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IITRI Report C06538-3
TOTAL SYSTEM HAZARDS ANALYSIS FOR THE WESTERN AREA DEMILITARIZATION FACILITY AT HAWTHORNE ARMY AMMUNITION PLANT
PRIORITY 3 - DECONTAMINATION BUILDING, LARGE ITEMS FLASHING CHAMBER, DRIVERLESS TRACTOR SYSTEM, OFFLOADING DOCK, AND MAGAZINES
Volume 1, Summary Report and Appendices

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December, 1982

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FOREWORD

This is the third of three reports submitted under Contract No. DAAA09-81-C-3006 conducted by IIT Research Institute, Chicago, Illinois, for the U. S. Army ARRCOM, Rock Island, Illinois. This report describes the results of a hazards analysis of the Decontamination Building, Large Items Flashing Chamber, Driverless Tractor System, Offloading Dock and Magazines (Priority 3) at the Western Area Demilitarization Facility (WADF) at Hawthorne, Nevada. A hazards analysis report was submitted during July 1982 for Priority 1 (Steam and Hydraulic Systems) and a hazards analysis was submitted during November 1982 for the Priority 2 systems (Preparation building, Accumulator, Mechanical Removal Building and Large Cells). The Priority 3 Report is submitted in two volumes, Volume 2 containing fault tree diagrams for the systems evaluated. The primary IIT Research Institute project team consisted of Ronald Pape, Edmund Swider, Kim Mniszewski, Charles Heilker, and Dwayne Eacret. Mr. Thomas Grady, a private consultant with considerable experience in explosive and propellant operations, helped scrutinize the results of the analysis. Mr. Arne Wiederman of AT Research Associates, Inc. (a consultant to IITRI on this program) did an independent evaluation of the potential hazard to personnel in corridors and control rooms from the air blast produced by an explosion in the various cells. This analysis is presented in Appendix B.

Respectfully submitted

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1. INTRODUCTION

This report contains the results of a hazards analysis of the Decontamination Building, Large Items Flashing Chamber, Driverless Tractor System, Offloading Dock and Magazines at the Western Area Demilitarization Facility (WADF) at Hawthorne, Nevada. The methodology used was a combination of failure modes and effects analysis (FMEA) and fault tree analysis (FTA), with quantification accomplished through the use of a fault tree computer model. These techniques were described in the Priority 1 report and are repeated here in Appendix A.

The hazards analysis that was conducted produced two types of results. First, the scenarios that can lead to a hazardous outcome were identified by constructing fault tree logic diagrams for each plant section. Such scenarios are chains of events or combinations of events that must occur together or in sequence to cause the outcome of concern. For example, for an operator to become burned by touching a hot surface, several things must happen:

1. the surface must be sufficiently hot to burn someone, and
2. an operator must touch the hot surface

Both of these events are necessary in order for the operator to become burned. The combination of events is a scenario. To evaluate whether such a scenario is significant, "probability of occurrence" values are derived for each event in the scenario, thereby making it possible to compute the overall scenario probability per year, or expected frequency of occurrence averaged over an extremely long time frame.

All the scenarios for the specific plant section are then compared based on their derived probabilities per year. Naturally, those scenarios with the highest probability values are most critical and must be addressed first.

Section 2 of this report summarizes the systems at the Western Area Demilitarization Facility that have been evaluated under Priority 3. Section 3 presents the hazards analysis results for each plant area. Section 4 provides recommendations and conclusions based on the results of this analysis. In addition to a discussion of the hazards analysis methodology in Appendix A, the Appendix B provides an independent evaluation of potential hazards to personnel in corridors or control rooms of the various buildings at WADF, particularly concerning the protection provided by the blast doors or cells.

2. PRIORITY 3 SYSTEMS

The systems at WADF evaluated for potential hazards under Priority 3 include the Decontamination Building the Large Items Flashing Chamber, the Driverless Tractor System, the Offloading Dock and the Storage Magazines. These systems are described briefly in this Section.

2.1 DECONTAMINATION BUILDING

This building contains three furnaces to decontaminate various items. First, a rotary type furnace is used for small arms ammunition containing lead. The items are placed into a rotating dumper and transferred into a conveyor which carries them to the furnace feeder. The lead items furnace is a rotary type oil burner furnace. At the burner end, a narrow opening is left between the furnace and burner flanges for liquid lead (1) to drip into a trough, (2) be carried to a water bath for cooling and (3) then be carried by conveyor to a hopper for subsequent removal by truck. The remaining refuse from the furnace is deposited onto a second conveyor and carried to a magnetic (ferrous/ nonferrous) separator where it is directed into a "ferrous or nonferrous" semi-trailer positioned under the separator chute.

A second rotary furnace, the detonating items furnace, is quite similar to the lead items furnace. This incinerator does not have the spacing between flanges at the burner end since liquid lead is not to be removed. A separate conveyor is used to recycle some of the refuse to maintain the proper depth of material in the furnace body. Since this furnace must withstand items detonating within, the walls are stronger than the lead items furnace, and the center section is recessed to increase the residence time of the items near the center of the cylinder.

The fifth and sixth cells in the decontamination building house the tray type flashing furnace. Here, moderate sized processed items (cleaned out), which can be inspected to preclude presence of a significant amount of energetic material, will be decontaminated. Items will be processed through a conventional heat-treating type furnace (fire brick walled) where they will be heated to a temperature at which any residual energetic material decomposes or burns. Typical items to be processed include rocket warheads (e.g. 2.75 in., 5.0 in.), depth charge warheads (e.g. MK4, MK5), and gun ammunition projectiles (e.g. 40mm through 5"/54). Items are loaded into trays in the loading area, either manually or with the help of a mechanical assist. The trays are then loaded through a blast lock into the furnace. Four trays are continally present in the furnace. At intervals of approximately 7 1/2 minutes, a new tray enters and a processed tray leaves the furnace where it is checked for proper final temperature conditions. Then it is raised on a skip loader where the items are dumped into a dumpster. Trays are returned by first being cooled in a water spray chamber and then sent into the tray loading area for recycling, by means of conveyor equipment.

2.2 LARGE ITEMS FLASHING CHAMBER

In the flashing chamber, smokeless powder is used to burn off residual explosive left in larger items from which the bulk of the explosive already has been removed. Decontamination of these items is required before the metal components can be sold as scrap. Deactivation and/or decontamination of contaminated items has been accomplished in the past primarily by exposing the material to a high temperature for a prolonged time such that the energetic material decomposes, burns or detonates. This is accomplished by placing the items in a bonfire in a field burn. Short duration high temperature exposures have also been used in the past by placing smokeless powder in the internal cavities of the item and igniting the powder. According to the Batelle report (reference 1), such "flashing has been found to be effective in completely destroying residues of explosive on or in the ammunition items". As discussed in the results section, there is some question as to whether flashing really will be effective in all cases due to the shortness of the high temperature pulse.

At WADF flashing is to be accomplished inside a containment chamber designed to prevent products of combustion from escaping to the atmosphere. It is designed to maintain structural integrity in the event of the detonation of a 120 lb (TNT equivalent) line charge along the chamber's axis. During a burn, the combustion products are ducted underground to a regenerative heat exchanger (a mass of steel tubes) and to a bag house for pollution control.

Pneumatically driven mine cars are to be used to carry the contaminated items from the driverless tractor (item receiving area) into the car preaparation enclosure, where the smokeless powder is layed, and then into the flashing furnace. A narrow gage track loop routes the mine cars into the chamber and then back out to a cool off area. A massive door covers the chamber's entrance during a burn, and all personnel are to return to the Decontamination Building at that time.

2.3 DRIVERLESS TRACTOR SYSTEM

A driverless tractor (DLT) and ammunition cart system utilizing Prontow 601 vehicles has been installed at WADF. Two independent DLT control systems are present. One network (region 1) moves tractors between the Off Loading Dock and the Preparation Building. The second network (region 2) moves tractors between the Preparation Building and the various process buildings at the site. The battery powered tractors are guided by a low frequency signal transmitted from wires layed in slots cut in the concrete guide paths. An amber strobe light indicates when a vehicle is operating automatically. A horn sounds on all automatic starts and stops. Dynamic braking of the vehicle is accomplished by means of the traction motor. A safety bumper is attached to the front of the tractor which actuates an emergency stop if it strikes a person or other object. High pressure nitrogen or air supplies power for quick braking of the train. A DLT train consists of a tractor and one to four carts, the total live load being up to 22,500 pounds. The minimum train speed is 2.5 mph and the maximum is 3.5 mph. The tractors can be operated in either the automatic mode while on the guide paths or in the manual mode of operation. In the manual mode the operator stands on the cart. A deadman switch must be depressed as the vehicle moves in this mode. The vehicle is accelerated using a foot pedal with several discrete speed positions.

2.4 OFF LOADING DOCK

Munitions items to be demilitarized enter the facility at the off loading dock. The off loading dock is a conventional earth covered unloading structure designed to handle delivery of energetic materials by train or truck. It consists primarily of two adjacent earth covered tubes for unloading trains, but also has unprotected docks next to the igloo type structure. Items are to be taken from the unloading dock to the preparation building via the driverless tractor system.

3. SUMMARY OF HAZARDS ANALYSIS RESULTS

In this section, the dominant hazard scenarios are discussed for each of the Priority 3 systems. The estimated probabilities per year and typical or "worst case" scenarios are presented for each of these potential problem areas.

3.1 DECONTAMINATION BUILDING - DETONATING ITEMS ROTARY FURNACE

Results of the fault tree analysis of the detonating items rotary furnace yield an overall major system Category I or II incident frequency of 8.07×10^{-4} per year. The analysis showed that the three most probable scenarios caused loss of production due to repair time greater than 3 days. These were caused by premature erosion of the furnace retort necessitating replacement and system damage from detonation of items outside of the furnace. These scenarios are discussed below.

PREMATURE WEAR OF FURNACE RETORT

Two scenarios described premature erosion of the furnace retort resulting from human error during furnace operation.

The first scenario has an estimated frequency of 1.45×10^{-4} per year. It is described in the summary table below:

Fault Tree Component No.	Description	Probability/ Frequency Used
C93	Detonable items are fed into rotary furnace	1.
C94	Operator incorrectly permits excessive amount of items to be fed into furnace	.07/hr
C95	Control room operator does not catch the error via CCTV	.001
C96	Excessive amounts of explosive are detonated in furnace	1.0
C97	Control room operator does not pick up cues to reason that excessive amounts of explosive are detonated.	.01

Fault Tree Component No.	Description	Probability/ Frequency Used
C98	Premature erosion of furnace retorts over an extended time cause need for repair	1.
C276	Time to repair furnace retort $\geq$ 3 days	.05

The second production loss scenario has an estimated frequency of 1.17×10^{-4} per year. It is described below:

Fault Tree Component No.	Description	Probability/ Frequency Used
C55	Detonable items are fed into rotary furnace	1.
E33	Operator incorrectly adjusts controls	3.75×10^{-4}/hr
C56	Items detonate in unstrengthened furnace retort	.5
C63	Operator does not detect improper explosion location from acoustical detector	.003
C57	Premature erosion of unstrengthened furnace retort over an extended time causes repair	1.
C58	Time to repair unstrengthened furnace retort $\geq$ 3 days	.05

SYSTEM DAMAGE FROM DETONATION OF ITEMS OUTSIDE OF THE FURNACE

The third scenario described furnace system damage caused by items which have passed through the furnace and detonate outside of it. This scenario has an estimated frequency of 7.80×10^{-5} per year. It is detailed in the summary table below:

Fault Tree Component No.	Description	Probability/ Frequency Used
C147	Detonable items are fed into rotary furnace	1.
C154	Latent heating of items occur due to operator incorrectly adjusting furnace controls	3.75×10^{-4}/hr

Fault Tree Component No.	Description	Probability/ Frequency Used
C148	Operator is unaware of latent heating condition - does not check acoustical detector	.01
C149	Items detonate on scrap recycle conveyor	.1
C150	Major system damage occurs i.e. scrap conveyor, fuel oil pump etc. Repair time is greater than 3 days	.05

OTHER POTENTIAL HAZARDS

The scenarios described above were categorized as a level I or II incident because of the lengthy repair time but were of little other consequence. A potential hazard with far greater consequences is that of a truck driver hitting the nearby unprotected propane tank while transporting the scrap metal recovery trailer. This scenario has an estimated frequency of 3.25×10^{-6} per year and is detailed below.

Fault Tree Component No.	Description	Probability/ Frequency Used
C164	Empty semi-truck & trailer arrives to transport full trailer of scrap metal	6.25×10^{-3}
C165	Semi-truck parks and unhooks empty trailer near propane tank	.05
C166	Semi-truck attaches to full trailer and also parks it near propane tank	.05
C167	Semi-truck attaches to empty trailer to manuever under recovery chute	1.
C168	Truck driver maneuvers truck and trailer but does not see propane tank	$1. \times 10^{-3}$
C169	Truck driver hits propane tank and ruptures it or damages valve causing leak	.1
C171	Ignition source present	.5
C172	Explosion occurs causing damage/severe injury	1.

While the probability of such an incident happening is low at a frequency of 3.2×10^{-6} per year, the consequences dictate protection of the propane tank. This protection could be provided at low cost by strategically located posts similar to those positioned around the lightning poles. Proper placement would still allow easy access for filling the tank.

