4}
	750-lb Bomb	8.0×10^{-4}
U###LKRFRKDP2	Pallet Dropped During Forklift Operation During Restacking	
	M55 Rocket	1.1×10^{-4}
	8-inch Projectile	2.7×10^{-4}
	155mm Projectile	2.0×10^{-4}
	500-lb Bomb	8.0×10^{-4}
	750-lb Bomb	8.0×10^{-4}

Notes:

[a] Per hour over the entire stockpile
[b] Conditional probabilities per munition

The first two questions (table 14-2) of the continued storage internal event tree identify the campaign during which an accident occurs and what munitions are in the storage yard. Answers to "What is the operation?" are linked to the Quantus scheduler and have a value of 1 or 0 depending on which campaign is active. Only one campaign is active at any given time and that campaign returns a value of 1 while all others return a value of 0. Answers to "What munition igloos are present in the storage yard?" also are linked to the Quantus scheduler and also have values of 1 or 0. As munitions are removed from the storage yard and processed the value of 0 is returned for the processed munitions representing depletion of the munitions. Until specific munitions are processed, a value of 1 is returned.

Logic for treatment of rocket autoignition is illustrated in table 14-3. Autoignition of a rocket is possible due to heat generation during degradation of energetic chemical species in the rocket propellant and reduced propellant stabilizer effectiveness over time. The generated heat could potentially lead to propellant ignition unless heat removal from the rocket is sufficient to prevent a runaway chemical reaction.

Table 14-2. Campaign and Scheduler Dependent Information in the Accident Progression Event Tree

Branch Point Question	Description of Question and Answers
What is the operation? —•GB Rocket (1) —•GB MC-1 Bomb & GB Rocket —•GB MK-94 Bomb & GB Rocket —•GB Rocket (2) —•Changeover-GB Rocket to VX Rocket —•VX Rocket (1) —•VX Spray Tank & VX Rocket —•VX Rocket (2) —•Changeover-VX Rocket to VX 8-inch —•VX 8-inch —•Changeover-VX 8-inch to VX 155mm —•VX 155mm —•Changeover-VX 155mm to VX Mine —•VX Mine —•Changeover-VX Mine to GB 155mm —• GB 155mm —•Changeover-GB 155mm to GB 8-in —•GB 8-in —•Changeover-GB 8-in to HD TC —•HD TC —•Closure	The answers to this question are used in the APET sequence descriptor for identification of the campaign for each accident sequence. The answers are linked to the Quantus scheduler to cue the campaign.
What munition igloos are present in the storage yard? —•No munition igloo present —•GB Leaker Igloo K18810 —•GB M55 80' Igloo —•VX M55 80' Igloo —•GB Burstered 8-in 80' Igloo —•VX Burstered 8-in 80' Igloo —•GB Burstered 155mm 80' Igloo —•VX Burstered 155mm 80' Igloo —•VX Mine 80' Igloo —•GB 500-lb Bomb 80' Igloo —•GB 750-lb Bomb 80' Igloo	The answers list the particular munitions treated for autoignition and handling accidents during leaker overpack. The answers to this question are linked to the Quantus scheduler for indication of munitions presence during solving of the APET for each campaign.

Unless the propellant is contaminated with chemical agent, depletion of the propellant stabilizer is very slow and, as a result, autoignition is not considered credible during the period of interest in the QRA (PMCD, 1997b). If, however, the propellant becomes contaminated with chemical agent, the stabilizer depletion rate is greatly accelerated and an autoignition condition could be reached prior to demilitarization of the rockets (PMCD, 2001). In the QRA, autoignition is considered possible for either overpacked or non-overpacked (i.e., undetected) leaking rockets.

Table 14-3. Autoignition of Rockets Logic in the Accident Progression Event Tree

Branch Point Question	Description of Question and Answers
Has autoignition of an overpacked or non-overpacked rocket occurred? —•No Autoignition —•Autoignition	Overpacked and non-overpacked rocket autoignition frequencies are provided in the answers to this question. These are based on recent findings of a 4-year investigation of this issue.
Does the autoignition upset propagate? —•No Autoignition Propagation —•Autoignition Propagation	Propagation as a result of the autoignition event is considered in this question. Propagation to other rockets or the entire igloo is of interest. The probability of propagation is dependent on whether it is an igloo of overpacks or not.
What fraction of the igloo is involved in the propagating upset? —•No Autoignition Propagation —•10 percent —•25 percent —•50 percent —•75 percent —•100 percent	Answers indicate what percentage of an igloo is involved in the propagation. The percentage varies according to the type of igloo involved. The overpacked rocket igloo has a smaller inventory than the regular, non-overpacked rocket igloos.
Was there autoignition of a rocket? —•Autoignition Sequence —•No Autoignition Sequence	Answers indicate the occurrence of autoignition of an overpacked or non-overpacked rocket. Answers to this question are convenient for use in later APET rules.

As listed in table 14-3, the autoignition of overpacked and non-overpacked rockets section of the APET begins with a question that asks if autoignition has occurred. Next, propagation of the autoignition upset is addressed. The probability of propagation is dependent on the kind of rocket igloo. The overpacked rocket igloo has a small inventory of rockets in steel containers spaced about the igloo, which allows for a small probability of propagation (0.1) to other overpacked rockets. The non-overpacked igloos have a much greater inventory of rockets stacked closely about in the igloo. The probability of propagation (0.5) is greater. Next, the fraction of the contents of a full igloo involved in the propagated autoignition upset is addressed. A fraction of 10 percent is assigned for the overpacked igloo and 100 percent for the non-overpacked igloo. Finally, this section ends with a question that asks if an overpacked rocket autoignited. The answers to this question are convenient for use in later APET questions.

Logic for consideration of leaker munitions handling is illustrated in table 14-4. During storage, chemical munitions igloos are constantly monitored for leaking munitions.

When a leaking munition is discovered, the munition is removed from the igloo, placed in a steel airtight container (overpack), and moved to an igloo used to store overpacked leaking munitions. During this process, there are opportunities for mishandling of munitions resulting in an agent

Table 14-4. Handling of Leaker Munitions Logic in the Accident Progression Event Tree

Branch Point Question	Description of Question and Answers
What leaking munitions are found in the stockpile? —•No Leaker —•Leaker	Answers indicate if a leaking munition is found. The question includes cases that must be considered separately, based on the type of munition igloo present. For example, leaking GB M55 rockets will be found if they remain in the storage yard.
Is there an upset during handling of leaking munitions in the stockpile? —•No leaking handling event —•URKTLKRFRKIM1 —•URKTLKRFRKDP1 —•URKTLKRMANDP1 —•URLTLKRMANDP2 —•URKTLKRFRKIM2 —•URLTLKRFRKDP2 —•Munitions-specific list of handling events	Answers are munition-specific leaker handling initiators. The question considers cases that must be considered separately, based on the type of munitions and if there is a leaker. These initiators include forklift accidents or accidental drops of munitions during overpacking. The MANDP1 and MANDP2 events do not apply to 155mm projectiles, 8-inch projectiles, 500 pound bombs, or 750 pound bombs because these munitions are too heavy for operators to lift.
What is the result of the upset during handling of leaking munitions in the stockpile? —•No Leaker Release —•Leaker Leaks —•Leaker Explodes	This question considers possible results of leaker handling initiators. Question rules consider cases that must be considered separately, based on the type of munitions handled and the leaker handling initiator. Probabilities are based on models of munition response to physical impacts.
How many munitions are involved in the stockpile upset? —•No Leaker Involvement —•Single Leaker —•Pallet Leaker	Answers list the number of munitions involved in the upset. Question rules consider cases that must be considered separately, based on the leaker handling initiator and the result of the initiator.
What is the release mode from the propagating upset in the stockpile? —•No Leaker Propagation —•Leak Propagation —•Explosion Propagation	The mode of propagation to other munitions and how agent is released is of concern.
How many munitions are involved in the propagating upset at the stockpile? —•No Propagation —•Pallet Propagation —•Igloo Propagation	The number of munitions involved in propagation is the focus. There are two rules: one considers explosions causing leaks, the other explosions causing other explosions.
Was there a leaker handling event? —•Leaker Handling Event Sequence —•No Leaker Handling Event Sequence	The occurrence of a leaker handling accident is returned. Answers to this question are convenient for identification of a leaker handling event during APET solution.
Was there a leaker handling event release? —•No Leaker Release —•Leaker Release	The occurrence of a leaker handling accident release is returned. Answers to this question are convenient for identification of a leaker handling event release during APET solution.

release. The logic in table 14-4 considers mishandling of munitions during overpacking operations and the possible consequences.

The leaker munitions handling section of the APET begins with a question that asks what leaker munitions were found. The leakage frequency of each munition type, taken from the U.S. Army's munitions storage databases is used here. In the following question, munition-specific handling initiators are considered. Six initiators tailored for rockets and four initiators tailored for other munitions types are considered. The manual handling events do not apply to the 155mm projectiles, 8-inch projectiles, 500-pound bombs, and 750-pound bombs because these munitions are too heavy for personnel to lift. Possible initiator results in question 3 are leaks and explosions. The number of munitions involved in the single and pallet upsets is listed in the next question. Release mode due to rocket explosion propagation is considered. The next question handles the number of munitions involved in the propagating upset. To end the section, there are questions asking if a leaker handling event occurred and if there was a leaker handling event release. The answers to these questions are convenient for use in APET solution.

14.4.2 Development of UMCDF Continued Storage External Event Accident Progression Event Tree. The logic in the continued storage external event APET is divided into three sections. The sections treat seismic, aircraft crash, and lightning initiated external events.

The first question (table 14-5) of the continued external event storage tree is used to identify the campaign during which an accident occurs. Answers to "What is the operation?" are linked to the Quantus scheduler and have a value of 1 or 0 depending on which campaign is active. Only one campaign is active at any given time and that campaign returns a value of 1 while all others return a value of 0.

Logic considering treatment of seismic-initiated events is illustrated in table 14-6. Here the results of subjecting every chemical munition igloo to 20 seismic g-levels are considered. Questions are asked for igloo collapses and fires, munition spills, explosions, and rocket igloo fires. The questions in this section must be asked for each munition igloo because a seismic event can affect all munitions igloos at the same time.

The seismic logic analyzes munitions responses of explosions, leaks, and rocket igloo collapses and fires. The answers to the questions are determined by user functions that process input such as seismic level, pallet-tipping fragility, probability of leakage, and probability of explosion. The functions return the number of igloo collapses, rocket igloo fires, pallet leaks, and pallet explosions. The non-integer values are compared to threshold values to ultimately return integer values for number of igloo collapses, igloo fires, igloo explosions, pallet explosions, and pallet

Table 14-5. Campaign Information in the External Event Accident Progression Event Tree

Branch Point Question	Description of Question and Answers
What is the operation? —•GB Rocket (1) —•GB MC-1 Bomb & GB Rocket —•GB MK-94 Bomb & GB Rocket —•GB Rocket (2) —•Changeover-GB Rocket to VX Rocket —•VX Rocket (1) —•VX Spray Tank & VX Rocket —•VX Rocket (2) —•Changeover-VX Rocket to VX 8-inch —•VX 8-inch —•Changeover-VX 8-inch to VX 155mm —•VX 155mm —•Changeover-VX 155mm to VX Mine —•VX Mine —•Changeover-VX Mine to GB 155mm —•GB 155mm —•Changeover-GB 155mm to GB 8-in —•GB 8-in —•Changeover-GB 8-in to HD TC —•HD TC —•Closure	The answers to this question are used in the APET sequence descriptor for identification of the campaign for each accident sequence. The answers are linked to the Quantus scheduler to cue the campaign.

leaks. These integer values are input to the source term algorithms. Refer to appendix L3 for a discussion of how the user function works.

The answers to the questions that ask "How many..." range from one, two, up to the maximum number of responses. Instead of listing all the possible responses here, the text "Values up to..." is included for author convenience.

Next, there is a question (table 14-7) that asks if certain types of igloos are present. The answers to this question are all the agent and munition igloo type combinations in the storage yard. The answers are connected to the Quantus scheduler. If a given igloo type is not present, as indicated by the scheduler, the igloo cannot participate in subsequent external events.

Logic considering the impact of aircraft crashes into munition igloos is listed in table 14-8. Large and medium aircraft crashes are included. Fires affecting a storage igloo and munition leakage are results of aircraft crashes.

Table 14-6. Seismic Events Logic in the Accident Progression Event Tree

Branch Point Question	Description of Question and Answers
What is the g-level of the seismic event? —•No Seismic Event —•Seismic Level 1 —•Seismic levels up to Level 20	One of twenty possible seismic levels causes a seismic event. Various parameters and their values used in calculation of leaks, explosions, and fires are defined in this question.
Was there a seismic event? —•Not a Seismic Event —•Seismic Event	The occurrence of a seismic event is returned. If any of the seismic levels take place in the previous question, then there was a seismic event. Also, additional parameters used in calculations are defined.
How many GB M55 Igloos Collapse? —•None —•One —•Two —•Values up to forty-one	The number of GB rocket igloo collapses is returned. A user function is called with inputs of g-level of the earthquake, igloo fragility, seismic fragility uncertainty parameter, and number of GB igloos in the storage yard to return the number of collapsed igloos.
How many VX M55 Igloos Collapse? —•None —•One —•Two —•Values up to six	The number of VX rocket igloo collapses is returned. A user function is called with inputs of g-level of the earthquake, igloo fragility, seismic fragility uncertainty parameter, and number of VX igloos in the storage yard to return the number of collapsed igloos.
Was there a GB M55 igloo fire following igloo collapse? —•GB M55 igloo fire following igloo collapse —•No GB M55 igloo fire following igloo collapse	The occurrence of a GB rocket igloo fire following collapse is returned. A user function is called with inputs of number of collapsed GB M55 igloos and probability of igloo explosion after collapse to calculate if there is an igloo fire following collapse.
Was there a VX M55 igloo fire following igloo collapse? —•VX M55 igloo fire following igloo collapse —•No VX M55 igloo fire following igloo collapse	The occurrence of a VX rocket igloo fire following collapse is returned. A user function is called with inputs of number of collapsed VX M55 igloos and probability of igloo explosion after collapse to calculate if there is an igloo fire following collapse.
How many GB M55 igloo fires following igloo collapse? —•None —•One —•Values up to forty-one	The number of GB M55 igloo fires following collapse is returned. The answer returned in the question that asked if there was a GB M55 igloo fire following collapse is used here and compared with threshold values to determine number of GB M55 igloo fires following collapse.
How many VX M55 igloo fires following igloo collapse? —•None —•One —•Values up to six	The number of VX M55 igloo fires following collapse is returned. The answer returned in the question that asked if there was a VX M55 igloo fire following collapse is used here and compared with threshold values to determine number of VX M55 igloo fires following collapse.
How many GB 155mm igloos collapse? —•None —•One —•Values up to seven	The number of GB 155mm igloos collapsed is returned. A user function is called with inputs of number of GB 155mm igloos, g-level, seismic fragility uncertainty parameter, and igloo fragility to return the number of collapsed igloos.

Table 14-6. Seismic Events Logic in the Accident Progression Event Tree (Continued)

Branch Point Question	Description of Question and Answers
How many VX 155mm igloos collapse? —•None —•One —•Values up to five	The number of VX 155mm igloo collapses is returned. A user function is called with inputs of number of VX 155mm igloos, g-level, seismic fragility uncertainty parameter, and igloo fragility to return the number of collapsed igloos.
How many GB 750-lb bomb igloos collapse? —•None —•One —•Values up to five	The number of GB 750-lb bomb igloos collapsed is returned. A user function is called with inputs of number of GB 750-lb bomb igloos, g-level, seismic fragility uncertainty parameter, and igloo fragility to return the number of collapsed igloos.
How many GB 8-inch igloos collapse? —•None —•One —•Values up to five	The number of GB 8-inch igloo collapses is returned. A user function is called with inputs of number of GB 8-inch igloos, g-level, seismic fragility uncertainty parameter, and igloo fragility to return the number of collapsed igloos.
How many VX 8-inch igloos collapse? —•None —•One —•Values up to two	The number of VX 8-inch igloos collapsed is returned. A user function is called with inputs of number of VX 8-inch igloos, g-level, seismic fragility uncertainty parameter, and igloo fragility to return the number of collapsed igloos.
How many VX mine igloos collapse? —•None —•One —•Values up to three	The number of VX mine igloo collapses is returned. A user function is called with inputs of number of VX mine igloos, g-level, seismic fragility uncertainty parameter, and igloo fragility to return the number of collapsed igloos.
How many HD/HT TC igloos collapse? —•None —•One —•Values up to twenty-four	The number of HD/HT ton container igloos collapsed is returned. A user function is called with inputs of number of HD/HT ton container igloos, g-level, seismic fragility uncertainty parameter, and igloo fragility to return the number of collapsed igloos.
How many VX spray tank igloos collapse? —•None —•One —•Values up to twelve	The number of VX spray tank igloo collapses is returned. A user function is called with inputs of number of VX spray tank igloos, g-level, seismic fragility uncertainty parameter, and igloo fragility to return the number of collapsed igloos.
Did an 80-ft GB rocket igloo explode? —•80-ft GB rocket igloo exploded —•No 80-ft GB rocket igloo exploded	The occurrence of an 80-foot GB rocket igloo explosion is returned. A user function is called with input of g-level, number of pallets available to fall, beta factor, median fragility, explosion probability, probability of propagation, and number of 80-foot GB rocket igloos to calculate if a rocket igloo exploded.
Did an 80-ft VX rocket igloo explode? —•80-ft VX rocket igloo exploded —•No 80-ft VX rocket igloo exploded	The occurrence of an 80-foot VX rocket igloo explosion is returned. A user function is called with input of g-level, number of pallets available to fall, beta factor, median fragility, explosion probability, probability of propagation, and number of 80-foot VX rocket igloos to calculate if a rocket igloo exploded.

Table 14-6. Seismic Events Logic in the Accident Progression Event Tree (Continued)

Branch Point Question	Description of Question and Answers
How many 80-ft GB rocket igloos explode? —•None —•One —•Values up to twenty	The number of 80-foot GB rocket igloo explosions is returned. The answer returned from the question that asked if an 80-foot GB rocket igloo exploded is used here and compared with threshold values to the determine number of 80-foot GB rocket igloo explosions.
How many 80-ft VX rocket igloos explode? —•None —•One —•Values up to six	The number of 80-foot VX rocket igloo explosions is returned. The answer returned from the question that asked if an 80-foot VX rocket igloo exploded is used here and compared with threshold values to determine the number of 80-foot VX rocket igloo explosions.
How many VX M55 rocket pallets spill in each 80-ft igloo? —•None —•One —•Values up to twenty	The number of leaking 80-foot VX rocket pallets are returned. A user function is called with input of g-level, number of pallets available to fall, beta factor, median fragility, and leakage probability to calculate number of leaking pallets.
How many GB M55 rocket pallets spill in each 80-ft igloo? —•None —•One —•Values up to twenty	The number of leaking 80-foot GB rocket igloo pallets are returned. A user function is called with input of g-level, number of pallets available to fall, beta factor, median fragility, and leakage probability to calculate the number of leaking pallets.
How many VX 155mm projectile pallets spill in each 80-ft igloo? —•None —•One —•Values up to twenty	The number of leaking 80-foot igloo VX 155mm projectile pallets are returned. A user function is called with input of g-level, number of pallets available to fall, beta factor, median fragility, and leakage probability to calculate number of leaking pallets.
How many GB 155mm projectile pallets spill in each 80-ft igloo? —•None —•One —•Values up to twenty	The number of leaking 80-foot igloo GB 155mm projectile pallets is returned. A user function is called with input of g-level, number of pallets available to fall, beta factor, median fragility, and leakage probability to calculate the number of leaking pallets.
How many mine pallets spill in each 80-ft igloo? —•None —•One —•Values up to twenty	The number of leaking VX 80-foot igloo mine pallets is returned. A user function is called with input of g-level, number of pallets available to fall, beta factor, median fragility, and leakage probability to calculate the number of leaking pallets.
How many mine pallets explode in each 80-ft igloo? —•None —•One —•Values up to three	The number of exploding VX 80-foot igloo mine pallets is returned. A user function is called with input of g-level, number of pallets available to fall, beta factor, median fragility, and explosion probability to calculate the number of exploding pallets.
How many GB 8-inch projectile pallets spill in each 80-ft igloo? —•None —•One —•Values up to twenty	The number of leaking GB 80-foot igloo 8-inch pallets is returned. A user function is called with input of g-level, number of pallets available to fall, beta factor, median fragility, and leakage probability to calculate the number of leaking pallets.

Table 14-6. Seismic Events Logic in the Accident Progression Event Tree (Continued)

Branch Point Question	Description of Question and Answers
How many VX 8-inch projectile pallets spill in each 80-ft igloo? —•None —•One —•Values up to twenty	The number of leaking VX 80-foot igloo 8-inch pallets is returned. A user function is called with input of g-level, number of pallets available to fall, beta factor, median fragility, and leakage probability to calculate the number of leaking pallets.
How many spray tanks spill in each 80-ft igloo? —•None —•One —•Values up to twenty	The number of leaking 80-foot igloo spray tanks is returned. A user function is called with input of g-level, number of spray tanks available to fall, beta factor, median fragility, and leakage probability to calculate the number of leaking spray tanks.
How many 500-lb bombs (MK-94) spill in each 80-ft igloo? —•None —•One —•Values up to twenty	The number of leaking 80-foot igloo 500-lb bombs is returned. A user function is called with input of g-level, number of bombs available to fall, beta factor, median fragility, and leakage probability to calculate the number of leaking 500-lb bombs.
How many 750-lb bombs (MC-1) spill in each 80-ft igloo? —•None —•One —•Values up to twenty	The number of leaking 80-foot igloo 750-lb bombs is returned. A user function is called with input of g-level, number of bombs available to fall, beta factor, median fragility, and leakage probability to calculate the number of leaking 750-lb bombs.
How many HD ton containers spill in each 80-ft igloo? —•None —•One —•Values up to twenty	The number of leaking HD ton containers is returned. A user function is called with input of g-level, number of ton containers available to fall, beta factor, median fragility, and leakage probability to calculate the number of leaking ton containers.
Was there a seismic event in the storage yard? —•No Seismic Event Sequence —•Seismic Event Sequence	The occurrence of a seismic event is returned. Answers to this question are convenient for identification of the occurrence of a seismic event in later questions.
Was there a seismic release in the storage yard? —•No Seismic Release —•Seismic Release	The occurrence of a seismic event release is returned. Answers to this question are convenient for identification of seismic event releases in later questions.

Table 14-9 lists APET logic for a lightning strike of rocket igloos. Rockets are potentially susceptible to ignition if an arc occurs in an igloo, or possibly as a result of EMF. A variety of elements must be in place for lightning-induced rocket ignition.

As illustrated in the lightning strike logic, many factors must be in place for a lightning strike to cause a rocket to ignite. First, a rocket pallet must be too close to the igloo arch or headwall. Next, there must be arcing to the pallet. Finally, the lightning must ignite the rocket squib.

Table 14-7. Scheduler Dependent Information in the External Event Accident Progression Event Tree

Branch Point Question	**Description of Question and Answers**
What munitions are present in the storage yard? —•No Munition Storage Present —•GB M55 80' Igloo —•VX M55 80' Igloo —•GB Burstered 8-inch 80' Igloo —•VX Burstered 8-inch 80' Igloo —•GB Burstered 155mm 80' Igloo —•VX Burstered 155mm 80' Igloo —•VX Mine 80' Igloo —•GB 500-lb 80' Igloo —•GB 750-lb 80' Igloo —•VX Spray Tank 80' Igloo —•HD Ton Container 80' Igloo	The answers are linked to the Quantus scheduler for treatment of each agent-munition type in an accident as the storage yard inventory is depleted. The answers are used in logic in the upcoming aircraft crash and rocket igloo lightning strike sections.

Table 14-8. Aircraft Crash Events Logic in the Accident Progression Event Tree

Branch Point Question	**Description of Question and Answers**
Is there an aircraft crash in the storage yard? —•No Aircraft Crash —•Large Aircraft Crash Into Igloo —•Medium Aircraft Crash Into Igloo	The occurrence of a large or medium aircraft crash into a munition igloo is returned. The frequencies of both types of aircraft crashes are provided. Small aircraft cannot penetrate igloos.
Did the aircraft cause a fire? —•Fire —•No Fire	The probability of igloo fire as a result of an aircraft crash is assigned in this question.
How many igloos were hit? —•No Igloo Struck by Aircraft —•1 Igloo Struck by Aircraft —•2 Igloos Struck by Aircraft	The number of igloos struck by an aircraft crash is assigned. Only a large aircraft is assumed to be able to strike two igloos.
Was there an aircraft crash in the storage yard? —•No Aircraft Crash Sequence —•Aircraft Crash Sequence	The occurrence of an aircraft crash event is returned. Answers to this question are convenient for identification of the occurrence of an aircraft crash event in later questions.
Was there an aircraft crash release in the storage yard? —•No Aircraft Crash Release —•Aircraft Crash Release	The occurrence of an aircraft crash release is returned. Answers to this question are convenient for identification of the occurrence of an aircraft crash release in later questions.

Table 14-9. Lightning Strike Events Logic in the Accident Progression Event Tree

Branch Point Question	Description of Question and Answers
Did lightning strike an igloo? —•No Lightning Strike —•80-ft GB Rocket Igloo Strike —•80-ft VX Rocket Igloo Strike	The frequency of a lightning strike of a rocket igloo is provided. There is a rule for each type of rocket igloo.
What type of lightning protection does the igloo provide? —•None —•Good —•Intermediate —•Bad	The degree of lightning protection offered by the rocket storage yard igloos is returned. The split fractions provided for these answers are based on a study of the closeness of rocket pallet stacking to the igloo arch in the Anniston munitions storage area. The study is assumed to be applicable to Umatilla. More on this study can be found in the rocket igloo lightning strike analysis in appendix J2.
How severe was the igloo strike? —•None —•Extreme —•Nominal	The degree of rocket igloo strike is returned. The difference between extreme and nominal lightning is the amount of energy associated with the lightning strike. Appendix J2 discusses the differences in more detail.
Was a pallet too close to the arch? —•No pallets too close to arch —•Pallets too close to arch	The probability that the pallets are too close to the igloo arch is assigned. Pallets too close to the arch have a greater chance of being struck by a lightning-induced arc.
Was a pallet too close to the headwall? —•No pallets too close to the headwall —•Pallets too close to the headwall	Probability that pallets are too close to the igloo headwall is assigned. Pallets too close to the headwall have a greater chance of being struck by a lightning-induced arc.
Was there arcing to a rocket pallet? —•No arcing to the rocket pallet —•Arcing to the rocket pallet	A lightning strike arcing from the headwall or arch to a rocket pallet is indicated. Arcing to a rocket pallet leads to a significant chance of ignition.
Was there a squib ignition? —•No Squib Ignition —•Squib Ignition	The probability of rocket squib ignition upon arcing to a rocket pallet is assigned in this question.
Was there lightning-induced propagation? —•No Lightning Propagation —•Lightning Propagation	The probability of propagation to the rest of the igloo upon a rocket squib ignition is assigned in this question.
Was there a lightning strike in the storage yard? —•No Lightning Strike Sequence —•Lightning Strike Sequence	The occurrence of a rocket lightning strike event is returned. Answers to this question are convenient for identification of the occurrence of a rocket lightning strike event in later questions and in the APET solution.
Was there a lightning strike release in the storage yard? —•No Lightning Strike Release —•Lightning Strike Release	The occurrence of a rocket lightning strike release is returned. Answers to this question are convenient for identification of the occurrence of a rocket lightning strike release in later questions and in the APET solution.

14.4.3 Solution of the Event Trees for Source Term Calculations. As discussed in section 6 for the disposal APETs, the continued storage internal and external event APETs use accident sequence solutions to enable source term analysis. A discussion of both sequence solutions and their descriptors follows.

14.4.3.1 Continued Storage Internal Event Sequence Solution. Accident sequences resulting from rocket autoignition and handling accidents during leaker rocket overpacking are defined using 17 unique sequence descriptors. The descriptors used for internal event accident sequences are summarized in table 14-10.

Table 14-10. Internal Event Accident Descriptors for Source Term Specification

Accident Descriptors
Campaign
Event
Release Mode Source Term Model Call
Release Mode
Propagation Mode
Agent
Munition
Storage Location
Amount
Mode
Release Quantity
Propagation Quantity
Drain Status
Breach
HVAC
Dispersion Model Release
Population

These 17 descriptors define accident sequences used in the source term analysis. Table 14-11 summarizes the internal event accident sequence descriptors.

