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APPLICATION OF THE
SIMPLIFIED DOW CHEMICAL COMPANY
RELATIVE RANKING HAZARD ASSESSMENT
METHOD FOR AIR COMBAT COMMAND BASES

THESIS

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AFIT/GEE/ENV/93S-14

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THESIS

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Abstract

This study investigated the possibility of determining the hazard potential of chemicals on Air Force bases using a relative ranking hazard assessment method. Hazard assessment includes both the identification and evaluation of the hazards. Title III of the Superfund Amendments and Re-Authorization Act of 1986 requires hazard assessments by all facilities with extremely hazardous substances to prepare release prevention and emergency response plans.

The purpose of hazard assessments in this research is find the materials with the largest potential for hazard. Identifying high hazard potential materials can improve spill prevention, control and countermeasure plans and provide a ranked list of substances to eliminate and reduce.

Using a simplified relative ranking assessment method developed by the Dow Chemical Company, assessments were performed for three Air Combat Command Bases. The results from the bases' assessments showed several substances in the high and medium hazard potential categories.

This study recommends an assessment be performed for all bases in each command to identify the higher hazard potential substances. Hazard potential should be reported in spill prevention plans identifying high hazard areas and release mitigation procedures and equipment.

APPLICATION OF THE SIMPLIFIED DOW CHEMICAL COMPANY RELATIVE RANKING HAZARD ASSESSMENT METHOD FOR AIR COMBAT COMMAND BASES

I. THE NEED FOR HAZARD ASSESSMENT

On 2 December 1984 a major chemical release in Bhopal, India killed 3000 people and injured 200,000 (Abrams and Ward, 1990:135). The international attention to this accident has changed how the United States industry prepares for accidents. Because of this accident the United States passed the Superfund Amendments and Re-authorization Act of 1986 (SARA, Title III) requiring facility owners and operators to participate in accident prevention planning.

This law requires owners and operators of facilities to participate in accident prevention activities. One of the first requirements for facilities is to prepare accident prevention plans. There can be many stages or steps to preparing a prevention plan, but the first step is the identification of hazards and the second to evaluate those hazards. The two steps together are known as hazard assessment. (Davis 1987:42-53)

The Air Force has begun this first step by preparing and implementing Spill Prevention Countermeasures and Contingency (SPCC) plans. These plans, prepared at every Air Force base, identify the hazardous materials and the quantities on the base, but do not include a hazard evaluation or meet all the needs of the laws. According to the July 1992 Air Force (AF) Pamphlet 19-33, the Hazardous Material Planning Guide, the SPCC Plans are prepared to comply with Environmental Protection Agency (EPA) regulations on Oil Pollution Prevention. The AF Pamphlet says a comprehensive plan is needed in addition to the SPCC plans to comply with SARA, Title III and the many other regulations mandating prevention plans. The proposed comprehensive hazardous materials plan will include a site specific hazard assessment, that includes hazard identification and evaluation. "The resulting plan identifies the site-specific hazards; populations, property and environment which are potentially vulnerable; and the probability of risk that a release will occur." (AFP 19-33, 1992:1-2)

This study focuses on the hazard evaluation portion of the hazard assessment area, because this evaluation portion has not been accomplished in SPCC plans. It is important to complete the evaluation portion to comply with the EPA regulations and to differentiate between hazards, identifying the "high" hazard potential areas. Identifying areas with high hazard potential is important because once identified, management attention can be directed to reducing the hazard that have the potential to cause the most harm.

In reducing potential for accidents, those areas which have the highest potential for harm to people, property, and the environment should be reduced or eliminated first. Also, when searching for pollution prevention options, those areas with the highest accident potential should be examined first to reduce pollution where the reduction will also reduce potential hazards.

This research proposes using the Dow Chemical Company hazard assessment method (Dow 1973) to complete the hazard assessment portion of comprehensive accident prevention plans. This paper will determine (1) if the Dow method of relative ranking is suitable for evaluating Air Force facilities, and (2) if a base can be evaluated using the existing inventories in the spill prevention plans. The background for hazard assessment, the methodology for performing the assessment and the results will be presented in separate chapters.

Relative ranking hazard assessments were performed using the Dow method on the SPCC plan inventories from Davis-Monthan, Shaw, and Seymour Johnson Air Force Bases. The methodology used to perform the assessment will be presented in Chapter 3. The results of the assessment, conclusions and recommendations for further research are found in Chapter 4.

II. Background

Clearly the Bhopal chemical accident caused major changes in spill regulations in the United States. Authors refer to the accident as, "a stark symbol of one of the possible consequences of marriage between modern society and the chemical industry" (Chiras 1991:315), a "chemical tragedy" (EPA OSWER 89-008.1 1989:i), and a "chemical catastrophe" (Abrams and Ward 1990:135). Most chemical accidents are not on this scale. Knowing about different scales of accidents and other chemical release information will help the planner understand scale and character of the problem faced.

According to Andrew Fritzsche, in a 1992 article on severe accidents in the Risk Analysis journal, most Americans wrongly believe disasters are a major risk in our society. He states, that man-made technological disasters make up only 0.01 percent of total deaths in the United States (Fritzsche 1992:327). In order to be informed on actual data concerning chemical accidents, this Chapter will review the definition of a catastrophic accident and discuss two databases compiled by the Environmental Protection Agency.

This information from the chemical accident databases will begin to answer the question, "What accidents need prevention planning?" The question, "Why planning is important?" is next. The main reason for planning is the many regulationsthat require plans. Many of these plans will be discussed with an emphasis on SARA, Title III. The first step in accident prevention planning, hazard assessment, can be done using any one of ten methods. The ten methods of hazard assessment and the situations for which each is appropriate are discussed. A detailed presentation of the Dow relative ranking method will end this Chapter.

Chemical Accident Information.

There is no standard for placing accidents into different categories. In 1974 an Environmental Protection Agency (EPA) report defined a catastrophic accident as having at least one of the following characteristics: ten or more people killed, 30 or more people injured, or three million dollars in property damage (EPA 520/3-75-96 1974:3). The choice of characteristics in this definition was arbitrary, to distinguish between truly catastrophic accidents and all other accidents.

Another definition of a catastrophic accident can be the Swiss Re's definition of a disaster. The Swiss national insurance company, Swiss Re, defines an event causing more than 20 deaths as a "disaster" (Fritzsche, 1992:327).

Both definitions arbitrarily draw a line between catastrophic accidents and all other accidents. Using either of these definitions, the accident at Bhopal would certainly classify as a catastrophe.