3.2 DECONTAMINATION BUILDING - LEAD ITEMS ROTARY FURNACE

The fault tree analysis for the lead items rotary furnace gave an overall major system category I or II incident frequency of 1.68×10^{-4} per year. The main scenarios were those of production loss due to repair time greater than 3 days. In many respects the lead items rotary furnace is similar to the detonable items rotary furnace described in section 3.1. The starred scenarios identified below are so similar to the detonable items rotary furnace that their discussion is not repeated here.

- Excess explosive detonated in furnace due to incorrect feed rate involving human error. Premature erosion of furnace retort necessitates early repair/replacement of retort. (1.45×10^{-4} per year)*
- Human error results in incorrect large caliber (20 mm etc.) detonable items fed into lead items furnace. Premature erosion of furnace retort necessitates early repair/replacement of retort. (1.28×10^{-5} per year).
- Propane tank explosion due to semi-truck driver hitting nearby unprotected tank (3.25×10^{-6} per year)*

INCORRECT LARGE CALIBER DETONABLE ITEM FED INTO LEAD ITEMS FURNACE

Due to the proximity and similarity between the two rotary furnaces in the Decontamination Building, it is possible that items meant for the detonating items furnace could be fed into the lead items furnace by mistake. If this occurs, the retort on the lead items furnace could be damaged or at a minimum experience premature excessive wear.

Fault Tree Component No.	Description	Probability/ Frequency Used
C21	Operator does not inspect items and loads 20mm or other large caliber detonable items into dumper	6×10^{-3}/hr
C22	Control room operator dumps items and does not see that 20mm items are fed into furnace	.01
C23	Excessive amounts of explosive are detonated in furnace	.1
C24	Control room operator does not pick up cues to reason that excessive amounts are detonated	.01
C25	Premature erosion of retorts over an extended time cause repair	1.
C26	Time to repair retort $\geq$ 3 days	.05

3.3 TRAY TYPE FLASHING FURNACE

Results of the fault tree analysis of the tray type flashing furnace operation indicate a category I or II accident frequency of 8.93×10^{-3} per year, excluding injuries and illnesses of various causes. Of these 8.93×10^{-3} incidents per year, 8.28×10^{-3} are mainly due to in-furnace detonations and baghouse fires. Various equipment damage scenarios and less probable explosion scenarios constitute the remaining 6.48×10^{-4} incidents per year.

In order to quantify the fault tree analysis, scheduling data was required. Since long term production rates for this area and the types and quantities of items to be processed are not firmly established at this time, estimates based on a Batelle report were used. The values used are summarized below:

- The nominal production rate is 73 items/hour, based on a projected average of processing rates for rocket warheads, depth charge warheads, and gun ammuniiton projectiles (assuming there are equal quantities of each item type available)
- The nominal skid processing rate is 5.17 skids/hour, based on furnace capacity requirements, an estimated operating time of 310 minutes per shift, an estimated furnace processing time of 30 minutes/skid, and the abovementioned nominal production rate.

• operations will take place during two shifts per day (16 hours)

The most serious incidents considered are those involving explosion and fire because of the high potential human and property losses. The most significant of these are described below.

FULL ITEM DETONATION IN FURNACE (8.2×10^{-3}/year)

The scenario dominating the fault tree results here is that of a full item accidently being processed through the furnace, as a result of several human errors in succession. This particular scenario has an estimated frequency of 8.2×10^{-3} per year. It is described in the summary table below.

Fault Tree Component No.	Description	Probability/ Frequency Used
103	Items processed through furnace	73/hour
156	Full items brought from preparation building by mistake and processed*	2.7×10^{-8}
105	Item detonates in furnace**	1.0
106	Major damage to furnace results**	1.0

* based on 3 human errors of commission, in sending the driverless tractor to the wrong destination, and 2 additional inspection errors, several of these errors being of common cause.

**conservative engineering estimates

PARTIALLY LOADED ITEM DETONATES IN FURNACE (8.2×10^{-5}/year)

Another somewhat similar scenario is that of an item not fully cleaned out being entered into the furnace, again as a result of several human errors in succession. This particular scenario has an estimated frequency of 8.2×10^{-5} per year. It is described in the summary table below.

Fault Tree Component No.	Description	Probability/ Frequency Used
103	Items processed through furnace	73/hour
157	Items not fully cleaned out, with significant amount of explosive remaining are processed*	2.7×10^{-10}

Fault Tree Component No.	Description	Probability/ Frequency Used
105	Item detonates in furnace**	1.0
106	Major damage to furnace results**	1.0

*based on an estimated one out of every hundred items has significant explosive remaining, together with 3 human errors of commission, which can be inspection errors or misorientation types (e.g. placing item in tray upside down so that explosive cannot drain out)

BAG HOUSE FIRES (6×10^{-4}/year)

A couple of scenarios result in hot exhaust gas temperatures entering the baghouse above the ignition or damage point of the baghouse materials. The estimated frequency of these events is 6.0×10^{-4} per year. An example of these scenarios is given in the table below.

Fault Tree Component No.	Description	Probability/ Frequency Used
117	Items are being processed (furnace in operation)	1.0
123	Severe corrosion occurs in recuperators, reducing heat transfer*	2.4×10^{-5}/hour
118	Exhaust of recuperator rises above prescribed level**	1.0
119	Operator doesn't notice indicator displaying excessive temperature in baghouse (human error)	0.003
120	Baghouse materials at or above ignition temperature**	1.0
121	Baghouse fire ensues**	1.0

* estimated once in ten years

**conservative engineering estimates

EQUIPMENT DAMAGE DUE TO BUILDING CRANE PROBLEM (3.49×10^{-5}/year)

In this scenario, the handling of heavy equipment with the building crane results in sufficient equipment damage to suspend furnace operations for a prolonged time. The estimated frequency of this event is 3.49×10^{-5} incidents/year. An example of this scenario is given below.

Fault Tree Component No.	Description	Probability Frequency Used
138	Building crane and during maintenance (assume once per month)	2.8×10^{-3}/hour
139	Heavy item lifted	1.0
144	Operator makes crane control errors causing item to drop (human error)	0.003
140	Drop is sufficient for equipment damage*	1.0

*conservative engineering estimate

OTHER POTENTIAL HAZARDS IN TRAY TYPE FLASHING FURNACE AREA

Other hazards of concern here include the following:

- There may be an operator exposure problem from Yellow D particles remaining in some items
- Since some of the items to be processed as well as the trays/skids weigh over 40 pounds, there is concern for operator safety in transfer operations.
- There is concern for the safety of operators handling potentially hot trays/skids in the event of spray cooling chamber malfunction.

3.4 LARGE ITEMS FLASHING CHAMBER

The hazards analysis of the large item flashing furnace yielded an extremely high expected frequency of occurrence of 266/year. This was due primarily to "items not decontaminated" (237/year) and "operators cut on items" (28/year). Items not being fully decontaminated is considered to be a major hazard, not to plant personnel, but to the purchaser of the scrap metal. The dominant hazards for the Large Items Flashing Chamber were found to include the following:

1.	Items not Decontaminated	237/year
2.	Operator Cut on Items	27.7/year
3.	Initiations due to Electrostatic Discharge	1.17/year
4.	Camera in Chamber Ruined due to No Cooling	0.469/year
5.	Initiations due to Local Impacts	7.9×10^{-2}/year
6.	Item Impact Scenarios	5.39×10^{-2}/year
7.	Operator Injured due to Use of Nonelectric Ignition of Powder Train	4.68×10^{-2}/year
8.	Significant Chamber Damage due to Explosion in Chamber	1.78×10^{-2}/year
9.	Operator Burned on Hot Item	1.56×10^{-3}/year
10.	Gondola Incidents (i.e. Derailments or Collisions)	1.067×10^{-3}/year
11.	Initiation due to Tightening or Loosening a Contaminated Bolt While Changing Fixture for Type III or MK7 Container	1.12×10^{-4}/year
12.	Initiation due to Smoking in Area	7.8×10^{-5}/year
13.	Operator Locked in Chamber During Flashing	4.62×10^{-5}/year
14.	Baghouse Damaged due to Explosion in Flashing Chamber	4.47×10^{-5}/year

This analysis is based on a single shift operation since there are only six sets of mine cars currently available (only enough for a single shift due to cool down). Six flashing operations are to take place per shift (0.75 flashing operations/hour). It is estimated that about one driverless tractor carrying items will arrive per hour on the average, and one driverless tractor load per hour will arrive carrying smokeless powder.

The dominant hazard scenarios are discussed in the paragraphs that follow.

ITEMS NOT DECONTAMINATED (237/year)

The estimated rate of 237 incidents per year of ineffective flashing operations corresponds to about 15 per cent of the items processed being sold as scrap with energetic material still on bolt threads or other hidden/protected areas. Although "flashing has been found to be effective" according to Reference 1, IITRI personnel are not confident that all the contamination will be deactivated. The basic concept of decontamination by means of emersing the item in a fire is to heat all of the contaminant above the temperature at which the contaminant will decompose, burn or detonate. In a long duration exposure, a reasonable assurance can be attained that the metal parts (and contaminant) are all heated in depth. In a short duration (flash) fire, there may not be adequate time for the high temperature to penetrate to all the areas where a contaminant may be present, e.g., on bolt threads. Therefore, a serious question exists as to whether decontamination will occur consistently using this process; and it is recommended that frequent detailed inspections of the items (bolt threads, etc.) be accomplished at WADF until a sound data base is developed to assure that contaminated scrap is not being sold to an unknowing user. Visual Inspection of the exposed surfaces will not necessarily assure adequacy of decontamination. Cracks, threaded areas, and subsurface cavities or flaws can still house hidden and undetectable explosive material.

This category of hazards was projected to come about by several possible means. The most dominant cause was merely that the normal flashing procedure is ineffective and the remaining contamination is not uncovered during final inspection of the items (234/year). In addition, the powder being layed wrong was estimated to cause 2.34 incidents/year; wrong orientation of the item or the mine car was estimated to cause 0.234/year; and, a wrong ignition sequence was estimated to cause 0.234/year.

A typical scenario of this type is outlined below:

Fault Tree Component No.	Description	Probability/ Frequency Used
2	Flashing Operation Frequency	0.75/hour
18	Normal Flashing Procedure does not decontaminate items on cart	0.1*
27	Operator does not Observe Contamination (in bolts etc).	0.99

*Based on technical judgement

OPERATOR CUT ON ITEMS (2.77/year)

It was estimated that operators would be cut on the burrs left in the holes cut in items or at saw cuts about 28 times per year. A typical scenario of this type is as follows:

Fault Tree Component No.	Description	Probability/ Frequency Used
386	Operator must work on item with saw cuts present (5 handlings/flashing X .75 flashings/hour)	3.75/hour
389	Operator does not wear gloves	0.1
391	Exposed skin is seriously cut on saw cut burr	.05

The values used here probably correspond more to an operator getting cut on the burr than seriously cut --i.e., the values may be somewhat conservative. However, some serious cuts during handling of the items should be expected. These will occur when protective clothing including leather gloves are not worn or are not worn properly -- e.g. sleeves rolled up, improper gloves, gloves excessively worn, no gloves worn, etc.

ELECTROSTATIC DISCHARGE IGNITION SCENARIOS (1.17/year)

Three categories of electrostatic discharge (ESD) initiation scenarios were calculated to have relatively high probabilities of occurrence:

1. Operator Charged Outside of Building Due to Dry Concrete Pad — 1.17/year
2. Operator Charged due to Improper Clothing/Shoes — 5.46×10^{-4}/year
3. Ungrounded equipment (e.g. mine car, forklift, jib crane — 2.42×10^{-4}/year

By far the most dominant of these scenarios is an operator becoming charged outside the building while working on the concrete pad. Unless the concrete is moist from rains or manual washdown, it will have a fairly low electrical conductivity. Electric charge that an operator picks up while working in the area will not drain off back to ground readily even if he is wearing grounded shoes. This problem was recognized in the design of WADF, as evidenced by the grounding bars that personnel are supposed to grab as they enter each building. Outside the Flashing Chamber Building the concrete pad is not grounded and ESD from an operator is possible. Since the operator is handling contaminated items, the contamination could become ignited by a discharge from the operator.

Fault Tree Component No.	Description	Probability/ Frequency Used
121	Flashing Operation being Setup	0.75/hour
164	Prolonged Dry Period Causes Concrete to become low conductivity*	0.2
166	Manual Wetting of Pad is not kept up (Not Part of Procedure)	1.0
167	Operator Becomes Charged	1.0
168	Operator Discharges Exposed Explosive in Item (based on configuration)	0.25
169	ESD Causes Initiation of Item	0.1
76	Resultant Fire Injures Operator or Damages Equipment	0.05

*Fraction of year with prolonged dry periods

If manual wetting of the concrete pad is incorporated as part of the procedure, the estimated probability of this event can be reduced by at least 2 or 3 orders of magnitude, i.e. to about 10^{-2} to 10^{-3} per year (human error probability). It also should be noted that component 76 (that an initiation results in a serious outcome) is probably overly conservative at 1 in 20.