Similarly, a set of descriptors was developed for external events. The descriptors are listed in table 14-12. They cover the basic type of accident occurring and are more directly associated with initiating events than the internal event accident sequence descriptors. The 45 descriptors are very similar to those for internal events, but are customized to ensure appropriate source term assignment for every type of accident. Twenty-six of the forty-five descriptors specifically

Table 14-11. Internal Event Accident Sequence Description for Source Terms

Branch Point Question	Description of Question and Answers
Campaign? —•GB Rocket (1) —•GB MC-1 Bomb & GB Rocket —•GB MK-94 Bomb & GB Rocket —•GB Rocket (2) —•Changeover-GB Rocket to VX Rocket —•VX Rocket (1) —•VX Spray Tank & VX Rocket —•VX Rocket (2) —•Changeover-VX Rocket to VX 8-inch —•VX 8-inch —•Changeover-VX 8-inch to VX 155mm —•VX 155mm —•Changeover-VX 155mm to VX Mine —•VX Mine —•Changeover-VX Mine to GB 155mm —•GB 155mm —•Changeover-GB 155mm to GB 8-in —•GB 8-in —•Changeover-GB 8-in to HD TC —•HD TC —•Closure	The descriptor identifies the campaign during which the accident has occurred. This is useful in identifying the degree of risk of each campaign.
Event? —• None —• Overpack Rocket Autoignition —• Non-Overpacked Rocket Autoignition —• Forklift Impact Pallet of Rockets-Remove (Fork Imp Pal of Rkt-Remove) —• Forklift Drop Pallet of Rockets-Remove (Fork Drp Pal of Rkt-Remove) —• Manual Drop of Rocket (Mnl Drp of Rkt) —• Manual Drop of Leaker Rocket (Mnl Drp of Lk Rkt) —• Forklift Impact Pallet of Rockets-Replace (Fork Imp Pal of Rkt-Replace) —• Forklift Drop Pallet of Rockets-Replace (Fork Drp Pal of Rkt-Replace) —• *16 other events*	This descriptor identifies the cause of the accident sequence. The listed events for rockets, except for manual drops, also apply to all other munitions types in the storage yard.
Release Mode Source Term Model Call? —• None —• Munitions Explode-Evaporate (MunsExplodeEvap) —• Munitions Spill-Evaporate (MunsSpillEvap) —• Igloo Fire (IglooFire)	This descriptor is used to signal which source term model to call given an accident sequence. Sequences that result in no agent release do not call a model.

Table 14-11. Internal Event Accident Sequence Description for Source Terms (Continued)

Branch Point Question	Description of Question and Answers
Release Mode? —• None —• Spill —• Explosion	This descriptor identifies how agent is initially released for a given accident.
Propagation Mode? —• None —• Spill —• Explosion	This descriptor identifies how a given accident propagates to other munitions.
Agent? —• None —• GB —• VX —• HD	Categorizes all accident sequences by the type of agent involved. This is obviously needed for determination of the agent source term.
Munition? —• None —• Overpack Rocket —• Non-Overpack Rocket —• 155mm —• 8-inch —• 500-lb Bomb —• 750-lb Bomb	Categorizes all accident sequences by the type of munition involved.
Storage Location? —• None —• Igloo80ft	This determines where the initial accident occurs so that the appropriate agent inventories can be considered.
Amount? —• None —• P100 —• P075 —• P050 —• P025 —• P010	This accident characteristic identifies the percentage of the contents of an igloo involved in an accident.
Mode? —• None —• Autoignition —• Handling	This accident characteristic informs the source term models of what event caused the accident sequence.
Release Quantity? —• None —• Single —• Pallet —• Igloo	This accident characteristic identifies the number of a given munitions type involved in the upset.
Propagation Quantity? —• None —• Single —• Pallet —• Igloo	This accident characteristic identifies the number of munitions propagated to during an upset.

Table 14-11. Internal Event Accident Sequence Description for Source Terms (Continued)

Branch Point Question	Description of Question and Answers
Drained Status? —• Undrained —• Drained	Even though munitions are always *Undrained* in the storage yard, this descriptor is necessary input for all source term models. Thus, the drained status of munitions must be defined.
Breach? —• Not Applicable (NotAppl) —• No Breach (NoBreach) —• External Breach (ExtBreach) —• Internal Breach (IntBreach)	This descriptor identifies the presence of an MDB wall breach during an upset. This obviously does not apply to the continued storage trees, but since the processing and storage trees share many source term models, this descriptor is necessary input. *NotAppl* is always the answer for the continued storage trees.
HVAC? —• Not Applicable (NotAppl) —• HVAC On (HVACon) —• HVAC Off Global (HVACOffGlobal) —• HVAC Off Local (HVACOffLoc)	This descriptor identifies the status of the MDB HVAC system during an upset. This obviously does not apply to the continued storage trees, but since the processing and storage trees share many source term models, this descriptor is necessary input. *NotAppl* is always the answer for the continued storage trees.
Dispersion Model Release? —• No special characteristics —• Daytime only release	This descriptor identifies conditions under which a certain release can occur. The handling upsets are restricted to daytime, and autoignition upsets have no special characteristics. This descriptor is input to CHEMMACCS.
Population? —• Public – Facility Accident —• Public – Storage Yard Accident —• Worker – Facility Accident —• Worker – Storage Yard Accident	This descriptor identifies the population for which accident effects are of interest. For the upsets in the internal event tree, only *Public – Storage Yard Accident* is considered. This descriptor is input to CHEMMACCS.

address seismic sequences. The 26 descriptors are necessary because a seismic event can potentially affect every igloo in the storage yard.

Table 14-13 summarizes the accident sequence characteristics associated with each descriptor.

14.5 Stockpile Storage Area Source Term Analysis

Because the stockpile storage source term analysis is almost identical to that performed for UMCDF, only differences in the analysis are described here. Accidents that can occur in both stockpile storage and UMCDF are analyzed in the same fashion with no regard to when the accident takes place other than accounting for other agent sources that could contribute to the overall release. Source term analysis for accidents that are unique for stockpile storage is discussed in the following section. Source term analysis for UMCDF is described in section 10.

Table 14-12. External Event Accident Descriptors for Source Term Specification

Accident Descriptors
Campaign
Event
Release Mode Source Term Model Call
GB M55 – Igloo Collapses
VX M55 – Igloo Collapses
GB M55 – Igloo Collapse and Fire
VX M55 – Igloo Collapse and Fire
GB M55 – Spills per 80-foot Igloo
VX M55 – Spills per 80-foot Igloo
GB 155mm – Igloo Collapses
VX 155mm – Igloo Collapses
GB 750-pound Bomb – Igloo Collapses
GB 8-inch – Igloo Collapses
VX 8-inch – Igloo Collapses
VX Mine – Igloo Collapses
HD/HT Ton Container – Igloo Collapses
VX Spray Tank – Igloo Collapses
GB M55 80-foot Rocket Igloo Fires
VX M55 80-foot Rocket Igloo Fires
GB 155mm – Spills per 80-foot Igloo
VX 155mm – Spills per 80-foot Igloo
Mines – Spills per 80-foot Igloo
VX Mines – Pallet Explosions per 80-foot Igloo
GB 8-inch – Spills per 80-foot Igloo
VX 8-inch – Spills per 80-foot Igloo
VX Spray Tanks – Spills per 80-foot Igloo
GB 500-pound Bombs – Spills per 80-foot Igloo
GB 750-pound Bombs – Spills per 80-foot Igloo
HD Ton Container – Spills per 80-foot Igloo
Number of Pallet Spills Due to Igloo Collapse with Evaporation
Number of Igloo Fires Due to Igloo Collapse with Fire
Dispersion Model Release
Population
Release Mode

Table 14-12. External Event Accident Descriptors for Source Term Specification (Continued)

Accident Descriptors
Propagation Mode
Agent
Munition
Storage Location
Quantity
Propagation Quantity
Amount
Mode
Drain Status
Breach
HVAC

14.5.1 Source Term Algorithm for Stockpile Storage. Source term models calculate source terms for the storage accident sequences. The stockpile storage algorithm behaves like the disposal processing algorithm, in that accident sequences are binned, bins are processed to evaluate source terms using source term models, and source terms may be assigned to source term groups. Most external events involve a single storage unit and can be adequately described using keywords similar to those used for internal events (see appendix O3). The source term then can be determined using the models described in section 10.

Due to the nature of stockpile storage seismic accidents and with many different combinations of munition failures possible simultaneously, numerous keywords are used to indicate the levels of the various outcomes for each type of storage unit. For example, one keyword will indicate how many 80-foot igloos of GB M55 rockets will collapse and burn. Another keyword will indicate how many pallets of munitions will fall and leak in another igloo of the same type that does not collapse. The various keywords used for describing external event outcomes are discussed in appendix O3.

After source terms are calculated for each accident progression bin, they are grouped using the same grouper used for UMCDF disposal sequences (see table 10-6). This source term production continues until all the accident progression bins have been processed. Then CHEMMACCS input file is created for each identified source term group.

14.5.2 Estimation of Source Terms for Continued Storage Bins. Numerous accident progression sequences were generated from quantification of the stockpile storage area APET.

Table 14-13. External Event Accident Sequence Description for Source Terms

Branch Point Question	Description of Question and Answers
Campaign? —•GB Rocket (1) —•GB MC-1 Bomb & GB Rocket —•GB MK-94 Bomb & GB Rocket —•GB Rocket (2) —•Changeover-GB Rocket to VX Rocket —•VX Rocket (1) —•VX Spray Tank & VX Rocket —•VX Rocket (2) —•Changeover-VX Rocket to VX 8-inch —•VX 8-inch —•Changeover-VX 8-inch to VX 155mm —•VX 155mm —•Changeover-VX 155mm to VX Mine —•VX Mine —•Changeover-VX Mine to GB 155mm —•GB 155mm —•Changeover-GB 155mm to GB 8-in —•GB 8-in —•Changeover-GB 8-in to HD TC —•HD TC —•Closure	The descriptor identifies the campaign during which the accident has occurred. This is useful in identifying the degree of risk of each campaign.
Event? —• None —• Seismic 1 (Seis 1) —• Seismic 2 (Seis 2) —• *22 other events*	This descriptor identifies the cause of the accident sequence. Considered are 20 seismic levels, medium and large aircraft crashes, and lightning strike of rocket igloos.
Release Mode Source Term Model Call? —• None —• Storage Seismic (StgSeismic) —• Storage Collapse Evaporate (StgCollapseEvap) —• Storage Collapse Fire (StgCollapseFire) —• Igloo Fire (IglooFire) —• Munitions Explode Evaporate (MunsExpEvap)	This descriptor signals which source term model to open given an accident sequence. Sequences that result in no agent release do not call a model.
GB M55 - Igloo Collapse —• None —• Level 01 —• Level 02 —• *41 other levels*	This descriptor indicates the number of igloos that collapse during a seismic event. Answers of none to forty-one, the total number of GB rocket igloos, are available. The number in the answer is the number of igloo collapses.
VX M55 - Igloo Collapse —• None —• Level 01 —• Level 02 —• *6 other levels*	This descriptor indicates the number of igloos that collapse during a seismic event. Answers of none to six, the total number of VX rocket igloos, are available. The number in the answer is the number of igloo collapses.

Table 14-13. External Event Accident Sequence Description for Source Terms (Continued)

Branch Point Question	Description of Question and Answers
GB M55 - Igloo Collapse and Fire —• None —• Level 01 —• Level 02 —• *41 other levels*	This descriptor indicates the number of igloo fires following collapse during a seismic event. Answers of none to forty-one, the total number of GB rocket igloos, are available. The number in the answer is the number of igloo collapses and fires.
VX M55 - Igloo Collapse and Fire —• None —• Level 01 —• Level 02 —• *6 other levels*	This descriptor indicates the number of igloo fires following collapse during a seismic event. Answers of none to six, the total number of VX rocket igloos, are available. The number in the answer is the number of igloo collapses and fires.
GB M55 – Spills per 80-ft Igloo? —• None —• Level 01 —• Level 02 —• *18 other levels*	This descriptor indicates the number of pallets that leak during a seismic event. The number in the answer is the number of pallets that leak.
VX M55 – Spills per 80-ft Igloo? —• None —• Level 01 —• Level 02 —• *18 other levels*	This descriptor indicates the number of pallets that leak during a seismic event. The number in the answer is the number of pallets that leak.
GB M55 80-ft Rocket Igloo Fires? —• None —• Level 01 —• Level 02 —• *18 more levels*	This descriptor indicates the number of igloo fires that may develop during a seismic event. The number in the answer is the number of igloo fires that develop.
VX M55 80-ft Rocket Igloo Fires? —• None —• Level 01 —• Level 02 —• *4 more levels*	This descriptor indicates the number of igloo fires that may develop during a seismic event. The number in the answer is the number of igloo fires that develop.
GB 155mm - Igloo Collapses —• None —• Level 01 —• Level 02 —• Level 03 —• Level 04 —• Level 05 —• Level 06 —• Level 07	This descriptor indicates the number of igloo collapses during a seismic event. Answers of none to seven, the total number of GB 155mm igloos, are available. The number in the answer is the number of igloos that collapse.

Table 14-13. External Event Accident Sequence Description for Source Terms (Continued)

Branch Point Question	Description of Question and Answers
VX 155mm - Igloo Collapses —• None —• Level 01 —• Level 02 —• Level 03 —• Level 04 —• Level 05	This descriptor indicates the number of igloo collapses during a seismic event. Answers of none to five, the total number of VX 155mm igloos, are available. The number in the answer is the number of igloos that collapse.
GB 750-lb Bomb - Igloo Collapses —• None —• Level 01 —• Level 02 —• Level 03 —• Level 04 —• Level 05	This descriptor indicates the number of igloo collapses during a seismic event. Answers of none to five, the total number of GB 750-pound bomb igloos, are available. The number in the answer is the number of igloos that collapse.
GB 8-inch - Igloo Collapses —• None —• Level 01 —• Level 02 —• Level 03 —• Level 04 —• Level 05	This descriptor indicates the number of igloo collapses during a seismic event. Answers of none to five, the total number of GB 8-inch igloos, are available. The number in the answer is the number of igloos that collapse.
VX 8-inch - Igloo Collapses —• None —• Level 01 —• Level 02	This descriptor indicates the number of igloo collapses during a seismic event. Answers of none to two, the total number of VX 8-inch igloos, are available. The number in the answer is the number of igloos that collapse.
VX Mine - Igloo Collapses —• None —• Level 01 —• Level 02 —• Level 03	This descriptor indicates the number of igloo collapses during a seismic event. Answers of none to three, the total number of VX mine igloos, are available. The number in the answer is the number of igloos that collapse.
HD/HT - Igloo Collapses —• None —• Level 01 —• Level 02 —• *Values up to 24*	This descriptor indicates the number of igloo collapses during a seismic event. Answers of none to twenty-four, the total number of HD/HT ton container igloos, are available. The number in the answer is the number of igloos that collapse.
VX Spray - Igloo Collapses —• None —• Level 01 —• Level 02 —• *Values up to 12*	This descriptor indicates the number of igloo collapses during a seismic event. Answers of none to twelve, the total number of VX spray tanks igloos, are available. The number in the answer is the number of igloos that collapse.
GB 155mm – Spills per 80-ft Igloo? —• None —• Level 01 —• Level 02 —• *18 other levels*	This descriptor indicates the number of pallets that leak during a seismic event. The number in the answer is the number of pallets that leak.

Table 14-13. External Event Accident Sequence Description for Source Terms (Continued)

Branch Point Question	Description of Question and Answers
VX 155mm – Spills per 80-ft Igloo? —• None —• Level 01 —• Level 02 —• *18 other levels*	This descriptor indicates the number of pallets that leak during a seismic event. The number in the answer is the number of pallets that leak.
VX Mine – Spills per 80-ft Igloo? —• None —• Level 01 —• Level 02 —• *18 other levels*	This descriptor indicates the number of pallets that leak during a seismic event. The number in the answer is the number of pallets that leak.
VX Mine – Pallet Explosions per 80-ft Igloo? —• None —• Level 01 —• Level 02 —• Level 03	This descriptor indicates the number of pallets that explode during a seismic event. The number in the answer is the number of pallets that explode.
GB 8-inch – Spills per 80-ft Igloo? —• None —• Level 01 —• Level 02 —• *18 other levels*	This descriptor indicates the number of pallets that leak during a seismic event. The number in the answer is the number of pallets that leak.
VX 8-inch – Spills per 80-ft Igloo? —• None —• Level 01 —• Level 02 —• *18 other levels*	This descriptor indicates the number of pallets that leak during a seismic event. The number in the answer is the number of pallets that leak.
VX Spray Tanks – Spills per 80-ft Igloo? —• None —• Level 02 —• Level 04 —• *18 other levels*	This descriptor indicates the number of spray tanks that leak during a seismic event. The number in the answer is the number of spray tanks that leak.
500-lb Bombs – Spills per 80-ft Igloo? —• None —• Level 01 —• Level 02 —• *18 other levels*	This descriptor indicates the number of 500-pound bombs that leak during a seismic event. The number in the answer is the number of bombs that leak.
750-lb Bombs – Spills per 80-ft Igloo? —• None —• Level 01 —• Level 02 —• *18 other levels*	This descriptor indicates the number of 750-pound bombs that leak during a seismic event. The number in the answer is the number of bombs that leak.

Table 14-13. External Event Accident Sequence Description for Source Terms (Continued)

Branch Point Question	**Description of Question and Answers**
HD TC – Spills per 80-ft Igloo? —• None —• Level 01 —• Level 02 —• *18 other levels*	This descriptor indicates the number of ton containers that leak during a seismic event. The number in the answer is the number of ton containers that leak.
Number of pallet spills due to igloo collapse with evaporation? —• None —• Level 01 —• Level 02 —• *3 more levels*	This descriptor indicates the number of pallets that leak due to an igloo collapse during a seismic event. Analysis shows that the igloos will not collapse during seismic events. Thus, the answer to this question is always *None*.
Number of igloo fires due to igloo collapse with fire? —• None —• Level 01 —• Level 02 —• *3 more levels*	This descriptor indicates the number of igloo fires due to an igloo collapse during a seismic event. Analysis shows that the igloos will not collapse during seismic events. Thus, the answer to this question is always *None*.
Dispersion model release? —• No special characteristics —• Seismic release	This descriptor identifies conditions under which a certain release can occur. Seismic sequences have *Seismic release* as an answer; lightning and aircraft sequences have *No special characteristics* as answers. This descriptor is input to CHEMMACCS.
Population? —• Public – Facility Accident —• Public – Storage Yard Accident —• Worker – Facility Accident —• Worker – Storage Yard Accident	This descriptor identifies the population for which accident effects are of interest. For the upsets in the external tree, only *Public – Storage Yard Accident* is considered. This descriptor is input to CHEMMACCS.
Release Mode? —• None —• Spill —• Explosion without Fire —• Explosion with Fire	This descriptor identifies how agent is initially released for a given accident.
Propagation Mode? —• None —• Explosion with Fire	This descriptor identifies how a given accident propagates to other munitions.
Agent? —• None —• GB —• VX —• HD	Categorizes all accident sequences by the type of agent involved. This is needed for determination of the agent source term.

Table 14-13. External Event Accident Sequence Description for Source Terms (Continued)

Branch Point Question	Description of Question and Answers
Munition? —• None —• Rocket —• 155mm —• 8-inch —• Land Mine —• Spray Tank —• 500-lb Bomb —• 750-lb Bomb —• Ton Container	Categorizes all accident sequences by the type of munition involved.
Storage Location? —• None —• 80-ft Igloo (Igloo80ft)	This determines where the initial accident occurs so that the appropriate agent inventories can be considered.
Quantity? —• Not Applicable —• Pallet	This accident characteristic identifies the number of a given munition type involved in the upset.
Propagation Quantity? —• None —• Igloo	This accident characteristic identifies the number of munitions propagated to during an upset.
Amount? —• Not Applicable —• P200 —• P100 —• P075 —• P050 —• P025 —• P010	This accident characteristic identifies the percentage of the contents of an igloo involved in an accident.
Mode? —• None —• Seismic —• Medium Aircraft (MdAircraft) —• Large Aircraft (LgAircraft) —• Lightning	This descriptor signals the source term models to which upset is causing a given accident sequence.
Drained Status? —• Undrained —• Drained	Even though munitions are always *Undrained* in the storage yard, this descriptor is necessary input for all source term worksheets. Thus, the drained status of munitions must be defined.
Breach? —• Not Applicable (NotAppl) —• No Breach (NoBreach) —• External Breach (ExtBreach) —• Internal Breach (IntBreach)	This descriptor identifies the presence of an MDB wall breach during an upset. This obviously does not apply to the continued storage trees, but since the processing and storage trees share many source term worksheets, this descriptor is necessary input. *NotAppl* is always the answer for the continued storage trees.

Table 14-13. External Event Accident Sequence Description for Source Terms (Continued)

Branch Point Question	Description of Question and Answers
HVAC? —• Not Applicable (NotAppl) —• HVAC On (HVACon) —• HVAC Off Global (HVACOffGlobal) —• HVAC Off Local (HVACOffLoc)	This descriptor identifies the status of the MDB HVAC system during an upset. This obviously does not apply to the continued storage trees, but since the processing and storage trees share many source term worksheets, this descriptor is necessary input. *NotAppl* is always the answer for the continued storage trees.

For each sequence, a source term was determined based upon the section 10.2 source term models (i.e., evaporation, seismic events, aircraft crashes). However, the following additional assumptions have been made:

a. The median number of munitions breached under a collapsed 155mm projectile igloo is 89 (Christman, 2002c). All the agent within those munitions will spill and form a pool. The collapsed structure will cover a large portion of the pool, leaving 25 percent available for evaporation. These estimates are uncertain and are assigned probability distributions as described in appendix P.

b. Spills within a standing igloo will tend to flow down the sloped floor, under the main door, and out the igloo. However, a portion of the spill's volume will not exit as the igloo floor area remains wetted. It is assumed that any igloo can hold a spill volume defined by half its floor area times a median 1/32-inch pool depth. Any volume in excess of that threshold will flow outside and be subject to the outdoor evaporation rate.

c. Based on the structural analysis, which indicates that the available kinetic energy involved in a large aircraft crash can result in considerable damage to the storage igloo and the munitions therein, the source term for this event assumed that the entire inventory of agent within the igloo was involved in the release.

One important difference between the UMCDF source terms and those associated with the stockpile storage area was the fact that DFs were not considered for stockpile storage area sequences. Because the igloos have vents and agent can leak directly outside, DFs were not credited with limiting the potential for a stockpile storage area release.

14.6 Stockpile Storage Area Consequence Analysis

The consequence analysis for the stockpile storage area sequences is identical to that described in section 11 for the UMCDF sequences. Health effects to the public population surrounding the site were estimated for each source term group. CHEMMACCS is used within Quantus to run each sequence through dispersion analysis and produce the resulting health effects.

The external event sequences identified for the stockpile storage area could occur at any time during the day or night; therefore, no discrimination was made for the time of an accident for these sequences. Only daytime hours were considered for handling accidents at the stockpile storage area. In all cases, the same emergency response actions and evacuation times used for CDF sequences were used for stockpile storage area sequences.

The results of the stockpile storage area consequence analysis include mean values for societal impacts, individual impacts, and CCDFs for each health effect. Health effects are expressed as the numbers of acute fatalities and latent cancers that could be associated with a given release.

14.7 Stockpile Storage Area Risk Assembly

The risk assembly process for storage follows the same method described in section 12. Risk is calculated for continued storage, assuming that the current inventory remains stored, and for storage risk during processing. The storage risk during processing accounts for the disposal of munitions as munition campaigns are completed. To simplify the risk calculations, the risk is calculated at the end of each munition campaign, accounting for the new inventory when all of a given type are removed. Using Quantus, one could calculate intermediate points in a processing campaign also (some fraction of a given munition type removed from the stockpile and destroyed), but the stepwise calculation of storage risk is acceptable for reporting purposes. Table 14-14 lists the time increments derived from the disposal schedule that are used in the calculations.

Table 14-14. Schedule Used in the QRA for Calculation of Storage Risk

Munition		Start Date	Finish Date	Days[a]	Weeks	Total Hours	Number of Munitions	Average Rate[b] (munition/hr)
1a	GB M55 Rockets (1)	02/28/03	07/03/03	126	18.0	3,024	19,299	6.38
1b	GB M55 Rockets with MC-1 Bombs	07/04/03	03/05/04	246	35.1	5,904	37,680/2,418	6.38/0.41
1c	GB M55 Rockets with MK-94 Bombs	03/06/04	03/06/04	1	0.1	24	153/27	6.38/1.13
1d	GB M55 Rockets (2)	03/07/04	10/16/04	224	32.0	5,376	34,310	6.38
	Changeover	10/17/04	04/24/05	190	27.1	4,560		
2a	VX M55 Rockets (1)	04/25/05	06/22/05	59	8.4	1,416	6,253	4.42
2b	VX M55 Rockets with Spray Tanks	06/23/05	08/02/05	41	5.9	984	4,345/156	4.42/0.16
2c	VX M55 Rockets (2)	08/03/05	09/08/05	37	5.3	888	3,921	4.42
	Changeover	09/09/05	11/11/05	64	9.1	1,536		
3	VX 8-inch Projectile	11/12/05	12/14/05	33	4.7	792	3,752	4.74
	Changeover	12/15/05	01/25/06	42	6.0	1,008		
4	VX 155mm Projectile	01/26/06	03/30/06	64	9.1	1,536	32,313	21.04
	Changeover	03/31/06	05/18/06	49	7.0	1,176		
5	VX Land Mines	05/19/06	07/18/06	61	8.7	1,464	11,685	7.98
	Changeover	07/19/06	01/24/07	190	27.1	4,560		
6	GB 155mm Projectile	01/25/07	04/21/07	87	12.4	2,088	47,406	22.70
	Changeover	04/22/07	06/02/07	42	6.0	1,008		
7	GB 8-inch Projectile	06/03/07	07/27/07	55	7.9	1,320	14,246	10.79
	Changeover	07/28/07	02/02/08	190	27.1	4,560		
8	HD Ton Containers	02/03/08	11/22/08	294	42.0	7,056	2,635	0.37
	Closure	11/23/08	11/22/09	365	52.1	8760		
	Totals			2,460		59,040	220,599	
	Total operating days (no closure)			2,095				
	Total operating years			5.7				

Notes:

[a] The schedule provided here is the calendar time associated with operations. This includes fully operational periods as well as downtime for maintenance, etc.

[b] This is an average rate across the calendar time. It is used in the risk calculations to ensure that the entire calendar time of a campaign is considered. It is not the typically cited "throughput" of the equipment itself, because it also includes downtime.

(This page intentionally left blank.)

SECTION 15
RISK RESULTS AND INSIGHTS FOR STOCKPILE STORAGE

The results of the risk analysis of chemical munition stockpile storage at UMCD are presented in this section. Both the risk of stockpile storage during the disposal process and the risk associated with continued storage for a period of 20 years are included. The stockpile storage risk assessment is limited to the risk of fatality or cancer incidence in the offsite public population; worker risk was not included. Additional conclusions regarding these results are provided in section 16. Specifically, section 16 includes a comparison of stockpile storage risk to the risk of both disposal processing and risk estimates previously published in the UMCDF Phase 1 QRA (SAIC, 1996a).

Box 15-1 summarizes some of the number formats used in this report.