Accidents below the catastrophic level have not been defined by categories. Some spill prevention plans place spills into categories by the quantity spilled, but the quantity of a chemical released cannot be used as a measure of accident severity. Information collected in databases show that quantity is not a valid measure of the seriousness of an accident because both large and small releases may cause extensive damage, public evacuation, injury and death (EPA 89-008.1 1989:15)

The EPA has collected information in several databases covering hazardous chemical accidents and an examination of that information can show trends in the release of chemicals. Prevention planners can compare this information on chemical releases to improve their planning. For example, knowing the most common chemicals released can shows the planner where additional management attention may reduce the probability of an accident.

> The National Response Center (NRC) database, consisting of release reports received under the Superfund (CERCLA) requirement that parties report to the NRC hazardous substance releases exceeding specified reportable quantities.
>
> The Accidental Release Information Program (ARIP) is compiled from questionnaires completed by selected facilities that have reported releases to the NRC, as required by law. ARIP is unique among databases because of its focus on the causes of accidents.

The Acute Hazardous Events Database (AHE/DB) on the causes and consequences of releases is compiled by EPA from a wide variety of sources, including NRC reports and press stories.

The Emergency Response Notification System (ERNS), compiled by EPA from reports to the NRC, the Coast Guard, and EPA Regional Offices, is a national database used to collect information on releases of oil and hazardous substances as well as subsequent responses to such releases.

The Hazardous Materials Information System (HMIS), bases on written reports transport carriers are required to file, is the central system for hazardous materials transportation spill data.
(EPA 89-008.1 1989:12)

According to the AHE data base prepared in December 1985, injuries are most often associated with toxic release while deaths are most often associated with fire and explosions (see Figure 1). Since fires and explosions that

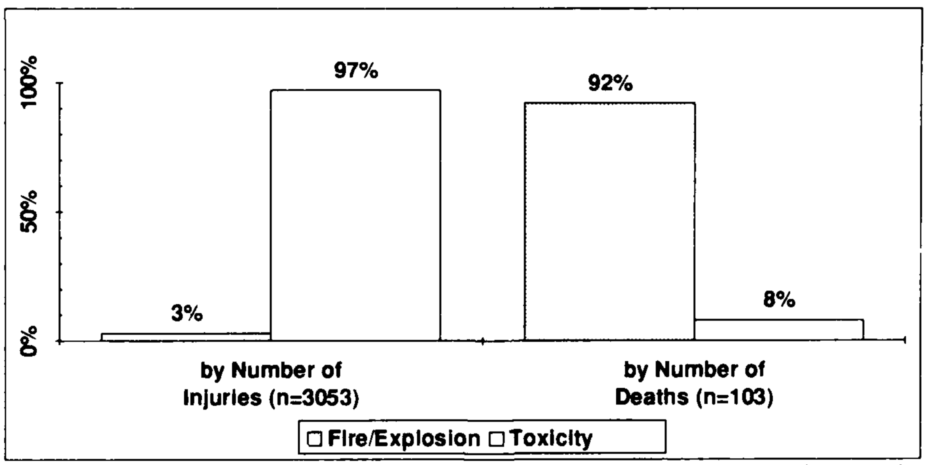


Figure 1: Acute Hazardous Events Database: Role of Fire And Explosions vs. Toxicity in Chemical Accidents (Cummings-Saxton 1985: Exhibit G).

accompany toxic releases are responsible for a greater number of deaths than toxic releases without fires and explosions, the planner may want to emphasize prevention planning for chemicals with low flashpoints, boiling points and auto-ignition.

Both the AHE and the ARIP report the same six chemicals as those occurring most often in chemical release accidents. Those six chemicals are: chlorine, methyl chloride, ammonia, sulfuric acid, sodium hydroxide, and hydrochloric acid (EPA 89-008.1 1989:14). See Figure 2. Wherever these chemicals are used, the planner should ensure additional training and equipment are included in prevention planning.

The most frequent causes of chemical releases are equipment failure and operator error according to the ARIP database (see Figure 3). This shows that even though equipment is in place, releases will occur because of equipment failure and planning is needed to minimize the occurrence and effects.

Extremely hazardous substances are assigned a threshold reportable quantity by the EPA. If releases equal or exceed

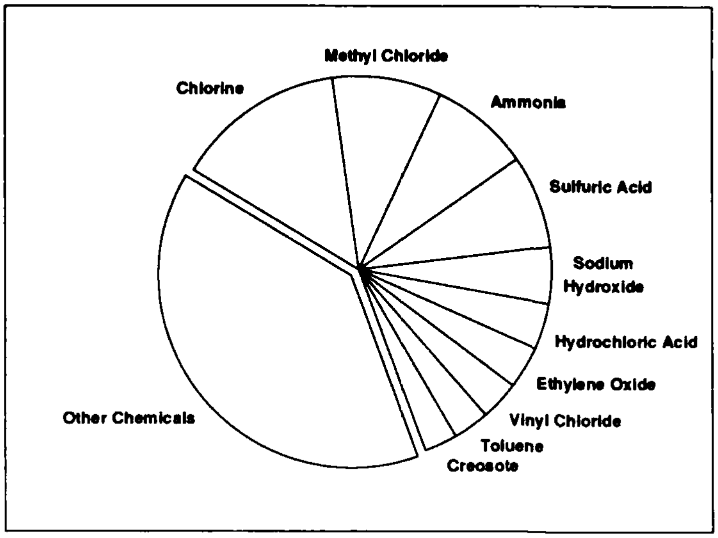


Figure 2. Accidental Release Information Program (ARIP) Database: Most frequently released chemical (EPA 89-008.1 1989:Exhibit 1).

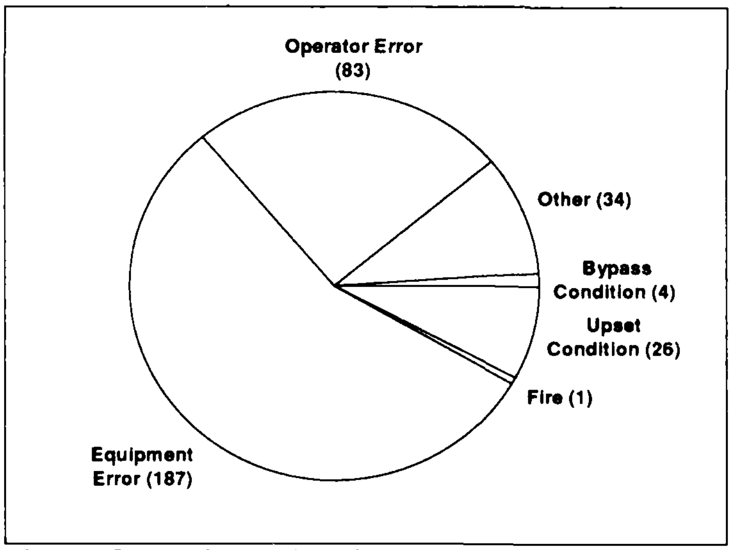


Figure 3. Accidental Release Information Program: Most common causes of releases (EPA 89-008.1 1989:Exhibit 4).

the threshold reportable quantity a report is required from the facility to the EPA. The higher the toxicity of the chemical, the lower the threshold reportable quantity. From the information on quantities of chemicals released, the database showed approximately 60 events involving chemicals with a reportable quantity (RQ) of ten pounds, 55 events at an RQ of 100 pounds and 65 events at an RQ of 1000 pounds. There is no relationship between the frequency of releases and the toxicity. In other words, less hazardous substances are not released more, or less often than substances with greater toxicity. The information on the quantity released showed no trends. (EPA 89-008.1 1989:15) See Figure 4.