CAMERA INSIDE CHAMBER RUINED DURING FLASHING (0.469/year)

The camera inside the flashing chamber could be ruined during a burn if cooling to the camera is lost. Cooling can be lost by a controller error or due to mechanical failure of the cooling system. A typical scenario in this category is summarized below:

Fault Tree Component No.	Description	Probability/ Frequency Used
2	Flashing Operation Frequency	0.75/hour
36	Controller Fails to Start Coolant Flow	0.003
37	Controller does not notice coolant flow is off (some common cause with Component 36)	0.1
35	Camera is ruined due to lack of cooling	1.0

LOCAL IMPACT SCENARIOS (7.9×10^{-2}/year)

Several local impact initiation hazards were identified in the analysis. The first of these involved unburned smokeless powder or explosive (remaining on a mine car from a previous flashing operation) being initiated while raking out the mine car sand bed. This scenario had an estimated probability of 7.8×10^{-4} per year. Contamination could remain in the sand bed, for example, if propellant grains or explosive fallen out of an item is inadvertently buried in the sand during setup. The sand could then insulate the contamination during flashing and prevent ignition. Then while raking out the sand bed in preparation for the next operation, the contamination could be ignited by impact from the rake onto the metal bottom of the mine car. Most likely such an initiation would involve only a small amount of energetic material, but there is a finite probability that an injury or damage to the mine car could result.

Fault Tree Component No.	Description	Probability/ Frequency Used
2	Flashing Operation Frequency	0.75/hour
185	Excessive Contamination Remains in Mine Car After Flashing	0.01
186	Metal Rake is used to clean/smooth sand in mine car	1.0
187	Rake impacts exposed contaminated metal	0.01
188	Impact causes initiation	1.0
189	Reaction Propagates to Bulk of Contamination Present	0.1
76	Resultant Fire Injures Operator or Damages or Damages Equipment	0.05

The second category of local impact scenarios involves contamination on couplers between mine cars or DLT carts being initiated by impact. In this case it is quite unlikely that more than a spark would be produced, but the spark could in turn ignite contamination in items on smokeless powder layed for flashing on a mine car. Injury to a nearby operator or damage to equipment is then possible. This category of scenarios has an estimated probability of about 5.85×10^{-4} per year.

Fault Tree Component No.	Description	Probability/ Frequency Used
196	Powder is being Layed in Preparation for Flashing	0.75/hour
203	Couplers between mine cars carrying items become contaminated	0.05
204	Impacts from start/stop of mine cars ignites ignites contamination	1.0
205	Smokeless powder is layed in items and on mine cars	1.0
206	Reaction Spreads to Smokeless Powder on Mine Car	0.001
207	Resultant Fire Injures Operator or Damages Equipment	0.2
41	Detection/Deluge is ineffective to protect equipment	0.03

The third category of scenarios involve the air hose used to power the mine cars being inadvertently reeled in causing the metal quick connect to impact contaminated items and/or smokeless powder layed on a mine car prepared for flashing. There are several locations on the track loop where it may be most convenient to use a hose with the reel in front of the car being moved, i.e. the hose must be pulled past the mine car in order to make the connection. The hose could be inadvertently reeled in and slip out of the operator's hand while he is trying to make the connection. The hose probably will be layed to the side of the mine car in these cases, but could be stretched across the car by mistake. Even if the hose is stretched next to a car it could flip up onto a car as it is being reeled in. An impact initiation on a mine car layed with powder with an operation present is likely to result in a serious injury. This group of scenarios was estimated to have a probability of occurrence of 3.35×10^{-4}/year.

Fault Tree Component No.	Description	Probability/ Frequency Used
196	Powder is being Layed in Preparation for Flashing	0.75/hour
349	Air hose is stretched across loaded mine car (human error--should be stretched to side of car)	0.01

Fault Tree Component No.	Description	Probability/ Frequency Used
350	Rewind mechanism is activated before quick connect is made, and hose gets pulled from operator's hands	0.01
351	Metal Connection impacts propellant or contamination on mine car	1.0
352	Release occurs before powder is layed	0.5
353	Impact ignites contamination	0.2
354	A significant amount of energetic material becomes involved	0.1
197	Resultant fire injures operator or damages equipment	0.2

The last category of local impact scenarios involve contamination remaining in the sand bed of a mine car as discussed above in the raking scenarios. However, in this case, the sand bed has not been raked out adequately, and an item being positioned on the car impacts an exposed area not protected by sand. The impact causes initiation of contamination remaining in the sand bed or fallen out of the contaminated item prior to the impact. The reaction then must propagate, e.g. to involve contamination in the item, in order for significant damage or an injury to result. The probability of occurrence for this scenario is estimated to be 3.9 X 10^{-5} per year.

Fault Tree Component No.	Description	Probability/ Frequency Used
2	Flashing Operation Frequency	0.75/hour
180	Contamination is not removed from sand bed. A significant amount remains.	0.01
181	Sand bed is not leveled prior to movement of next items to mine car	0.01
182	During item transfer to car, item impacts at exposed contaminated metal bottom of mine car*	.05
183	Impact causes initiation	1.0
184	Reaction propagates to contaminant in item	0.1
76	Resultant fire injures operator or damages equipment	0.05

* Geometry factor, conservative value used.

ITEM/CONTAINER IMPACT SCENARIOS (5.39×10^{-2}/year)

A number of scenarios were identified in which a contaminated item or a smokeless powder container falls or is moved into a fixed object causing initiation by impact. These include:

• mine car impacts bump post causing braced items to fall	3.12×10^{-2}/yr
• items or containers fall off DLT due to emergency braking or rough handling of container	7.8×10^{-3}/yr
• item or container dropped by jib crane	5.0×10^{-3}/yr
• DLT backed into wall or fixed object	3.9×10^{-3}/yr
• forklift driven into smokeless powder container or contaminated item	4.04×10^{-3}/yr
• item falls due to inadequate bracing on mine car	1.3×10^{-3}/yr
• mine car impacts closed chamber door	4.4×10^{-4}/yr
• item falls off mine car due to hand braking	9.36×10^{-5}/yr
• smokeless powder container falls out of dumper clamping fixture due to gross misalignment of container by operator	9.36×10^{-5}/yr

A typical scenario is outlined below:

Fault Tree Component No.	Description	Probability/ Frequency Used
2	Flashing operation frequency	0.75/yr
117	Rough handling/hand braking of DLT Cart	0.01
118	Cart dumps items due to the quick deceleration	0.2*
119	Items impact rigid surface	1.0
120	Impact causes initiation	0.05**
76	Resultant fire injures operator or damages equipment	0.05

*Calculations indicate that hand braking will cause tall stacks to fall but short stacks will not be affected. It was judged that 20 percent of the time high stacks or items lined up sitting on their tails will be used and 80 percent of the time stable arrangements (e.g. items on their sides) will be used.

**Based on the geometry of where contaminant would be exposed and a probability of 0.1 for propagation.

OPERATOR INJURY DUE TO USE OF NONELECTRIC POWDER TRAIN (4.68×10^{-2}/year)

To ignite the smokeless powder in the flashing chamber, two general alternatives exist: 1) remote electrical initiation and 2) nonelectrical initiation of a powder train. As discussed in the Batelle report (reference 1) squibs or other devices containing sensitive energetic materials susceptible to ESD initiation are not desireable and should not be used for remote electrical initiation. A purely electrical element appears to be the most desireable option. Use of a nonelectrical powder train is potentially hazardous in several respects. First, the most convenient ignition source would appear to be a match or cigarette lighter. However, having such materials in an area where contaminated items and smokeless powder are present is a hazardous practice and should not be allowed. Chemical initiation (mixing two separated chemicals) may be somewhat safer but is a less common practice and not as convenient. Chemical initiation could impose its own hazards in that one of the chemicals being mixed could be an acid. In either case, if the operator cannot get away to a safe area quickly enough, he could be seriously injured. The escape of the operator would be at risk if the powder train is set too short, if it is inadvertently ignited too close to the items on the mine cars, or if the operator slips or trips as he is leaving and becomes injured to the point that he cannot escape (e.g. hits his head and gets knocked out). It was estimated that the probability of occurrence for this category of hazards is 4.68×10^{-2} per year.

Fault Tree Component No.	Description	Probability/ Frequency Used
371	Nonelectric ignition of powder train is used (assumed to be used half the time).	0.375/hour
374	Operator slips/trips upon exit and cannot escape	0.001
375	Fire seriously injures operator	0.05

EXPLOSION IN CHAMBER (1.78 X 10^{-2}/year)

The flashing chamber has been designed to contain the blast of a 120 pound TNT equivalent line charge distributed along the axis of the chamber, but such an explosion could do significant damage to the chamber and make it unuseable for further flashing. The blast of a 10 pound TNT equivalent internal explosion can be contained without damaging the chamber. In the analysis of the flashing chamber an explosion involving more than 10 pounds of TNT equivalent was taken as the criteria for significant damage to the chamber. Several scenarios were identified leading to such an event:

- explosion due to excessive propellant packed into the item — 1.56 X 10^{-2}/year
- explosion due to excess explosive contamination left in item during flashing — 1.56 X 10^{-3}/year
- explosion due to mistaken/misrouted waste explosive used in lieu of smokeless powder for flashing (inexperienced operators or gross negligence) — 6.24 X 10^{-4}/year

A typical scenario is described in the table below.

Fault Tree Component No.	Description	Probability/ Frequency Used
2	Flashing Operation Frequency	0.75/hr
3	Steamout process is incomplete	0.01
4	Inspections do not reveal excess amounts of explosive*	0.001
5	Greater than 10 pounds of explosives left in the items to be decontaminated	0.1
6	Sufficient depth and extent of explosive exist making detaonation possible	1.0**
7	Sufficient confinement exists for detonation	1.0**
1	Explosion result in severe damage to the chamber (a certainty, given that 5, 6 and 7 occur)	1.0

* This represents two inspection errors, but with some common cause involved. For example, the large amount of left over explosive may be hidden behind a pipe and missed in the same way by both operators inspecting the item.

** The conservative extreme values were used here.

GONDOLA INCIDENTS (1.067×10^{-3}/year)

Train derailments and collisions occur at a fairly steady rate across the country each year primarily in switch yards and other locations where trains are maneuvered. Such incidents are relevant at the flashing furnace because trains must travel deep into the plant to remove the scrap metal. Statistics for train accidents can be obtained from the U.S. Department of Transportation, Federal Railroad Administration, Office of Safety," Accident/Incident Bulletins and other relevant data (e.g. train-miles travelled each year) can be obtained from the Association of American Railroads Yearbook of Railroad facts. Based on these references, it is estimated that about 2.49×10^{-8} collisions and 1.62×10^{-8} derailments occur per train car mile each year. A factor of 100 can be applied to these rates to account for switchyard and similar operations having a higher rate than straight track. It is estimated that about 0.125 train car miles will be travelled per hour on the flashing furnace spur (based on one train trip in and out of the plant per day over about a 1/2 mile track section). Thus, on the flashing chamber spur, it is expected that about 6.47×10^{-4} collisions and 4.2×10^{-4} derailments will occur per year.

OPERATOR BURNED ON HOT ITEM OR MINE CAR (1.56×10^{-3}/year)

Several scenarios were identified in which an operator is seriously burned on the hot metal of decontaminated items or the mine car because of handling the items before they are given sufficient time to cool off. A typical scenario is outlined below:

Fault Tree Component No.	Description	Probability/ Frequency Used
392	Flashing is completed	0.75/hr
394	Items are not allowed a long enough time to cool in cool-off area	0.01
395	Operator does not sense high temperature	0.01
396	Operator not wearing protective clothing	0.01
397	Operator contacts hot metal with skin	1.0
398	Contact results in skin burn	1.0

OTHER HAZARD SCENARIOS

Several other scenarios were identified for the flashing chamber operation, but were of lesser significance. These include (1) initiation due to contamination on bolt threads while changing the container dumper fixtures for Type III and MK7 containers (1.12×10^{-4}/year), (2) initiation due to smoking in the area (7.8×10^{-5}/year), (3) baghouse damage due to an explosion in the flashing chamber along with failure of the pressure relief vent at the regenerator (4.47×10^{-5}/year) and (4) operator injury or death due to an operator getting locked in the chamber during flashing (5.62×10^{-5}/year). This last category of scenarios involves one operator being injured (e.g. temporarily knocked out or intoxicated) while in the chamber, and a second operator not noticing this and closing the chamber door on him. This scenario requires several human errors (i.e. the original incapacitation error, closing the door, controller not noticing on the video and a head count not taken at the Decontamination Building), but it is possible that someone could be closed in the chamber and not get oriented quick enough to escape in time.

3.5 DRIVERLESS TRACTOR SYSTEM, OFFLOADING DOCK, AND MAGAZINES

The fault tree analysis for the DLT System, Off Loading Dock and Magazines was quite voluminous, considering specific DLT operations for each process building independently. However, very little that is new was uncovered in the analysis. Almost all of the dominant scenarios involved hazards that have already been discussed for the specific process building involved. These included initiation of items or containers falling off of a DLT cart due to hard braking or initiation due to a cart being backed into a wall or fixed object, or initiation due to a DLT or other vehicle (e.g. a forklift or Flashing Chamber Car) riding over a contaminated surface and initiating the contamination by pinch or friction.

The only new scenario of importance involving this system is at the Offloading Dock. It was estimated that an operator would become seriously injured while unloading a freight train boxcar with a probability of 0.52 per year. This scenario involves items in the boxcar shifting during transport, ready to fall out of the door upon opening. The unaware operator is then injured as the items/packages fall onto him upon opening the door of the boxcar.