Box 15-1. Numbers Used in Presenting Risk Values

Scientific	Decimal	Scientific Used in Graphs	Numeric Description if it is a Probability	Word Description if the Number is a Probability
1.0×10^{-1}	0.1	1.0E-01	1 in 10	1 in ten chance
1.0×10^{-2}	0.01	1.0E-02	1 in 100	1 in one hundred chance
1.0×10^{-3}	0.001	1.0E-03	1 in 1,000	1 in one thousand chance
1.0×10^{-4}	0.0001	1.0E-04	1 in 10,000	1 in ten thousand chance
1.0×10^{-5}	0.00001	1.0E-05	1 in 100,000	1 in one hundred thousand chance
1.0×10^{-6}	0.000001	1.0E-06	1 in 1,000,000	1 in one million chance
1.0×10^{-7}	0.0000001	1.0E-07	1 in 10,000,000	1 in ten million chance
1.0×10^{-8}	0.00000001	1.0E-08	1 in 100,000,000	1 in one hundred million chance
1.0×10^{-9}	0.000000001	1.0E-09	1 in 1,000,000,000	1 in one billion chance

15.1 Acute Fatality Risk for Stockpile Storage During the Disposal Process

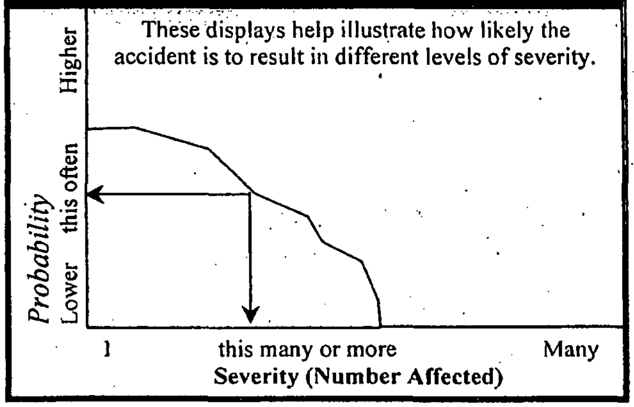
As described in section 2.6, the acute fatality risk measure represents the risk of agent-related fatalities to the public. It is presented as *societal risk*, which is defined as the number of fatalities in the population at risk, and *individual risk*, which is defined as the probability of fatality for an individual in the population at risk (see box 15-2):

Box 15-2. Societal and Individual Risk

Societal	Risk to society, the total impact. For example, there are about 40,000 people killed in U.S. car accidents each year.
Individual	Per-person risk, the chance that an individual is affected. For example, typical citizens have a 1 in 6,000 chance of being killed in a car accident each year.

Figure 15-1 depicts the risk of acute fatality to the public from stockpile storage at UMCD during the UMCDF disposal process. This figure takes into consideration the depletion of munitions from the stockpile as they are processed at UMCDF. (The models were simplified by assuming that all munitions being disposed of in a campaign are in the storage area until the end of that campaign, at which time all of the munitions are removed from the risk calculation.) This CCDF illustrates the public acute fatality risk, which indicates the frequency of exceeding various levels of consequences over the UMCDF processing duration (approximately 6 years). The vertical axis is the probability of exceeding a given number of fatalities due to stockpile accidents during the disposal period, and the horizontal axis is the number of fatalities (see box 15-3).

Box 15-3. CCDFs



The impact of uncertainties is depicted in figure 15-1 through curves corresponding to different levels of confidence in the results. As described in section 12, uncertainties were derived by quantifying the risk model many times and developing a CCDF for each solution. The curves in figure 15-1 represent the 5th, 50th (median), and 95th percentiles of those many CCDFs at each

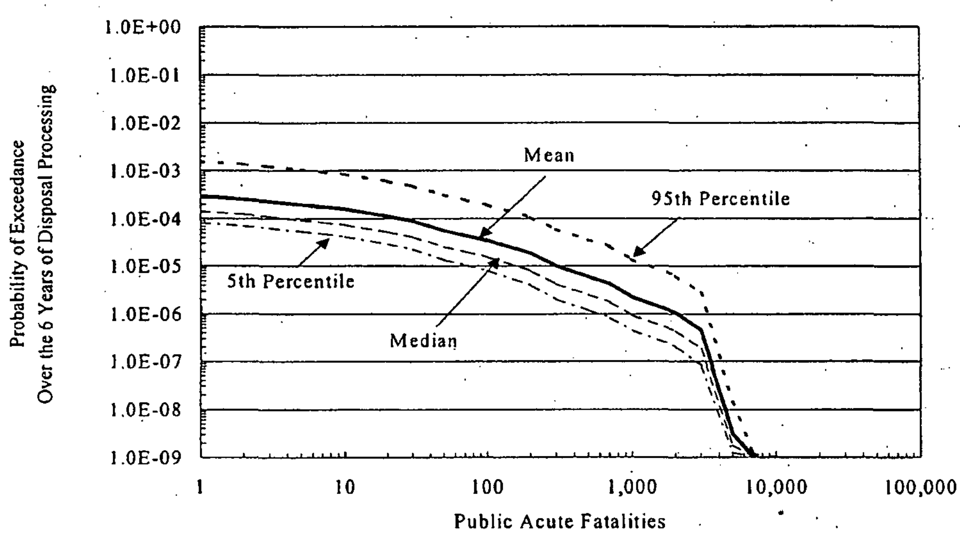


Figure 15-1. Public Societal Acute Fatality Risk of UMCD Stockpile Storage over the 6 Years of Disposal Processing

fatality level. The mean curve developed from all the CCDFs also is shown. Although it varies at different fatality levels, there is typically about a factor of 20 spread between the 5th and 95th percentiles.

The area under the mean curve, referred to as the "risk" (also referred to as "mean expected fatalities"), is 1.8×10^{-2}. This value represents the number of public fatalities expected from stockpile storage during the UMCDF disposal-processing period.

The probability of exceeding one or more fatalities is approximately 3.0×10^{-4}, as seen from the mean curve in figure 15-1. Events that affect large numbers of people are much less likely. (A consequence of approximately 2,000 fatalities has a one in one million probability, 1×10^{-6}.) The consequence at a one in one billion probability (1×10^{-9}) is 7,000 fatalities.

The stockpile storage risk during disposal processing is dominated by external events, specifically earthquakes. Lightning is also a small contributor. Figure 15-2 presents the contributors to risk for public acute fatalities for munition storage during the 6-year UMCDF disposal period. As seen in figure 15-2, earthquakes totally dominate the storage risk at UMCD. The earthquake-induced effects involve igloo collapses and munitions (primarily rockets) sliding and falling from their storage configurations leading to spills, fires, and/or explosions. The lightning sequences involve ignition of one or more rockets within an igloo leading to a fire or explosion.

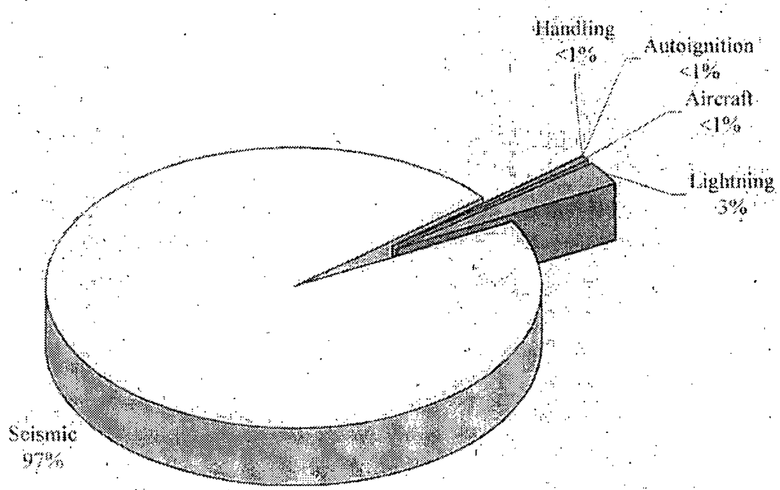


Figure 15-2. Contributors to Mean Public Societal Acute Fatality Risk of UMCD Storage During the 6 Years of Disposal Processing

The aircraft crash sequences include the possibility of an accidental crash into an igloo. The potential for either an overpacked or non-overpacked rocket to autoignite in storage also has been included and, as seen in figure 15-2, has a negligible contribution to risk. Handling accidents, which include drops of munitions during leaker identification and isolation activities, also were found to have negligible contributions to public fatality storage risk. These contributors to the stockpile storage risks are discussed in section 15.3.

The measure illustrated in figure 15-1 is termed *societal risk* because it applies to the public as a whole. This societal risk also may be calculated for subpopulations surrounding the facility. The CCDFs for societal acute fatality risk during the disposal period, categorized by population ring, are shown in figure 15-3. (Figure 11-1 in section 11 displays the population rings.) Figure 15-3 identifies the contribution of risk from the various population rings to the overall CCDF, previously shown in figure 15-1. The 8- to 15-kilometer ring dominates the storage risk and also includes the maximum fatalities. (This ring includes approximately 25,000 people.) The 5- to 8-kilometer ring is closer to the site and is also a significant contributor; however, it has fewer maximum fatalities due to its lower population (approximately 4,000). The 45- to 60-kilometer ring is also an important contributor to storage risk because it includes the populated tri-city area (approximately 200,000). The population ring closest to the site (2 to 5 kilometers) has a small contribution to total risk due to its limited population (less than 50).

Table 15-1 lists the societal risk of acute fatality for each population ring surrounding UMCD.

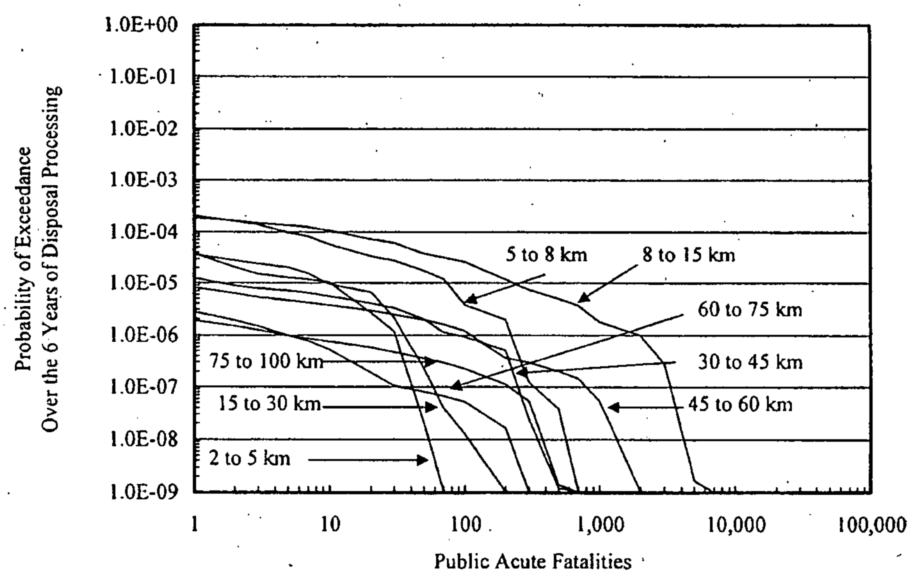


Figure 15-3. Mean Public Societal Acute Fatality CCDFs for Munition Storage During the 6 Years of Disposal Processing by Distance from UMCD

Table 15-1. Total Public Societal Acute Fatality Risk of Stockpile Storage over the 6 Years of UMCDF Disposal Processing by Distance from UMCD

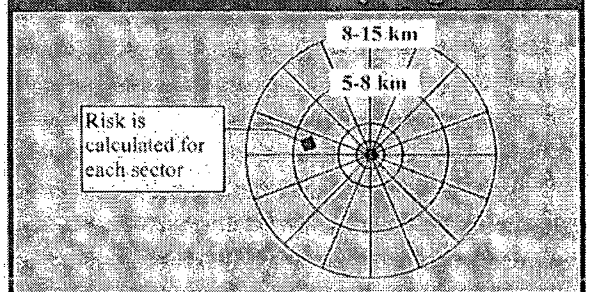
	0-2 km[a]	2-5 km	5-8 km	8-15 km	15-30 km	30-45 km	45-60 km	60-75 km	75-100 km
Societal Acute Fatality Risk	–	2.5×10^{-4}	3.2×10^{-3}	1.3×10^{-2}	3.7×10^{-4}	3.7×10^{-4}	4.5×10^{-4}	2.7×10^{-5}	7.4×10^{-5}
Fraction of Total Risk from Each Ring	–	1%	18%	73%	2%	2%	3%	<1%	<1%

Note:

[a] Within facility boundaries; no public population.

The results show that only about 1 percent of the storage risk is associated with the first populated ring (2 to 5 kilometers). Although this ring is close to the site, the low population results in few acute fatalities compared to the more populated rings containing Umatilla, Hermiston, Stanfield, Echo, and Boardman. The majority of the risk (91 percent) is controlled by the population living between 5 and 15 kilometers from the site. External events, dominated by earthquakes and lightning, account for nearly 100 percent of the risk in each ring.

Box 15-4. Risk by Ring



The individual risks are calculated for each of 16 sectors in a ring. This allows more accurate consideration of both weather and population in developing average individual risk values. For societal risk by distance, the sum of all 16 sectors is presented.

Table 15-2 lists the individual risk of acute fatality, calculated by distance from the facility. This table provides an average risk rate (risk per year) over the 6 years of disposal processing. As described earlier (box 15-2), individual risk is an important display because it provides a point of comparison to other risks to which individuals might be subjected. As described in box 15-4, the risks are actually calculated for each of the 16 sectors in each ring. The individual risk is highest near the site and drops rapidly with increasing distance. The societal risk was highest in the 8- to 15-kilometer ring because of the large population in that ring. Individual risk divides out the impact of population; therefore, risk is highest nearest the facility.

Table 15-2. Mean Public Individual Acute Fatality Risk (per Year) of Stockpile Storage over the 6 Years of Disposal Processing by Distance from UMCD

	0-2 km[a]	2-5 km	5-8 km	8-15 km	15-30 km	30-45 km	45-60 km	60-75 km	75-100 km
Average Individual Fatality Risk	–	3.8×10^{-7}	3.7×10^{-6}	1.1×10^{-6}	1.3×10^{-7}	3.3×10^{-8}	7.8×10^{-9}	3.8×10^{-9}	1.0×10^{-9}

Note:

[a] Within facility boundaries; no public population.

15.2 Acute Fatality Risk for 20 Years of Continued Stockpile Storage

For comparison purposes, and in the event that disposal processing is delayed for an extended period, public risk was calculated for continued munition storage (assuming no processing). Risk was calculated on an annual basis and then was calculated assuming a 20-year storage period.[6] The risk is given per year so that risk can be calculated for any number of years of continued storage.

It should be noted that these calculations are based on the assumption that the current storage risks remain constant during 20 years of continued storage. The population is assumed to remain constant and any potential increases in risk due to munition degradation are neglected. Agent leakage rates have not shown any substantial increasing trend, and even if they did, the public risk associated with leakage of individual items is quite limited. In addition, the propellant in the M55 rockets has been found to be stable for time periods well exceeding 20 years. Thus the straight-line extrapolation over 20 years appears to be reasonable except for the influence of population changes.

Figure 15-4 shows the CCDF for public acute fatalities during 20 years of continued storage. The curves in figure 15-4 also represent the 5th, 50th (median), and 95th percentiles of CCDFs at each fatality level. The mean curve is shown as well. Although it varies at different fatality levels, there is typically about a factor of 24 spread between the 5th and 95th percentiles. As indicated in the figure, the mean probability of one or more fatalities over a 20-year period is approximately 3.6×10^{-3}. There is a one in one million probability of exceeding 4,000 or more fatalities for a 20-year storage duration. The consequence at 1×10^{-9} probability is approximately 20,000 fatalities.

[6] A 20-year continued storage duration was chosen to be comparable to the 25-year storage duration used in the FPEIS report.

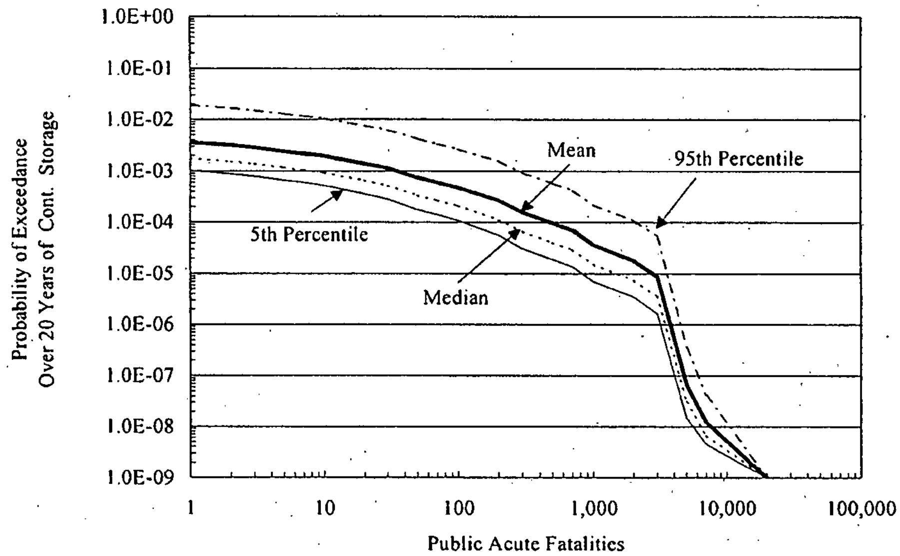


Figure 15-4. Public Societal Acute Fatality Risk of Stockpile Storage over 20 Years of Continued Storage at UMCD

The mean acute fatality risk (expected fatalities) for continued storage is the area under the mean curve in figure 15-4. This value is 0.26 for 20 years of continued storage with no disposal processing, or approximately 1.3×10^{-2} fatalities per year.

It should be noted that the risk includes contributions from infrequent accidents that would have large consequences. Therefore, although the risk per year multiplied by 35 years of past storage at UMCD suggests a 50 percent chance of a fatality by now, in reality the risk is influenced by very infrequent events involving more than one fatality. For example, although the munitions have been stored for more than 35 years, there have been no large earthquakes during that period that would have caused a significant release and large numbers of fatalities.

The contributors to the risk of continued storage are the same as for the risk of storage over the disposal period (see figure 15-5). In this case, seismic events still dominate, accounting for approximately 97 percent of the total mean risk. Lightning events contribute a smaller portion (3 percent). Rocket autoignition, accidental aircraft crashes, and handling activities still have negligible contributions to storage risk. Additional discussion of risk contributors is provided in section 15.3.

The societal and individual risks within each population ring also were calculated for continued munition storage. Figure 15-6 shows the CCDF for public societal acute fatality risk of 20 years of continued storage as a function of distance from UMCD. This CCDF shows the same pattern

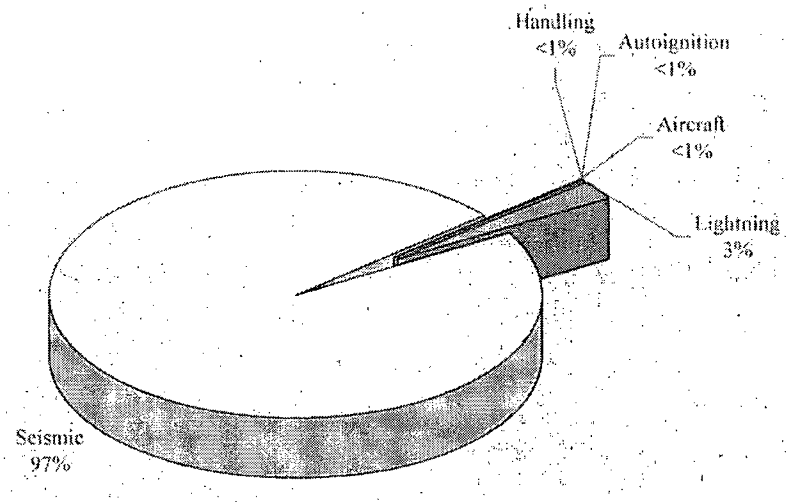


Figure 15-5. Contributors to Mean Public Societal Acute Fatality Risk over 20 Years of Continued Stockpile Storage at UMCD

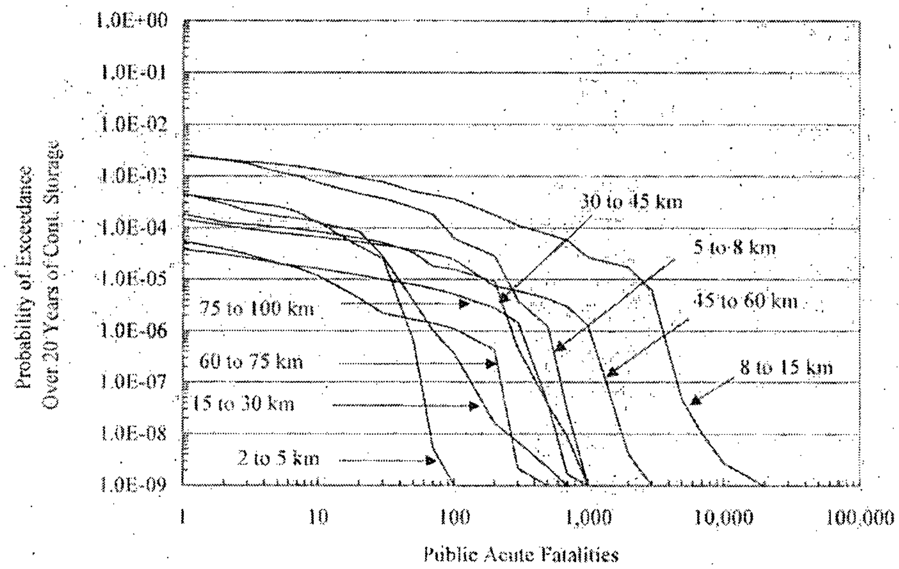


Figure 15-6. Mean Public Societal Acute Fatality CCDFs for 20 Years of Continued Storage by Distance from UMCD

as the previous CCDF for stockpile storage during the disposal process illustrated in figure 15-3. The 8- to 15-kilometer population ring is still the largest contributor to public acute fatality risk, especially at the upper end of the consequence scale.

Table 15-3 lists the societal public acute fatality risk by distance from UMCD. The results show the same pattern as seen in section 15.1 for storage risk during disposal processing. As with the storage risk during processing, approximately 90 percent of the risk is associated with the 5- to 15-kilometer rings, and releases caused by external events contribute nearly 100 percent of the risk to all rings.

Table 15-3. Total Public Societal Acute Fatality Risk for Continued Stockpile Storage (per Year) by Distance from UMCD

	0-2 km[a]	2-5 km	5-8 km	8-15 km	15-30 km	30-45 km	45-60 km	60-75 km	75-100 km
Societal Acute Fatality Risk	–	1.7×10^{-4}	2.2×10^{-3}	9.4×10^{-3}	2.3×10^{-4}	3.0×10^{-4}	4.5×10^{-4}	2.9×10^{-5}	8.4×10^{-5}
Fraction of Total Risk from Each Ring	–	1%	17%	73%	2%	2%	4%	<1%	<1%

Note:

[a] Within facility boundaries; no public population.

Table 15-4 lists the individual risks of acute fatality per year for continued storage assuming no disposal occurs. Individual risk is highest closest to UMCD and drops off as distance from the site increases.

15.3 Discussion of Events Contributing to Stockpile Storage Fatality Risk

Figures 15-2 and 15-5 summarize the key classes of accidents that contribute to the public acute fatality risk for storage. Because the contributors for stockpile storage during processing and continued storage are nearly the same, they are discussed together in this section. As indicated in the previous section, storage risk at UMCD is dominated by earthquakes with a small contribution from lightning, and negligible contributions from accidental aircraft crashes, handling, and rocket autoignition. The following sections describe the accident sequences that make up the contributors to the stockpile risk.

Table 15-4. Mean Public Individual Acute Fatality Risk (per Year) for Continued Storage by Distance from UMCD

	0-2 km[a]	2-5 km	5-8 km	8-15 km	15-30 km	30-45 km	45-60 km	60-75 km	75-100 km
Average Individual Fatality Risk	–	3.7×10^{-6}	5.7×10^{-7}	3.6×10^{-7}	2.0×10^{-8}	8.6×10^{-9}	2.4×10^{-9}	7.8×10^{-10}	8.9×10^{-10}

Note:

[a] Within facility boundaries; no public population.

15.3.1 Seismic Risk. The assessment of seismic risk includes analysis of the frequency of earthquakes of different peak gravitational accelerations (PGAs) and the response of stored munitions and storage igloos to the ground motion created by the earthquakes. Seismic risk assessment is discussed in greater detail in section 5 and appendix H.

Igloo collapse is possible, but very unlikely, for the reinforced concrete igloos at UMCD. Computer modeling of the seismic response of these igloos indicated that they have a median capacity of 1.69 g, which means that cracking of the igloo walls would occur half of the time for ground motion at this level. Earthquakes capable of producing this level of ground motion at UMCD are extremely rare. If an igloo collapses, the munitions stored inside could be damaged sufficiently that they leak agent. In addition, explosions or fires could occur for munitions with energetics.

If the igloo does not collapse, the munitions inside can still pose a risk because the munition stacks could fall during an earthquake, causing a leak or explosion. Computer models yielded the following estimates of the seismic fragilities for the munition stacks of interest: 1) stacks of M55 rocket pallets have a median tipping fragility of 0.60 g, 2) stacks of mines have median tipping fragilities of 0.76 g, 3) stacks of 155mm projectiles have median tipping fragilities of 0.24 g, 4) stacks of 8-inch projectiles have median tipping fragilities of 0.44 g, 5) 500-pound bombs have a slipping fragility of 0.76 g, 6) 750-pound bombs have a slipping fragility of 0.76 g, 7) spray tanks have a slipping fragility of 0.76 g, and 8) ton containers have a slipping fragility of 0.94 g. Appendix H describes the computer models used in the fragility analysis.

Calculations have been performed for earthquake PGA levels between 0.1 g and 2.0 g, and the results integrated to calculate the seismic damage to the stockpile. Leakage, explosions, and fires are addressed in the risk model. Similar to handling events at UMCDF, pallets falling in an igloo during a seismic event have a small probability of exploding or igniting. In seismic events, pallets may fall onto other pallets that have previously fallen. If this happens, the resulting potential for puncturing the munition casing increases the probability of explosion or ignition. The potential for explosion or ignition is particularly important for rockets because ignition a rocket could lead to a fire that spreads to the remaining rockets in the igloo. Because of this, the rockets were found to be the most risk-significant munition in storage. Rockets also were much less robust than the other munitions and more likely to leak or explode given a pallet fall.

The other outcome of interest is leakage of agent. The major concern is leakage of GB, which is much more volatile than either VX or HD. The number of stacks falling and the number of munitions that leak after falling were calculated. This calculation includes the probability that the munition fails when it falls.

A variety of munition failures could occur in any given earthquake: some igloos may collapse causing munitions to leak or explode; others may have stacks that topple, causing munitions to leak; others may have munitions that fall and explode; and still others may have explosions that lead to igloo-wide fires. All of these outcomes happen simultaneously. The resultant source terms must be calculated individually and then combined into a single source term that characterizes the accident scenario.

At each g-level, a source term was derived based on which munitions leaked or exploded, and a consequence calculation was performed. Table 15-5 illustrates the seismic results for continued storage. (Storage during disposal has a similar breakdown.) As shown in table 15-5, earthquakes with ground motions in the range from 0.25 g to 0.75 g have the greatest contribution to risk because they have sufficient earthquake motion to cause damage leading to agent release and have a relatively low recurrence interval. The table also shows that the consequences for earthquakes can be considerable due to the large agent releases that could occur. The consequences shown in table 15-5 are much greater than those calculated for any processing accident.

15.3.2 Lightning Risk. The M55 rocket is potentially vulnerable to lightning because of its electrical firing circuit. Because of this firing circuit, lightning strikes on or near rocket igloos could produce sufficient buildup of electric charge in the steel igloo reinforcement to cause direct arcing to the stored rockets. A lightning strike may also cause electromagnetic fields that induce a current or voltage in the firing circuit. Any of these effects may cause the rocket propellant to ignite. As noted earlier, ignition of one rocket could cause a fire that spreads to the other rockets in the igloo. In a worst-case scenario, the entire igloo inventory of rockets (up to 176 pallets or over 2,500 rockets) may become involved. A more detailed discussion of lightning effects on M55 rockets is provided in appendix J2.