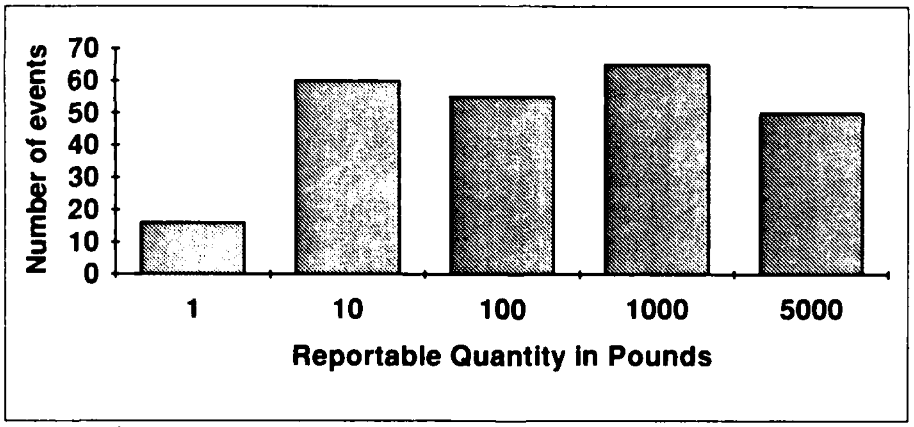


Figure 4. Acute Hazardous Events Database: Number of events by reportable quantity for death and injury events (EPA 560-5-85-029(a) 1985:Exhibit F).

The data from these two databases and the resulting charts show no method of determining which material will be the cause of the next major hazard on a facility. Even though six chemicals were identified as spilled most often, they comprise only about half of all the chemicals spilled. The systematic way to prevent spills and respond effectively to spills comes from comprehensive assessments of the hazardous materials and evaluation of the hazard potential.

Planning Regulations.

Ten Emergency response and accident prevention plans for hazardous materials are required in different places in the Code of Federal Regulations (CFR). Emergency response plans are required under Title III of the Superfund Amendments and Re-authorization Act (SARA Title III). SARA Title III requires Federal, State and local governments, and industry to prepare emergency response plans for extremely hazardous substances (EHS). The EPA has published a list of EHS and a threshold quantity for each substance. Plans are developed by conducting hazard assessments for extremely hazardous substances in quantities equal to or greater than the threshold planning quantity listed in 40 CFR 355. (AFP 19-33 1992:1-2) Spill Prevention Control and Countermeasures (SPCC) plans are prepared and implemented as required under 40 CFR Section 112 which are the EPA regulations on oil and hazardous substance pollution prevention for all non-transportation facilities that could discharge oil into navigable waters.

The safety and health of employees involved in the cleanup of hazardous waste, the storage of hazardous waste or in emergency response to incidents involving hazardous substances is covered under 29 CFR 1910, the Office of Safety and Health Administrations regulations. While each of these regulations requires management and response plans, they do not require a separate plan for each regulation. To avoid duplication, SARA Title III plans may incorporate requirements to satisfy other regulations.

Under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), 40 CFR 300 Requires pollution contingency plans discussing reporting and responsibility requirements. Emergency response plans are directed to be accomplished in accordance with SARA Title III requirements.

Of all the regulations, SARA Title III is the most critical regulation that applies to emergency planning (Bare 1988:2) because of the requirements it makes for local emergency response planning. Only one of the four major sections of SARA deal with emergency planning, while the other three, emergency notification, community right-to-know reporting requirements, and toxic chemical release reporting all deal with keeping the public informed.

Under the emergency planning sections, 301-303, all facilities that use or store hazardous substances must report details of those substances and must participate in the planning process (EPA 90-536-P, 1990:1). In the emergency planning section of SARA, Title III, states are required to create State Emergency Response Commissions (SERCs). SERCs are to appoint Local Emergency Planning Districts and each district is to establish Local Emergency Planning Committees (LEPCs).

SARA charges LEPCs with establishing emergency response plans, and because Air Force bases provide their own emergency response to chemical releases, including a police and fire department separate from the local community, the Air Force base is considered a LEPCs and is required to prepare the emergency response plans in accordance with SARA. Section 303(d) of SARA "requires facilities to provide the committee with information relevant to development or implementation of the local emergency response plan." (Bare 1988:2) The way the law is written, the Air Force base takes on the role of the facility owner/operator and the LEPC committee. In addition to SARA, OSHA requires hazardous material emergency response personnel, including fire police department personnel, to be protected by the employer through training and preparation of response and prevention plans.

The LEPC emergency response plan must include, among other things, "methods for determining the occurrence of a release and the probable affected area and population" (Bare 1988:2). To address methods of determining the probable occurrence of releases, hazard identification and evaluation methods are used.

The draft Air Force Pamphlet 19-33, the Hazardous Material (HAZMAT) Planning Guide, encourages bases to prepare a comprehensive plan as an annex to the base Disaster Preparedness Plan. This HAZMAT plan would satisfy several different regulatory documents including LEPC requirements and simplify environmental regulatory requirements by meeting the needs of all the regulations in one document. (AFP 19-33 1992:1-1)

Compliance. Failure to comply with a LEPC requests for installation emergency response planning and notification information could result in an EPA penalty of up to $25,000 per day (EPA 90-536-P, 1990:4). If the base is the LEPC the base would not make requests and fail to comply with itself, but other areas of SARA encourage compliance SARA Title III entitles local groups and citizens to bring civil action suits in US District Court against owners and operators of facilities that fail to comply with the law (EPA 90-536-P, 1990:4). In a civil action suit, failure to comply with SARA may be offered as evidence of negligence. (Lowry, 1988:39-40) It is possible that if a base does not prepare a comprehensive hazard materials plan that includes assessment and evaluation, a case of negligence could be brought for each chemical release reported.

Importance of Hazard Identification and Evaluation.