Fault Tree Component No.	Description	Probability/ Frequency Used
813	Freight car is fully loaded at off-loading dock	0.167/hr
814	Load has shifted in car during transit	0.01
815	Worker is unaware of shifted load	1.0
816	Operator opens door of freight car	1.0
817	As door is opened, items/containers fall out	0.1
818	Worker cannot get out of the way in time	0.1
819	Worker is severely injured by falling items/containers	0.5

It is also worth mentioning here that in the course of the study of the DLT system it was discovered that type EE tractors were purchased for WADF, whereas type EX were specified initially. Type EX certainly would have been the more conservative choice, although the requirements are somewhat borderline in many of the areas at WADF. This is discussed further in the Recommendations and Conclusions section.

4. RECOMMENDATIONS AND CONCLUSIONS

In this section, the recommendations and conclusions resulting from the Priority 3 hazards analyses are consolidated. They are presented for each area of the facility that was evaluated under Priority 3 and have been prioritized using descriptive terms such as (in decreasing order of urgency) "strongly recommended", "recommended", "suggested/good practice", and "concluded". General recommendations that apply to more than one area are presented separately at the end of the section.

4.1 ROTARY FURNACES IN THE DECONTAMINATION BUILDING

- By far the majority of problem areas that were identified will result in lost production and not a major hazard.
- The potential hazard with by far the greatest consequence is that of the truck driver hitting the nearby unprotected propane tank while moving the scrap metal recovery trailer. It is recommended that strategically located posts similar to those protecting the lightning poles be positioned around the propane tank. Proper placement of such posts would still allow easy access for filling the tank. An alternate approach would be to relocate the propane tank.

4.2 TRAY TYPE FLASHING FURNACE IN THE DECONTAMINATION BUILDING

- Strict controls must be enforced to assure that inspection procedures are accomplished with care so that filled or partially filled items are not put into the tray type furnace.
- It is recommended that a deluge type sprinkler system be installed in the baghouses at the Decontamination Building.

4.3 LARGE ITEMS FLASHING CHAMBER

- It is strongly recommended that detailed inspections be carried out on decontaminated items processed in the Flashing Chamber. The items should be disassembled and or sectioned so that bolt threads and other tight areas can be observed to assure that contamination does not remain after flashing is completed. Since "flashing" is a short duration high temperature exposure it is quite likely that the heat will not have time to penetrate to all of the interior contaminated rigions of an item. This type of inspection procedure should be accomplished until a reasonable data base has been developed to assure that decontamination by flashing does indeed work and is reliable. It should be noted that visual inspection of a treated item will not necessarily assure adequacy of decontamination. Cracks, threaded areas, and sub-surface cavities or flaws can still house hidden and undetectable explosive material.

- Raking of the sand beds on the mine cars should be carried out with care for each flashing cycle to assure that very little contamination remains in the sand and that a cushion is present to prevent direct metal - metal contact. It is recommended that non-metal rakes be used for this purpose to minimize the possibility of impact initiation of contamination that remains on the mine car.
- It is recommended that the concrete pad outside the flashing chamber be periodically wetted down to minimize the possibility of electrostatic discharge from operators or equipment as contaminated items are handled in this area.
- It is strongly recommended that remote purely electrical ignitors be used to initiate the burns in the Flashing Chamber. Squibs or other ignitors that contain explosives that are sensitive to ESD are undesirable because of the potential for premature initiation. Use of a powder train is undesireable due to the possibility that the operator could inadvertently light the powder train too close to the items, or not set up a long enough powder train, or become injured on his way out and not be able to escape in time.
- It is recommended that reliable non-combustible bracings be designed for each type of item to be decontaminated in the Flashing Chamber. "Make-shift" arrangements should not be used because of the high potential for the bracing to collapse and items to fall. The smokeless powder and/or contamination could become ignited from the impact in such an event.
- It is recommended that operators at the Flashing Chamber be trained to know what all possible smokeless powders to be used will look like. Any material that does not fit this pattern should not be used in any event. For example, flakes, chips, or small pieces, etc. could be explosive misrouted and actually intended for processing in the Bulk Incinerator. Packing items on a flashing car with such a material could result in a major explosion inside the chamber.

- It is recommended that driverless tractor loads be positioned with the lowest possible center of mass. This will minimize the chance for the load falling off of the carts in the event of a fast stop.

- The driverless tractor system that has been installed at WADF is rated as EE type equipment, rather than EX as was required in the specifications for the DLT. According to AMCR385-100, these two classifications for battery powered equipment can be used as follows:

  "Type EX equipment is approved for use in Class 1 Group D and Class II Group G hazardous locations." "Equipment used in atmospheres containing explosives dusts, flammable vapors or flammable gases, must meet requirements for EX industrial trucks."

  "Type EE industrial trucks are satisfactory for handling all classes of ammunition and explosives packed in accordance with Department of Transportation Regulations. Type EE industrial trucks may be used for handling partially loaded ammunition in corridors or ramps connecting hazardous operations, providing the ramps and corridors are not Class I or Class II hazardous locations as defined in paragraph 6-3f. Type EE equipment shall not be used in Class I or Class II hazardous locations."

  Use of Type EE equipment in some buildings at WADF appears to be borderline at best. The Type EE DLT should not be used in any areas where explosive dust or flammable vapors may be present.

- The highest probability scenario in the DLT/Offloading Dock/Magazine category was that of items/containers falling out of a railroad boxcar onto an operator when the boxcar door is opened. This could happen if the load is not properly tied down and shifts during transit. Great care should be exercised by the operators to carefully open the boxcar doors to assure that the load is not in a tenuous position. To guard against operator injury from falling loads resulting from shifted cargo, it is recommended that a come-along be used to open box-car doors. The operator, then is more likely to be removed from the door opening area.

4.5 AIR BLAST PROTECTION FROM AN EXPLOSION IN A CELL

The adequacy of protection from air blast was evaluated under this project and is discussed in Appendix B. Conclusions of that study are repeated here:

- Pressures transmitted to the corridor due to the "piston action" of a cell door were determined to be reasonably low, but on the order of the 2.3 psig criteria for safety adequacy.

- Pressures transmitted to the corridor due to leakage around the edges of the cell door were determined to be quite high in many cases and up to about 42 psig in one instance. Therefore, it is expected that unacceptably high pressures are possible locally close to the cell doors in the event of the explosion of a maximum or nominal quantity of explosive detonating in several of the cells.

- At the mechanical room for the Bulk Incinerator Building, a ventilation duct provides a fairly direct route for air blast to channel into the mechanical room. Calculations showed that the average pressure in the mechanical room would be quite low, but locally at the entrance to the duct the pressures could exceed the 2.3 psi criteria significantly if a maximum sized explosion occurs in the process area of the Bulk Incinerator Building. Because the traffic flow pattern for personnel in the control room/mechanical room is likely to have personnel in the vicinity of the ducts, a severe injury could occur in the event of an explosion. It should be noted that the probabilistic analysis indicated that such an explosion would be quite unlikely, and the low probability should be considered in deciding whether corrective action is warranted in this case.

4.6 GENERAL RECOMMENDATIONS FOR THE PRIORITY 3 SYSTEMS

Many of the general recommendations presented for the Priority 1 and 2 Systems are pertinent here also. These recommendations are repeated below:

- Every operation on every equipment item must be covered by a written procedure, reviewed and approved by operating and safety management personnel.

- A comprehensive training program should be required for all plant personnel, including information on potential hazards.

- All equipment operators should be given appropriate training courses and certified or licensed for operations in which they will be involved.

- All plant personnel should be tested for electrical grounding of footgear at least once a day with a sign-in sheet.

- Frequent cleanup of each plant area is mandatory to prevent buildup of contamination. Such cleanups should be scheduled as part of the operating procedures for each area.

- Area surfaces should be kept wet during maintenance as part of the procedure. The equipment should be thoroughly cleaned/decontaminated prior to any maintenance operation.

- It is recommended that a 2 locker system be adopted for plant personnel. One locker should be for street clothes and a second locker for work clothes. All clothing should be changed at the beginning and end of the shift. Clothing should be supplied by the plant - nothing taken home. A shower should be taken enroute from taking off work clothes to putting on street clothes. This procedure will also help avoid street shoes being mistakenly worn in the plant areas.

- An area entry and hot work permit program should be set up to assure that all temporary repairs and maintenance operations are well thought out and accomplished with several levels of safety and management checks.
- During maintenance, tools should be connected to the workmen by a cord wherever practical to help break the fall of the tool if it is dropped.
- Strict cleanliness must be enforced at all times in the plant, particularly when personnel leave contaminated areas to go to lunch or at the end of the shift. Nothing should be eaten in the work area. No food should be allowed in the work area.
- A medical surveillance program should be set up to screen personnel for specific jobs at hiring and to assure that long term health damage is avoided.
- Any major system modifications made in the future should be safety analyzed upon completion of their design.

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APPENDIX A

HAZARDS ANALYSIS APPROACH

APPENDIX A HAZARDS ANALYSIS APPROACH

Basically, the following steps were used in the analyses:

a) Collect Available Information

b) Review Information/Learn System

c) Conduct an Informal Failure Modes and Effects Analysis (FMEA)

d) Develop Fault Tree Logic Diagrams for System (FTA)

e) Quantify Fault Tree (derive scenario probabilities)

f) Interpret and Summarize the FTA Results

For the purposes of this program, the failure modes and effects analyses served to identify types of consequences and types of scenarios to be expected in different areas of the WADF. The FMEA's were used to learn the system and guide the development of the fault trees. Fault tree analysis was the primary methodology used to identify and quantify credible hazards at the facility. The FMEA and Fault Tree methods are described below:

A.1. FAILURE MODES AND EFFECTS ANALYSIS (FMEA)

Failure Modes and Effects Analysis is a relatively simple and direct approach for identifying basic sources of failure and their consequences. This method is not rigid and can be used for widely differing applications. It is especially applicable for identifying sources of malfunctions in hardware systems or in process equipment. The primary purpose of the analysis is to identify and remove failures that can cause hazards. However, as a side benefit, the analysis also leads to the identification of failures that are in themselves not hazardous but might affect the reliability of the functioning of a system. The results of such an analysis also may serve as an input to a Fault Tree Analysis, although more generally the two methods are used independently.

A Failure Modes and Effects Analysis is carried out by filling in a table having column headings such as the ones shown in Figure A1. This format is the one used for the Priority 1 systems. The first two columns list the

Systems/ Task	Component	Initial Failure	Chain of Events	Consequence

Figure A1 Failure Modes and Effects Analysis Format Used for Priority 1 Systems system parts and procedure steps obtained from the available drawings, written descriptions, etc. The third column is used to identify the different possible failure modes for each entry listed in the previous columns. There may be several entries in column 3 for each system part or task. Given these initial failures, the possible chains of events were described in the next column, and the ultimate effect on the system was given in the last column. The Priority 1 FMEA tables were relatively formal and time consuming to produce. These tables were used primarily as "shopping lists" for fault tree development, a function not necessitating the formal presentation. In Priority 2 and 3 analyses a less formal FMEA presentation is being utilized, although this method is still used to provide the basis for fault tree diagramming.

A.2. FAULT TREE ANALYSIS

A powerful method that has developed rapidly since 1962 is the Fault Tree Analysis. This method may be viewed as a systematic and comprehensive investigation of a postulated accident before it occurs. The term "accident" in this case is used to signify any kind of undesired event. The procedure is to define this undesired event and to identify all immediate causes that could have brought it about. These causes, in turn, are traced back through the system until one arrives at the ultimate causes that initiated the sequence of events that led to the undesired event. These ultimate causes may be failures of individual hardware components, or human errors, or other factors which either singly or in combination could have initiated the hazardous action.

An immediate result of such an analysis is a highly visible graphical representation of all basic failures and the paths whereby they can combine to create the undesired event. The method also can be used quantitatively. If data are available for the probability of occurrence of the basic failures, it is possible to calculate the probability of occurrence of the undesired event. In doing so it is also possible to identify those basic failures that are most critical, and the most critical sets of events (scenarios), so priorities can be established for taking corrective action.

An analysis begins by identifying an Undesired Event whose causes are to be traced. Graphically, this event is placed at the top of the page and represents the base of a tree whose branches are developed and extend downward. Once the undesired event, also called a Top Event is specified, it is necessary to identify the immediate causes which directly could cause this top event. Each of these causative events, in turn, is further broken down into subordinate events.

This process is continued until one arrives at basic input events that cannot be broken down further, or for which probability data are available so there is no need to go further. This process creates a diagram which resembles a tree whose branches extend and spread out downward, with each branch terminating in basic input events.

Figure A2 illustrates the diagrammatic arrangement of a fault tree, and Figure A3 identifies the goemetric symbolism that is commonly used in fault tree construction. It is to be noted that a fault tree consists of three essential elements -- input events, logic gates, and output events. The basic logic gates are of two kinds, namely OR gates and AND gates. If an output event can be caused by one or more input events, either when each acts by itself, or when they act together, these input events pass through an OR gate. On the other hand, if an output event can be caused only when all input events must act in combination, these input events pass through an AND gate.

This concept is illustrated in Figure A4 where the top event is defined as the lighting of the light bulb. For the circuit diagram which shows all the switches arranged in series, all four must be closed for the light to stay lit. In the logic diagram for this arrangement, these three switches are shown connected to an AND gate. In the other circuit diagram, where the four switches are arranged in parallel, it is evident that the closing of any one switch would be sufficient to light the bulb. The logic diagram for this case shows the four input events to pass through an OR gate. If the probability for each of the switches A, B, C, and D remaining closed were known, it would be possible to determine the probability of the bulb remaining lit for each circuit. That is, the symbolic logic relationships can be converted to algegraic expressions for numerical calculation.