Lightning risk is low at UMCD compared to the eastern stockpile storage sites (Anniston, Blue Grass, and Pine Bluff) because the flash density is so much lower in the Umatilla area. The

Table 15-5. Earthquake Accident Scenarios for Continued Storage

Earthquake PGA Level	Mean Earthquake Recurrence Interval (Years)	Mean Number of Agent-Related Fatalities per Earthquake	Mean Fatality Risk per Year of Continued Storage	Contribution to Total Risk per Year of Continued Storage
0.35 – 0.45 g	23,000	41	2.8×10^{-3}	22%
0.45 – 0.55 g	56,000	81	2.3×10^{-3}	18%
0.55 – 0.65 g	74,000	105	1.4×10^{-3}	11%
0.25 – 0.35 g	21,000	17	1.4×10^{-3}	11%
0.65 – 0.75 g	280,000	166	1.3×10^{-3}	10%
0.75 – 0.85 g	470,000	192	8.5×10^{-4}	7%
0.15 – 0.25 g	69,000	10	6.3×10^{-4}	5%
0.85 – 0.95 g	1.7 million	224	5.5×10^{-4}	4%
0.95 - 1.05 g	2.3 million	241	4.4×10^{-4}	3%
1.05 – 1.15 g	4 million	263	2.7×10^{-4}	2%
1.15 – 1.25 g	6.1 million	291	1.7×10^{-4}	1%
1.25 – 1.35 g	5.6 million	321	1.2×10^{-4}	1%
1.35 – 1.45 g	8.9 million	337	7.8×10^{-5}	1%
1.45 – 1.55 g	13 million	387	5.9×10^{-5}	1%
1.55 – 1.65 g	20 million	416	4.3×10^{-5}	< 1%
1.65 – 1.75 g	29 million	434	3.1×10^{-5}	< 1%
1.75 – 1.85 g	41 million	448	2.2×10^{-5}	< 1%
1.85 – 1.95 g	57 million	503	1.8×10^{-5}	< 1%
Total Seismic Risk (per year):			1.2×10^{-2}	97%

average flash density at UMCD is 0.15 strikes per year per square kilometer. Eastern sites such as Blue Grass and Anniston have flash densities that are 40 times higher. Table 15-6 shows that lightning accident scenarios are small contributors to continued storage risk.

15.3.3 Aircraft Crash. An aircraft crash into the storage yard could breach one or more igloos and cause the munitions stored inside to leak or explode. In addition, a fire may occur that involves all of the munitions in the igloo. Only large or medium aircraft are assumed capable of breaching an igloo.

Table 15-6. Lightning Accident Scenarios for Continued Storage

Type of Rocket Igloo Fire Caused by Lightning	Mean Event Recurrence Interval (years)	Mean Number of Agent-Related Fatalities per Event	Mean Fatality Risk per Year of Continued Storage	Contribution to Total Risk per Year of Continued Storage
GB M55	13,000	3	2.0×10^{-4}	2%
VX M55	90,000	11	1.3×10^{-4}	1%
Total Lightning Risk (per year):			3.3×10^{-4}	3%

The frequencies of the aircraft crashes are low, with a large aircraft crash into an igloo expected only about once every 10 million years. Therefore, even though the consequences may be high, the risk contribution was found to be very small overall, less than 1 percent of the total. Sequences that contribute to aircraft crash risk are presented in table 15-7.

Table 15-7. Aircraft Crash Accident Scenarios for Continued Storage

Type of Accidental Crash	Mean Recurrence Interval (years)	Mean Number of Agent-Related Fatalities per Event	Mean Fatality Risk per Year of Continued Storage	Contribution to Total Risk per Year of Continued Storage
Large Aircraft into GB Rocket Igloos	32 million	140	5.9×10^{-6}	<1%
Large Aircraft into GB Bombs Igloos	130 million	390	3.1×10^{-6}	<1%
Medium Aircraft into GB Rocket Igloo	20 million	60	2.7×10^{-6}	<1%
Large Aircraft into GB Projectile Igloos	120 million	275	2.3×10^{-6}	<1%
Large Aircraft into VX Projectile Igloos	150 million	320	2.1×10^{-6}	<1%
Total Aircraft Crash Risk (per Year):			1.9×10^{-5}	0.2%

15.3.4 Storage Yard Handling and Rocket Autoignition. The primary storage-related activities considered in the QRA are associated with identification, isolation, and containerization of leaking munitions. These activities use munition handling movements (e.g., forklift movements) similar to those described for munition handling during disposal processing. Accidents that can occur during these activities include forklift impacts, forklift drops, or munition drops during manual handling. Because leaking munitions are relatively rare at UMCD, the risk is significantly lower than the risk during UMCDF processing (see table 15-8).

Table 15-8. Other Accident Scenarios for Continued Storage

Accident Sequence	Mean Accident Recurrence Interval (years)	Mean Number of Agent-Related Fatalities per Accident	Mean Fatality Risk per Year of Continued Storage	Contribution to Total Risk per Year of Continued Storage
Rocket Igloo Fire from Non-Overpacked Rocket Autoignition	2 million	3	1.3×10^{-6}	<<1%
Handling During Leaker Isolation	16 billion	0.5	1.4×10^{-10}	<<1%
Total Handling and Autoignition Risk (per year):			1.3×10^{-6}	<<1%

The UMCDF Phase 2 QRA also includes scenarios associated with rocket autoignition. Rocket autoignition could occur if the propellant in a rocket becomes unstable as it ages, either as a result of normal aging processes or due to the effects of agent contamination. The probability of rocket autoignition was determined based on the results from extensive laboratory testing and chemical analysis of propellant taken from stored rockets. Based on this testing and analysis, the probability of autoignition was determined to be extremely remote. Rockets that have leaked and been overpacked have a higher probability than non-overpacked (undetected) leaking rockets and non-leaking rockets; however, ignition of an overpacked rocket is less likely to cause adjacent overpacked rockets to ignite. Consequently, the frequency of an igloo wide fire due to autoignition is generally higher for leaking, non-overpacked rockets. As shown in table 15-8, the contribution to risk from autoignition is negligible.

15.3.5 Storage Risk Contributors After Rockets Have Been Removed from the Stockpile. Once the M55 rockets are removed from the stockpile, the total storage risk drops by 99 percent. As shown in table 15-9, the remaining storage risk (for GB and VX projectiles; GB bombs; VX mines; VX spray tanks; and HD ton containers) is dominated by aircraft crashes (79 percent) and seismic events (21 percent). The remaining stockpile is not vulnerable to lightning.

Table 15-9. Total Continued Storage Risk After Rockets Have Been Removed from the Stockpile

Accident Sequence	Contribution to Total Risk of Continued Storage After Rockets are Processed
Large Aircraft Crash	59%
Medium Aircraft Crash	20%
Seismic	21%

15.4 Fatality Risk of Storage per Campaign

The stockpile risk for the overall disposal period was discussed in section 15.1. The results for each campaign, after individual munitions have been processed, also provide useful risk insights. Figure 15-7 illustrates the risk of stockpile storage during each individual munition processing campaign, as well as for the changeover periods between campaigns (designated with prefix Chgover in figure 15-7). The storage risk during each campaign is a function of the munitions remaining in the stockpile and the duration of the campaign. As indicated, the risk per campaign is highest during the rocket campaigns.

Another way to view the risk is as a function of time. Figures 15-8 and 15-9 illustrate the mean expected fatality risk per year of storage (or *risk rate*) during each campaign. These figures therefore eliminate the effect of campaign duration and illustrate the impact of removing munition types from the stockpile. For example, at the end of the last GB rocket campaign, the risk per year of stockpile storage is lowered by 74 percent. After all rockets are processed, the risk per year is reduced by over 99 percent. The risk rate continues to drop as munitions are removed from the stockpile in successive campaigns. The risk rate remains relatively constant until all GB and VX projectiles are removed from the stockpile. The Quantus Risk Management Workstation can be used to determine the risk at any time accounting for the actual remaining inventory.

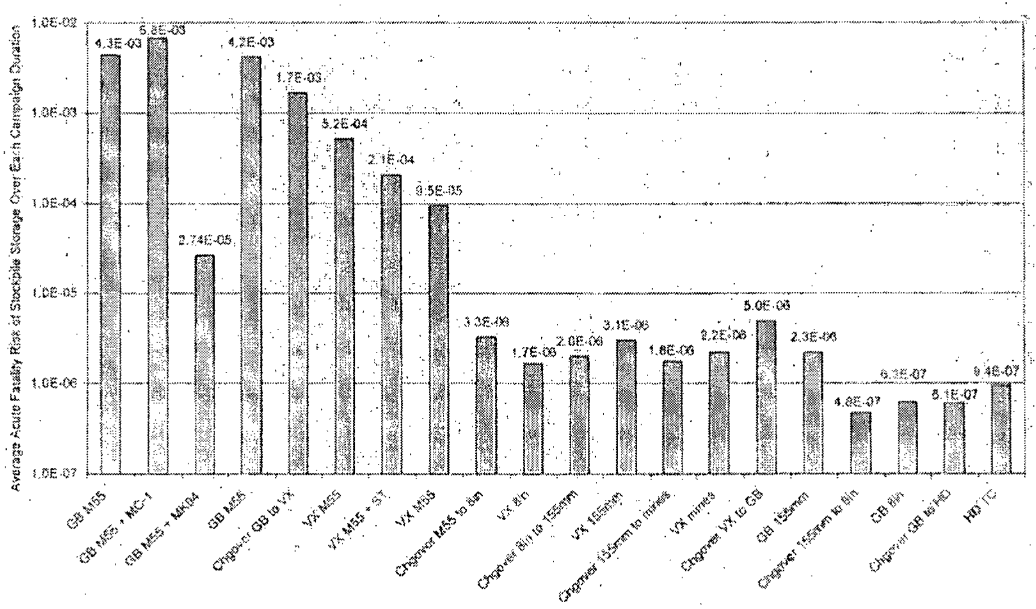


Figure 15-7. Mean Public Societal Acute Fatality Risk of Stockpile Storage at UMCD During each Disposal Processing Campaign

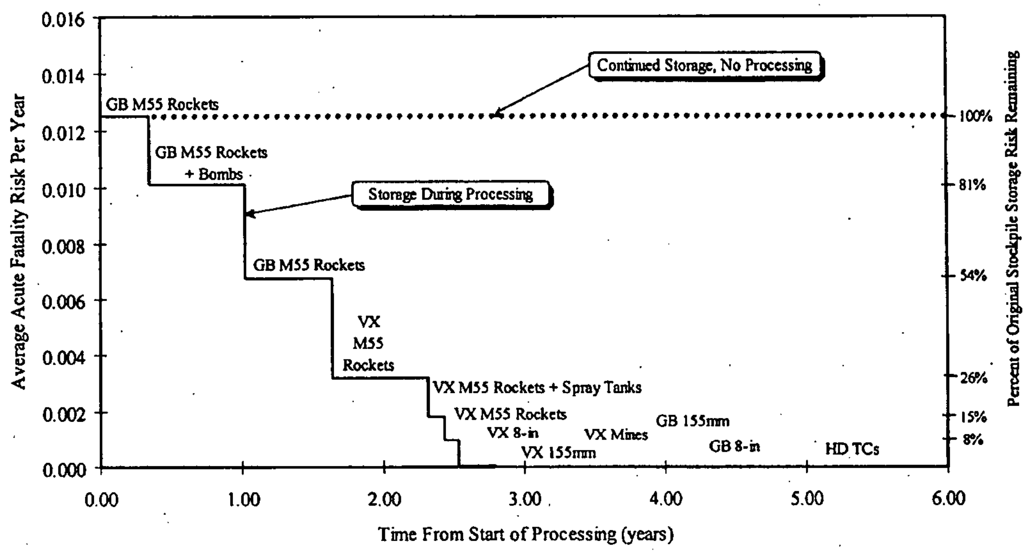


Figure 15-8. Mean Public Societal Acute Fatality Risk of Stockpile Storage at UMCD on a Per-Year Basis for each Disposal Processing Campaign (Linear Scale)

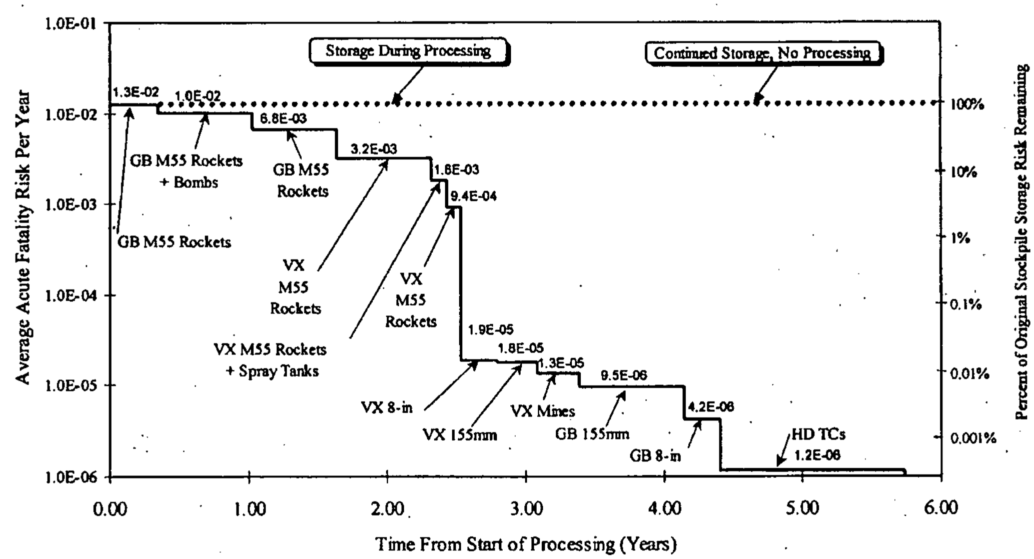


Figure 15-9. Mean Public Societal Acute Fatality Risk of Stockpile Storage at UMCD on a Per-Year Basis for each Disposal Processing Campaign (Logarithmic Scale)

15.5 Latent Cancer Risk Results

In addition to the possibility of immediate public fatalities associated with agent exposure, the potential for latent cancers that could appear years after the exposure also was investigated. Since only mustard agents are known carcinogens, the cancer risk is associated only with accidents involving mustard munitions. The latent cancer risk due to a one-time agent exposure also is called excess cancer risk because it must be calculated as an increase in cancer risk over the normally occurring rate of cancer within a population.

The societal latent cancer risk associated with the stockpile during the disposal period is approximately 1.0×10^{-6}. The results indicate that the risk of latent cancers is significantly less than the risk of immediate fatalities from agent exposure. A CCDF is not illustrated because none of the outcomes result in even one predicted excess cancer. The latent cancer risk for continued storage is 1.8×10^{-7} per year, or 2.1×10^{-6} for 20 years of continued storage.

Seismic events and aircraft crash sequences account for all of the latent cancer risk (see figure 15-10). The seismic events are dominated by the potential for the earth-covered concrete igloos to collapse during an earthquake and cause some of the stored mustard ton containers to leak. The number of ton containers that leak was estimated based on simplified models for igloo collapse. The total number of ton containers that could leak in a severe earthquake is quite large since there are several igloos used to store mustard ton containers. The aircraft crash sequences consider the potential for large aircraft crashes into one or two igloos, and medium aircraft crashes into one igloo. Some aircraft crash sequences involve fire, whereas others do not.

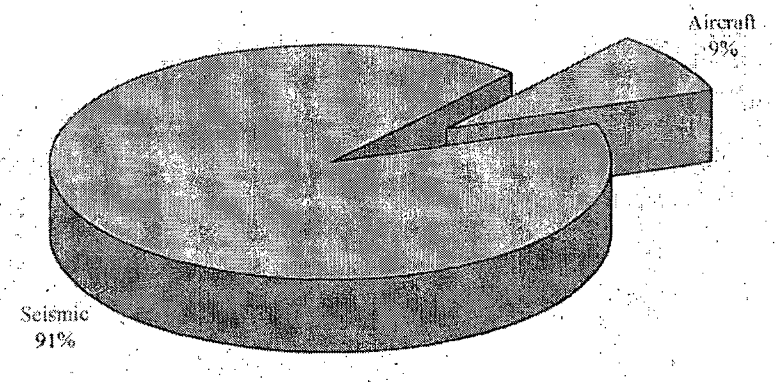


Figure 15-10. Contributors to Mean Public Societal Latent Cancer Risk over 20 Years of Continued Stockpile Storage

Table 15-10 lists the societal cancer risk as a function of distance from UMCD for continued stockpile storage. Because even very small exposures lead to some probability of cancer with the model used, the larger population rings at some distance from the site contribute significantly to cancer risk. Table 15-11 illustrates the individual, or per-person, cancer risk as a function of distance. Those living closest to the site have the highest individual risk. Overall, however, the cancer risk is very low compared to the acute fatality risk, as seen through a comparison of tables 15-10 and 15-11 with tables 15-3 and 15-4.

Table 15-10. Mean Public Societal Cancer Risk over 20 Years of Continued Stockpile Storage by Distance from UMCD

	0-2 km[a]	2-5 km	5-8 km	8-15 km	15-30 km	30-45 km	45-60 km	60-75 km	75-100 km
Societal Cancer Risk	–	3.1×10^{-9}	1.3×10^{-7}	1.3×10^{-6}	8.6×10^{-8}	1.2×10^{-7}	2.9×10^{-7}	3.0×10^{-8}	1.7×10^{-7}
Fraction of Total Risk from Each Ring	–	<1%	6%	61%	4%	6%	14%	1%	8%

Note:

[a] Within site boundaries; no public population.

Table 15-11. Mean Public Individual Cancer Risk over 20 Years of Continued Stockpile Storage by Distance from UMCD

	0-2 km[a]	2-5 km	5-8 km	8-15 km	15-30 km	30-45 km	45-60 km	60-75 km	75-100 km
Average Individual Cancer Risk	–	6.8×10^{-11}	3.5×10^{-11}	5.0×10^{-11}	7.4×10^{-12}	3.5×10^{-12}	1.5×10^{-12}	8.1×10^{-13}	1.8×10^{-12}

Note:

[a] Within site boundaries; no public population.

15.6 Sensitivity of Results to Protective Actions

As with the risk assessment for UMCDF disposal processing, a sensitivity study was conducted to determine the impact of protective actions for storage risk during disposal processing and for 20 years of continued storage. Figure 15-11 illustrates the acute fatality risk of munition storage without protective actions. For comparison purposes, the mean curve from the same analysis with protective actions also is illustrated. The figure shows that the risk with protective actions is generally a factor of 10 lower than the risk without protective actions.

For some specific scenarios, the protective action model in CHEMMACCS caused the evacuated population to be exposed to the agent plume twice. This is not a realistic representation of what would happen in an actual emergency since a specific protective action strategy would be developed based on actual weather conditions at the time of the accident. It should be noted, however, that this anomaly in the CHEMMACCS analysis does not significantly affect the overall risk results.

15.7 Sensitivity of Continued Storage Risk to Toxicity Values

Upon request from the expert panel, a set of sensitivity studies has been developed to cover a range of toxicity values. This range reflects more recent toxicological data for the effects of chemical agent on healthy soldiers and expert judgment regarding the extrapolation of these data

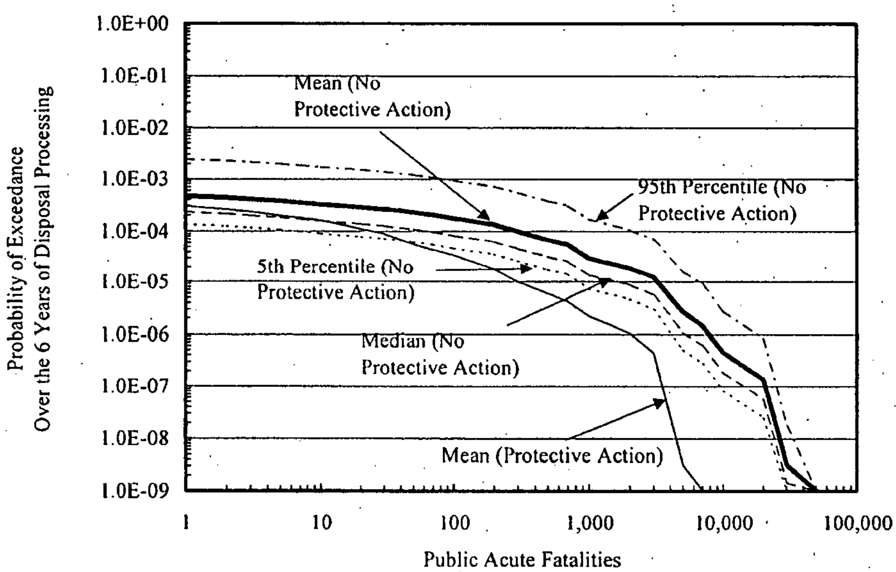


Figure 15-11. Risk Results With and Without Protective Actions for Public Risk of Stockpile Storage During the Disposal Process

to the general population, including sensitive subgroups. The toxicity values are used as input to the dispersion model. The intent of these sensitivities was to ascertain if other risk drivers are present that were not identified as a result of using baseline toxicity values. For more information regarding the sensitivity study case inputs, see section 11.7.3.

As stated previously, baseline toxicities have not changed from the U.S. Army's currently accepted values, but to meet the goal of having a comprehensive QRA including uncertainty, alternative toxicities were used in sensitivity studies. Results from the sensitivities are used primarily to identify any new risk scenarios needing risk management attention. This approach will ensure that the entire range of risk drivers is identified and addressed as part of the QRA process. Table 15-12 presents the risk results of the toxicity sensitivities for storage.

Table 15-12. Total Public Societal Acute Fatality Risk of Stockpile Storage over the 6 Years of UMCDF Disposal Processing for Varying Toxicity Values

	Baseline (case 1)[a]	Sensitivity (case 2)[a]	Sensitivity (case 3)[a]	Sensitivity (case 4)[a]	Sensitivity (case 5)[a]
Risk Results	2×10^{-2}	7×10^{-2}	2×10^{-1}	7×10^{-1}	2

Notes:

[a] Toxicity sensitivity cases are defined in detail in section 11.7.3.

Figure 15-12 illustrates the mean CCDFs for the sensitivity cases. As with the results in the table, the numerical estimates of risk are quite sensitive to the uncertainty in the toxicology. It is obvious from this sensitivity study that the toxicity value has a tremendous impact on the numerical estimate of risk; however, it does not change the contributors to risk. The risk contributors resulting from the sensitivity studies are the same as the baseline toxicity contributors. However, the sensitivity results show the large amount of uncertainty associated with toxicity values.

15.8 Summary of Stockpile Storage Risk Results

The risks of storage of the munitions and bulk containers at UMCD have been calculated for the disposal period, on a per-year basis, and over a 20-year period assuming no processing. Section 16 provides further discussion of these findings and includes comparisons to previous studies and to the processing risks.

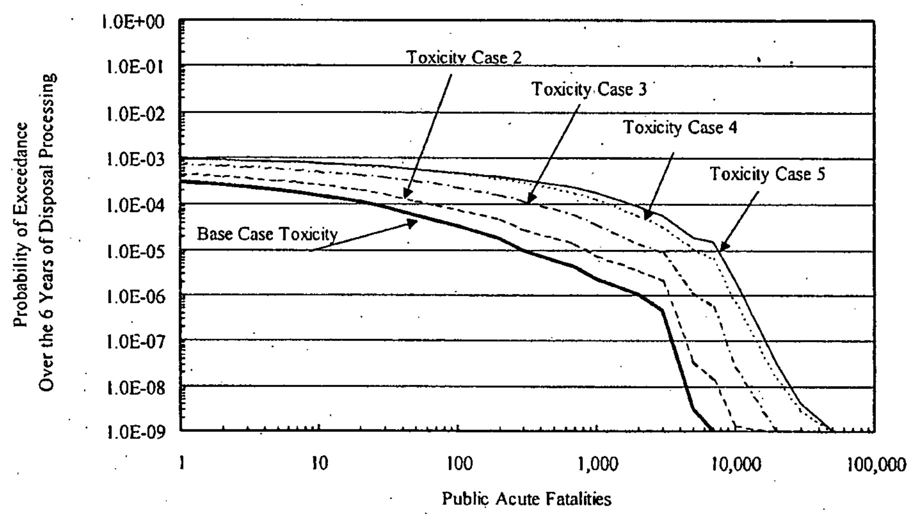


Figure 15-12. Risk Results with Varying Toxicity Values for Public Risk of Stockpile Storage During the Disposal Process

Seismic initiators clearly dominate the risk of storage due to the susceptibility of rockets pallets to accidental ignition during large earthquakes. Lightning initiators also have a small contribution to the total storage risk. Following the disposal of rockets, fatality risk decreases dramatically, and aircraft crashes become the dominant contributors to storage risk.

(This page intentionally left blank.)

SECTION 16
SUMMARY AND CONCLUSIONS

A QRA of chemical agent disposal processing at UMCDF and chemical munition stockpile storage at UMCD has been completed. The risk to the public has been estimated using up-to-date methods and the latest information available on the specific disposal processes to be implemented at UMCDF. A summary of the risk is provided in section 16.1, including a comparison of disposal processing versus continued stockpile storage. Risk contributors and insights are discussed in section 16.2. Section 16.3 discusses the results of this assessment in comparison to the results of the previous UMCDF Phase 1 QRA that was published in 1996. Worker risk associated with the chemical agents also has been evaluated and is summarized in section 16.4. The QRA results must be used with an understanding of the study's uncertainties and limitations, which are summarized in section 16.5. Frequently, when presented to parties that are not directly involved in risk assessment, there is a request that some risk perspective be provided. Section 16.6 includes some information on risks that may be useful to decision-makers. The remaining sections discuss risk management and the overall conclusions.

The results presented in section 16 are summaries of results presented in section 13 for disposal processing and in section 15 for continued storage. Those sections include a great deal more discussion for readers wanting more detailed information about some of the risk results and displays included here.

16.1 Summary of Public Risk Results

Risk results are calculated and displayed in a variety of ways to help in the understanding and management of risk. Summaries of the material discussed in this report are provided here. The mean values, or averages, of the distributions are discussed first, followed by a discussion of the range of uncertainty.

16.1.1 Public Societal Fatality Risk. The risk of disposal processing is best viewed in comparison to the risk of continued storage of the stockpiled chemical munitions in the UMCD. Figure 16-1 is one way of illustrating all the risk results produced in this QRA. The figure includes the CCDFs for average public acute fatality risk, which are comprehensive representations of risk because they allow an understanding of the relationship between probability and consequence. The vertical scale on figure 16-1 illustrates the probability of exceeding the number of fatalities shown on the horizontal scale. (Both the horizontal and vertical scales are logarithmic, evenly subdivided by factors of 10.)

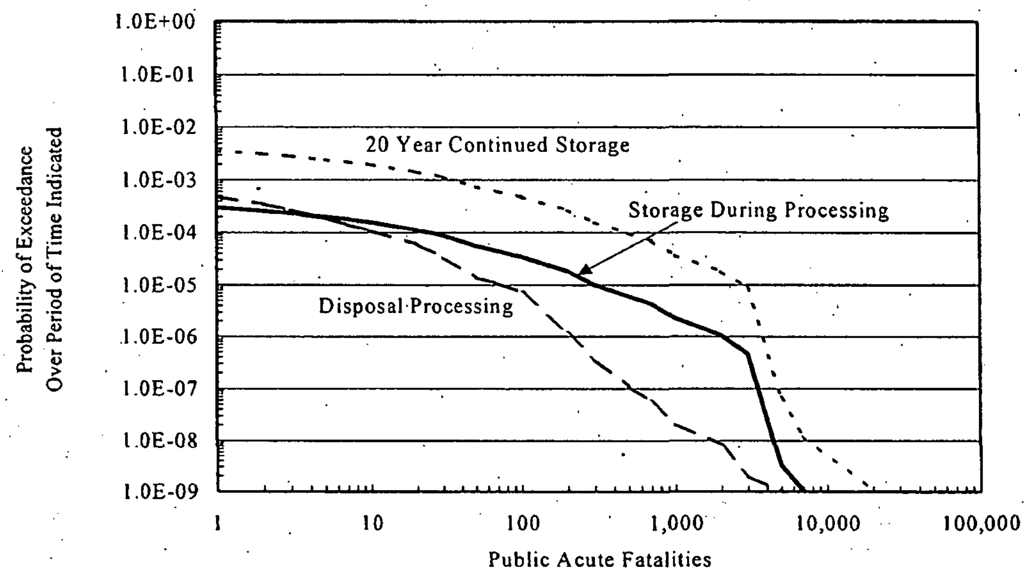


Figure 16-1. Average Public Societal Acute Fatality Risk for UMCDF Processing, Storage During Processing, and 20 Years of Continued Storage

This figure displays the differences in risk among disposal processing, storage during the disposal period, and continued storage. For example, the probability of one or more fatalities is approximately 4.7×10^{-4} (1 in 2,100) for the entire UMCDF disposal process, estimated to have a duration of almost 6 years. In contrast, the probability of one or more fatalities due to storage over this same processing period is 3.0×10^{-4} (1 in 3,300). Extended over 20 years to represent continued storage at UMCD, the probability of one or more fatalities is 3.6×10^{-3} (1 in 280).

The average total public risk during the 6 years of disposal operations is the sum of the disposal processing risk and storage risk during processing. (Storage risk during disposal accounts for the depletion of munitions from the storage yard once they have been processed at UMCDF.) The average total risk is shown compared against 20 years of continued storage in figure 16-2. From this figure it can be seen that the probability of one or more fatalities is 7.7×10^{-4} for the total risk during the disposal period. This value is about a factor of 5 times less than the risk of continued storage over 20 years.