As discussed earlier, regulations require the Local Emergency Planning Committee to develop a local emergency response plan including methods for determining the occurrence of a release and the probable affected area and population (Bare 1988:2). In the emergency planning process, hazard assessment is a two step process. Hazard identification is the first step and evaluation of those hazards the second step (Lees, 1980:805)(ILO, 1988:7)(Davis, 1987:42)(EMI 1985:6)(EPA 9223.0-1A, 1988:3-4 to 3-5). Many advocates of emergency planning list these two steps as crucial to the effectiveness of the spill prevention plans.

Hazard identification takes inventory of the facility. This inventory should include all possible hazards relating to transportation, handling, use, processing, or storage of hazardous materials. Hazard evaluation then determines the potential hazard presented by each inventory item or manufacturing process. Without a hazard evaluation, the planner cannot determine hazard potential and would allocate the same resources to each area.

Spill response is the complex integration of numerous departments, technologies and techniques. Safe effective response can only be achieved with careful planning and assessment. (Hosty 1992 ix) By knowing which areas have the highest hazard potential, reduction in quantity or replacement with non-hazardous materials can be planned.

Fire departments can be informed of which areas have the highest potential for explosion and fire so that safety checks can be made more often. Additional personnel may be needed to perform routine maintenance in higher hazard potential areas.

<u>Standard Methods of Hazard Identification and Evaluation</u>.

In the past twenty years hazard assessment techniques have gone through major developments (Holden 1985:164-165). Chemical hazard assessment has evolved from engineering reliability analysis and safety studies into an independent study of hazards involving hazardous materials.

Hazard assessment can trace its roots to the first engineering studies of air travel and air travel reliability. The earliest use of quantification techniques came in the 1950's determining the safety of air travel, nuclear and defense fields. In the 1960's the Mercury and Gemini space programs made extensive use of engineering reliability to ensure the safety of space programs.

Reliability studies were developed to determine the frequency of failure of equipment in order to correct problems before an accident. In the 1950s and 1960s assessment was aimed at ensuring aircraft, space equipment and nuclear power were safe, but the chemical process industry quickly adapted methods for use in chemical manufacturing plants. The leader in hazardous materials safety assessments, the chemical process industry, has been testing systems using reliability techniques to determine the probability of equipment failure since the 1960's.

Determining risk to individuals was the next step in the evolution of hazard assessments. The US Atomic Energy Commission conducted comprehensive risk studies concerning reactor safety in the 1970s. These studies included reliability of equipment failure and an assessment of the risk to workers and the surrounding population. (IChemE, 1985:290)

From this history, ten different methods of hazard assessment are reported in the literature. There is no single system of hazard identification procedures (Lees, 1980:133), but there are ten methods that each have different qualities and are applicable to meet different needs. There are ten common methods capable of assessing hazards to meet this requirement: 1. preliminary hazard analysis, 2. checklists, 3. safety reviews, 4. what-if analysis, 5. hazard and operability studies, 6. failure mode, effects and criticality analysis, 7. fault tree analysis, 8. event tree analysis, 9. cause-consequence analysis, and 10. the Dow hazard indices for relative ranking.

Some methods are more applicable to early stages of design, others are better for operational plants. Different methods require different levels of staffs and various amounts of time to complete. The requirements of the situation are taken into account when determining the appropriate method to use.

Several authors have published comparisons and summaries of the most common methods, highlighting the situations where each method is best suited. Table 1 is from the 1987 EPA Prevention Reference Manual. This manual is the first to compare methods of hazard assessment.

Choosing an Assessment Method for the Air Force.

All the methods have common features, but their differences make them more suitable for specific situations (Davis 1987:53). These differences are: plant construction phase (planning, design, under construction or in operation), numerical probabilities of equipment failure required, qualitative relative ranking results, personnel requirements, cost, and staff experience required.

For use in this study, the method needs to be one that can be reproduced at the Air Force base level, because each base needs to have the ability to assess hazard potential. To be suitable for an Air Force base, the method must require a small staff and not require engineering reliability expertise. The results of an assessment at the base level requires qualitative results and is limited to methods suitable for use in an operational setting.

Preliminary Hazard Analysis (PHA). PHA is the term applied to any method that is used at the planning stages of

TABLE 1
Summary of Key Features of Hazard Identification and Evaluation Methods from 1987 EPA Manual (Davis 1987:44-47).

Method	**Purpose**	**When to Use**	**Nature of Result**	**Staff Size Needed**	**Relative Cost**
Checklist	Identify Common Hazards, Ensure Compliance	Design Constr. Startup Operation Shutdown	Qualitative	Small	Low
Safety Review	Identify Hazards, Ensure Compliance Identify Changes, Review Adequacy of Maintenance	Startup Operation Shutdown	Qualitative	Small to Moderate	Low to Moderate
Relative Ranking, Dow/Mond, Method	Provide relative process ranking by risk	Design Operation	Relative Qualitative Ranking	Moderate	Moderate
Preliminary Hazard Analysis	Identify hazards early in process life cycle prior to final plant design	Early Design	Qualitative	Small	Low

TABLE 1. (Cont.)

Method	Purpose	When to Use	Nature of Result	Staff Size Needed	Relative Cost
What-if Analysis	Identify hazards, Identify event sequences, Identify possible methods of risk reduction	Process Development Pre-startup Operation	Qualitative	Small to Moderate	Moderate
HAZOP	Identify hazards, Identify operability problems Identify event sequences Identify possible methods of risk reduction	Late Design Operation	Qualitative	Moderate to Large	Moderate to high
Failure Modes, Effects and Criticallity Analysis	Identify system/ equipment failure modes Identify effect of failure on system/ plant Rank criticallity of each failure mode	Design Construct. Operation	Qualitative	Small	Low to Moderate

TABLE 1 (Cont.)

Method	Purpose	When to Use	Nature of Result	Staff Size Needed	Relative Cost
Fault Tree Analysis	Determine causes and event sequence leading to a defined event Identify combinations of causes including both equipment failures and human errors	Design Operation	Qualitative Quantitative	Small to Large	Low to High
Event Tree Analysis	Determine consequences sequence of defined initiating event	Design Operation	Qualitative Quantitative	Small to Large	Low to High
Cause Consequence Tree Analysis	Identify both cause con-sequence and consequence sequences of events	Design Operation	Qualitative Quantitative	Small to Large	Low to High

a chemical plant design. Some methods are not suitable for this planning stage because they require hard data. The planning stage is before the actual design begins, and PHA is used to identify potential hazards for the design teams to eliminate or mitigate in the design. This is a very useful method for pollution prevention because designers can design systems that do not pollute. (Armenante 1991:352, Davis 1987:49) This method is not applicable to this study because the Air Force Bases being assessed are all in operation.