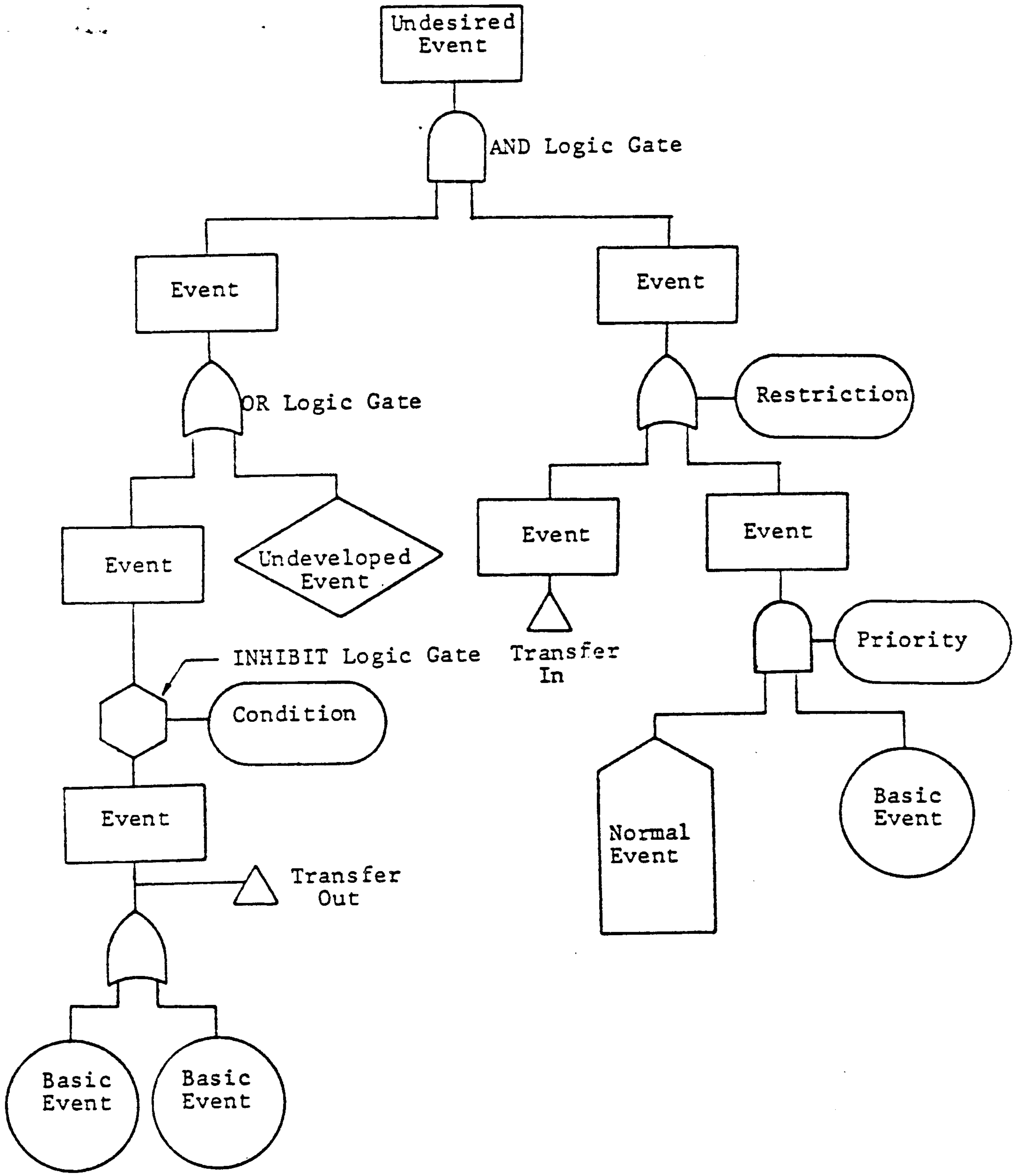
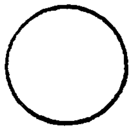
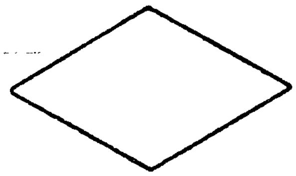


Figure A2 Diagramatic Arrangement of Fault Tree

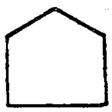
An event caused by one or more other events which are identified



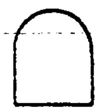
A basic input event that does not require further development as to causes



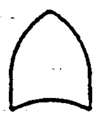
An event which is not developed further as to its causes because of lack of information or significance



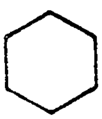
An event which is normal for the system; not a fault or failure per se



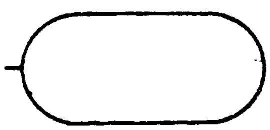
AND gate - output event occurs only if all the input events are present



OR gate - output event occurs when one or more of the input events are present



INHIBIT gate - output event is caused by input event only if specified condition is satisfied



Attached to logic gate to specify a condition

Continuation symbol to identical portion of fault tree

 Transfer In

 Transfer Out

Continuation symbol to similar (but not identical) portion of fault tree

 Transfer In

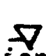
 Transfer Out

Figure A3 Symbols Used in Fault Tree Construction

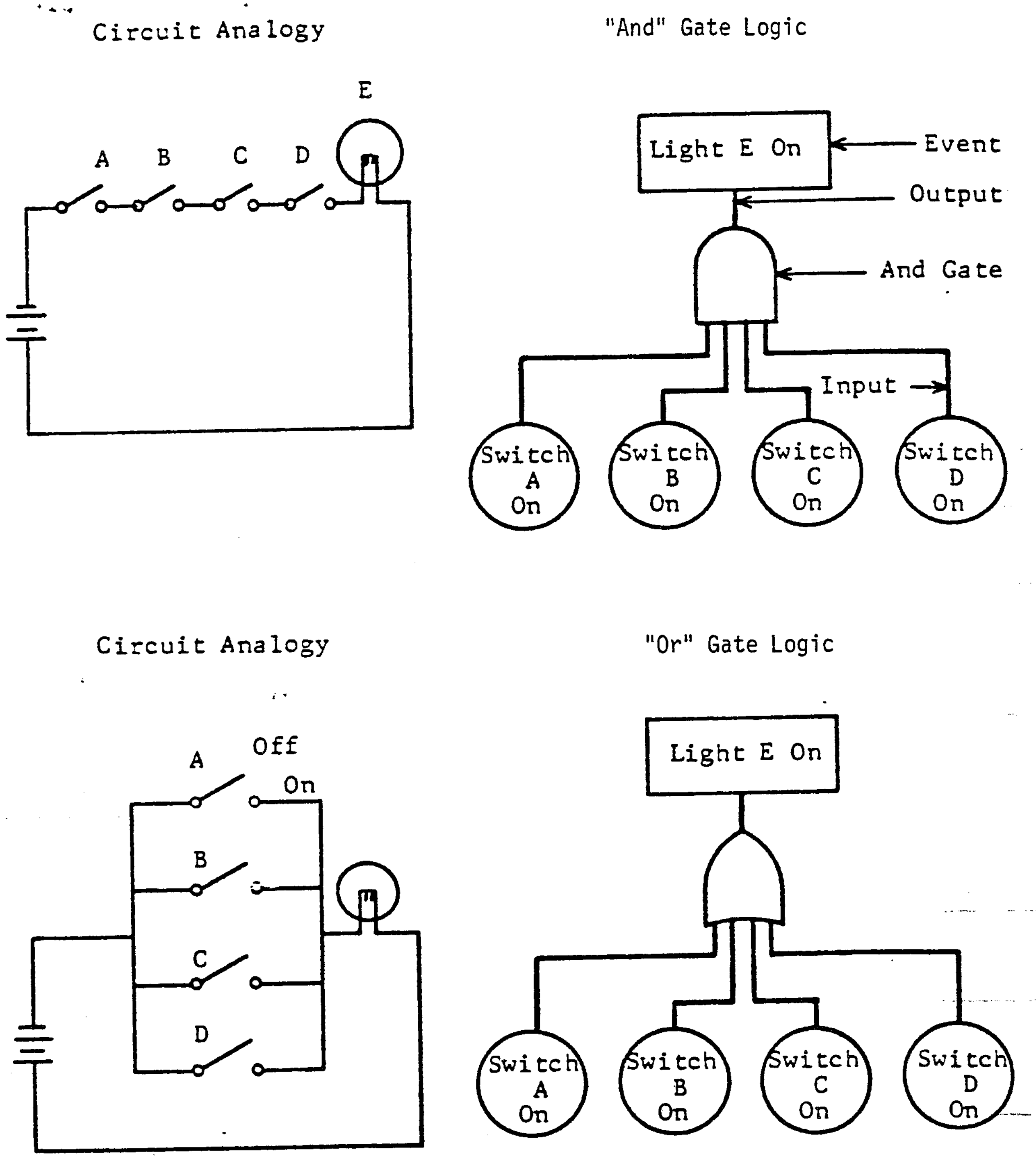


Figure A4 EXAMPLES OF USE OF AND AND OR GATES

A.3 QUANTIFICATION

IITRI has a fault tree analysis computer program for evaluating the fault tree diagrams. The first portion of the computer code uses a matrix approach known as the Boolean Indicated Cut Set (BIC) method to reduce the tree logic to a list of scenarios (cut sets) that "lead to" the undesired top event of the tree. These cut sets are the hazard scenarios that must be evaluated.

Each basic event on the fault tree must be provided a probability of occurrence or a failure frequency (with associated downtime) for quantification of the tree. Four types of data had to be compiled to quantify the trees:

1. System Scheduling Data
2. Part Reliabilities
3. Human Error Probabilities
4. Initiation Probabilities

Scheduling information was largely inferred from the Batelle Report (reference 1). Part reliability data has been compiled at IITRI during prior hazards and reliability analyses from numerous sources. The primary source of reliability data used, however, was a compilation of non-electronic parts data developed by the Reliability Analysis Center, an IITRI organization in Rome, New York (reference 2). Human error data has been compiled under a recent project conducted by IITRI for the Chicago Transit Authority (reference 3) and that was the primary source for for human error probabilities used. For initiation probabilities, the primary source of data was the Hercules Hazards Analyses for WADF presented in the Batelle report (reference 1). The most sensitive material for which data was available was used for each stimulus type. HBX-1 data was adopted for the majority of cases studied. In addition, there were numerous cases where data was unavailable and subjective judgements had to be used. For example, the probability that a significant amount of explosive would remain is a vessel during maintenance operations or that a local initiation would propagate into the bulk of material present were not easily quantified. Therefore, subjective judgements had to be used to establish probability values for the analysis.

The criteria for safety adequacy is stated in the contract as:

"The minimum acceptable level of risk for the operation and maintenance for the entire WADF complex and any subsystem is 97.5 percent probability with a 95 percent confidence level that a category 1 or 2* accident will not happen during 25 years of operation (40 hours per week)."

This translates to specifying that the hazard incident probability per year for the entire facility is less than or equal to 1/1000 with a 95 percent confidence level. The 95 percent confidence level criteria will be evaluated for the facility as a whole using the dominant cut sets derived for the different plant sections as the basis. Once the dominant cut sets for the facility as a whole have been identified using average failure frequencies and error probability values, Monte Carlo simulations will be run (on these dominant cut sets) to develop a distribution of failure frequencies for the WADF as a whole. The distribution created for the WADF will reflect uncertainties involved in predicting basic event frequency or probability values, for example due to variations in equipment, training of personnel, scheduling, etc. The 95 percent confidence level will then be determined using the derived distribution. These "total facility" results will be presented in the final report. For the mean time, a probability criteria of 1/10,000 will be used as a cutoff value instead of "1/1,000 with a 95 percent confidence level" in order to interpret the fault tree analysis results for each plant area.

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* Hazard categories are defined as follows:

Category 1 - Catastrophic. May cause death or system loss. System loss shall be defined as damage which results in the loss of 25 percent or more production capability and requires 30 days or more to repair.

Category 2 - Critical. May cause severe injury, severe occupational illness or major system damage. Major system damage shall be defined as that which results in more than 10 percent loss of production capability and requires more than 3 days to repair.

Category 3 - Marginal. May cause minor injury, occupational illness or minor system damage. Minor system damage shall be defined as that which results in 10 percent or less loss of production capability or requires 3 days or less to repair.

Category 4 - Negligible. Will not result in injury, occupational illness or system damage.

APPENDIX B

EVALUATION OF EXPLOSION HAZARDS CREATED BY THE ACCIDENTAL DETONATION OF MUNITIONS AND/OR COMPONENTS WHILE UNDERGOING DEMILITARIZATION OPERATIONS

APPENDIX B EVALUATION OF EXPLOSION HAZARDS CREATED BY THE ACCIDENTAL DETONATION OF MUNITIONS AND/OR COMPONENTS WHILE UNDERGOING DEMILITARIZATION OPERATIONS

B.1. INTRODUCTION

A number of potential explosion hazards and concerns were identified initially, and have been evaluated in order to ascertain if these events would create an unacceptable environment with respect to the safety of the operational personnel. These evaluations follow a rather extensive series of blast and structural response analyses which were conducted during the initial design and review processes of the facility. Thus, the current study is limited to a few specific events and effects. Some of these previous studies are presented in the list of references (1 to 7).