Figure 16-3 is another way of comparing the relative risks. This figure shows the estimate of public acute expected fatalities per year for stockpile storage as it decreases with time during the munition disposal campaigns. Figure 16-3 also includes the risk of processing to allow comparison to the storage risk. Also shown on the figure (as a dotted line) is the fatality risk per year of continued storage with no processing, assuming that the risk remains constant.

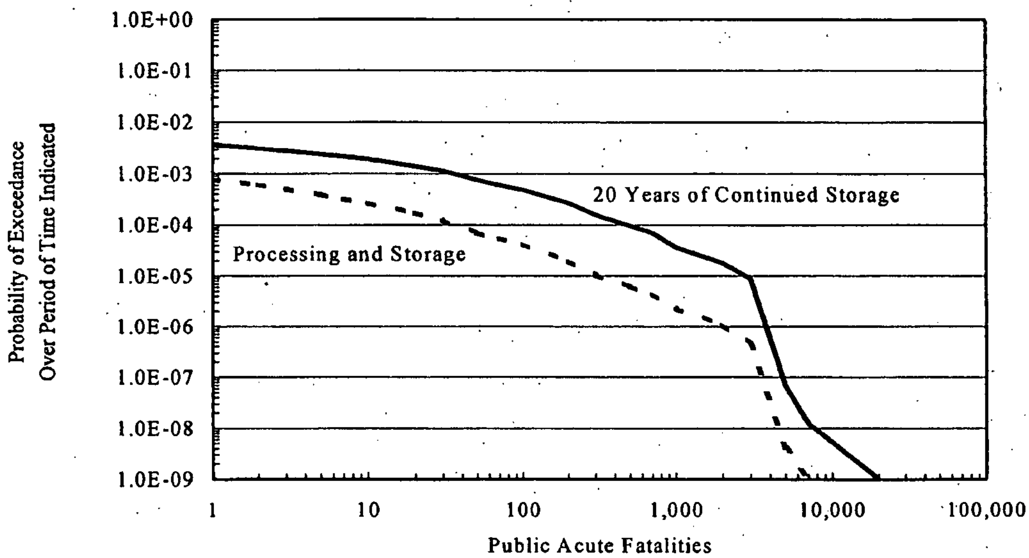


Figure 16-2. Total Average Public Societal Fatality Risk During UMCDF Operation (Processing plus Storage) and 20 Years of Continued Storage

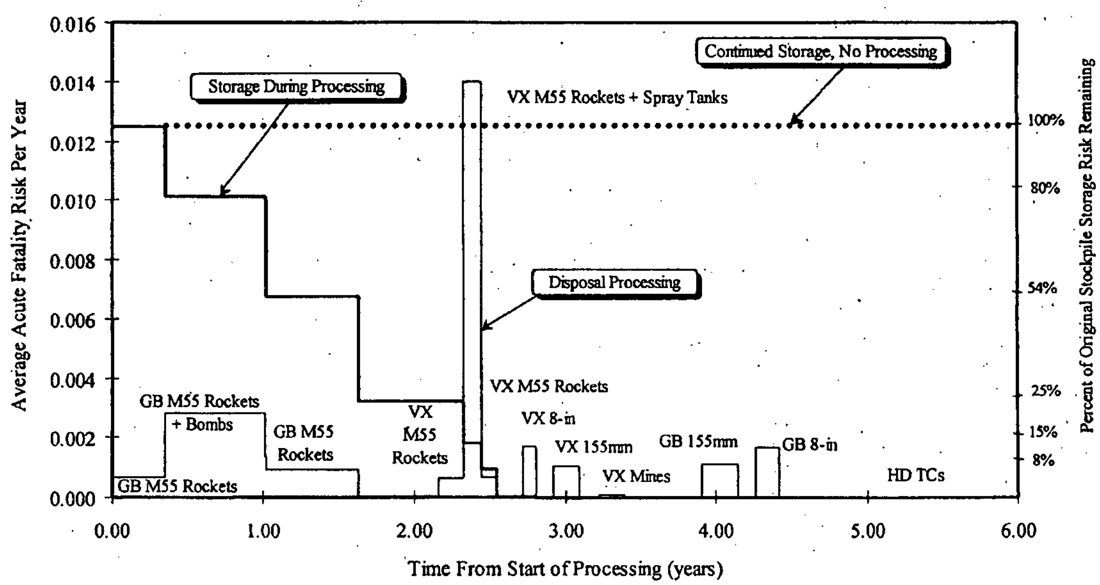


Figure 16-3. Average Public Societal Fatality Risk per Year for Stockpile Storage and Disposal Processing over the Disposal Duration at UMCDF (Linear Scale)

The risk measures depicted in the figure are the average public acute expected fatalities per year during each campaign. The total risk per campaign is the average expected fatalities per year multiplied by the campaign duration. For ease of display, the storage risk during disposal processing is shown as constant during individual campaigns (stepping down to the next level at the end of the campaign), although there would actually be a reduction in risk as each campaign progressed and portions of the munition stockpile were destroyed. From figure 16-3 it can be seen that risk to the public from the stockpile is greatly reduced following destruction of the GB and VX rockets. After the rockets are destroyed, the expected fatalities per year associated with disposal are sometimes greater than the expected fatalities per year associated with munition storage. This is because by then the storage risk is almost negligible (over 99 percent of the storage risk has been eliminated) and most of the remaining processing campaigns still have measurable risk.

As with figure 16-1, the first conclusion to be drawn from figure 16-3 is that the total risk of disposal processing is lower than the total risk of continued storage. It is important to note that even though there will be periods of time following the processing of M55 rockets that disposal risk is higher on a day-to-day basis, total storage risk will be higher than total disposal risk because the remaining munitions in the stockpile will continue to accrue risk as long as they are stored.

Figure 16-4 provides the same information as figure 16-3 on a logarithmic scale to more clearly illustrate the processing and storage risk differences. While the differences are graphically easier to see in this figure, it must be remembered that the risk scale is evenly subdivided by factors of 10. To more easily interpret this illustration, another scale is provided on the right side of the figure to show the current stockpile risk as 100 percent and the percent of that risk remaining as munitions are destroyed. For example, following the removal of GB rockets from the storage yard, annual storage risk will fall by approximately 75 percent. When the VX rockets are processed, the total storage risk rate will be reduced by over 99 percent. The items remaining in storage at that point have significantly lower seismic risk.

The processing risks (on a per-year basis) vary significantly among campaigns based on the munition and agent being processed and the campaign duration. As shown in figure 16-4, the changeover periods following processing of GB munitions have measurable risk due to the possibility of release of GB previously captured on the HVAC filters if there was a fire during changeover.

Figures 16-3 and 16-4 also show that the risk of continued storage will exist until some disposal activity is undertaken. In the past, such as during the development of the FPEIS, some of the decision-making was aided by comparing the total risk of disposal processing to the integrated risk of continued storage for 25 years. That comparison also has been made here, adjusted to

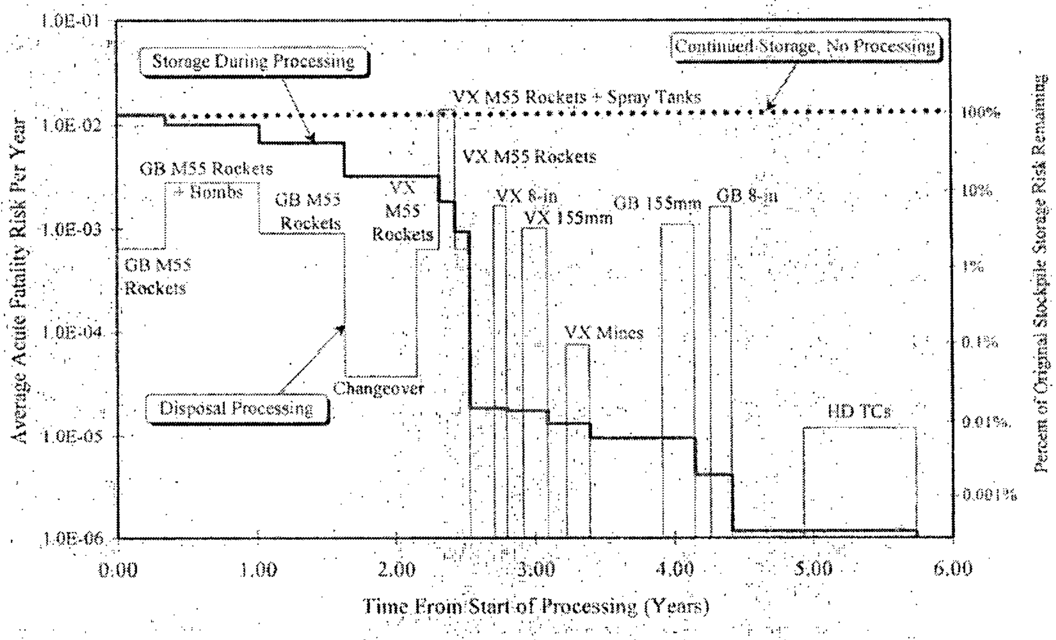


Figure 16-4. Average Public Societal Fatality Risk per Year for Stockpile Storage and Disposal Processing over the Disposal Duration at UMCDF (Logarithmic Scale)

20 years, consistent with the Phase 1 QRAs. While somewhat useful as a point of comparison, the comparison of all processing risk to 20 years of storage also has its limitations. First, the population surrounding the site would not likely remain static for 20 years, and an increase in population would translate to an increase in societal risk. Also, a comparison of processing to 20 years of storage could be misleading because the 20-year storage value does not include the additional risk of disposing of the munitions and agents that would still exist at the end of 20 years.

As indicated by the straight dotted line in figures 16-3 and 16-4, the continued storage risk is assumed to be constant over the 20-year period. It is frequently assumed that the risk per year will increase as the stockpile degrades. The QRA team did not uncover any evidence that a substantial increase in risk would be associated with long-term storage on the order of 20 years. The agent leakage rates have not shown any substantial increasing trend, and even if they did, the public risk associated with leakage of individual items is quite limited. In addition, the propellant in the M55 rockets, which had previously been thought to become unstable as it aged, has been found to be stable for time periods well exceeding 20 years. Thus, there are no contributors to risk that would become increasingly likely with time, and a straight-line extrapolation appears to be reasonable. The risk per year does not increase but the risk is cumulative, in that each additional year of storage exposes the population to another annual increment of risk.

Given these limitations, the average risk results (expected fatalities) over the 6-year and 20-year periods are presented in table 16-1. This is the integrated risk, or the area under the curves presented earlier. As indicated, the total risk of processing is less than continued storage risk and less than storage risk during the 6 years of disposal.

Table 16-1. Summary of Average Public Societal Acute Fatality Risk at UMCDF

Average Public Societal Acute Fatality Risk at UMCDF of:	
Disposal Processing (for 6 Years)	5.3×10^{-3}
Stockpile Storage During the 6-Year Processing Duration	1.8×10^{-2}
20 Years of Continued Storage	0.26

It should be noted that the risk is a summation over all accident sequences of the product of accident probabilities coupled with the associated consequences. Therefore, the risk of an infrequent accident with large consequences can contribute comparably with a frequent accident with smaller consequences. In fact, although the average risk for continued storage indicates an approximate 26 percent chance of a fatality in 20 years, the risk is dominated by less frequent events such as seismic-induced rocket igloo fires that could involve more than one fatality if they occurred, but that occur much less frequently than once every 20 years.

16.1.2 Public Fatality Individual Risk. Another way of expressing risk is the risk to individuals living various distances from the site. As described in box 16-1, individual risk is the societal risk divided by the number of people in a given area. Sections 13 and 15 list these risks in detail; table 16-2 summarizes the individual risk for people closest to the site (in the 2- to 5-kilometer ring). Even within this population ring the individual risk varies. The risks are provided for the entire processing duration and for 20 years of continued storage. The risks also are presented as average yearly values, which are the values presented most frequently in other assessments of individual risk.

Box 16-1. Societal and Individual Risk	
Societal	Risk to society, the total impact. For example, there are about 40,000 people killed in U.S. car accidents each year.
Individual	Per-person risk, the chance that an individual is affected. For example, typical citizens have a 1 in 6,000 chance of being killed in a car accident each year.

The individual risk is higher for disposal processing than storage during processing; disposal risk remains relatively constant because of fire risk whereas storage risk drops considerably after the

Table 16-2. Summary of Mean Individual Risk of Fatality for Population Closest to the Site

Mean Individual Risk of Fatality for Population Nearest the Site		
	Over Entire Duration	Average per Year
Disposal Processing for 6 Years	1.1×10^{-5}	1.9×10^{-6}
Stockpile Storage During the 6-Year Processing Duration	5.4×10^{-6}	9.5×10^{-7}
20 Years of Continued Storage	7.4×10^{-5}	3.7×10^{-6}

rockets are processed. Individual risk for continued storage is highest because of the storage of GB and VX rockets. Processing accidents generally result in smaller releases than storage accidents because the latter are dominated by severe accidents (e.g., earthquakes) that can result in large agent releases. The agent plume from a small release cannot reach the large population centers around the UMCDF, whereas the large releases can.

16.1.3 Public Cancer Risk. This QRA included an estimate of the public risk of latent cancers associated with a one-time accidental exposure to HD agent. This risk, summarized in table 16-3, was found to be much less than the fatality risk (summarized in table 16-1). Public latent cancer risk due to storage of mustard is almost negligible because ton containers having no lightning susceptibility and low seismic vulnerability. As a result, storage risk is dominated by accidental aircraft crash sequences, which are extremely rare events. Cancer risks from processing are also very small but are greater than storage because facility fires during HD processing are more likely than the very rare accidents (such as aircraft crashes) that could affect these items in storage.

Table 16-3. Summary of Average Public Societal Latent Cancer Risk

Average Public Societal Latent Cancer Risk of:	
Disposal Processing (for 6 years)	1.7×10^{-5}
Stockpile Storage During the 6-Year Processing Duration	1.0×10^{-6}
20 Years of Continued Stockpile Storage	2.1×10^{-6}

16.1.4 Public Fatality Risk Uncertainty. In order to simplify the presentations, the information provided to this point has not explicitly addressed uncertainty. Interpretation and use of the risk results must always consider the important fact that the estimates of numerical risk are very uncertain. In order to understand this uncertainty, the models used to estimate risk have been evaluated with uncertainty in the various model inputs included to generate a statistical distribution of risk results. From these evaluations it is possible to examine the characteristics of the uncertainty distribution, such as the upper and lower percentiles, as well as the central tendencies described by the mean and median. Although other values can be calculated, this report includes the 5th and 95th percentiles as the bounds of the distributions on risk values. When individual values are provided in this report, they are most typically the means (or average values) across all of the uncertainty distributions. The development of the uncertainties is described in more detail in section 12.

In this section the range of the results is provided to ensure that decision-makers have the necessary information about the mean value, as well as the full distribution including the upper and lower uncertainty bounds. There is a great deal of data generated when the QRA models are solved with full consideration of uncertainty. It is difficult to display all these data in ways that are useful to every various viewpoint of the different readers. The Quantus Risk Management Workstation can be used to further investigate specific aspects of the uncertainty distribution results that are not specifically included here.

One word of caution is in order. Not every uncertainty associated with the estimate of risk has been explicitly quantified. Also, the focus has been on risk-significant uncertainties, so the uncertainty in minor risk contributors was not included. Consequently, the lower end of the uncertainty distribution may not be fully characterized. The risk results are subject to further limitations as discussed in section 16.5.

Figure 16-5 illustrates the uncertainty distributions in comparison to the risks of disposal processing and 20 years of continued storage. The curves in the figure illustrate several important aspects of the uncertainty. First, at the lower levels of consequence, such as one-or-more fatality, there is about a factor of 100 between the upper and lower bounds of the disposal uncertainty distribution. At the higher level of consequence (e.g., 1,000 fatalities or more), there is about a factor of 30 between the upper and lower bounds. It is clear from the distribution that the risk of disposal processing, even when considering the uncertainty in the evaluation, is significantly lower than the risk from continuing to store the chemical agents and munitions for an extended period.

Figure 16-6 illustrates the uncertainty in the total risk during the 6 years of processing. Uncertainty distributions for the risk of disposal processing and the risk of storing munitions (accounting for the depletion in inventory as processing progresses) are displayed. The uncertainty in stockpile storage risk during disposal is similar to the uncertainty for continued storage over 20 years, as shown in figure 16-5. As indicated in figure 16-6, the mean value, which is quoted most typically as the risk value, is substantially above the median (50th percentile). This result is due to the shape of the various uncertainty distributions used in the model.

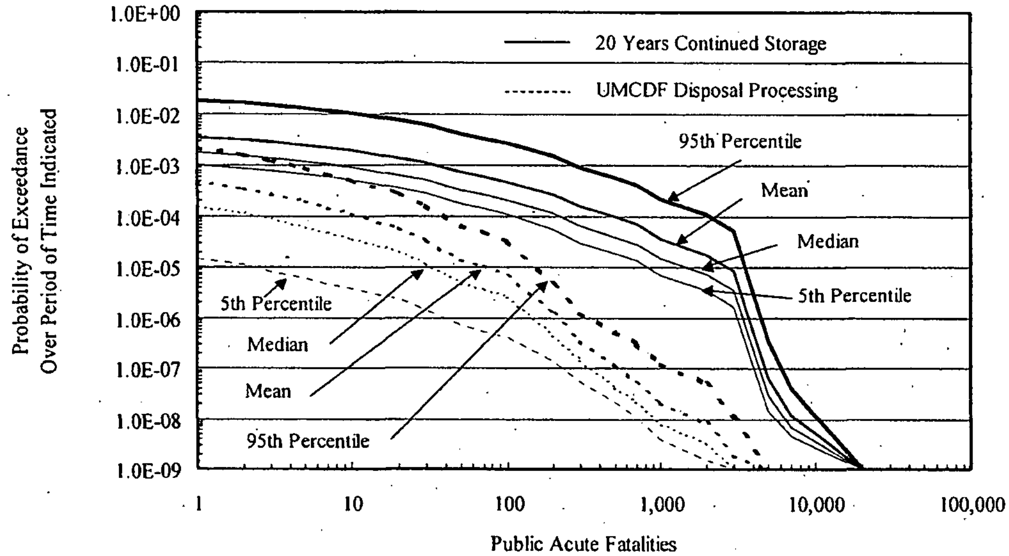


Figure 16-5. Comparison of Public Fatality Risk Uncertainties of UMCDF Disposal Processing for 6 Years with 20 Years of Continued Storage

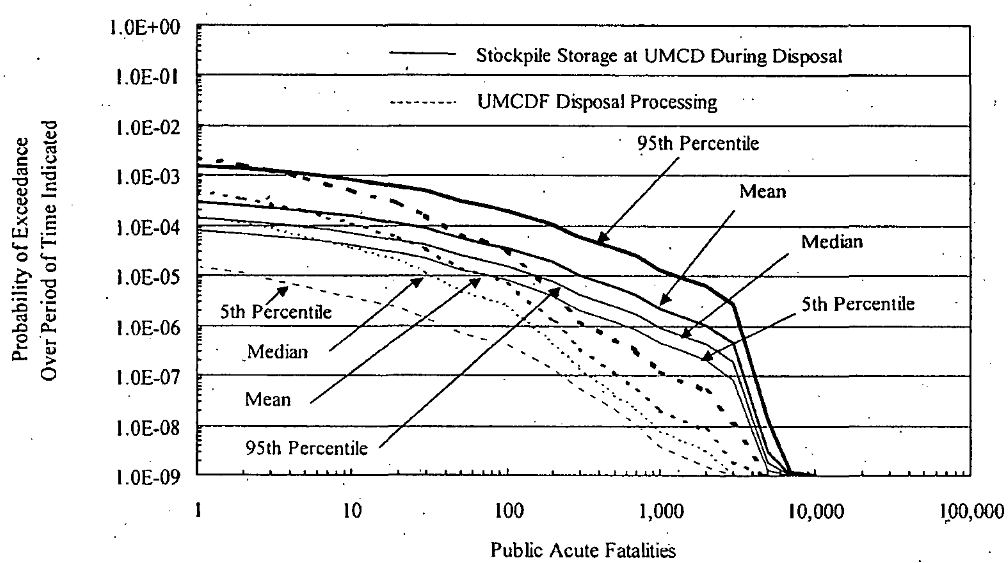


Figure 16-6. Comparison of Public Fatality Risk Uncertainties of UMCDF Disposal Processing for 6 Years and Storage During Disposal Processing

The results displayed in the figures 16-5 and 16-6 can be used to determine the uncertainty in the societal acute fatality risk. The risk comparisons previously presented should be considered in light of this uncertainty. Table 16-4 provides the mean, median, 5th and 95th percentiles of the uncertainty distributions. The results show that the upper bound on disposal risk is still lower than the lower bound on storage risk.

Table 16-4. Summary of Public Societal Acute Fatality Risk at Umatilla

Public Societal Acute Fatality Risk at Umatilla of:	Mean	5th Percentile	Median	95th Percentile
Disposal Processing	5.3×10^{-3}	2.6×10^{-4}	2.0×10^{-3}	2.2×10^{-2}
Stockpile Storage During the Processing Duration	1.8×10^{-2}	7.6×10^{-3}	7.8×10^{-2}	1.0×10^{-1}
20 Years of Continued Storage	2.6×10^{-1}	5.7×10^{-2}	1.1×10^{-1}	1.5

16.2 Summary of Public Risk Contributors

Sections 13 and 15 include discussions of the contributors to risk for disposal processing and stockpile storage, respectively. Figure 16-7 summarizes the contributors to the mean processing risk. For disposal processing at UMCDF, the following insights were developed:

- Public risk of the disposal process is dominated by the potential for a facility fire that affects agent inventories within the facility (MDB) and also can lead to release of agent from the HVAC filter units. Fire initiators account for 87 percent of the total mean risk. This type of facility fire originates within individual rooms of the MDB and spreads to other portions of the facility.

- A portion of the fire risk (27 percent of the 87 percent) is associated with fires in the MDB that, in addition to agent release from the building, also result in heating of the HVAC carbon filter units with a release by desorption of previously captured agent.

- Seismic-induced fires contribute approximately 6 percent to total public disposal risk. These fires result from earthquakes and can affect a large portion of the facility.

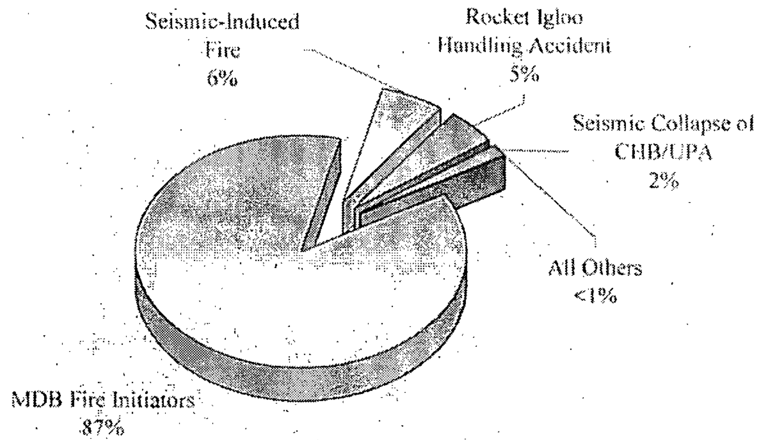


Figure 16-7. Contributors to Public Acute Fatality Risk from UMCDF Disposal Processing

- About 5 percent of the public fatality risk is due to handling of M55 rockets when they are being removed from igloos to be transported to the disposal facility. These scenarios are risk-significant because of the potential for an igloo fire involving the entire igloo inventory. Although handling accidents are not frequent events, this type of accident would have greater consequences than most other disposal accidents because of the relatively large inventory that could become involved in the igloo fire.

- Approximately 2 percent of the risk is associated with the potential for a structural failure of the CHB/UPA. While the facility is built to appropriate earthquake building codes, the second floor area has been determined to be vulnerable for large and infrequent earthquakes (larger than those for which the facility was designed).

- Other events associated with processing activities account for much less than 1 percent of the UMCDF risk. Very few of the processing-related activities contribute to risk. In general, the equipment fails in a safe status and the amount of agent involved in any step is quite limited.

The uncertainty results also have been examined with a conclusion that the contributors to mean risk are representative of the overall risk contributors. In other words, the bounds of the uncertainty distribution are not controlled by uncertainties in some particular type of accident initiating event. The uncertainty bounds include uncertainties in accident frequencies and their associated agent releases, but there are no unique insights concerning accident contributors at the bounds of the analysis.

The public risks associated with chemical stockpile storage at UMCD during munition processing or continued storage are described in detail in section 15. The dominant contributors to risk are illustrated in figure 16-8, and summarized as follows:

- Earthquakes completely dominate the risk of continued storage, accounting for 97 percent of the average public fatality risk. Even for the reinforced concrete igloos at UMCD, igloo collapse is possible. While earthquakes capable of producing this level of ground motion are extremely rare, a collapse could damage the munitions stored inside. This could result in a leak or explosion. If the igloo does not collapse, the munitions inside can still pose a risk because the munition pallets stacked inside the igloos could fall during an earthquake, causing a leak or explosion. The M55 rockets are the most significant contributors to seismic risk because they are more susceptible to accidental ignition than most other munitions and ignition of one rocket could cause a fire that spreads to the other rockets in the igloo.

- Lightning contributes approximately 3 percent to storage risk. If lightning strikes an igloo, a rocket could ignite if there is a direct arc from the igloo walls to the rocket stack. Arcing can occur if the reinforcing steel bar (rebar) in the floor and arch of the igloo is poorly connected or discontinuous. This could allow charge to buildup sufficiently in a portion of the rebar that an arc occurs. Arcing is very unlikely to occur if the rebar in the affected igloo forms a continuous, well-connected path for dispersing the electric charge. Although the igloos at

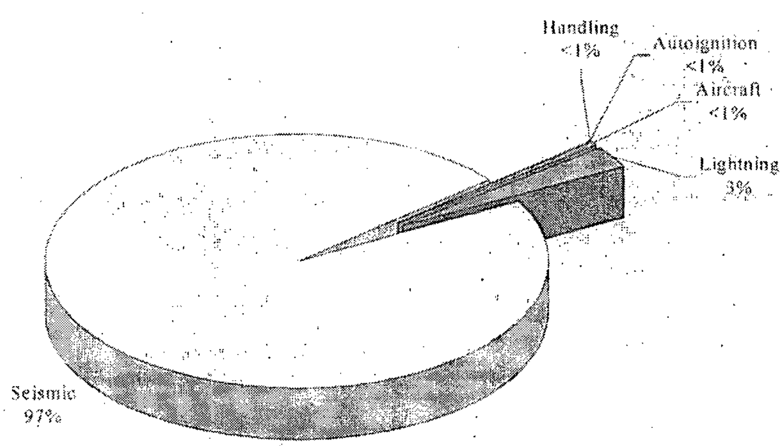


Figure 16-8. Contributors to Public Acute Fatality Risk from Continued Stockpile Storage at UMCD

UMCD have not been tested for lightning attenuation, the results from lightning testing of similarly constructed igloos were used in the analysis.

- Autoignition of M55 rockets accounts for much less than 1 percent of storage risk. The frequency of an autoignition for non-leaking rockets is negligible, while the frequency of autoignition for leaking rockets is higher, but still extremely small.

- Two other events with potentially high consequences but low frequency each contribute much less than 1 percent of storage risk. The only contributor during normal storage maintenance activities is a handling accident during isolation and overpacking of a leaking M55 rocket, which could lead to an igloo fire. The frequency of handling accidents that result in a rocket ignition is very small. An accidental aircraft crash could also lead to a significant agent release; however, the frequency of aircraft crashes is estimated to be very small.

One frequent question is why the handling operations at the igloo contribute to disposal risk but not to storage risk. This is principally a function of accident frequency. For disposal risk, every munition pallet must be retrieved from within the igloo and moved out of the igloo. Isolation of a leaking munition is a relatively infrequent event. Even though several pallets may have to be moved to isolate the leaking munitions, the total number of operations within a year is very small. Even though the human error and accident rates are increased during leaker isolation to account for the impact of the stress and encumbrance created by the necessary personal protective equipment, the frequency of a munition leak is still low.

The findings described here are some of the principal insights concerning contributors to the risk of both processing and continued storage. More discussion of the findings is provided with the results in sections 13 and 15. The key conclusion is that building fire initiators contribute significantly to disposal risk because a facility-wide fire can affect all agent within the MDB as well as agent on the HVAC filters. Fires, though rare, have the potential for larger consequences than other types of accidents.