Checklists and Safety Review Methods. These two methods are very similar in that they both use lists to identify hazards. The major difference is that the checklist method gives a specific requirement that must be met, while the safety review method gives general requirements that the evaluator must apply to each area.

The checklist method provides specific facility or operational requirements that any person, regardless of experience, can use to identify short falls. The list contains detailed requirements of a certain topic, and is prepared by some one with experience in the topic. The greater the experience, the better the checklist. Many times the items on a checklist are in the form of a question, such as, "Is there secondary containment for the hydrazine storage tank?" By answering the questions, or "checking-off" the items on the list, the evaluator determines if there are deficiencies. The evaluator cannot qualify or rank the deficiencies, and (IChemE 1985:292, Davis 1987:48) because of this, it is considered hazard identification rather than a hazard assessment method.

The Safety Review Method is very similar to the checklist because it uses a list of requirements for the facility. The evaluator using the list provided, must have the experience and ability to know where to apply the requirements, making this method dependant on the abilities of the evaluator to perform a thorough assessment. To obtain the range of experience and abilities needed, safety reviews are performed by multidisciplinary teams of experts. The team identifies compliance problems, based on the regulations and practices provided in the listing, and relies on the experience of the team to qualify or rank the problems found. (Armenante 1991:353-355)

The Air Force currently uses both Safety Reviews and Checklists in their Inspector General Inspections and Environmental Compliance Assessment and Management Program. For this paper, the Safety Review method is not practical because of the need for a team and the time required to perform an assessment. This method is also limited in that it provides a subjective ranking of hazards that cannot be compared from one base to another because different assessors are used for each assessment.

<u>What-If Analysis and Hazard and Operability Studies (HAZOP)</u>. Both of these methods use systematic ways of considering the consequences of unexpected events. In the What-If Method, experts looking for unexpected events, follow the probable consequences of the event to determine the effect on product, or ultimate hazard potential.

For example, they ask, "What if the automatic valve sticks open?" The evaluators then trace the possible consequences of that problem. They then ask, "What if the valve sticks closed?," and follow the same procedure as before. The attempt is to exhaust all possible problems and all probable consequences, assigning a probability of hazard to each consequence based on the probability of occurrence. (Davis 1987:50)

HAZOP studies use the What-If method combined with a structured approach that uses guide words to trace the consequences of an unexpected event. The purpose of the guide words is to explore problems and consequences in an organized manner. Examples of guide words include: none, more of, less of, part of, more than, other than, and reverse. When examining the flow through a valve, for example each of the guide words would be applied to search for possible consequences. For the guide word, None, what are the consequences when there is no forward flow when there should be. For the guide words, More of, what are the consequences when there is more of any physical property than there should be, including: higher flow quantity, higher flow rate, higher temperature, higher pressure, higher viscosity or any other physical property that could be applied. A similar procedure is used with each guide word.

Both methods are able to provide a complete qualitative list of potential hazards, possible causes, and consequences. The dependance on teams of experts and the time required to perform a thorough study made these methods impractical for use in this study. The need for engineering reliability experience to calculate probabilities of failure also contributed to the methods not being selected.

Failure Modes, Effects and Criticality Analysis (FMECA). This method examines the consequences of failure for each system or piece of equipment. The three parts of each FMECA include: 1. How the equipment or system can fail, 2. The effect of the failure on the process, and 3. The seriousness of the consequences. Failure probability and frequency data are required to perform the first two parts of the FMECA. (Davis, 1987:50, Armenante, 1991:362)

A small group of technical people can perform this method in a short amount of time if the probability and frequency data is available. The results are qualitative, but detailed, because the analysis can be carried out at different levels, depending on the scope (Armenante, 1991:362). This method was not considered because of the lack of probability and frequency data for releases of materials that are needed to use this method.

Fault Tree Analysis, Event Tree Analysis, and Cause Consequence Analysis. These three methods are very similar because they each use a logic tree format to trace an event. The Fault Tree Analysis searches for all events that may lead to a particular failure event. Event Tree Analysis is similar except it begins with an event and searches for all the possible consequences. Cause Consequence Analysis combines characteristics of both the previous methods analyzing both multiple causes and multiple consequences.

The failure probability and frequency data associated with the occurrence of each even are required for these three methods. Each method develops a chain of interrelated events, which, when constructed, look similar to a flow chart using "if-then", "and" and "or" gates. (Davis, 1987:52; Armenante, 1991:367-375; Kandel and Avini, 1988:21-60)

A major problem in using all three methods is the lack of available comprehensive failure probability and frequency data (DeWolf and Others, 1988:11). Comprehensive data is needed for each branch of the tree to calculate the probability of possible hazard.

Dow Hazard Indices or Relative Ranking. The Dow Method is a quantitative method to "numerically rate a chemical process unit for hazards, and indicate measures that may be taken to neutralize or minimize them" (Dow 1973:2). This Index was first published in 1964 as the Fire and Explosion Index for chemical processing plants. Originally Dow Index had an objective and a subjective evaluation. The subjective evaluation was eliminated in subsequent editions, but the authors admit the opinion of the evaluator can still be expressed in the selections made. (Dow 1973:2)

The index produces a number that is used to determine the level of hazard potential. The number is generated by a formula that takes into account hazardous process and accident prevention equipment. Each facility is divided into process working elements, then, for each element, positive scores are given to process features that prevent accidents while negative scores are given to processes that are hazardous. The scores are added and placed into the formula to yield a ranking index for the each working element (Davis 1987:49).

Based on the ranking index, the investigator can place the element in a low, medium or high hazard potential category. This method has been revised and augmented by different organizations and was selected by the International Labor Office (ILO) to aid developing countries in identifying hazards. The ILO made changes to simplify the method and to identify toxic hazards. (ILO 1988:7)

This Dow method, as simplified by the ILO, is the most appropriate for this study because it provides a ranking of hazards, results are qualitative, can be detailed if the identification is detailed, does not require failure probability and frequency data, requires a small staff and no experience with engineering reliability calculation.

Simplified Version of Dow Chemical Company Relative Ranking Method (ILO, 1988).

The ILO published a book to help countries develop hazard assessment methods. In that book, the ILO presented a simplified relative ranking method based on the Dow Chemical method. The simplified method will be explained in detail here as the method chosen for this research. The following description is taken from the International Labor Office publication, Major Hazard Control, A Practical Manual (ILO. 1988:57-69).

The International Labor Office (ILO) divided the ranking system into three parts: 1. The subdivision of the installation, 2. The determination of the fire and explosion index and the toxicity index, and, 3. The classification of hazards into categories.

In the first step, the subdivision of the installation into parts, a process plant is separated into each working element. Each of these elements has a fire and explosion index and a toxicity index which determined in Step 2. Using formulas provided, the two indexes are calculated in Step 2 using numerical factors that represent the characteristics of the material and the processes involved. From the results in Step 2, the element is then assigned a classification of hazard potential. This method uses three classifications, low, medium and high.