The potential explosion hazards evaluated during this study deal primarily with the detonation of some explosive material in one of the relatively small working cells, while the munition is undergoing one of many demilitarization operations. The detonation of a munition, munition component, or a collection of munitions will rapidly release blast and fragment energy which may impose significant loads upon the confining structure, and structural and mechanical elements. Some of this energy may leak out of the confining cell region or may be transmitted out due to the response of the structure and/or its attendant components such as doors, access covers, or frangible elements. The safety of the plant employees or operators located in the adjacent corridor region is the primary concern of this blast hazard evaluation. Specifically, this study examines the nature and intensity of the blast waves which are induced by the rapid motion of the closure devices, that is doors and access covers, as they respond to the relatively intense primary explosion environment in the cell. Furthermore, this study examined the blast enviornment induced by the gas blowby or leakage through the narrow gaps located at the edges of these closure devices.

In addition to the above problems occurring in the small working cells, the detonation of rather large quantities of explosive materials in the preparation areas of the Bulk Incinerator Building was examined with respect to the above door and access cover effects as it may influence the safety of personnel located in the associated work corridor. Finally, the safety of personnel in the control room, due to the propagation of blast energy through the air intake system, was evaluated.

The safety criteria applied in this evaluation is a simple peak overpressure criteria of 2.3 psig. This overpressure level is reasonably conservative with respect to the average response of working adults to sudden pressure increases associated with blast environments. No impulse criteria is included in this safety definition due to the low overpressure level. In any event, when applying this criteria, the prediction methodology employed to estimate the blast environments must be reasonably conservative in nature. It must be emphasized that the prediction of the safety criteria and the estimation of the blast environments are, at best, nominal.

The potential multiplicity of the cell configurations, explosion sites, explosion yields, and response elements (doors and access covers), require that a limited series of specific cases be evaluated for each of the response modes of concern. This approach is warranted due to the similarity of these events in the various scenarios. Furthermore, the multiplicity of results will also provide some guidance with respect to the sensitivity of the various parameters which are involved in each event. In general, the phenemona which will be encountered are extremely complex and difficult to deal with in a precise manner. This is due to the strong nonlinearities associated with the blast phenomenon, the multidimensional and transient aspects of the events, and to the real gas effects of the strong waves which influence the thermodynamic properties of the gas (i.e., air). Lorenz (Reference 5) presents a recommended internal blast loading prediction procedure after criticizing a previously used methodology. Such criticism may be partially justified; however, it must be fully recognized that the internal blast environment, which also involves multiple shock events, is too complex to predict accurately. Rather, an appropriate rationale applied conservatively must be employed.

B.2. CELL PARAMETERS

A typical cell configuration is illustrated in Figure B-1. These cells generally consist of four essentially rigid surfaces and two frangible surfaces (the back wall and the ceiling). Doors and access ways are located in the

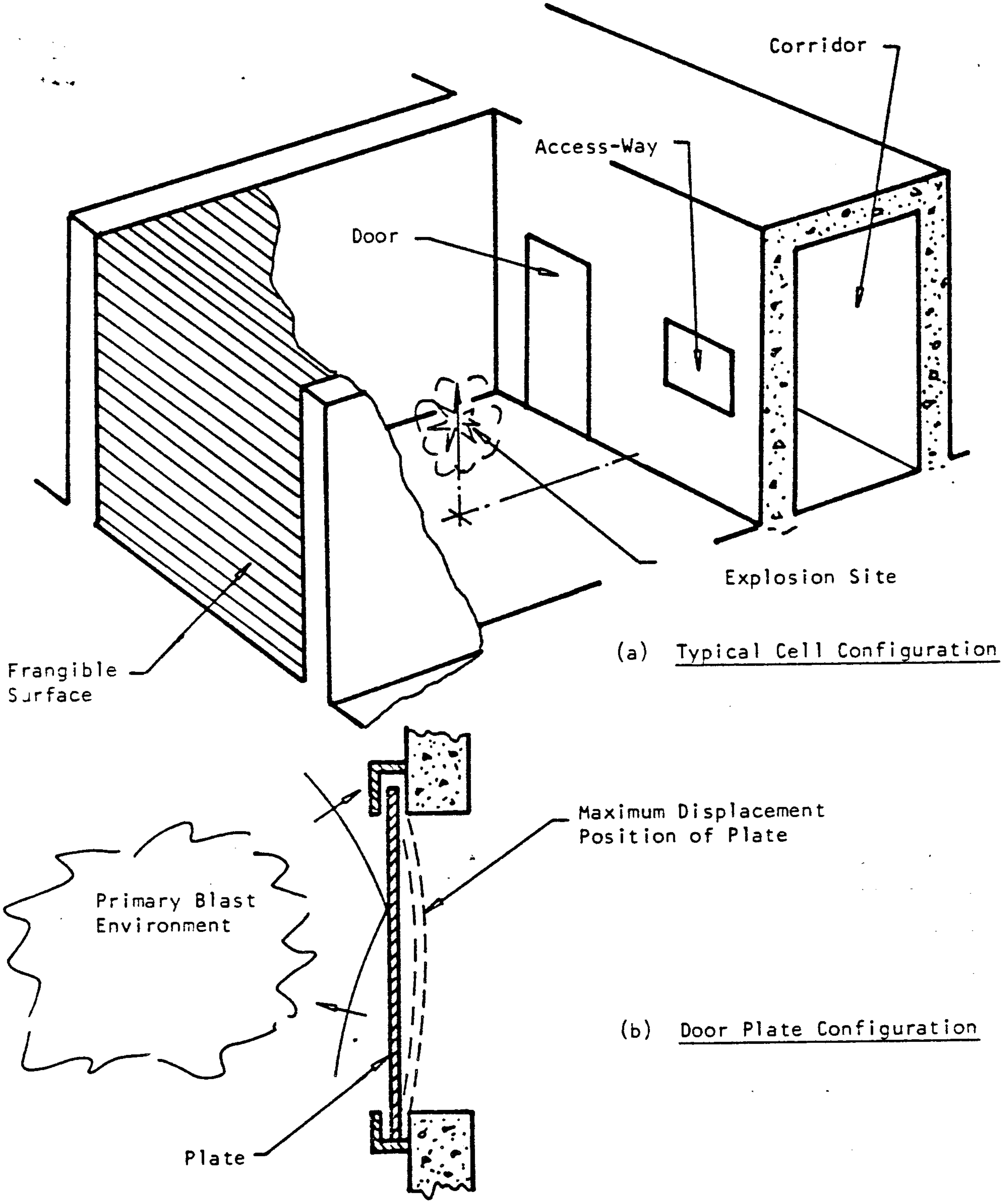


Figure B-1 Internal Cell Explosion

front wall (i.e., the wall adjacent to the corridor) and, additionally, access ways may be located in the side wall to permit the movement of material to adjacent cells or terminal areas. The nominal dimensions of these cells are approximately 15 feet on edge. The doors considered in this evaluation are 3 ft by 7 ft and the access covers, also called doors, are approximately 3 ft by 3 ft. All of these doors are of the sliding type and are constrained to move in suitable framing systems. The cells contain a variety of operational equipment and appropriate handling devices for one or more munitions depending upon the size of the munitions and the nature of the operation being performed in a particular cell.

A survey was made of the uses of these cells and a set or range of nominal explosive quantities, as well as a maximum explosive weight was selected for each cell. A summary of these explosive weights is presented in Table B-1. These weights represent the equivalent TNT weight of the explosive materials involved. In addition, a stand-off distance was selected, which represents the minimum (and therefore a conservative value) distance between the explosion source and a door. In most cases the angle between the door normal and this line-of-site vector is small such that the primary shock reflection process is well represented by the normal shock reflection treatment.

Similar data for the Bulk Incinerator Preparation Building is also presented, however, the associated preparation areas are considerably larger and are enclosed by three frangible surfaces. Furthermore, these areas are partially below grade. In this building the doors are located in an elevated position and connect to the work corridor which is at grade level.

The detonation of a large quantity of explosive material within the cell will create a rather severe blast environment in almost all cases considered. The intensity of the fragment environment will depend upon the details of the munition, however, it appears that most of these fragments will be captured by the surrounding equipment. It is clear that these fragments will not compromise the integrity of the doors or the thick concrete walls. Furthermore, the fragment energy and its effects will be small compared to that of the blast energy. The detonation of several hundred pounds of TNT in a closed region of the general size of these cells will increase the mean pressure to several hundreds of pounds per square inch, such that it is clear that the frangible surfaces are sufficiently far removed from the responding elements

TABLE B-1 SUMMARY OF EXPLOSION WEIGHTS

Building/Room	Nominal Wt. (lb)	Max. Wt. (lb)	Distance (ft)
Preparation Building:			
Cell No. 2	35-200	300	7
3	6- 60	300	10
4	0	300	10
5	4- 60	300	12
6	3- 48	300	12
Mechanical Building:			
Room 1	0-500	500	10
2	0-500	500	10
Cell No. 1	0-100	300	15
2	0-300	300	15
3	50-125	300	15
Bulk Building:			
Area No. 1	2500	2500	14

(i.e., the doors) that their influence on the primary blast environment adjacent to the doors is neglible or nonexistent.

The prediction of the primary blast environment is, as stated above, very difficult to define with any great accuracy. Therefore, the following conservative methodology was adopted. The peak pressure associated with this environment was determined by using the normal reflected pressure for free air explosion at the appropriate stand-off distance, and to use the impulse associated with the reflected pressure wave for a surface burst (an effective 2W source), again, at the appropriate stand-off distance. This simple procedure assumes that the maximum pressure of the primary explosion environment in the cell at the door location (an average load over the door area) is due to the reflection of the incident or primary shock wave, and that the impulse associated with the additional shock reflection effects from adjacent rigid surfaces, which will increase the local pressure environment at later times, are adequately accounted for by increasing the source strength. In general the explosion environment is rather short lived, say a few milliseconds or less. Furthermore, the shock arrival time will also be very short, again, about one millisecond. These time comparisons clearly indicate that the potential relief effects from the failure of the frangible surfaces will not influence the local blast environment at the corridor wall of the cells.

The above procedure is considered to be conservative and is consistent with the internal cell loading methodology defined in TM5-1300 (Reference B-8). The TM5-1300 procedure was not used since it is limited to the prediction of the average load over the entire wall. In the current evaluation the pertinent area is limited to the door area. TM5-1300 was used as the primary source for the blast data used in the analysis. It was further assumed, in the current analysis, that the influence of the added impulse due to multiple shock reflection effects, tends to increase the late time pressure environment such that the pressure-time wave shape becomes essentially linear. In this manner a pressure pulse duration could be readily determined. A summary of the primary blast environment parameters are presented in Table B-2. It should be noted that for most of the severe environments encountered, that the scaled distance range the basic blast data is somewhat uncertain. In part, for this reason the above defined procedure was used. The use of the linear wave shape

TABLE B-2 SUMMARY OF PRIMARY BLAST ENVIRONMENT

Building/Room	Nominal Max. Explosion			Max. Explosion		
	Pressure (psi)	Impulse (psi-ms)	Duration (ms)	Pressure (psi)	Impulse (psi-ms)	Duration (ms)
Preparation Bldg:						
Cell No. 2	4800	2760	1.15	6300	3880	1.23
3	870	590	1.36	3000	2210	1.47
4	-	-	-	3000	2210	1.47
5	500	450	1.80	2050	1690	1.65
6	370	390	2.11	2050	1690	1.65
Mechanical Removal Bldg:						
Room No. 1	4500	3400	1.51	4500	3400	1.51
2	4500	3400	1.51	4500	3400	1.51
Cell No. 1	420	527	2.51	1260	1240	1.97
2	1260	1240	1.97	1260	1240	1.97
3	92	630	13.70	1260	1240	1.97
Bulk Incinerator Bldg:						
Area No. 1	6600	8200	2.48	6600	8200	2.48

was also motivated by the convenience that it affords in some of the subsequent analyses. It must be emphasized that these assumptions did not significantly influence the subsequent results of the evaluation since most of the severe effects can be attributed to the early portion of the primary blast environment.

3. DOOR MOTION ANALYSIS

The blast doors used as the closure devices in these cells are solid steel plates, 2 to 3 inches thick, which cover the entire wall penetration or opening. These doors are constrained, as needed, by suitable framing systems, but are separated from the wall or framing by a narrow gap or clearance which permits the relatively free sliding motion needed for normal door operation. Thus, the rapid application of a rather severe blast load will cause the plate to translate towards the wall, reducing the gap width until the plate impacts on the wall/rail system at its edges. The door will continue to move until the load is relieved and the kinetic energy is converted to the deformation of the plate, however, this average translational motion will be associated with a buckling or bending mode of the plate. The following analysis will demonstrate that the plate will impact its supports rather early in its loading phase, say 0.3 to 1 ms after the application of the load. Furthermore, since the frequency of the plate in its lowest mode of vibration is approximately 80 cps, the loading phase will terminate before plate rebound will occur. Maximum displacement will occur approximately 3 ms after impact. At this time the average velocity will be zero.

The rapid motion of the plate, as defined by its average translation velocity, will induce a blast pressure environment in the corridor region. The blast wave will initially be confined to the wall recess (about 3.5 to 5 ft long) region but will subsequently propagate out into the general corridor region in a substantially weakened form. The following analysis will define the strength, duration and general wave shape of this induced blast wave as it exists in the recess region. Since operational personnel may be at the door location (i.e., in the recess region) during an explosion event, this location is a meaningful one.