16.3 Comparison to UMCDF Phase 1 QRA

The UMCDF Phase 1 QRA analysis of disposal processing and continued storage was completed in September 1996 (SAIC, 1996a). The results of the UMCDF Phase 2 QRA replace the previously published UMCDF Phase 1 QRA results. The Phase 1 QRA was similar in scope to this assessment; however, the UMCDF disposal assessment is now based on the as-built facility and there have been refinements in several key areas of the risk assessment. Table 16-5 summarizes some of the differences between the assessments.

Table 16-5. Summary Comparison of UMCDF Phase 1 and Phase 2 QRAs

Topic	UMCDF Phase 1 QRA	UMCDF Phase 2 QRA
Scope	All potential initiating events except sabotage. Public risk only. Point-estimate evaluation.	All potential initiating events except sabotage. Public and worker risk. Evaluation includes propagation of uncertainties in the model inputs.
Design Basis	TOCDF "as-constructed" with UMCD site-specific weather and external event initiators.	UMCDF "as-constructed" with UMCD site-specific weather and external event initiators.
Major Design Differences	CHB/UPA assessed at seismic capacity of 0.50 g, based on programmatic decision to change design to limit likelihood of seismically induced failure. LPG tank was assessed as a 50,000-gallon tank filled only to 10,000 gallons.	CHB/UPA assessed at seismic capacity of 0.50 g, based on analyzed capacity of structure. LPG tank was assessed "as built."
Munition Inventories	CHB holds up to 48 onsite containers; each onsite container holds multiple pallets.	Onsite containers replaced with EONCs. CHB capacity and onsite container/EONC capacity are the same.
Operational Information	Incorporated data and insights from JACADS operation and TOCDF systemization.	Reflects actual TOCDF and JACADS operations, including actual incidents, PLL data, and site observations by QRA team members. Manual operations and human actions modeled in more detail.
Facility Fire Analysis	Based on methodology used in nuclear plant risk assessments.	Industrial fire data were obtained and used in a new model and updated methodology.
Population/ Weather Data	1990 U.S. Census population data and UMCDF-specific weather data	2000 U.S. Census data projected to 2002 and UMCDF-specific weather data
Quantification	Various computer codes were used, as discussed in the Phase 1 report.	The Quantus Risk Management Workstation was used. The overall method is the same.

16.3.1 Comparison of Results. Table 16-6 lists the disposal processing risk results for the public acute fatality risk measures that are comparable between the two UMCDF QRAs: 1) expected fatalities, 2) probability of one or more fatalities, and 3) fatalities at a probability of 1×10^{-9}. As seen in this table, there was an increase in the estimate of all risk measures for the Phase 2 QRA. This is a direct result of the new fire methodology used in the Phase 2 QRA that better tracks industrial fire experience than the method used in the Phase 1 QRA. The new results have higher frequencies of fires with the potential for large agent inventory involvement.

Figure 16-9 shows the Phase 1 and Phase 2 CCDFs on one chart for easy comparison (the mean CCDF from the Phase 2 QRA is displayed as being most comparable to the Phase 1 QRA point estimate CCDF). The biggest difference between these two curves is that the Phase 2 QRA indicates more frequent events producing one or more fatalities. This effect also is largely due to the facility fire initiators, which have a much higher frequency than the seismic sequences that dominated disposal risk in the Phase 1 QRA. In the Phase 2 QRA, the recurrence rate of the

Table 16-6. Comparison of UMCDF Phase 1 and Phase 2 QRA Disposal Processing Risks

Risk Measure	UMCDF Phase 1 QRA	UMCDF Phase 2 QRA
Expected Fatalities	2.0×10^{-5}	5.3×10^{-3}
Probability of One or More Fatalities	3.0×10^{-6}	4.7×10^{-4}
Fatalities at 1×10^{-9} Probability	170	5,000

most risk-significant initiator, a second floor fire, is about once every 1,000 years and this event results in an average of 1.0 fatalities. In the Phase 1 QRA, the most risk-significant sequence was a CHB/UPA collapse with a recurrence interval of 30,000 years and resulting in 0.4 fatalities. Differences between the contributors for both QRAs are discussed in more detail in section 16.3.2. The Phase 1 QRA also did not fully account for the large amounts of agent on the HVAC filters during some campaigns. In addition to these differences, the Phase 1 QRA risk results were based on a disposal processing duration of 3.3 years compared to 5.7 years in the Phase 2 QRA.

A comparison of the risk of continued storage is presented in table 16-7. As seen from this table, the storage risk decreased by 50 percent between the Phase 1 and Phase 2 QRAs. The probability of one or more fatalities increased and the fatalities at a probability of 1×10^{-9}

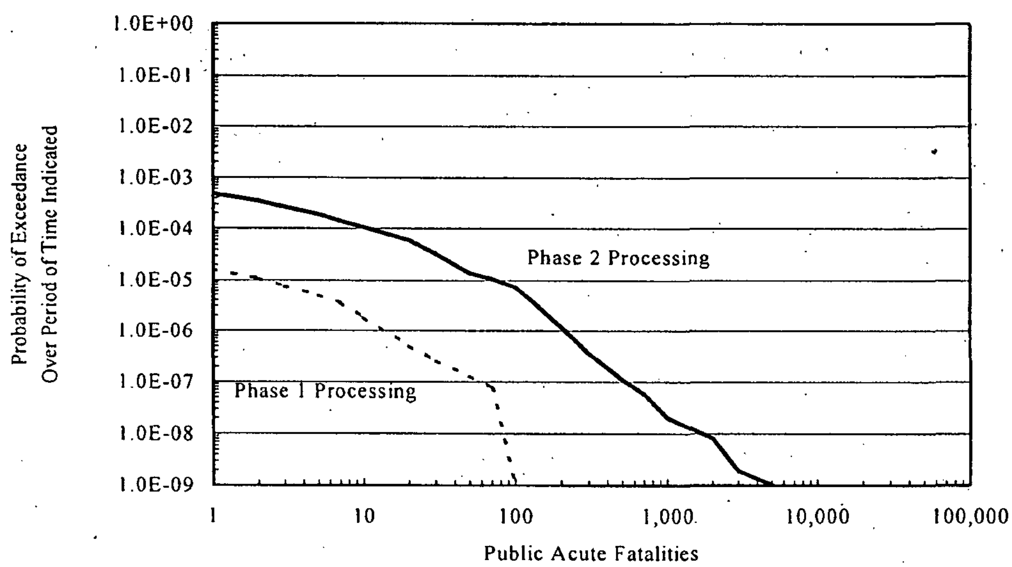


Figure 16-9. Average Public Societal Acute Fatality Risk for UMCDF Processing, UMCDF Phase 1 and Phase 2 QRAs

Table 16-7. Comparison of UMCDF Phase 1 and Phase 2 QRA
Societal Storage Risk Over 20 Years

Risk Measure	UMCDF Phase 1 QRA	UMCDF Phase 2 QRA
Expected Fatalities	0.60	0.26
Probability of One or More Fatalities	2.0×10^{-3}	3.6×10^{-3}
Fatalities at 1×10^{-9} Probability	30,000	20,000

decreased. The primary reason that the total risk is now lower than previously assessed is because the seismic analysis has been refined. Figure 16-10 shows both CCDFs on one chart for easy comparison. As with the Phase 1 QRA, seismic events are still the dominant contributors to storage risk. The overall conclusion from the comparison is that the processing risk is lower than the continued storage risk for both the UMCDF Phase 1 and Phase 2 QRAs. The dominant contributors to risk for the Phase 1 and Phase 2 QRAs are compared in section 16.3.2.

16.3.2 Comparison of Contributors. As described in section 16.2, facility fires dominate the processing risk at UMCDF (87 percent) with smaller contributions from seismic-induced fires (6 percent) and igloo handling accidents (5 percent). The UMCDF Phase 1 QRA reported that

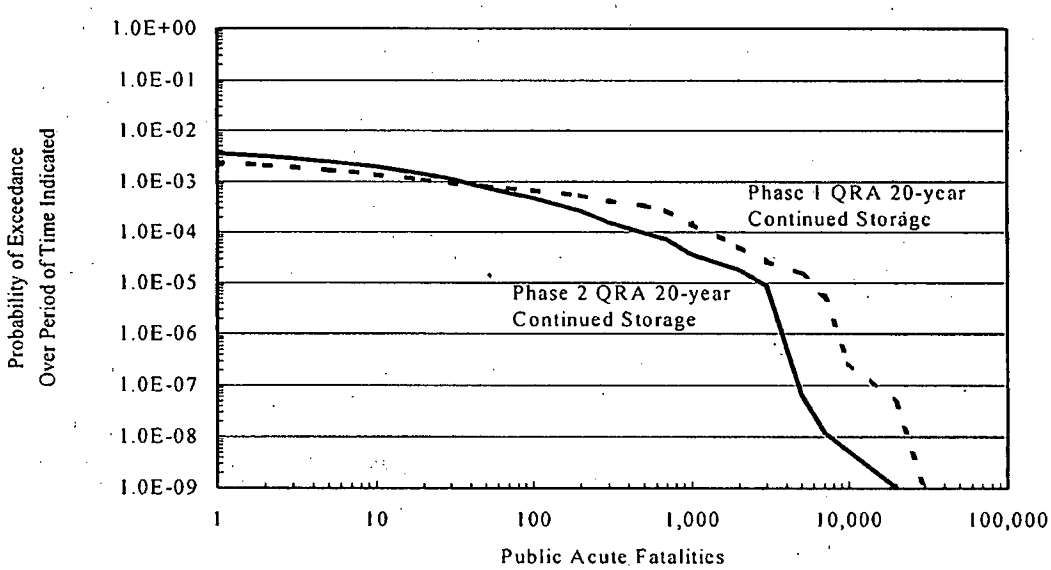


Figure 16-10. Average Public Societal Acute Fatality Risk for 20 Years of Storage at UMCD, UMCDF Phase 1 QRA Versus UMCDF Phase 2 QRA

public risk from disposal processing was dominated by seismic events (72 percent), handling-induced rocket igloo fires (14 percent), and accidental aircraft crash (13 percent). Table 16-8 summarizes these comparisons. No comparison table is shown for storage risk because the risk contributors are essentially the same.

Table 16-8. Summary of the Comparison of Disposal Processing Contributors

UMCDF Phase 1 QRA	UMCDF Phase 2 QRA
Seventy-one percent of disposal risk was associated with seismic collapse of the CHB/UPA.	This event was still important but because facility fires completely dominated facility risk, this event was a minor contributor (only 2 percent). Also, because of inventory refinements, this event resulted in fewer average fatalities than in the previous study.
Fourteen percent of disposal risk was associated with rocket handling in the storage yard.	Handling was less significant to overall risk but is still an important contributor (5 percent).
Thirteen percent of disposal risk was associated with aircraft risk.	Aircraft risk was much less important primarily because facility fire scenarios added significantly to risk.
Less than 1% of disposal risk was attributed to facility fires.	Previous QRA efforts relied on methodology used for nuclear power plant fire risk. The fire analysis for the UMCDF Phase 2 QRA was refined to include industrial facility fire data from the NFPA, which showed that similar purpose facilities have had catastrophic fires. These data were used as applicable.

16.4 Worker Risk Results and Insights

Worker risk associated with UMCDF processing also has been assessed quantitatively. The worker risk evaluation is limited to agent operations and therefore is not a comprehensive representation of all activities or hazards that could pose a threat to worker health. In spite of these limitations, the worker risk analysis has led to some insights regarding potential worker risk.

Worker risk has been evaluated for two populations:

a. *Disposal-Related Workers* – All workers at UMCDF, including all support and administrative staff located at the facility or in nearby buildings and munition handlers responsible for removal of the munitions from the stockpile and transportation to the CDF.

b. *Other Site Workers* – All other personnel working at UMCD.

The Other Site Worker risk is evaluated in the same manner as the public risk, and in essence acts as a population group around UMCDF where there is no public population. The average risk for Other Site Workers is 2.0×10^{-5}. The contributors to risk for Other Site Workers are essentially the same as for the public risk, with fire sequences dominating (see figure 16-11).

The risk for Disposal-Related Workers is substantially different from the risk for Other Site Workers. The processing and handling workers can be affected by the agent dispersion from an accident, but they also can be affected directly. For example, a munition handler could potentially be splashed with liquid agent in a handling accident, or workers in the vicinity of an explosion could be affected directly by the blast.

Disposal-Related Worker risk is discussed in sections 13.6 to 13.9. Many different scenarios that contribute to the risk are discussed in detail in section 13.7. The average Disposal-Related Worker fatality risk has been assessed to be 0.50 over the entire 6 years of disposal processing. This is a risk rate that results in an average of 0.09 fatalities per year. A summary of acute societal Disposal-Related Worker fatality risk is shown in table 16-9. The models for Disposal-Related Worker risk have been expanded considerably from the Phase 2 TOCDF QRA.

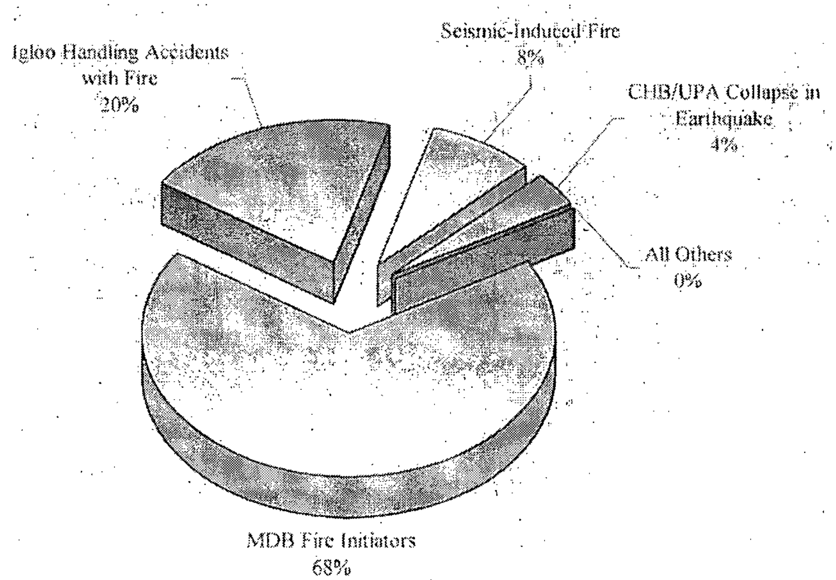


Figure 16-11. Contributors to Other Site Worker Acute Fatality Risk from UMCDF Disposal Processing

Table 16-9. Summary of Disposal-Related Worker Societal Acute Fatality Risk at UMCDF

Disposal-Related Worker Societal Acute Fatality Risk at UMCDF of:	Mean	5th Percentile	Median	95th Percentile
Disposal Processing (6 years)	5.0×10^{-1}	1.1×10^{-1}	3.2×10^{-1}	1.6
Disposal Processing (per year)	8.8×10^{-2}	1.9×10^{-2}	5.6×10^{-2}	2.8×10^{-1}

Disposal-Related Worker risk is composed of many different contributors. A summary of the types of contributors is provided in figure 16-12. Detailed discussion is provided in section 13.7. The following insights regarding worker risk have been developed:

- Worker risk is dominated by the potential for an explosion during activities to clear a DFS chute jam. The probability of an explosion of a pocket of energetics cannot be ruled out because of the possibility for many different types of jams and clearance activities. This scenario is currently 61 percent of the worker risk.

- About 13 percent of the Disposal-Related Worker risk is associated with building fires. These are the same fires that dominate public and Other Site Worker risk.

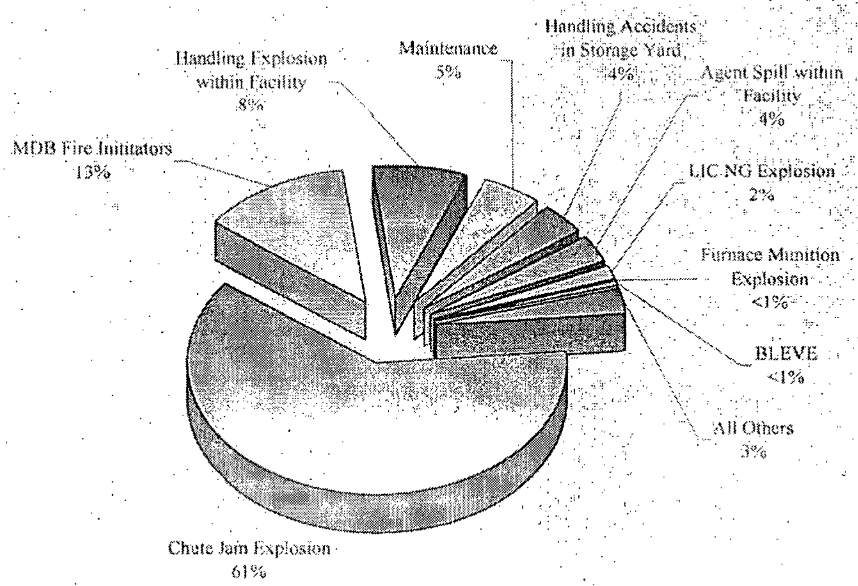


Figure 16-12. Contributors to Disposal-Related Worker Acute Fatality Risk from UMCDF Disposal Processing

This risk is associated with agent release during the fire, not a function of any efforts to fight the fire.

- Maintenance activities account for about 5 percent of the Disposal-Related Worker risk. This risk was assessed using available data and models of protective equipment reliability. This accounts for all activities involving maintenance that could involve agent contact—essentially all activities performed in DPE.

- Handling accidents in the storage yard account for approximately 4 percent of the Disposal-Related Worker risk. These accidents include munition explosions, fires and spills that result from handling accidents in the igloo or on the apron.

- Handling accidents in the facility leading to spills or explosions account for about 12 percent of the Disposal-Related Worker risk. These accidents include spills and explosions in the UPA and ECV during normal munition handling, as well as leaker handling in the ECV.

- Another important contributor to Disposal-Related Worker risk includes LIC natural gas explosions (2 percent).

The remaining Disposal-Related Worker risk is comprised of a large variety of sequences. The accidents dominating worker risk tend to involve energetic events. Even though explosions are much less likely than other facility upsets, they typically have higher consequences. This is understandable because explosions can potentially affect more people, and plant staff members are less likely to be protected by their equipment in an energetic event.

As described in section 16.5, the probabilistic assessment of worker risk should primarily be used to provide insight, because the numerical estimates are uncertain. Assessed uncertainties including those related to worker risk are provided in table 16-10. As with other estimates, the mean values being used as the risk results are above the median (or 50th percentile) risk value. Thus there is a considerable range of uncertainty below the provided mean.

The results can be compared to industrial statistics, although the industrial values are actuarial data while the QRA values are estimates generated from models. The mean worker risk fatality rate is 0.09 fatalities per year of operation, or 0.09 deaths per approximately 500 workers for a rate of 1.8×10^{-4} per worker per year. This can be compared to the average industrial fatality rate from actual statistics of roughly 4 deaths per 100,000 workers per year, or 0.02 per year for a facility like UMCDF with approximately 500 workers (National Safety Council, 1995). Thus the QRA estimate of agent-related fatalities appears to be high when compared to industrial statistics for all causes. This alone does not prove that the assessment is conservative, because there is

Table 16-10. Discussion of Uncertainties in the Risk Estimations

Element of the Model Used to Evaluate Risk	Uncertainty Included in Estimates?	Analysts' Discussion
Frequency of Accidents Resulting from Processing Activities	Yes	The accidents have been evaluated using available data for equipment and estimates of human reliability. Variables contributing to risk-significant sequences have been sampled in the uncertainty analysis. It is judged that the uncertainty in numerical values is fairly well captured directly in the uncertainty distributions.
Completeness of Accidents Resulting from Processing Activities	Not numerically estimated	Completeness is always an issue because it cannot be proven. The analysts judge that the step-by-step process (described in section 4) is good at capturing the types of accidents that could happen at each step of the process and lead to various size agent releases. Events that have already occurred at JACADS and TOCDF are evaluated for inclusion in the QRA, through use of the PLL Database. Thus it is judged likely that the range of potential releases is well represented in the QRA. However, given the uncertainties in human processes, the specific causes of accidents are unlikely to be fully captured. This is considered important to the worker risk evaluation; it is unlikely that all worker risk issues are captured in the QRA.
Frequency of Risk-Significant Fires	Yes	This is an important element because it now appears that previous analytical methods (in Phase 1 QRA) underestimated the risk. A detailed discussion is provided in appendix K2. While uncertain (as recognized in the numerical assessment), this assessment is well supported by industrial data. The analysts judge that fires are as well characterized as most of the processing accidents.
Frequency of Accidents Initiated by External Events	Yes	It is judged that the analysis and the associated uncertainty distributions well characterize the level of risk associated with the external events dominating risk. The specifics of the impact on the facility are probably not fully characterized, but the models have erred on the side of conservatism (overestimating risk) for most events and they still were not significant. For example, the exact impact of an earthquake at the facility is probably not well known, but the assumptions in the risk model characterize the range of possible outcomes. There has been less focus on less important events so the lower bound of uncertainty is less characterized.
Completeness of Accidents Initiated by External Events	Not numerically estimated	Given the number of other audits available for external events and the thorough assessment of a large list of possible initiating events that occur in nature and as a result of people's activities, the analysts have high confidence that this part of the analysis is complete.
Uncertainty in the Representation of the Amount of Agent Released	Yes	Each projected accident sequence requires an estimate of agent release and the conditions surrounding the release. The analysts judge that the uncertainty is largely captured in the distributions included in the analysis, but that any given accident could have greater uncertainty. In other words, the uncertainty in the overall answer is judged to be well characterized, but specific accidents pulled out for special consideration would likely have to be studied further to fully characterize the uncertainty for a single accident.

Table 16-10. Discussion of Uncertainties in the Risk Estimations (Continued)

Element of the Model Used to Evaluate Risk	Uncertainty Included in Estimates?	Analysts' Discussion
Randomness in the Amount of Agent that Could be Involved in an Accident	Yes	While not capturing all of the random aspects that could determine the outcomes, this QRA includes explicit accident sequences that account for the range of possible outcomes that might be generated by the random nature of how much chemical agent might be involved. For example, handling-induced igloo fires could occur in full or nearly empty igloos, or anywhere between. This was modeled by developing accident sequences for four levels of possible igloo inventory. This direct characterization of randomness was focused on risk-significant model inputs.
Uncertainty in the Dispersion of Agent in the Atmosphere	No	Even though the calculations are detailed, modeling atmospheric dispersion is a very difficult task. While there have been strides in recent years due to the advent of greater computing power, it is not yet practical to use highly sophisticated models. The relatively simple Gaussian plume models are used here, but the uncertainty in the various model parameters is not explicitly evaluated. It is judged by the analysts that the current analysis is somewhat conservative in this regard, in that the simplified model likely overestimates risk.
Uncertainty in the Weather Associated with an Agent Release	Yes	Weather is known to be a controlling influence. This is captured by analyzing the possible agent releases for 1,460 different weather samples. Thus, notwithstanding the uncertainties in the dispersion model, the range of weather is captured. However, due to the simplicity of the model, the dynamics of changing weather over the full time of the release are not well captured.
Modeling of Emergency Protective Actions in the Community	Not numerically estimated	Although not included in the uncertainty characterization, sensitivity studies have been included that report the results with and without protective actions. The models assume a 95 percent participation (based on data for other evacuations) but the uncertainty in this has not been evaluated. The models used here for protective actions are quite simple and are judged adequate for estimating risk but are judged inadequate for specific emergency planning issues, which are better evaluated with more detailed models.
Randomness of Number of Workers Near Accidents	Yes	Different accident sequences have been generated to account for the fact that the accident could occur when there were many workers in the immediate vicinity and when there were very few workers around. This remains uncertain, but it was explicitly evaluated.
Uncertainty in the Impact of Accidents on Nearby Workers	Yes	Uncertainty distributions have been developed for worker impact, but this area remains highly judgmental—detailed modeling is not practical. Thus there is considerable analysts' judgment and the simplified assessment of fatality/no fatality makes coverage of this difficult. The models have been greatly extended since earlier QRAs, but this area is still highly uncertain. It is judged that the numerical results, even including the uncertainty distributions, might have a conservative bias that would tend to overestimate risk.
Uncertainty in the Response of Humans to Various Agent Doses	No	This has not been explicitly evaluated using uncertainty distributions—there are accepted values for dose-response that were used. Work is underway to re-evaluate the standards and all the work to date has been aimed at workers, whereas risk also is estimated for the full range of population in the surrounding community. Sensitivity studies have been used to address this. Given the results of the sensitivity studies, it is the QRA analysts' judgment that this is the controlling uncertainty in the estimates of public risk.

wide variation in the industry. But there is another factor: the chemical agents were produced, uploaded into munitions, and shipped without a high incidence of agent-related fatalities. The demilitarization operations at CAMDS, JACADS, and TOCDF also represent over 20 years of agent operations without an agent-related fatality. Probabilistic evaluation of worker risk is a relatively new endeavor and should not be considered a precise predictive tool.

16.5 Uncertainties and Limitations

Use of the results of these analyses must be augmented with an understanding of the uncertainties and limitations. These factors do not negate the usefulness of the study but should be used to understand how best to use the information in risk management.

The QRA models have been solved with inclusion of uncertainty distributions for parameters in the models, generating an uncertainty distribution for the numerical estimates of risk. The use of uncertainty analysis in the assessment has been discussed in section 12 and the distributions assigned to individual parameters are described in appendix P and related appendices. Even with this characterization, the use of the numerical values in this study must be tempered with an understanding that there are additional uncertainties that are not fully assessed. Table 16-10 provides a discussion of the analysts' view of the relative importance of the uncertainties, whether quantified or not.

In spite of the uncertainties, the risk evaluations meet their objectives by providing a risk management tool. In other words, the risk assessment can be used by extracting the insights while recognizing the numerical uncertainties. For example, the evaluations have been examined and it has been concluded that the types of accidents contributing to risk are largely independent of the numerical uncertainty in the risk values. Thus the analysis, even considering uncertainties, suggests that seismic is the greatest storage risk and fire is the greatest disposal risk. In addition, while the numerical estimates are uncertain, they are useful for comparing different activities and in a more limited sense, for comparing to other risks.

In addition to the uncertainties, there are also some limitations. These are generally associated with the specific scope of analysis or the availability of information.

One timely topic is sabotage and terrorism. These are not included in the scope of the QRA. As described in section 5.7, sabotage and terrorism are addressed through other methods of assessment and protection. Assessments of sabotage and terrorism cannot be included in unclassified risk assessments because detailed assessments would, in effect, create a roadmap for such activities. There are two conclusions that can be drawn concerning terrorism and sabotage. The first is that the risk models very likely include the levels of agent release that could be associated with such events if they occurred in storage or processing areas. The QRA includes earthquakes and accidental airplane crashes and other very catastrophic events that include the potential for very large releases. The second conclusion is that the chemical agents and munitions only pose a threat as long as they exist. Therefore, whatever threat exists is a direct function of how long the stockpile continues to be stored.

A summary of some of the other key limitations is provided as follows:

- The current results represent a snapshot view of an ongoing risk management process. These risk results therefore should be used for insight, but are not anticipated to represent the final risk because PMCD has committed to continued efforts to manage and minimize risk.

- The analysis is only for agent-related risk of accidental releases and for the risks of disposing of the energetics associated with munitions.

- The QRA models have been developed to capture the UMCDF-specific operations, but not all details are available at this time. The models should continue to be updated as the specifics of UMCDF operations and the final procedures become available.

- The analysis is based on the current schedule of approximately 6 years. The RMP calls for an update of the QRA prior to new campaigns and any changes in schedule should be included at that time. Increases in schedule do not always have a linear impact on risk because the risk is very different for each munition and agent. Re-evaluation of the QRA models is needed to assess risk based on schedule changes.

- There were some assumptions made regarding the processes, as detailed in section 3.13. Some of these assumptions could be critical to the results, so it will be an important risk management activity to verify the assumptions or update the models as information becomes available.

- The HVAC carbon filters will collect significant amounts of agent. Currently, a final disposal method has been tested but details of implementation at UMCDF are not yet available. This risk assessment includes the risks of transporting the carbon to an onsite storage igloo and the risk of external events such as accidental aircraft crashes affecting that igloo. The risks of final carbon disposal, however, are not included in this evaluation.