The first and third steps are fairly simple. The second step is the foundation of the ranking system. To determine the fire and explosion index (F), a material factor (MF), a general process hazard factor (GPH) and a special process hazard factor (SPH) are determined for each working element and are used in the following formula:

$$F = MF \times (1 + GPH_{tot}) \times (1 + SPH_{tot})$$

Material factor. The Material Factor (MF) is a measure of the potential energy of the most hazardous substance present and denoted by a number from 0 to 40. The material factor is the basis for determining the index of the material.

Flammability and reactivity are the two characteristics that determine the material factor for a given chemical or material. The material factor will be a constant for any given material.

To compute the material factor, the National Fire Protection Association (NFPA) rating for flammability and reactivity are used in the following table. NFPA ratings are published in a variety of sources and range from zero to four.

TABLE 2: DETERMINATION OF A MATERIAL FACTOR (ILO 1988:59).

		NFPA rating for reactivity				
		0	**1**	**2**	**3**	**4**
NFPA rating for Flammability	**0**	0	14	24	29	40
	1	4	14	24	29	40
	2	10	14	24	29	40
	3	16	16	24	29	40
	4	21	21	24	29	40

As examples, ethylene oxide with a flammability rating of 4 and a reactivity rating of 3 leads to a material factor of 29, and Butyl acrylate, with a flammability of 2 and a reactivity of 2, leads to a material factor of 24. (Table 2) Flammability and reactivity ratings are found in National Fire Protection Association codes, which are generally available in fire departments.

General process hazards. The total general process hazards (GPH) is a measure for the hazards commonly found in the manufacturing process. The general process hazards applicable to the working element are added together to compute the total general process hazards. In the original Dow method, there is a system of credits and penalties. Credits are positive scores given for prevention equipment, and penalties are negative scores given for the hazards. In the simplified method, only penalties are calculated to identify the hazards and the negative sign is removed for more simple calculations.

The following is a complete list of general process hazards and associated penalties that are listed in the simplified version of the Dow relative ranking method prepared by the ILO.

1.Exothermic Reactions	Penalties
1a. Combustion	0.20

	Penalties
1b. Condensation	0.50
1c. Neutralization	0.30
1d. Halogenation	1.00
1e. Oxidation	0.50
1f. Nitration	1.25
1g. Polymensation	0.50

2. Endothermic Reactions

2a. Electrolysis	0.20
2b. Pyrolysis	0.20

3. Handling and Transfer

3a. Loading and unloading of hazardous materials, especially coupling and uncoupling of transfer lines. 0.50

4. Warehousing and yard storage

4a. Materials with storage temperature below atmospheric boiling point. 0.30

4b. Materials with storage temperature above atmospheric boiling point. 0.60

5. Storage within a building

5a. Flammable liquids above flashpoint but below atmospheric boiling point: 0.30

	Penalties
5b. Flammable liquids or LPG above atmospheric boiling point	0.60

For example, the storage of 100 pounds of formaldehyde in the supply warehouse would have a GPH_{tot} of 0.8. The score is computed by adding a 0.5 penalty for loading and unloading of dangerous materials to the 0.3 penalty for warehousing. No other general process hazard penalties would apply.

<u>Special Process Hazards</u>. Special process hazard (SPH_{tot}) is a measure for the chemical and physical characteristics in the working element being assessed. Special process hazards are assigned for large quantity storage, pressurized gasses, and low material flashpoints. The following is a complete list of penalties that are listed in the simplified version of the Dow relative ranking method prepared by the ILO.

1. Process temperature	Penalty
Process conditions above material:	
1a. Flashpoint	0.25
1b. Boiling point	0.60
1c. Material has low auto-ignition temperature (hexane and carbon disulphide)	0.75

2. Low pressure (vacuum distillation): no penalty for operation at atmospheric or sub-atmospheric pressure if air leakage is not a hazard. If air leakage does create a hazard apply a 0.50 penalty for pressures from 1 to 0.67 bar and a penalty of 0.75 for pressures less than 0.67 bar.

3. Operation near flammable range:

3a. Outdoor tanks 0.50

If gas air mixture in vapor space is near flammable range.

3b. Any process operating in the flammable range: 1.00

4. Operating pressures above atmospheric pressure have variable penalties based on the amount of pressure.

1 - 10 bar	0.50 penalty
11 - 100 bar	1.00 penalty
>100 bar	1.50 penalty

5. Low temperature:

-30C to 0C	0.30 penalty
<-30C	0.50 penalty

6. Quantity of flammable material used in the process carries a penalty and is obtained by multiplying the kilograms of material in process by the heat of combustion, expressed in kJ/kg, to obtain the quantity of energy present, expressed in

kJ. Using Figure 5, the quantity multiplied by the heat of combustion will obtain a penalty between 0.30 and 1.5.

For flammable materials in storage the penalty is obtained by multiplying the kilograms of material in process by the heat of combustion and comparing that number to a separate figure. On Figure 6 a distinction is made between pressurized liquified gas and flammable liquids. The penalties range from 0.20 to 1.60. Both the process and the storage penalties can be calculated using formulas provided. Since this assessment is performed on each working element of

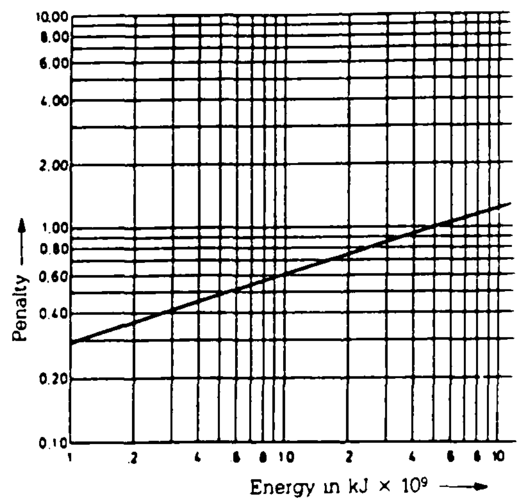
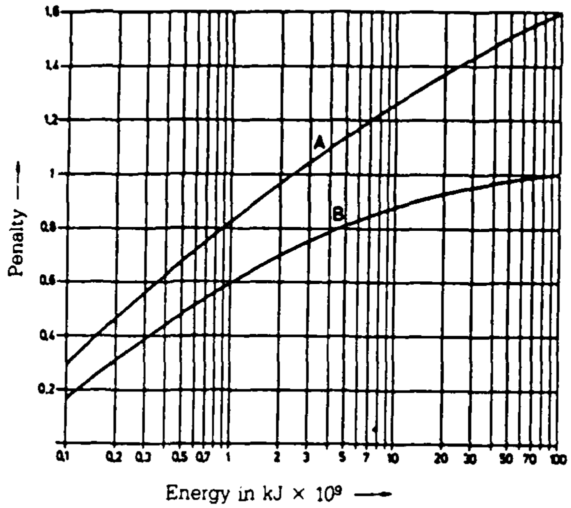


Figure 5: Penalty for quantity of energy present in the flammable material in process (ILO 1988:62)



Curve A. pressured liquefied gas.
Curve B. flammable liquids.