The analysis methodology treats the plate as a free lumped mass per unit area with a single degree of freedom, i.e., undergoing a translational motion. This linear motion is applicable prior to and after any impact effects. The following velocity and displacement relationships are valid prior to impact:

$$u = \frac{P_o t}{2w} \left[2 - \frac{t}{t_o} \right] \qquad (1)$$

and

$$x = \frac{P_o t^2}{2w} \left[1 - \frac{1}{3} \frac{t}{t_o} \right] \qquad (2)$$

where

u = plate velocity

x = plate displacement

t = time

P_o = peak pressure or primary blast environment

t_o = duration of primary blast environment

w = weight per unit area of plate

After impact occurs, the center portion of the door will tend to move as a free mass as described by the above relationships, whereas the velocity of the edge of the plate will impulsively change to zero. The average plate velocity will be somewhere between these limits as illustrated in Figure B-2 (a). The assumed form of the average velocity after impact occurs approximates a quarter sine wave which connects the impact point with the zero velocity point three milliseconds after impact.

The motion of the plate will induce a blast wave which, for moderately weak waves, is defined by the following characteristic equation:

$$\Delta p = P_\infty \left\{ \left[1 + \frac{K-1}{2} \; \frac{u}{c_\infty} \right]^{\frac{2K}{K-1}} - 1 \right\} \qquad (3)$$

where

Δp = overpressure

P_∞ = ambient pressure

k = ratio of specific heats

c_∞ = ambient sound velocity

If the blast wave is very weak, then the above relationship reduces to:

$$\Delta p = \frac{kP_\infty u}{c_\infty} \qquad (4)$$

At low overpressure levels the individual disturbances will propagate in such a manner that wave coalescence will not be significant. Thus, the pressure history will be proportional to the velocity history, i.e., they will have similar shapes.

The doors of the small cells are 2 inches thick and have a nominal clearance at the head and jamb edges of approximately 1/4 inch. These 3 ft by 7 ft doors have gaps of approximately 1/8 inch along the floor edge. This latter gap does not close as the plate is translated and thus this edge remains free during the impact process. The corresponding doors in the Bulk Incinerator Building are similar, except they are 3 inches thick. The access covers are 1-3/8 inches thick and appear to have a somewhat smaller gap. Furthermore, some seals may be present in the gaps of the access covers, however the extreme blast pressures will blow these seals out. A selected set of results is presented in Table B-3 and indicates that the peak overpressures are slightly greater than 2 psig for the doors. Four typical pressure histories are presented in Figure B-2 (b). The results presented in the table include the peak overpressure, the corresponding peak velocity (the impact velocity), and the time of impact. The total duration of these blast waves are approximately 3 ms longer than the time of impact. A similar examination of the thinner access

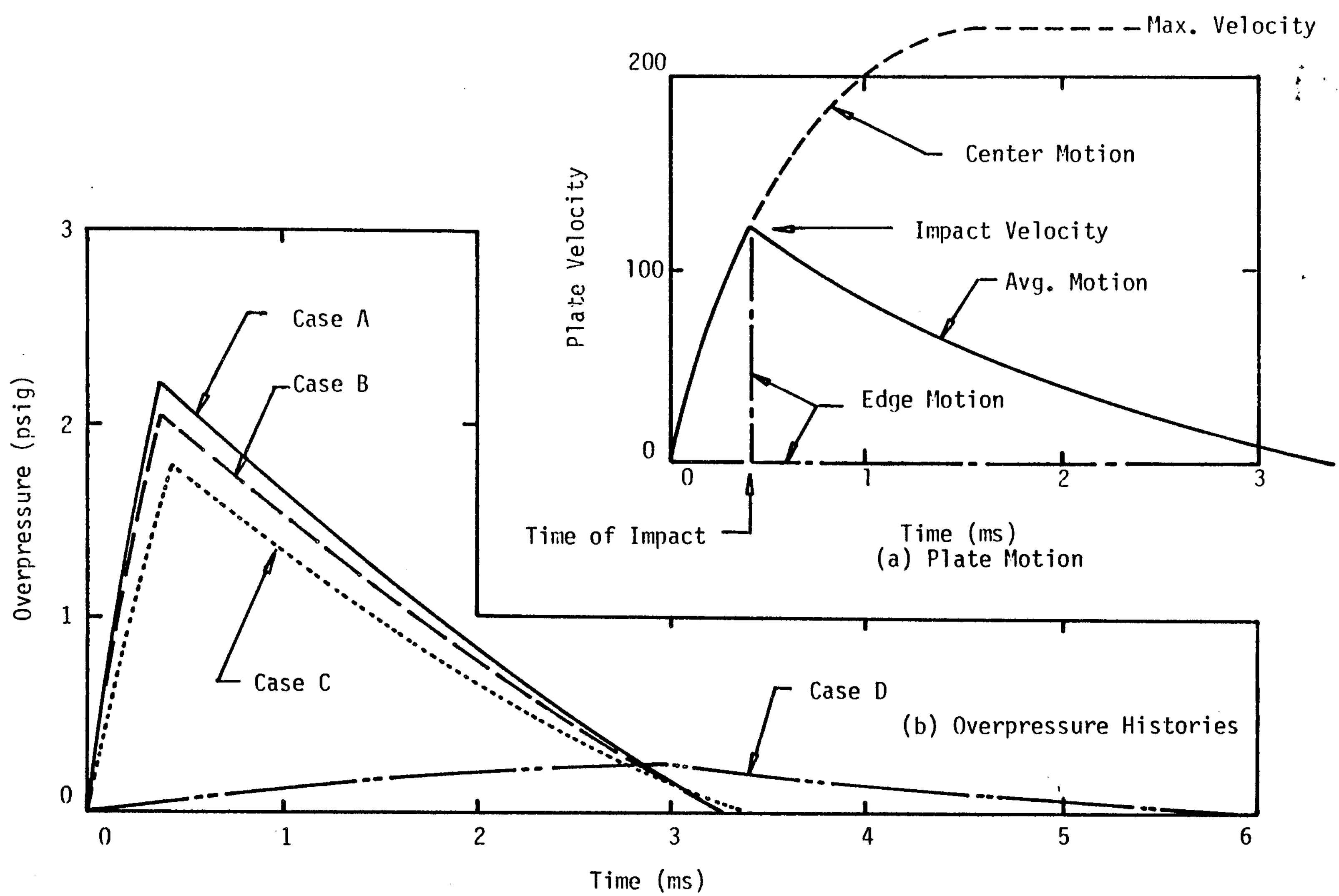


Figure B-2 Overpressure Histories due to Door Motion

TABLE B-3 PEAK PRESSURE ENVIRONMENT DUE TO DOOR MOTION

Building/Cell/Wt.	Case (Figure)	Impact Velocity (fps)	Time of Impact (ms)	Peak Overpressure (psig)
Preparation Bldg:				
Cell No. 2/Max.	B	111	0.36	2.02
2/Nom.		93.8	0.41	1.71
3/Nom.		32.3	1.06	0.59
6/Max.		61.2	0.64	1.12
6/Nom.		21.2	1.61	0.39
Mechanical Removal Bldg.				
Cell No. 3/Max.		47.1	0.83	0.86
3/Nom.	D	13.8	2.92	0.25
Bulk Incinerator Bldg:				
Typical Door, I5	A	120.2	0.34	2.19
Typical Door, I6	C*	97.7	0.42	1.78

* 3 in. thick

NOTE: Doors are solid steel - 2 in. thick with an initial separation of 0.25 in.

plates indicated that the induced blast environment is approximately the same. The peak pressure would be approximately 20 percent larger if a 1/4 inch gap is used and approximately 10 percent less if a 1/8 inch gap is used. It is clear that the blast waves which are induced by the rapid displacement of the enclosure plates are acceptable with respect to the safety of the operating personnel. While a few results exceed the 2.3 psig safety criteria (for the access covers) the degree of conservatism used in the analysis is sufficient to conclude that this effort does not represent a significant hazard to the operators located in the adjacent corridors of these cells during an explosion event.

4. GAS BLOWBY ANALYSIS

The presence of very high pressure gas in the vicinity of the doors and their edge gaps, allows a jet of energetic gas to flow through the thin gap and enter the recess region on the corridor side of the door. The rapid injection of this gas and its subsequent expansion to significantly lower pressures will generate a pressure wave in this recess region which will then propagate out into the general corridor region. This process is illustrated in Figure B-3 (a). The interface defines the boudary between the injected gas and the ambient air which was originally in this region. The injection of the gas acts like a piston and the ambient air is compressed to make room for this additional material. The mass flow rate associated with the leakage will correspond to sonic flow due to the very high pressures in the primary blast region. This region acts as a time dependent reservoir and the properties of the gas in this region will have a significant influence upon the mass flow rate and the subsequent blast wave in the recess region. The quantity of the gas injected by this process will depend upon the properties of the gas, the time dependent decay of the pressure, and the time dependent size of the gap. The latter has already been defined implicitly by the previous analysis of the motion of the plate loaded by the primary blast environment.

The pressure in the recess region is difficult to define with great precision due in part to the complex geometry of the region (i.e., highly three dimensional in the scale of the jets), and to secondary phenomenon such as mixing. Furthermore, the state of the gas in the primary blast region is significantly altered by real gas effects. The former can be grossly accounted for by employing a one-dimensional representation of the blast wave in the recess region. The latter was determined by using the thermodynamic properties of air (Reference B-9) in a manner corresponding to the double shock processes associated with the primary wave and its reflection from the essentially rigid surfaces of the cell. The mass flow rate will be proportional to the density and the sound velocity corresponding the the peak pressure state in the primary blast region. Typically, for the more intense cases, the density of this state will be approximately twenty times the ambient air density and the sound velocity will be about four times the ambient air sound velocity. Fortunately, the dependence upon the density is removed when the pressure formulation is developed. Thus, at least this uncertainty is eliminated.

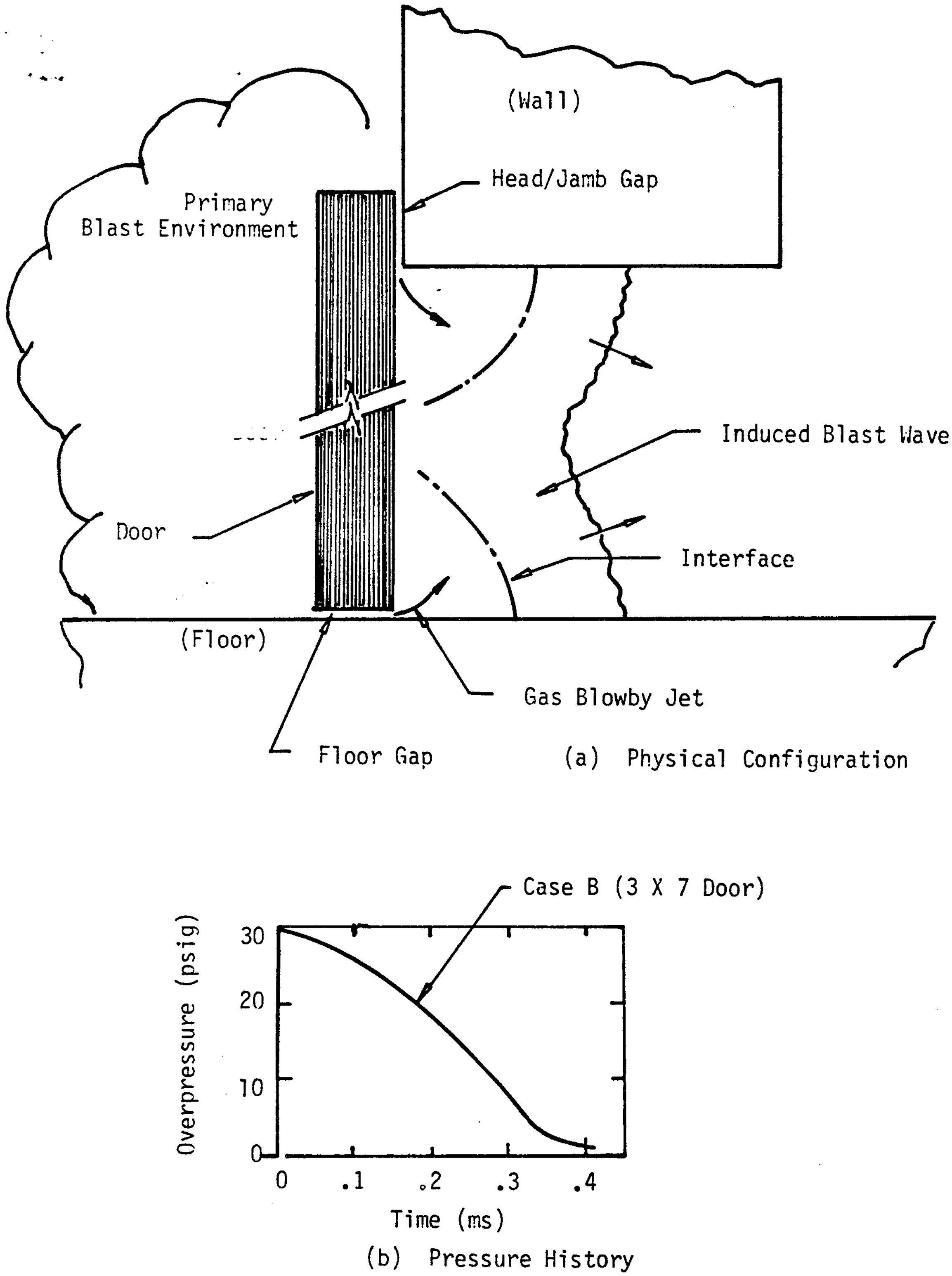


Figure B-3 Blast Environment Due To Gas Blowby At Doors

The results indicate that rather strong blast waves are generated in the recess region. Furthermore, the duration of these pressure waves are rather short (i.e., equal to the impact time of the plate), such that some wave shape distortion is expected to occur as the disturbance propagates in the recess region. A representative case is illustrated in Figure B-3 (b). The following relationship is based upon the equality of the volume rate of flow of the injected gas and the volume rate of flow corresponding to the compression of the ambient air. Furthermore, the pressure of both gases at the interface are equal. The relationship is:

$$\frac{(\zeta-1)\ \zeta^{0.714}}{\sqrt{1+6\zeta}} = 0.168 \left[\frac{A}{A^*}\right]\left[\frac{Co}{C\infty}\right]\left[\frac{Po}{P\infty}\right]^{0.714}\left[\frac{P}{Po}\right]^{0.857} \tag{5}$$

where the shock strength is

$$\zeta = \frac{\Delta p}{P\infty} + 1 \tag{6}$$

and

A = area of the gap

A* = area of the door

c_o = sound velocity of the reference primary blast region

P = pressure of the gas in the primary blast region

The factor 0.168 includes an orifice coefficient of 0.6 as well as other factor inherent in the gas dynamic relationships used in this formulation. In view of the complex wave shape inherent in this process (see Figure B-3 [a]) peak values can be readily obtained by simplifying the above equation to time equal to zero where the pressure ratio in the primary explosion region is unity and the gap area is equal to its initial value.