- The results include consideration of protective actions in the community, because consideration of protective action provides a more realistic estimate of risk. The protective action model is very simple and cannot be considered a detailed planning tool. As discussed in sections 13 and 15, elimination of protective actions would increase these public risk results by approximately a factor of 16 or 10 for disposal processing or storage during disposal, respectively. The important contributors to risk remain the same.

- Continued storage risk estimates also do not include potential changes in population. Therefore, it is possible that risk estimates of long-term storage are underestimated.

- The analysis of continued storage does not include the risk of whatever disposal process would be implemented after 20 years.

- The relatively recent discovery of the possibility of hydrogen overpressure in mustard-filled munitions and containers has been examined but only partially modeled. Worker risk was modified to account for an increased probability of splash/spray contact given a leak after an upset. The possibility of hydrogen combustion during processing was examined, and it was concluded that there would be no public or worker risk from such an event, although there could be some damage to equipment.

- Assessment of worker risk with detailed probabilistic models is a fairly new and unique activity. As such, there is less past methodological experience to draw on in the development and implementation of the models. Being less mature technically, the assessment of worker risk is likely subject to larger uncertainties. The worker risk results therefore should be used to provide insight, but it should be recognized that the numerical values are subject to substantial uncertainties. While useful for insight, the QRA worker risk models should not be a substitute for other traditional means of ensuring that worker risks are understood and controlled. The RMP requires both methods of control.

When assessing risk, completeness is always a concern. It is impossible to attain completeness, but QRA methods have evolved to help ensure systematic approaches that provide some confidence that the evaluation has captured the significant risks. The required development of an RMP that includes the QRA, as well as OSHA, USEPA, and U.S. Army safety and risk initiatives, will help ensure that facility operations remain safe (PMCD, 1996). Review of the QRA and facility as well as a detailed program to capture lessons learned from operations further enhances the information base for the QRA. The commitment to update the QRA models is the best assurance that the QRA results are as complete as possible.

16.6 Perspective of Numerical Risk Estimates

The QRA is only an assessment of risks and does not include conclusions regarding acceptability of risk. Acceptability is determined by society, often through elected or appointed officials. Many readers of PMCD risk-related materials have expressed a desire to have additional explanation of the numerical risk values by comparison to other risks that society and individuals face in everyday life. Comparisons need to be carefully selected by decision-makers. Society, individuals, and decision-makers have different perceptions of risk that are the controlling factor in risk decision-making. Without claim that these are the only way to view the risks, some risk perspectives are provided here.

The first risk results are societal, impacting the entire community. Societal risk comparisons are problematic when considering one activity (such as UMCDF disposal processing) where possible effects are limited to a specific population when most societal risks are compiled across larger populations. The individual risks, discussed later, better capture the impact on the people closest to UMCDF. Table 16-11 lists some societal risks in Oregon in terms of expected deaths per year. All the entries in the table except those for the QRA (which are shaded) are actuarial in

Table 16-11. Some Societal Risks in Oregon (Expected Deaths per Year)

Deaths in Oregon per Year[a]	Cause
1,130	All Accidental Deaths
479	Motor Vehicle
58	Drowning
43	Fires
22	Machinery (Including Farm)
7	Railway Accidents
2	Electric Current
0.2[b]	Dog Attacks
0.01[c]	Stockpile Storage at UMCD
0.0009[d]	Disposal Processing at UMCDF

Notes:

[a] National Safety Council, 1995, based on 1 year; most years are similar
[b] On average, one death every 5 years
[c] QRA estimate, one death every 100 years
[d] QRA estimate, one death every 1,100 years

that they are based on data from past years. The QRA numbers are average estimates using the QRA methodology. As noted in the previous section, these estimated values are uncertain.

When considering risk it is also important that the scope of the risk evaluations be considered. The QRA estimates risk of fatality as a result of accidental releases of agent. That is why the other statistics listed for perspective are accidental deaths. PMCD and the State of Oregon consider other risks (e.g., exposure to normal emissions) through a health risk assessment required for an operations permit. It has thresholds set to ensure that the disposal activity does not account for a significant percent of the population's chronic exposure risk.

The accidental death rate in table 16-11 is made up a large variety of risks, some voluntary and some involuntary. The QRA mean estimates for the possibility of fatalities associated with processing and storage are much less than 1 percent of the total accidental death rate. The risks associated with UMCDF and UMCD are somewhat different than many other societal risks in that they are of limited duration. The disposal process lasts approximately 6 years and the storage risk will exist until the stockpile is eliminated.

QRA risks also have been reported on a per-person basis. This is typically referred to as individual risk, although it is calculated for groups of people living in various geographic sectors, not for specific individuals. Table 16-12 illustrates at a high level the QRA risk results compared to Oregon accidental death statistics. (Sections 13 and 15 include results at different distances from the site, which show that the individual risk drops substantially as distance from the site increases.) The storage and disposal individual risks are on the same order of magnitude close to the site. At about 7 miles, the disposal risk is very small because most facility accidents involve limited quantities of agent. Storage risk is higher because of the larger agent quantities that could travel farther from the site.

Table 16-12. Estimated QRA Risk Compared to Individual Accidental Death Risk in Oregon

Likelihood per Person per Year	Description
380 in one million[a]	All Accidental Deaths in Oregon
4 in one million	Continued Storage, Average for People Living within 3 Miles
2 in one million	Disposal Processing, Average for People Living within 3 Miles
0.4 in one million	Continued Storage, Average for People Living about 7 Miles Away
0.02 in one million	Disposal Processing, Average for People Living about 7 Miles Away

Note:

[a] National Safety Council, 1995.

Table 16-13 provides some additional perspectives on individual risks of accidental death, including very rare events. (Oregon statistics were not available at this level of detail, so national averages are used.) This type of information is useful because it can be used to compare to other risks that society perceives to be important or unimportant. Included in the table are other risks that are a small percent of the total accidental death rate and some risks that are substantially smaller than the chemical weapons risks. Again, the values shown are the mean values of uncertainty distributions that indicate that the risk could be about a factor of 10 higher or lower, and the individual risks are also dependent on their specific locations relative to the site.

Table 16-13. Some Individual Risk Rates in the United States

Risk of Death in U.S. per Person per Year	Percent of Total	Cause of Accidental Death
340 in a million[a]	100%	All Accidental Deaths
160 in a million[a]	47%	Motor Vehicle
28 in a million[a]	8%	All Accidental Poisoning
22 in a million[a]	7%	Pedestrian Struck by Vehicle
6 in a million[a]	2%	Accidental Firearms
5 in a million[a]	1%	Choking on Food
4 in one million	1%	Chemical Weapons Storage for People within 3 Miles of UMCD (per year until disposal starts)
2 in one million	0.6%	Disposal Operations for People within 3 Miles of UMCDF (per year for about 6 years)
0.4 in one million	0.1%	Chemical Weapons Storage for People about 7 Miles from UMCD (per year until disposal starts)
0.2 in a million[a]	0.06%	Lightning
0.03 in a million[a]	0.008%	Venomous Snakes/Spiders
0.02 in one million	0.006%	Disposal Operations for People about 7 Miles from UMCDF (per year for about 6 years)
0.01 in a million[a]	0.002%	Fireworks Accidents

Note:

[a] National Safety Council, 1995.

16.7 Using the QRA in Risk Management

A number of uses of the QRA are specified in section 1.9. To date, the risk models have been used to study individual issues such as the risk impact of different disposal schedules. The results and models can be used to support the site-specific risk management process. It is likely that some changes to facility operations will be identified as the UMCDF procedures continue to evolve. The QRA results can also be translated into PMCD's existing risk assessment codes to ensure appropriate mitigations of risks.

16.8 Conclusions

The overall conclusions of this study regarding public risk are most effectively displayed in figures 16-3 and 16-4. From these figures, it is clear that the public fatality risk of disposal processing is less than the risk of continued storage for any extended period. This is the same conclusion reached in the UMCDF Phase 1 QRA. Also shown in the figures is the impact of processing on storage risk and total risk, showing the decreasing storage risk as munitions and agent are destroyed.

The factors determining the risk of disposal processing and storage have been identified and are discussed in detail in sections 13 and 15.

The public risk results have also been calculated for latent cancer. This is the risk of exposure-induced cancer long after the accident, as opposed to the acute fatality risk described previously. Of the agent stored at Umatilla, only HD has a carcinogenic effect. The findings from the QRA indicate that the latent cancer risk from accidental releases of HD is much lower than the acute fatality estimates.

Worker risk due to potential agent exposures also has been estimated. Compared with other risks identified in this study, Disposal-Related Worker risk from plant processes is more significant than the risk from external influences such as earthquakes. One action, clearing the jams in the DFS chute, accounts for a large portion of the worker risk. The risk for Other Site Workers has been assessed to be somewhat higher than that of the public located closest to the facility with very similar accident contributors.

The analysis described here is one tool used within a comprehensive RMP at UMCDF. There have already been numerous risk management actions based on the results of the TOCDF QRA, and this process with the UMCDF Phase 2 QRA will continue over the life of the facility. The comprehensive RMP implemented at UMCDF will help ensure that PMCD's goals toward the minimization of risk are met as the stockpile is destroyed.

(This page intentionally left blank.)

APPENDIX A
REFERENCES

APPENDIX A
REFERENCES

Anderson, J., *Cognitive Psychology and Its Implications*, W. H. Freeman, 1980.

Armament, Munitions, and Chemical Command (AMCCOM) data (*Leakers On Hand By Location*, Rock Island, IL: U.S. Army Armament, Munitions and Chemical Command, 1993) collected by MITRE for the Stockpile Risk Analysis (J. Perry, D. Tripler, G. Nelson, *Assessment of the U.S. Chemical Weapons Stockpile: Integrity and Risk Analysis*, Working Paper, WP 93W000080, U.S. Army, January 1994).

Ayer, J., *Nuclear Fuel Cycle Facility Accident Analysis Handbook*, NUREG-1320, U.S. Nuclear Regulatory Commission, Washington, D.C., 1988.

Bailey, R., *Agent Destruction from Munition Detonations within the MPF and the DUN*, SAF-452-95-0092, Revision 0, Science Applications International Corporation (SAIC), Abingdon, Maryland, 1995.

Bailey, R., "Estimation from Zero-Failure Data," *Risk Analysis*, Vol. 17, No.3, Society for Risk Analysis, 1997.

Bailey, R., *Agent Adsorption and Desorption in the HVAC Carbon Filters*, Revision 0, SAF-CLC-00-0008, SAIC, 27 October 2000a.

Bailey, R., *Frequencies, Conditional Probabilities, and Source Terms for Carbon Fire/Desorption Events in HVAC Filter Units and Storage Igloos*, SAF-CLC-00-0013, 28 November 2000b.

Bailey, R. and D. Bradley, *Heating of an Overpacked M55 Rocket due to Autoignition of an Adjacent Rocket Motor*, SAF-CLC-00-0003, Revision 0, Science Applications International Corporation (SAIC), Abingdon, Maryland, 2000a.

Bailey, R. and D. Bradley, *Overpacked M55 Rocket Propagation Event Trees*, SAF-CLC-00-0009, Revision 0, SAIC, Abingdon, Maryland, 2000b.

Bayes, T., "Essay Toward Solving a Problem in the Doctrine of Chances" (reprinted), *Biometrika*, Vol. 45, pp. 293-315, 1958.

Birk, D., *Agent Adsorption and Desorption in the HVAC Carbon Filters under Fans-On and Fans-Off Conditions during a Fire in the MDB*, SAF-CLC-01-0006, Revision 0, SAIC, Abingdon, Maryland, 2001.

Blackwell, P., LGGS, *Memorandum, Re: Declassification of the U.S. Chemical Weapons Stockpile*, Department of the Army, Office of the Deputy Chief of Staff for Operations and Plans, 19 December 1995.

Blanton, C. and S. Eide, *Savannah River Site Generic Data Base Development*, WSRC-TR-93-262, Westinghouse Savannah River Company, Aiken, South Carolina, June 1993.

Booth, T., *Test Report for Undrained GB M55 Rocket Challenge Testing of the CAMDS Deactivation Furnace System*, Test Report No. 04-31, Tooele Army Depot, Tooele, Utah, 29 July 1982.

Borkowski, R., W. Kahl, T. Hebble, J. Fragola and J. Johnson, *In-Plant Reliability Data Base for Nuclear Power Plant Components - Valve Component*, NUREG/CR-3154, U.S. Nuclear Regulatory Commission, Washington, D.C., December 1983.

Boyd, G., *Probabilities of Degraded Munitions*, SAF-452-96-0028, Revision 0, SAIC, 1996.

Bradley, D., *Estimate of Overpacked Rocket Propagation Probability Based on Dugway and Black Hills Test Data*, SAF-CLC-00-0010, Revision 0, SAIC, Abingdon, Maryland, 2000.

Brandyberry, M., C. Amos, W. Baker, D. Kearnaghan, K. O'Kula, J. Weingardt, and N. Woody, *Savannah River Site K-Reactor Probabilistic Safety Assessment*, WSRC-RP-91-041, Westinghouse Savannah River Company, Aiken, SC, 1992.

Briggs, G., *Plume Rise Predictions*, Environmental Research Laboratories, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, 1975.

Byrne, B., *Pool Fire Agent Release*, SAF-CLC-01-0003, Revision 0, SAIC, Abingdon, Maryland, 2002a.

Byrne, B., *Pool Fire Release Fractions*, SAF-CLC-00-0011, Revision 2, SAIC, Abingdon, Maryland, 2002b.

Center for Chemical Process Safety (CCPS), *Chemical Process Quantitative Risk Analysis*, American Institute of Chemical Engineers, New York, 1989a.

CCPS, *Guidelines for Process Equipment Reliability Data with Data Tables*, American Institute of Chemical Engineers, New York, 1989b.

Chanin, D., J. Sprung, L. Ritchie, and H-N Jow, *MELCOR Accident Consequence Code System (MACCS)*, User's Guide, Sandia National Laboratories, NUREG/CR-4691, Volumes 1, 2, and 3, 1990.

Chemical Stockpile Emergency Preparedness Program (CSEPP), Emergency Response Concept Plan for the Chemical Stockpile Emergency Preparedness Program, Revision 1, Volume 8, Emergency Planning Guide for the Umatilla Depot Activity CSEPP Site, CSEPP, 27 January 1995.

Christman, D., *Estimated Carbon Filter Agent Loadings*, SAF-452-95-0031, Revision 6, SAIC, Abingdon, Maryland, 2001.

Christman, D., *Probabilities of Leaks and Energetic Initiations Due to Drops and Collisions*, SAF-452-94-0048, Revision 6, SAIC, Abingdon, Maryland, 2002a.

Christman, D., *Leakage and Energetic Initiation Due to Crushing of Munitions by Gates*, SAF-452-94-0116, Revision 5, SAIC, Abingdon, Maryland, 2002b.

Christman, D., *Munitions Breached or Exploded Due to Collapse of Concrete or Steel Igloos*, SAF-452-95-0101, Revision 3, SAIC, Abingdon, Maryland, 2002c.

Cook, I. and S. Unwin, "Controlling Principles for Prior Probability Assignments in Nuclear Risk Assessment," *Nuclear Science and Engineering*, No. 94, pp. 107-119, 1986.

Coyle, J., Re: Oregon wildfires: historical data, E-mail to Cindy R. Ching, 12 July 2000, three pages, 1:04 p.m.

CRC-00-006a, *SAIC Umatilla Walkdown/Site Visit Trip Report*, 3 July 2000.

Data Systems & Solutions, *CAFTA Version 4.0b*, Los Altos, California, 2000.

Denson, W., G. Chandler, W. Crowell, A. Clark, and P. Jaworski, *Non-Electronic Parts Reliability Data*, NPRD-95, Reliability Analysis Center, Griffiss Air Force Base, Rome, New York.

Department of Defense Explosives Safety Board (DDESB), *Methodology for Chemical Hazard Prediction*, June 1980.

Department of Energy (DOE), *Accident Analysis for Aircraft Crash into Hazardous Facilities*, DOE Standard, DOE-STD-3014-96, October 1996.

Derdiger, J., K. Bhatt, and W. Siegfriedt, *Component Failure and Repair Data for Coal-Fired Power Units*, EPRI AP-2071, Electric Power Research Institute, Palo Alto, California, October 1981.

Drago, J., R. Borkowski, J. Fragola, and J. Johnson, *In-Plant Reliability Data Base for Nuclear Power Plant Components - Pump Component*, NUREG/CR-2886, U.S. Nuclear Regulatory Commission, Washington, D.C., December 1982.

Edgewood Research, Development and Engineering Center (ERDEC), *Expedient Sheltering in Place: An Evaluation for the Chemical Stockpile Emergency Preparedness Program*, Technical Report, Draft, December 1995.

Finney, D., *Probit Analysis*, 3rd Edition, Cambridge University Press, New York, 1980.

General Atomics (GA) Technologies, Inc., *Risk Analysis of the Onsite Disposal of Chemical Munitions*, SAPEO-CDE-IS-87010, GA-C18562, August 1987a.

GA Technologies, *Risk Analysis Calculations*, August 1987b.

GJB-00-001, *SAIC UMCDF QRA Kickoff Trip Report*, 6 March 2000.

Goldfarb, A., G. Anderson, J. Mahle, and D. Croft, *Development of a Simulation Model for a Pollution Abatement Carbon Filter System*, MTR 1998-003, Mitretek Systems, McLean, Virginia, October 1998.

González, F., *Tsunami!*, Scientific American, May 1999.

Grotte, J. and L. Yang, *Report of the Workshop on Chemical Agent Toxicity*, Institute for Defense Analyses, May 1998, Draft Final, August 1998.

Henry, P., "Understanding and Improving Risk in PLC-Based Burner Management Systems," *www.boilercontrol.com*; BMS Risk and Reliability page, 1998.

Hill, D., *Tests to Determine Extent of Propagation or Damage when 8-in or 155-mm Chemical Agent Simulant-Filled Projectile Detonates within Standard Pallet and in Pallet Overpack*, Report AED 17-89, Tooele Army Depot, Tooele, Utah, October 1989.

Holgate, H., L. Scherer, and A. Talib, *Assessment of Carbon Filter System Performance*, MITRE Report No. MTR 93W0000034, McLean, Virginia, September 1993.

Howard, P., R. Boethling, W. Jarvis, W. Meylan, and E. Michalenko, *Handbook of Environmental Degradation Rates*, 1991.

Iman, R. and W. Conover, *Sensitivity Analysis Techniques: Self-Teaching Curriculum*, NUREG/CR-2350, Sandia National Laboratories, Albuquerque, New Mexico, 1982.

Iman, R. and M. Shortencarrier, *A FORTRAN 77 Program and User's Guide for the Generation of Latin Hypercube and Random Samples for Use with Computer Models*, NUREG/CR-3624, Sandia National Laboratories, Albuquerque, New Mexico, 1984.

Institute of Electrical and Electronics Engineers (IEEE), *IEEE Guide to Collection and Presentation of Electrical, Electronic, Sensing Component, and Mechanical Equipment Reliability Data for Nuclear-Power Generating Stations*, IEEE Std. 500-1984, IEEE, New York, 1983.

IEEE, *IEEE Recommended Practice for the Design of Reliable Industrial and Commercial Power Systems*, IEEE Std. 493-1990, "IEEE Gold Book," IEEE, New York, 1991.

ITT Research Institute, *Test Report on RAM of ACAMS for TWA Levels in Work Areas at CAMDS*, January 1989.

Jack Benjamin Associates (JBA), *Probabilistic Seismic Hazard Assessment for the U.S. Army Chemical Demilitarization Facility, Umatilla, Oregon*, September 1995.

Jamali, K., *Pipe Failure Study Update*, EPRI TR-102266, Electric Power Research Institute, Palo Alto, California, April 1993.

Janis, I. and L. Mann, *Decision Making*, Free Press, 1977.

Karwacki, C., J. Buchanan, T. Rosso, L. Buettner, J. Mahle, and G. Wagner, *Effect of Temperature on the Desorption and Decomposition of HD from Activated Carbon*, ERDEC-TR-555, Edgewood Research, Development & Engineering Center, Aberdeen Proving Ground, Maryland, December 1998.

Karwacki, C., J. Buchanan, T. Rosso, L. Buettner, J. Mahle, and G. Wagner, *Effect of Temperature on the Desorption and Decomposition of GB from Activated Carbon*, ECBC-TR-035, Edgewood Chemical Biological Center, Aberdeen Proving Ground, Maryland, December 1999.

Kearney, A. T., Inc., *Tooele Chemical Demilitarization Facility Tooele Army Depot South Screening Risk Assessment*, prepared for the State of Utah Department of Environmental Quality Division of Solid and Hazardous Waste, February 1996.

Kirwan, B., *A Guide to Practical Human Reliability Assessment*, Taylor & Francis, 1994.

Kirwan, B., "The Validation of Three Human Reliability Quantification Techniques - THERP, HEART and JHEDI: Part I - Technique Descriptions and Validation Issues," *Applied Ergonomics*, Volume 27, No. 6, pp. 359-373, 1996.

Kirwan, B., "Human Error Identification Techniques for Risk Assessment of High Risk Systems - Part I: Review and Evaluation of Techniques," *Applied Ergonomics*, Volume 29, No. 3, pp. 157-177, 1998.

Kirwan, B., R. Kennedy, S. Taylor-Adams, and B. Lambert, "The Validation of Three Human Reliability Quantification Techniques - THERP, HEART and JHEDI: Part II - Results of Validation Exercise," *Applied Ergonomics*, Volume 28, No. 1, pp. 17-25, 1997.

Kletz, T., *What Went Wrong? Case Histories of Chemical Plant Disasters*, 2nd Edition, Gulf Publishing Company, 1988.

Kuchta, J., *Investigation of Fire and Explosion Accidents in the Chemical, Mining, and Fuel-Related Industries: A Manual*, PB87-113940, U.S. Bureau of Mines, Washington, D.C., 1986.

Lawrence, D., Memorandum to Chief, Safety Division, SDSTE-IRS, TEAD, Document Number MSHG-UIHS (40-5), dated 11 September 1993.

Lee, R., *Lightning Protection of Buildings*, IEEE Transactions on Industry Applications, Vol. IA-15, No. 3, May/June 1979.

Lees, F., *Loss Prevention in the Process Industries*, Volumes 1 and 2, Butterworth & Co., London, 1980.

Lees, F., *Loss Prevention in the Process Industries*, 4th Edition, Butterworth & Co., 1989.

Lisa, V., Re: wildfires at UMCDF, E-mail to Cindy R. Ching, 23 August 2000, two pages, 2:06 p.m.

Maumee Research and Engineering, Inc., *Study Report Covering Agent Vaporization Rates in the Metal Parts Furnace for JACADS Project*, Perrysburg, Ohio, 21 July 1987.

Maumee Research and Engineering, Inc., *Study Report Covering Simulants in the Metal Parts Furnace Including Weteye Bomb and Spray Tank for Testing in the JACADS Project*, Perrysburg, Ohio, November 1988.

McDonald, J., *A Methodology for Tornado Hazard Probability Assessment*, NUREG/CR-3058, Institute for Disaster Research, Texas Tech University, October 1983.

Miller, C., W. Hubble, D. Sams, and W. Moore, *Data Summaries of Licensee Event Reports of Selected Instrumentation and Control Components at U.S. Commercial Nuclear Power Plants*, NUREG/CR-1740, EG&G Idaho for U.S. Nuclear Regulatory Commission, May 1981.

Mishima, J., *Recommended Values and Technical Bases for Airborne Release Fractions, Airborne Release Rates, and Respirable Fractions at DOE Non-Reactor Nuclear Facilities*, DOE HDBK-0013-93, U.S. Department of Energy, Washington, D.C., 1993.

Mitretek Systems, *Report of the Panel of Experts on the Umatilla Chemical Agent Disposal Facility Quantitative Risk Assessment*, Prepared by the UMCDF QRA Expert Panel, 19 September 2002.

Mohamed, A., *Probabilities of Degraded Munitions*, SAF-CLC-99-0014, Revision 1, SAIC, Abingdon, Maryland, 2000.

Mosleh, A., N. Siu, C. Smidts, and C. Lui (editors), "Model Uncertainty: Its Characterization and Quantification," *Proceedings of Workshop I in Advanced Topics in Risk and Reliability Analysis*, Governor Calvert House and Conference Center, Annapolis, Maryland, sponsored by the Nuclear Regulatory Commission, NUREG/CP-0138, October 20-22, 1993.

National Fire Protection Association (NFPA), *NFPA 68: Guide for Venting of Deflagrations*, 1974 Edition, Quincy, Massachusetts, 1974.

NFPA, *NFPA 68: Guide for Venting of Deflagrations*, 1978 Edition, Quincy, Massachusetts, 1978.

NFPA, *The SFPE Handbook of Fire Protection Engineering*, Quincy, Massachusetts, 1988.

National Research Council (NRC), *Alternative Technologies for the Destruction of Chemical Agents and Munitions*, National Academy Press, Washington, D.C., 1993.

NRC, *Recommendations for the Disposal of Chemical Agents and Munitions*, National Academy Press, Washington D.C., 1994.

NRC, *Review of Systemization of the Tooele Chemical Agent Disposal Facility*, National Academy Press, Washington D.C., 1996.

NRC, *Risk Assessment and Management at the Deseret Chemical Depot and the Tooele Chemical Agent Disposal Facility*, National Academy Press, Washington D.C., 1997a.

NRC, *Review of Acute Human-Toxicology Estimates for Selected Chemical-Warfare Agents*, Committee on Toxicology, 1997b.

NRC, *Tooele Chemical Agent Disposal Facility Update on National Research Council Recommendations*, National Academy Press, Washington D.C., 1999.

National Safety Council, *Accident Facts*, 1995 Edition, Itasca, Illinois, 1995.

Nielson, L. and G. Bowers-Irons, *DPE Tear Report, Fourth Quarter 1999, DPE Tear Report 46-02*, Chemical Agent Munitions Disposal System Directorate, Deseret Chemical Depot, Stockton, Utah, March 2000a.

Nielson, L. and G. Bowers-Irons, *DPE Tear Report, First Quarter 2000, DPE Tear Report 46-02A*, Chemical Agent Munitions Disposal System Directorate, Deseret Chemical Depot, Stockton, Utah, May 2000b.

Nielson, L. and G. Bowers-Irons, *DPE Tear Report, Second Quarter 2000, DPE Tear Report 46-02*, Chemical Agent Munitions Disposal System Directorate, Deseret Chemical Depot, Stockton, Utah, September 2000c.

Nielson, L. and J. McEachern, Jr., *DPE Tear Report, Third Quarter 2000, DPE Tear Report 46-02*, Chemical Agent Munitions Disposal System Directorate, Deseret Chemical Depot, Stockton, Utah, January 2001.

Nisqually Earthquake Clearinghouse Group, *The Nisqually Earthquake of 28 February 2001 Preliminary Reconnaissance Report*, University of Washington, Seattle, Washington, March 2001.

Office of Nuclear Regulatory Research (ONRR), *Procedural and Submittal Guidance for the Individual Plant Examination of External Events (IPEEE) for Severe Accident Vulnerabilities*, NUREG-1407, Washington, D.C., June 1991.

Office of the Surgeon General (OTSG), *Interim Chronic Toxicological Criteria for Chemical Warfare Compounds*, Memorandum, Department of the Army Office of the Surgeon General, August 1996.

Offshore Reliability Data - 2nd Edition, OREDA-92, Det Norske Veritas (DNV), Technica, Høvik, Norway, 1992.

Organisation for the Prohibition of Chemical Weapons (OPCW), *Convention on the Prohibition of the Development, Production, Stockpiling and Use of Chemical Weapons and on Their Destruction*, January 1993.

Parsons, *ECR Blast Analysis*, Task B-11F6, January 1988.

Parsons, *Chemical Stockpile Disposal Program Structural Design Calculations for the TOCDF*, Volume 23, Aberdeen Proving Ground, Maryland, 1989.

Parsons, *Munition Handling System PHA - In Progress Report of ANCDF PHA*, The Ralph M. Parsons Company, Pasadena, California, August 1991.

Pasquill, F., *Atmospheric Diffusion*, 2nd Edition, Ellis Horwood Limited, New York, 1974.

Potter, J. and T. Mughal, *Sensitivity Testing of Explosives and Propellants at Cryogenic Temperatures*, Hercules Aerospace Company, Magna, Utah, December 1992.

Price, B., J. Perry, W. Fraize, W. Duff, R. Cutler, D. Ligon, L. Ettlinger, and W. Mitchell, *Final Safety Assessment of the Tooele Mixed Munitions Plant at 90 Percent Design*, MTR-89W00135-01, MITRE Corporation, McLean, Virginia, 1989.