Figure 6: Penalty for the quantity of energy present in the flammable material in storage (ILO 1988:62)

the facility, storage is considered to be the materials in a warehouse. If materials are stored in other locations, they should also be assessed and listed in the HAZMAT or SPCC plan.

<u>Example of Applying the Fire and Explosion Index</u>. Ammonia is a common hazardous material found on Air Force bases. Ammonia has an NFPA flammability rating of 1 and an NFPA reactivity rating of 0, giving it a material factor of 4 from Table 2. NFPA ratings can be found in the <u>Handbook of Hazardous Materials</u> published by the Alliance of American Insurers (Alliance 1983:74), or the <u>National Fire Codes</u> published by the NFPA (NFPA 1988:49-15). The GPH of ammonia, stored in a 500 gallon container would be 0.80, receiving 0.5

penalty for loading and unloading (para 3a), and 0.3 penalty for storage (para 4a). The SPH would be 1.0, received for the quantity (Figure 6). Using these figures the Fire and Explosion Index would be as follows.

$$F = MF \times (1 + GPH_{tot}) \times (1 + SPH_{tot})$$

$$F = 4 \times (1 + 0.8) \times (1 + 1.0) = 14.4$$

Toxicity Index. The toxicity index is based on the health hazards rating established by the National Fire Protection Association (NFPA) for each chemical. The formula for the Toxicity Index (T) is:

$$T = (T_h + T_s) \times (1 + GPH_{tot} + SPH_{tot})$$

A toxicity factor (T_h) is assigned, based on the NFPA health rating. Using the NFPA health rating, which ranges from zero to four, the toxicity factor is assigned using Table 3. The toxic substance factor (T_s) is determined based on the maximum allowable concentration (MAC) for the substance. The ILO used the German Research Society's MAK, or Maximum Allowable Concentration values for material classified as a workplace hazard (Lewis 1990:xii). MAK values are either in part per million or miligram per kilogram depending on the substance. The toxic substance factor is assigned using Table 4.

Applying the Toxicity Factor and the Toxic Substance Factor to the Toxicity Index equation will provide a number that can be used to classify the substance.

Example of Applying the Toxicity Index. Using ammonia as the example again, the Toxicity Factor is 1.25, based on a NFPA health rating of 2, and the Toxic Substance Factor is 0.75, based on a MAK value of 50 ppm found in the Rapid Guide to Hazardous Chemicals in the Workplace (Lewis 1990:10). The Toxic Index for ammonia is 5.6.

TABLE 3: TOXICITY FACTOR (T_H) BASED ON THE NFPA RATING

NFPA	T_h
0	0
1	.50
2	1.25
3	2.50
4	3.25

TABLE 4: TOXIC SUBSTANCE FACTOR
BASED ON MAXIMUM ALLOWABLE CONCENTRATION

MAC - ppm	**T**
< 5	1.25
5 - 50	.75
> 50	.50

Classification. The third and final step of this process is to use the Fire and Explosion Index number obtained and the Toxicity Index to determine the classification of the working element. The table below is used to determine the classification:

TABLE 5: CLASSIFICATION OF HAZARD POTENTIAL

	Fire and Explosion Index (F)	**Toxicity Index (T)**
Low	F < 65	T < 6
Medium	65 <= F < 95	6 <= T < 10
High	95 <= F	10 <= T

If the working element has both a Fire and Explosion Index and a Toxicity Index, and the indexes fall into different classifications, then the higher classification is used.

Example. Continuing the ammonia example, the F index is 14.4 and the T index is 5.6, placing this quantity of ammonia in the low probability for hazard range.

Chapter Summary.

In this chapter the most common methods of hazard assessment were described and comparisons between the methods used to explain the author's choice for using the Relative Ranking Method for this study. The simplified relative ranking method developed by the ILO was explained in detail because these are the procedures used in the next chapter.

III. Adapting and Applying the Relative Ranking Method

The Dow Relative Ranking Method as altered by the International Labor Office was applied to the hazardous materials at Davis-Monthan Air Force Base. Using the results from that assessment, Seymour-Johnson and Shaw Air Force Bases were then assessed using the same method. The results were then compared and analyzed.

Choice of Facilities.

The Air Combat Command (ACC) was selected as a test command because of the large number of bases and the fact that they have very few material testing or laboratory facilities not related to direct support of the flying operations. As a result their limited missions mean fewer chemicals to assess. Additionally, the ACC was chosen because the ACC recently contracted to have spill prevention, control and countermeasure (SPCC) plans developed for many bases. The inventories of hazardous materials from Seymour Johnson and Shaw AFBs' SPCC draft plans were made available for this study. In addition to the two plans provided by ACC, the SPCC Plan from Davis-Monthan Air Force Base was provided by the base.

Although the selection of the three bases was not a random choice, Table 6 shows that the physical features of the bases

TABLE 6: PHYSICAL DESCRIPTIONS OF DAVIS MONTHAN, SHAW AND SEYMOUR JOHNSON AIR FORCE BASES, FROM AIR FORCE MAGAZINE, MAY 1993.

	Davis-Monthan	Shaw	Seymour-Johnson
Mission	ACC base, A-10 combat crew training, OA-10 and FAC training,ops, and mgmt of 12th Air Force Operations GP; 41st and 43d Electronic Combat Sqdns, EC-130H electronic operations, 71st Special Operations Sqdn (AFRES), MH-60G Pave Hawk helicopter operations, Det 1, 120th Fighter Gp (Mont. ANG), F-16 air defense operations.Also site of AFMC's Aerospace Maintenance and Regeneration Center, storage location for excess DoD aerospace vehicles	ACC base, 363d Fighter Wing, F-16 fighter operations and A/OA-10 FAC operations, HQ 9th AF	ACC base, 4th Wing F-15E fighter and KC-10 tanker operations; 916th Air Refueling Gp (AFRES), KC-10 operations
Age	activated 1927	Aug 30, 1941	Jun 12. 1942
Area	11,000 acres	3363 acres, supports another 8353 acres	3233 acres
Alt	2629 ft	244 ft	109 ft
People	5155 mil 1369 civ	5865 mil 1100 civ	4641 mil 1194 civ
Hosp.	35 bed hospital	40 bed hospital	20 bed hospital

are similar in size, age, number of people and size of the hospital. Since there was no mathamatical basis for this sample group, no generalizations can be made from these three bases to the ACC.