Representative results are presented in Table B-4 and clearly indicate that the transmitted blast environment in the recess region and hence in the corridor proper is very intense and violates the safety criteria of a 2.3 psig peak overpressure. It should be noted that the wave lengths of these intense pressure waves are of the order of 0.5 ft, thus, it is unlikely that the one-

TABLE B-4 PEAK PRESSURE ENVIRONMENT DUE TO GAS BLOWBY AT DOORS

Building/Cell/Wt.	Peak Pressure (psi) 3 X 7 Door	(3 X 3 Door (Port)	Duration (ms)
Preparation Bldg:			
Cell No. 2/Max.	28.7	41.2	0.36
2/Nom.	22.8	32.7	0.41
3/Nom.	4.8	7.1	1.06
6/Max.	10.3	14.8	0.64
6/Nom.	2.0	2.9	1.61
Mechanical Bldg:			
Cell No. 3/Max.	6.6	9.7	0.83
3/Nom.	0.6	0.9	2.92
Bulk Bldg:			
Door	29.1	-	0.42
Port	-	42.3	0.34

dimensional represntation used is valid. It is more likely that the blast energy will be diffused over a larger volume and, perhaps, dispersed more in time. Thus, the peak overpressures may only be one-half of the values indicated by the above analysis methodology. Attenuation effects were examined and it would appear that no significant wave attenuation would take place before the wave propagates 2 to 3 feet. Based on these results, it must be concluded that a real and somewhat significant hazard to operating personnel in the corridor region could exist for the explosion scenarios treated. It should be noted, however, that although the 2.3 psig peak overpressure will be exceeded in many of the cases evaluated, the pulse duration would be quite short. Based on data in reference B-10, it appears that the predicted pressure-time histories would at most cause eardrum damage, and may not reach that threshold.

A supplementary evaluation was made of this gas blowby effect to establish the sensitivity of the gap size to the intensity of the transmitted blast environment. These results are presented in Table B-5. The results indicate that substantial reductions in the gap size must be implemented in order to achieve a safe environment in the adjacent corridor region. It should be noted that as the gap size is reduced the wave length also becomes small such that the one-dimensional representation becomes even poorer. A gap width of 0.032 inches would probably be adequate since a great deal of local mixing of the two gases will occur. Finally, it should be noted that this gas blowby effect and the previous plate motion effects are additive, although not necessarily in an algebraic sense.

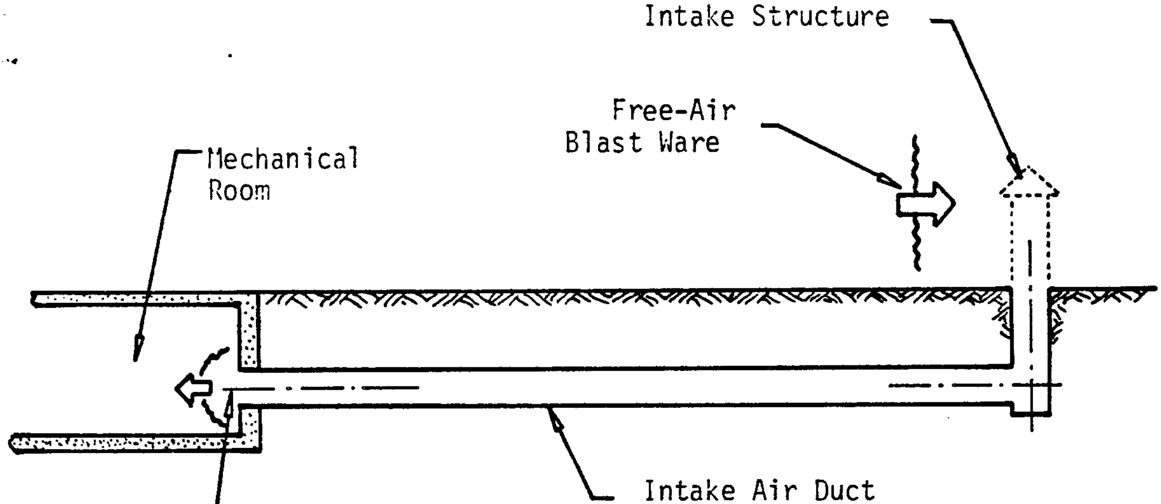
5. BLAST ENVIRONMENT IN CONTROL ROOM

The detonation of 2500 lb of equivalent TNT in the slurry tank located in the preparation area of the Bulk Incinerator Preparation Building would generate a rather strong blast environment which will propagate away from the building and sweep past the air intake structure or duct which provides fresh air to the compliment of underground rooms in this complex. The free air blast wave will enter this duct, propagate through the duct, and enter the Mechanical room. The blast wave will then diffract into the room and loose its intensity, but the mass injection caused by this wave will pressurize this room and any others which are connected to it. This problem was examined previously (Reference B-1), however, the analysis was deficient. The explosion was

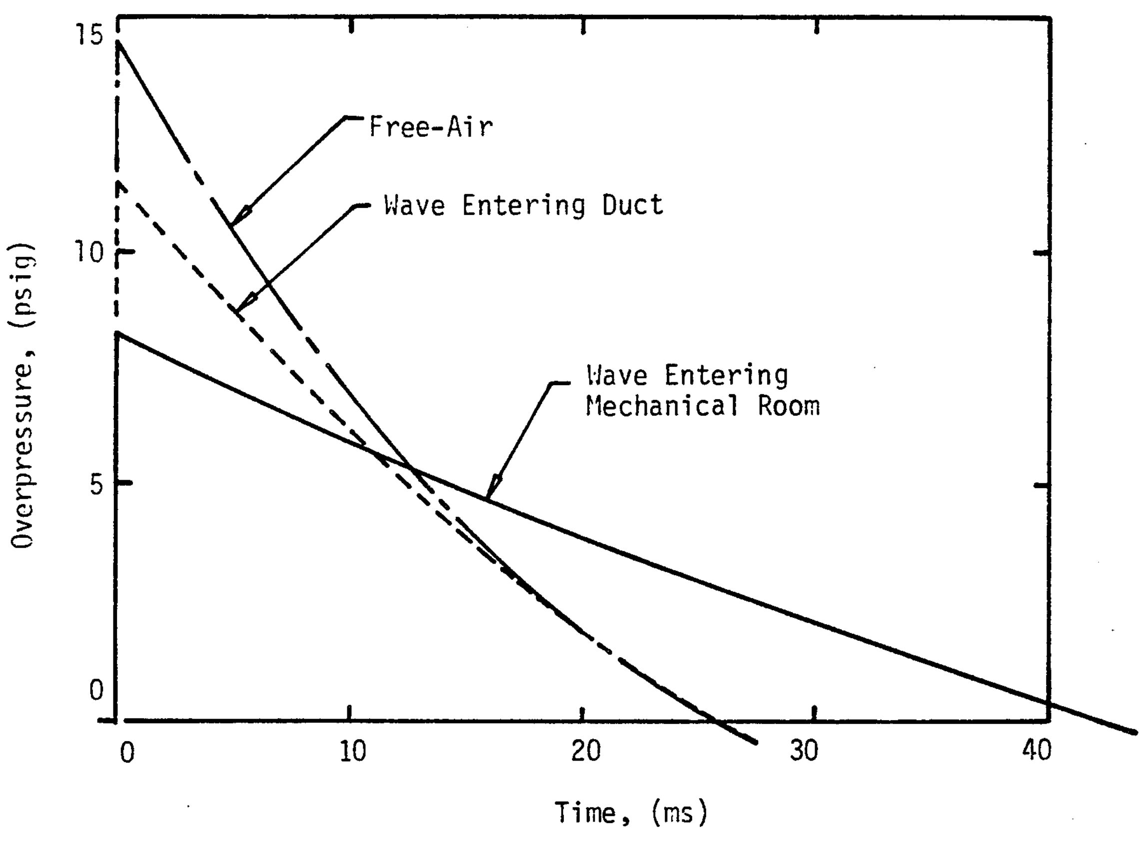
TABLE B-5 GAP SENSITIVITY FOR GAS BLOWBY EFFECT - CASE B

Initial Gap (in)	Peak Pressure (psi)	Duration (m)	Wave Length (ft)
.250	28.7	0.36	0.67
.125	15.6	0.25	0.38
.063	8.4	0.17	0.24
.032	4.8	0.12	0.16
.016	2.3	0.09	0.10

treated as a free air source. The explosion source is located close to the cell floor; a distance which is small compared to the range of the air intake. Thus, the explosion environment at the intake location will be in the Mach region and the appropriate burst condition is a surface burst condition. The previous analysis also used a shorter range than that which is indicated at the present time. The blast environment used at the intake location in that analysis was a 14.0 psi peak overpressure wave with a duration of 16.3 ms. The current treatment indicates that the blast environment corresponds to a peak overpressure of 14.5 psig and a duration of 26.0 ms. While these two pressure waves are not grossly different, the previous analysis did not define the strength and duration of the blast wave entering the Mechanical room. A graphical method-of-characteristics solution was performed and the results are presented in Figure B-4 together with an illustration of the general duct configuration. A total duct length of 75 feet was used. The influence of the light sheet metal intake structure was neglected on the assumption that the free air blast wave would quickly destroy this superstructure. The blast wave entering the duct undergoes some attenuation such that the peak overpressure of the wave which enters the Mechanical room is approximately 8.2 psig and has a duration of approximately 42 ms. The cavity filling process increases the pressure in the Mechanical room by only 0.21 psig, a value which is comparable to the 0.13 psi increase predicted by the previous analysis for the somewhat less intense wave. It is clear that with respect to the gradual pressure increase in this and possible adjacent rooms, the blast environment in the underground complex, which includes the Control room, is small and the area can be judged to be safe for plant personnel. However, it must be noted that the 8.2 psi peak overpressure blast wave which enters the Mechanical room does represent a substantial hazard to any personnel in that room, especially if they are near the air duct. Considering the arrangement of the rooms in this underground complex, it appears that some personnel may use the Mechanical room as a pathway rather than pass through the supervisors office; especially when one considers the potential routes between the washroom and the Control room.



(a) Physical Configuration



(b) Pressure Histories

Figure B-4 Explosion Environment for Air Intake Duct

6. CONCLUSIONS

The evaluation of explosion hazards created by the accidental detonation of munitions while undergoing demilitarization operations was examined for three general scenarios or events. These include the induced blast wave generated by the motion of doors and access covers due to the intense primary blast environment which will exist within the cell when an explosion occurs. This phenomenon produced blast waves, which for the more severe cases examined, had peak overpressure levels of approximately 2.0 to 2.5 psig. These blast environments essentially met the 2.3 psig peak overpressure safety criteria.

The second analysis dealt with the blast energy which was transmitted to the working corridor by high pressure gas blowby through the small gaps located along the edge of these closure devices. For this phenomenon, the blast waves transmitted to the working corridor, in many instances were quite intense (approximately 30 to 40 psig peak overpressures). Hence, a serious blast hazard does exist for operating personnel located in the adjacent corridor when a large explosion occurs in the cell.

Finally, the pressure environment within the Control room of the Bulk Incinerator Preparation Building was examined. The pressure rise in the underground rooms due to the transmission of a blast wave propagating through the air intake duct is very small (approximately 0.2 psig). However, the blast wave which enters the Mechanical room is intense (a peak overpressure of 8.2 psig) and it represents a hazard to any personnel which may be in this room when the slurry tank detonates. Personnel are not normally permitted in the room, however, they may make use of this room as a convenient path between the Control room and the washroom.

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