Program Manager for Chemical Demilitarization (PMCD), *Risk Analysis in Support of the Chemical Stockpile Disposal Program*, MITRE Report MTR-87W00230, December 1987a.

PMCD, *Risk Analysis of the Onsite Disposal of Chemical Munitions*, General Atomics Report GA-C18562, SAPEO-CDE-IS-97010, August 1987b.

PMCD, *Chemical Stockpile Disposal Program Final Programmatic Environmental Impact Statement*, January 1988.

PMCD, *System Safety Management Plan for the Chemical Stockpile Disposal Program*, April 1991.

PMCD, *Chemical Agent Disposal Facility Risk Management Program Requirements*, May 1996.

PMCD, *Guide to Risk Management Policy and Activities*, May 1997a.

PMCD, *Report of the Expert Elicitation on Autoignition of Nonleaking Rockets*, Aberdeen Proving Ground, Maryland, May 1997b.

PMCD, *Chemical Demilitarization Operations Manual*, Revision 7, September 1998.

PMCD, *Public Involvement in the U.S. Army's Program to Destroy Chemical Weapons*, Fiscal Year 1999, Public Outreach and Information Office, 1999.

PMCD, *Assessment of the Stability of M55 Rockets in Storage*, Aberdeen Proving Ground, Maryland, June 2001.

Ray, M., *Mechanistic Analyses for the QRAs*, SAF-452-95-0083, Revision 0, SAIC, Abingdon, Maryland, 1996.

Reason, J., *The Psychology of Mistakes: A Brief Review of Planning Failures*, in J. Rasmussen, K. Duncan, and J. Leplat (eds.), New Technology and Human Errors, John Wiley & Sons, New York, 1987.

Reason, J. and K. Mycielska, *Absent Minded? The Psychology of Mental Lapses and Everyday Errors*, Prentice-Hall, 1982.

Reinhold, T. and B. Ellingwood, *Tornado Damage Risk Assessment*, NUREG/CR2944, Center for Building Technology, National Bureau of Standards, September 1982.

Rife, R., *Calculation of Evaporation Rates for Chemical Agent Spills*, DRXTH-ES-TM-81101, U.S. Army Toxic and Hazardous Materials Agency, Aberdeen Proving Ground, Maryland, 1981.

Robbins, L., *Agent Aerosol/Vapor Distribution Following Munition Explosion*, SAF-452-96-0043, SAIC, Abingdon, Maryland, 10 April 1997.

Rogers, G., A. Watson, J. Sorensen, R. Sharp, and S. Carnes, *Evaluating Protective Actions for Chemical Agent Emergencies*, Oak Ridge National Laboratory, ORNL-6615, April 1990.

SAF-MC-00-001, *SAIC Umatilla Site Visit Trip Report*, 26 April 2000.

Salyer, W., G. Dyer, and R. Cumming, *Frequency Distribution of Leak Size in HD Ton Containers at the Edgewood Arsenal Aberdeen Proving Ground*, ORRIM 9607-001, Oak Ridge Risk Management, Inc., July 1996.

Sandia National Laboratories (SNL), *Thermal/Hydraulic Analysis Division, MELCOR 1.8.1 Computer Code Manual*, Volume 1: Primer and Packages Users' Guides, June 1991.

Science Applications International Corporation (SAIC), *Umatilla Chemical Agent Disposal Facility Phase 1 Quantitative Risk Assessment*, Abingdon, Maryland, September 1996a.

SAIC, *Tooele Chemical Agent Disposal Facility Quantitative Risk Assessment*, SAIC-96/2600, Abingdon, Maryland, December 1996b.

SAIC, *Chemical Agent Disposal Facility Quantitative Risk Assessment Methodology Manual,* Abingdon, Maryland, April 1997.

SAIC, *Umatilla Chemical Agent Disposal Facility Process Operations Diagrams*, Draft, Abingdon, Maryland, September 1999a.

SAIC, *Quantitative Risk Assessment of Chemical Agent Storage at Newport Chemical Depot*, Abingdon, Maryland, June 1999b.

SAIC, *Quantus User's Manual*, Version 2.1, Abingdon, Maryland, June 2002a.

SAIC, *Quantus Quick Start Guide*, Abingdon, Maryland, June 2002b.

SAIC, *Chemical Agent Disposal Facility Fire Hazard Assessment Methodology*, SAIC-01/2650, Abingdon, Maryland, March 2002c.

Soldier and Biological Chemical Command (SBCCOM), *Soldier and Biological Chemical Command Stockpile Tracking System Database*, Edgewood, Maryland, Data current as of August 2001.

Steindler, M. and W. Seefeldt, *A Method for Estimating the Challenge to an Air Cleaning System Resulting from an Accidental Explosive Event, Proceedings of the 16th DOE Nuclear Air Cleaning Conference*, February 1981, pp. 1165-1174.

Stevenson and Associates (S&A), *Seismic and Tornado Fragility Assessment for the Anniston Chemical Agent Disposal Facility*, SAF-DOC-0834, Revision 0, 30 September 1994.

S&A Calculation, 00Q4142-C001, *Response Spectra and Time History of Ground Motion*, July 2000a.

S&A Calculation, 00Q4142-C002, *Floor Response Spectra of MDB*, July 2000b.

S&A Calculation, 00Q4142-C003, *Soil Properties and Liquefaction Potential*, July 2000c.

S&A Calculation, 00Q4142-C004, *Fragility Analysis of MDB*, July 2000d.

S&A Calculation, 00Q4142-C005, *Fragility Analysis of CHB*, July 2000e.

S&A Calculation, 00Q4142-C006, *Fragility Analysis of CHB/UPA*, July 2000f.

S&A Calculation, 00Q4142-C007, *Fragility Analysis of LPG Tank*, July 2000g.

S&A Calculation, 00Q4142-C008, *Fragility Analysis of TOX Tank*, July 2000h.

S&A Calculation, 00Q4142-C009, *Fragility Analysis of TOX Overflow Tank*, July 2000i.

S&A Calculation, 00Q4142-C010, *Fragility Analysis of SDS Tanks*, July 2000j.

S&A Calculation, 00Q4142-C011, *Fragility Analysis of DFS*, July 2000k.

S&A Calculation, 00Q4142-C012, *Fragility Analysis of MPF and Its Afterburner*, July 2000l.

S&A Calculation, 00Q4142-C013, *Fragility Analysis of AQS Tanks*, July 2000m.

S&A Calculation, 00Q4142-C014, *Fragility Analysis of Primary and Secondary LIC*, July 2000n.

S&A Calculation, 00Q4142-C015, *Fragility Analysis of Diesel Generator System*, July 2000o.

S&A Calculation, 00Q4142-C016, *Fragility Analysis of Electrical Panels*, July 2000p.

S&A Calculation, 00Q4142-C017, *Fragility Analysis of 20-ton Crane in the UPA Area*, July 2000q.

S&A Calculation, 00Q4142-C018, *Fragility Analysis of Concrete Igloos*, July 2000r.

S&A Calculation, 00Q4142-C019, *Fragility Analysis of Munitions Stacking*, July 2000s.

S&A Calculation, 00Q4142-C020, *Fragility Analysis of Ton Containers*, July 2000t.

S&A Calculation, 00Q4142-C021, *Wind Fragility Analysis of Wall Panels*, July 2000u.

S&A Calculation, 00Q4142-C022, *Fragility Analysis of Miscellaneous Equipment*, July 2000v.

S&A Calculation, 00Q4142-C023, *Analysis of Basic Variables for Structures and Equipment*, July 2000w.

S&A Calculation, 00Q4142-C024, *Ground Mounted Equipment Response Analysis Variability*, July 2000x.

S&A Calculation, A00Q4143-R001, *Seismic Fragilities of Structures and Equipment - U.S. Army Umatilla Chemical Agent Disposal Facility*, Revision 0, 28 September 2000y.

Stringfield and Holderness, *Umatilla Chemical Demilitarization Facility Tornado Analysis*, Sigma Science, Inc., June 2000.

Swain, A., *Accident Sequence Evaluation Program Human Reliability Analysis Procedure*, U.S. Nuclear Regulatory Commission Report NUREG/CR-4772, February 1987.

Swain, A. and H. Guttmann, *Handbook of Human Reliability Analysis with Emphasis on Nuclear Power Plant Applications*, U.S. Nuclear Regulatory Commission Report NUREG/CR-1278, August 1983.

Tieszen, S., M. Sherman, S. Slesak, D. Stamps, and J. Tills, "Hydrogen Distribution and Combustion," *Ex-Vessel Severe Accident Review for the Heavy Water New Production Reactor*, Chapter 6, SAND90-0234, Sandia National Laboratories, Albequerque, New Mexico, January 1993.

Tremper, B., *Common Questions About Avalanches*, <http://www.avalanche.org/%7Eaaap/questions.html>, 15 November 1999.

Twisdale, L. *Tornado Data Characterization and Windspeed Risk*, Journal of the Structural Division, ASCE, 1978.

U.S. Army, *Determination of Chemical Agent Explosive Limits in an Oxidizing Atmosphere*, U.S. Army Toxic and Hazardous Materials Agency, 19 February 1985.

U.S. Army, *Risk Analysis Calculations*, Volume 1, Aberdeen Proving Ground, Maryland, August 1987.

U.S. Army, *Structures to Resist the Effects of Accidental Explosions*, Army TM 5-1300, November 1990.

U.S. Army Material Command (USAMC), *Storage in 60' and 80' Igloo Magazines*, Drawing 4041, September 1976a.

USAMC, Drawing 4513, October 1976b.

USAMC, *Storage in Igloos*, Drawing 4539/1, May 1992.

Underwriters Laboratories (UL), Inc., *Master Label No. 36582 for Tooele Facilities*, August 1993.

U.S. Army Nuclear and Chemical Agency (USANCA), *Dose Response Data for the Tooele Chemical Agent Disposal Facility Quantitative Risk Assessment*, June 1994.

U.S. Environmental Protection Agency (USEPA), *Upper-Bound Quantitative Cancer Risk Estimate for Populations Adjacent to Sulfur Mustard Incineration Facilities*, EPA/600/8-91/053, July 1991.

U.S. Nuclear Regulatory Commission (USNRC), *Design Basis Tornado for Nuclear Power Plants*, Regulatory Guide 1.76, April 1974.

USNRC, *U.S. Nuclear Regulatory Commission Standard Review Plan*, NUREG-0800 (Formerly NUREG-75/087), Revision 2, Section 3.5.1.6, Aircraft Hazards, Office of Nuclear Reactor Regulation, Washington, D.C., July 1981.

USNRC, *Methods for External Event Screening Quantification: Risk Methods Integration and Evaluation Program (RMIEP) Methods Development*, NUREG/CR-4839, July 1982.

USNRC, *PRA Procedures Guide*, NUREG/CR-2300, Washington, D.C., 1983.

USNRC, *Severe Accident Risks: An Assessment for Five U.S. Nuclear Power Plants*, NUREG-1150, Office of Nuclear Regulatory Research, Washington, D.C., December 1990.

USNRC, *Procedural and Submittal Guidance for the Individual Plant Examination of External Events (IPEEE) for Severe Accident Vulnerabilities*, NUREG-1407, Washington, D.C., June 1991.

USNRC, *Methods for External Event Screening Quantification: Risk Methods Integration and Evaluation Program (RMIEP) Methods Development*, NUREG/CR-4839, July 1992.

Unwin, S., *IMPAGE: An Information Theory-based Probability Assignment Generator, Brief Code Description and User's Guide*, Technical Report A-3829, Brookhaven National Laboratory, Upton, New York, August 28, 1987.

Van Wylen, G. and R. Sonntag, *Fundamentals of Classical Thermodynamics*, Third Edition, John Wiley and Sons, New York, New York, 1986.

Wagner, P., *Test Report for GB Challenge Testing of the CAMDS Metal Parts Furnace System*, SAF-DOC-0367, September 1978.

Wakefield, D., G. Parry, G. Hannaman, and A. Spurgin, *SHARP1—A Revised Systematic Human Action Reliability Procedure*, EPRI Report NP-7183-SL (Interim Report), December 1990.

Wark, K., *Thermodynamics*, Fourth Edition, McGraw Hill, New York, New York, 1983.

Welker, E. and M. Lipow, "Estimating the Exponential Failure Rate from Data with No Failure Events," *Proceedings of the 1974 Annual Reliability and Maintainability Symposium*, Los Angeles, California, IEEE Catalog Number 74CHO820-1RQC, Volume 7, Number 2, Institute of Electrical and Electronics Engineers, New York, New York, 1974.

Whitacre, C., J. Griner III, M. Myirski, and D. Sloop, *Personal Computer Program for Chemical Hazard Prediction (D2PC)*, Chemical Research, Development and Engineering Center, Aberdeen Proving Ground, Maryland, January 1987.

Williams, J., *A Data-Based Method for Assessing and Reducing Human Error to Improve Operational Performance*, Conference Record for 1988 IEEE Fourth Conference on Human Factors and Power Plants, Institute of Electrical and Electronics Engineers, June 1988.

Winfrey, C., *Meteorite Impact Rate at Storage Sites*, SAF-CLC-99-0006, Revision 0, SAIC, Abingdon, Maryland, 19 May 1999.

Yutmeyer, W., Memorandum to Distribution: *Maximum Credible Events and One Percent Lethality Calculations for Chemical Munitions*, U.S. Army Materiel Command, Field Safety Activity, Charlestown, Indiana, 15 October 1987.

Zentner, M., J. Atkison, P. Carlson, G. Coles, E. Leitz, S. Lindberg, T. Powers, and J. Kelly, *N-Reactor Level 1 Probabilistic Risk Assessment: Final Report*, Table 6-1; N-Reactor Plant-Specific Data Base, WHC-SP-0087, Westinghouse Hanford Company, August 1988.

APPENDIX B
ACRONYMS/ABBREVIATIONS

APPENDIX B
ACRONYMS/ABBREVIATIONS

A&I	Alarm and Interlock
AAF	Army Air Field
AASS	agent automatic sampling system
ACAMS	Automatic Continuous Air Monitoring System
ACI	American Concrete Institute
ACRAM	aircraft crash risk analysis methodology
ACS	Agent Collection System
AFB	auxiliary fume burner
AFD	Airport/Facilities Directory
AHU	air handling unit
AISC	American Institute of Steel Construction
AMC	U.S. Army Materiel Command
AMCCOM	U.S. Army Armament, Munitions and Chemical Command
AMSAA	U.S. Army Materiel Systems Analysis Activity
ANAD	Anniston Army Depot
ANCA	Anniston Chemical Activity
ANCDF	Anniston Chemical Agent Disposal Facility
ANSI	American National Standards Institute
APET	accident progression event tree
AQS	agent quantification system
AR	Army Regulation
ARDEC	U.S. Army Armament Research, Development and Engineering Center
ARTCC	Air Route Traffic Control Center
ASA(IL&E)	Assistant Secretary of the Army (Installation, Logistics and Environment)
ASC	allowable stack concentration
ASCE	American Society of Civil Engineers
ASD	adjustable speed drive
ASEP	Accident Sequence Evaluation Program
ASHRAE	American Society of Heating, Refrigerating and Air Conditioning Engineers
ASME	American Society of Mechanical Engineers
ASQC	American Society for Quality Control
ASTM	American Society for Testing and Materials
AT	air terminal

AV	airlock
AWFCO	automatic waste feed cut-off
AWG	American Wire Gauge
BCHS	bulk container handling system
BDS	bulk drain station
BE	Basic Event
BF	blast fraction
BGAD	Blue Grass Army Depot
BGCA	Blue Grass Chemical Activity
BHS	bulk handling system
BLAD	blast attenuation duct
BLEVE	boiling-liquid expanding-vapor explosion
BMS	burner management system
BPS	burster punch station
BRA	Brine Reduction Area
BRS	burster removal station
BSA	buffer storage area
BSR	burster size reduction
CA	combustion air
CAC	Citizens' Advisory Commission
CAFTA	Computer-Aided Fault Tree Analysis
CAM	chemical agent monitor
CAMDS	Chemical Agent Munitions Disposal System
CAS	Compressed Air System
CBP	composite building panel
CBR	chemical, biological, and radiological
CCDF	complementary cumulative distribution function
CCF	common cause failure
CCPS	Center for Chemical Process Safety
CCS	central control system
CCTV	closed-circuit television
CD-ROM	compact disk, read-only memory
CDD	continuous daily dose
CDF	chemical agent disposal facility
CDS	central decontamination supply
CDTF	Chemical Demilitarization Training Facility
CECOM	U.S. Army Communications - Electronics Command
CEMS	continuous emissions monitoring system

CESA	charge end subassembly
CEUS	Central and Eastern United States
CHB	container handling building
CHEMMACCS	Chemical MELCOR Accident Consequence Code System
CHWS	chilled water system
CIA	Central Intelligence Agency
CLA	Chemical Limited Area
CLPDF	crash location probability distribution function
CM	corrective maintenance
CON	control room
CONR	controller
CONUS	continental United States
COTS	commercial off-the-shelf
CP	contingency procedure
CPRP	Chemical Personnel Reliability Program
CRBG	Columbia River Basalt Group
CRDEC	Chemical Research, Development and Engineering Center (now ECBC)
CRE	Continental Research and Engineering
CRO	control room operator
CRT	Cathode Ray Tube
CSDP	Chemical Stockpile Disposal Project
CSEPP	Chemical Stockpile Emergency Preparedness Program
CSF	cancer slope factor
CW	continuous wave
D2PC	Cloud Transport Model (software program)
DA	Department of the Army
DAAMS	Depot Area Air Monitoring System
DAIG	Department of the Army Inspector General
DAPPLE	Damage Area Per Path Length
DCD	Deseret Chemical Depot
DDESB	Department of Defense Explosives Safety Board
DDT	deflagration-to-detonation transition
decon	decontamination (solution)
DF	decontamination factor
DFS	deactivation furnace system
DIA	Defense Intelligence Agency
DICO	digital intercontroller communication output
DM	Department Manager

DMMP	Dimethyl Methylphosphonate
DNV	Det Norske Veritas
DoD	Department of Defense
DOE	Department of Energy
DOR	Daily Operating Report
DOT	Department of Transportation
dP	delta P
DPD	discrete probability distribution
DPE	demilitarization protective ensemble
DPG	Dugway Proving Ground
DRE	destruction and removal efficiency
DRW	Disposal-Related Worker
DSA	DPE support area
DUN	Dunnage Incinerator
DWS	drinking water standard
ECBC	Edgewood Chemical Biological Center
ECF	Entry Control Facility
ECP	Engineering Change Proposal
ECR	explosion containment room
ECV	explosive containment vestibule
EDG	emergency diesel generator
EF	lognormal error factor
EHM	equipment hydraulic module
EIS	Environmental Impact Statement
EMF	electromagnetic field(s)
EOC	emergency operations center
EONC	enhanced onsite container
EPA	Environmental Protection Agency
EPC	error-producing condition
EPRI	Electric Power Research Institute
EPS	electrical power system
ER	energy ratio
ERA	Ecological Risk Assessment
ESRI	Environmental Systems Research Institute, Inc.
ESSP	Enhanced Stockpile Surveillance Program
ETL	extreme temperature limit
ETMS	Enhanced Traffic Management System

FAA	Federal Aviation Administration
FARS	Fuzewell Assembly Removal Station
FAWB	Functional Analysis Workbook
FBI	Federal Bureau of Investigation
FEM	fire extinguishing medium
FEMA	Federal Emergency Management Agency
FGS	fuel gas system
FM	Failure Mode
FPEIS	Final Programmatic Environmental Impact Statement
FPI	Fire Potential Index
FPP	Fujita-Pearson
FPS	fire protection system
FRP	fiber reinforced plastic
FRS	floor response spectra
FSA	Facility Site Analysis
FSAC	Facility Site Analysis C
GA	General Atomics
GAI	Global Atmospherics, Incorporated
GB	sarin (nerve agent)
GC-MSD	gas chromatograph-mass spectrometry detector
GEThresh	greater than or equal to threshold
GPS	Global Positioning System
HAZMAT	hazardous material
HAZOP	hazard and operability analysis
HD	mustard agent
HDC	heated discharge conveyor
HEART	Human Error Assessment and Reduction Technique
HEPA	high-efficiency particulate air
HFE	human failure event
HHRA	Human Health Risk Assessment
HRA	health risk assessment
HRR	heat release rate
HVAC	heating, ventilation, and air conditioning
HYPU	hydraulic power unit
HYVM	hydraulic valve manifold
IA	instrument air
IAS	instrument air system

IAW	in accordance with
ICS	instrumentation and control system
ID	induced draft
IDLH	immediately dangerous to life and health
IDS	Intrusion Detection System
IEEE	Institute for Electrical and Electronics Engineers
IEM	Innovative Emergency Management
IFR	instrument flight rule
IPS	Integrated Program Services
IRZ	Immediate Response Zone
ISA	Instrument Society of America
ISO	International Organization for Standardization
JACADS	Johnston Atoll Chemical Agent Disposal System
ka	thousands of years ago
LCO	limiting condition of operation
LCTR	load center
LDR	Land Disposal Restrictions
LEL	lower explosive limit
LFL	lower flammability limit
LHS	Latin Hypercube Sampling
LIC	Liquid Incinerator
LMC	Lower Munitions Corridor
LOP	loss of power
LOSP	loss of offsite power
LPG	liquefied petroleum gas
LPS	lightning protection system
LRFF	load of resistance factor design
LSB	life support bottle filling station
LSS	Life Support System
Ma	millions of years ago
MA	Military Aviation
MACCS	MELCOR Accident Consequence Code System
MCC	motor control center
MCE	maximum credible event
MDB	munitions demilitarization building
MDM	multipurpose demilitarization machine

MER	mechanical equipment room
MGD	mine gripping device
MHS	mine handling system
MIG	mine glovebox
MIN	mine machine
MLE	maximum likelihood estimate
MMI	Modified Mercalli Intensity
MMS	multi-munitions system
MOP	maintenance operating procedure
MPB	munitions processing bay
MPF	Metal Parts Furnace
MPL	multiposition loader
MPRS	miscellaneous parts removal station
MR	monitor room
MSB	Monitor Support Building
MTS	Munitions Tracking System
NAS	National Academy of Sciences
NCDC	National Climatic Data Center
NCRS	nose closure removal station
NDS	National Decision System
NECDF	Newport Chemical Agent Disposal Facility
NEHRP	National Earthquake Hazards Reduction Program
NEMA	National Electrical Manufacturers Association
NFIRS	National Fire Incident Reporting System
NFPA	National Fire Protection Association
NG	natural gas
NHTSA	National Highway Transportation Safety Administration
NLDN®	National Lightning Detection Network®
NMSZ	New Madrid Seismic Zone
NOAA	National Oceanic and Atmospheric Administration
NRC	National Research Council
NSSFC	National Severe Storms Forecast Center
NTS	Nevada Test Site
NWS	National Weather Service
OBV COR	observation corridor
OCR	Operating Condition Report
ODF	Oregon Department of Forestry
ODOT	Oregon Department of Transportation

OJT	on-the-job training
ONC	onsite container
ONRR	Office of Nuclear Regulatory Research
OPCW	Organisation for the Prohibition of Chemical Weapons
OR	occurrence rate
ORNL	Oak Ridge National Laboratory
OSHA	Occupational Safety and Health Administration
OSW	Other Site Worker
OTSG	Office of the Surgeon General
OVT	operational verification testing
P&D	pull and drain
P&ID	piping and instrument diagram
PA	process air
PAIS	Program and Integration Support
PAS	pollution abatement system
PAZ	protective action zone
PBCA	Pine Bluff Chemical Activity
PBCDF	Pine Bluff Chemical Agent Disposal Facility
PCA	Pueblo Chemical Activity
PCB	polychlorinated biphenyl
PCS	primary cooling system
PDAR	process data acquisition and reporting
PDISL	pressure differential indicating switch low
PDIT	pressure differential indicating transmitter
PDS	pull and drain station
PFB	primary furnace burner
PFD	process flow diagram
PFS	PAS filter system
PGA	Peak Ground Acceleration
PHA	preliminary hazard analysis
PHS	projectile handling system
PKPL	pick and place machine
PL	public law
PLA	plant air system
PLC	programmable logic controller
PLL	Programmatic Lessons Learned
PM	preventive maintenance
PMB	Personnel and Maintenance Building
PMCD	Program Manager for Chemical Demilitarization

PMCSD	Project Manager for Chemical Stockpile Disposal
PMD	projectile/mortar disassembly machine
PME	preventive maintenance of equipment
POD	Process Operations Diagram
PPE	personal protective equipment
PPS	primary power system
PRA	probabilistic risk assessment
PRO-RS	preroundout-restabilized
PRW	process water
PSB	process support building
PSD	power spectral density
PSHA	probabilistic seismic hazard assessment
PUB	process utility building
PW	Pearson Width
QA	quality assurance
QAPP	Quality Assurance Program Plan
QC	quality control
QM	Quality Manual
QRA	Quantitative Risk Assessment
RAC	risk assessment code
RAW	Rattlesnake-Wallowa lineament
RCF	review comment form
RCM	reliability centered maintenance
RCRA	Resource Conservation and Recovery Act
RDS	rocket drain station
RF	release fraction
RHS	rocket handling system
RMP	Risk Management Program
RO-RS	roundout-restabilized
RSM	rocket shear machine
RSS	rocket shear station
RTAP	real-time analytical platform
S&A	Stevenson and Associates
Sa	spatial acceleration
SAIC	Science Applications International Corporation
SATO	Security Operational Test Site
SATTLIF	Sandia Transportable Triggered Lightning Facility

SBCCOM	U.S. Army Soldier and Biological Chemical Command
SCW	secondary cooling water
SDS	spent decontamination system
SFPE	Society for Fire Protection Engineers
SHA	system hazard analysis
SHE	service machinery, HVAC, and electrical
SIP	shelter-in-place
SNL	Sandia National Laboratories
SOP	Standing Operating Procedure
SP	Standard Procedure
SPC	Storm Prediction Center
SPRA	seismic probabilistic risk assessment
SPS	secondary power system
SQUG	Seismic Quantification Utility Group
SR	stress ratio
SRC	single round container
SRDT	solar radiation-delta T
SRLC	product storage/receiving/loading/conveyor
SRS	slag removal system
SRSS	square root of the sum-of-the-squares
SSC	structure, system, or component
SSI	soil-structure interaction
STB	surrogate trial burn
STS	Stockpile Tracking System
TACOM	Tank and Automotive Command
TAR	temporary authorization request
TC	Type Code
TEAD	Tooele Army Depot
TEMAC	Top Event Matrix Analysis Code
THERP	Technique for Human Error Rate Prediction
TIP	tray information package
TLV	threshold limit value
TM	Task Manager
TMA	Toxic Maintenance Area
TMP	Task Management Plan
TNT	trinitrotoluene
TOCDF	Tooele Chemical Agent Disposal Facility
TOX	toxic cubicle
TRIM	trash/rubbish/incinerator/maintenance/laboratory

TSCA	Toxic Substances Control Act
TWA	time-weighted average
UBC	uniform building code
UFL	upper flammability limit
UHA	update hazard analysis
UHS	uniform hazard response spectrum
UL	Underwriters Laboratories, Inc.
UMC	Upper Munitions Corridor
UMCD	Umatilla Chemical Depot
UMCDF	Umatilla Chemical Agent Disposal Facility
UMDA	Umatilla Depot Activity
UPA	unpack area
UPS	uninterruptible power supply
UR	Unit Risk
USAAMCC	U.S. Army Armament, Munitions and Chemical Command
USACDRA	U.S. Army Chemical Demilitarization and Remediation Activity
USACE	U.S. Army Corps of Engineers
USANCA	U.S. Army Nuclear and Chemical Agency
USDOT	U.S. Department of Transportation
USEPA	U.S. Environmental Protection Agency
USFA	U.S. Fire Administration
USGFIP	U.S. Government Flight Information Publication
USGS	U.S. Geological Survey
USNRC	U.S. Nuclear Regulatory Commission
UV	ultraviolet
UVCE	unconfined vapor cloud explosion
VMMYSR	Von Mises membrane yield stress ratio
VMYSR	Von Mises yield stress ratio
VNTSC	Volpe National Transportation Safety Center
VRD	vacuum relief damper
VX	O-ethyl S-(2-diisopropylaminoethyl)methylphosphonothioate (nerve agent)
WIC	waste incineration container
WTS	water treatment system

(This page intentionally left blank.)