Adaptation of the relative ranking method.

In the Dow Method, the chemical plant is divided into elements of processing; however, operational Air Force flying wings do not have elements similar to chemical plants. Therefore, the working elements used for this study come from the base's Spill Protection, Control and Countermeasures plans. These plans list, by location, the quantity and type of hazardous materials stored which become the working elements. In addition, since many of the general process hazard and special process penalties are specific to chemical plants and do not apply on an Air Force. Hence, the penalties that will apply are handling and transfer, operation in a temperature near the flashpoint of a material, operating pressure above atmospheric pressure, and penalties for the quantity of hazardous material.

Also some penalties will not be able to be applied because the study will work from a list of materials, not from on-site investigations. For example, used battery acid found in battery repair shops is commonly neutralized. For this operation a penalty could be applied in the general process hazards section, but would not in this application because the actual quantity in operation is unknown.

Assessment.

The ILO adaption of the Dow Relative Ranking method includes a Toxicity Index based on a toxicity factor and a toxic substance factor. The toxicity factor is based on the NFPA health ranking and is available for all materials. The toxic substance factor is based on the maximum allowable concentrations. Where MAC values where not available, permissible exposure limits (PEL) were used to calculate the toxic substance factor.

To begin the study, all the hazardous materials listed in Davis-Monthan Air Force Base's SPCC Plan were assessed using the Dow Relative Ranking Method (see Appendix A). Seymour Johnson and Shaw SPCC plans were then assessed using the same method, but limiting the assessment to only the materials that had a possibility of entering the medium or high hazard potential categories (see Appendix B).

Materials that had a possibility of entering the higher classifications were: 1. Those that ranked in the medium or high range in Davis-Monthan's Assessment. 2. Chemicals not on Davis-Monthan's list. 3. Chemicals that exceeded the highest quantity for the same material at Davis-Monthan by twenty percent. This procedure eliminated the need to assess materials, like motor oil, that were consistently in the low hazard potential category regardless of quantity. The results of the assessments were compared to see if the same hazardous materials were consistently categorized in the medium to high hazard potential class across the three bases.

IV. Results and Suggestions for Continued Research.

Applying the Dow hazard assessment method to Davis Monthan's list of hazardous materials revealed six chemicals that were in the medium or high hazard potential categories. The assessments for Seymour Johnson Air Force Base produced 28 materials in the medium or high hazard category, but the assessment at Shaw Air Force Base presented only two materials in the same categories.

Davis-Monthan Assessment.

Six materials exceeded the low hazard potential classification: acetone, acetylene, ammonia, chlorine, hydrazine, and sulfuric acid. Acetone and acetylene were pushed into the medium and high potential categories because of their heat of combustion, and the conservative approach used in the assessment. The remaining four materials entered the medium category for hazard potential based on their National Fire Protection Association (NFPA) health ranking and the maximum allowable concentrations.

Acetone and acetylene were assigned penalties of 1.6 and 2.0 respectively in the special process hazards category. For acetone a penalty of 0.6 was assigned for process (storage) conditions at a temperature above the atmospheric boiling point and a 1.0 penalty for the quantity in storage. For acetylene a penalty of 0.5 was assessed for use of pressurized gas near the flammable range and a penalty of 1.5 was assessed for quantity. The quantity penalties are conservative estimations based on the quantities listed in the SPCC plan. The quantities in the plan for both chemicals were listed in cubic feet instead of pounds. A more accurate description of quantity would probably produce a lower penalty.

Examining the F Index (fire and explosion), the hazard potential category in which acetone and acetylene will be placed is dependent on the quantity. By evaluating both materials at various quantities, storage quantities can be found that will rank both materials in the medium hazard potential category instead of the high category (see Table 7). The next step would be for the base to determine if these storage quantities are viable. They would need to determine if this amount satisfied the basic requirements and if resupply could occur often enough to keep the minimum amount needed in stock.

TABLE 7: HAZARD CLASSIFICATIONS FOR ACETONE AND ACETYLENE

Acetone	**Acetylene**	**Hazard Class**
0	0	Low
1 - 850 lbs	1 - 155 lbs	Medium
> 850 lbs	> 155 lbs	High

The remaining materials, ammonia, chlorine, hydrazine, and sulfuric acid all ranked in the medium hazard potential category. While the quantity of material present effects the toxicity ranking, all four materials exceed a toxicity index of six at the smallest quantity. Hence, these chemicals will always be in a Table 5 medium or high hazard potential category. See Table 8. For all six materials, quantity was the variable that determined the hazard classification.

TABLE 8: TOXICITY INDEX OF CHEMICALS BASED ON EQUATION $T = (Th + Ts) * (1 + GPH + SPH)$

	T_h	T_s	Min GPH	Min SPH	T
Ammonia	2.5	.75	.8	.1	6.2
Chloride	2.5	1.25	.8	.2	7.5
Hydrazine	2.5	1.25	.8	.6	9
Sulfuric Acid	2.5	1.25	.8	0	6.8

Shaw and Seymour Johnson Assessments.

The assessments at Shaw Air Force Base and Seymour Johnson Air Force Base were limited to the materials that had a higher probability of being in the medium or high hazard potential classification. Only two chemicals were assessed at Shaw Air Force Base, hydrazine and chlorine, because there were no new materials listed at Shaw Air Force Base that were not already assessed from Davis-Monthan, and Shaw did not list any acetone, acetylene, ammonia, or sulfuric acid. Table 9 shows the assessment of the chlorine and hydrazine.

In addition to the listing of hazardous materials and quantities, Shaw Air Force Base's SPCC plan also listed chemicals used at the entomology shop. The list did not have quantities of materials, but did list active ingredients and percent volume. Without the quantity of active ingredients, the special process hazards (SPH) could not be calculated, and the Toxicity Index could not be calculated because many of the chemicals in the pesticide were not rated by the NFPA. Using Richard Lewis' book, Rapid Guide to Hazards in the Workplace, a scale was found that rated the listed chemicals. All of the chemicals were rated as extremely toxic by Lewis.

TABLE 9: HAZARD ASSESSMENT, SHAW AFB, SOUTH CAROLINA

Location	Material	Quantity	MF	F	T	H.C.
1207	Hydrazine	42.5 lbs	24	51.84	7.5	Med
1619	Hydrazine	412 gal	24	90.72	10.88	Med
Pool 1	Chlorine	50 lbs	29	62.64	7.5	Med
Pool 2	Chlorine	50 lbs	29	62.64	7.5	Med
Pool 3	Chlorine	50 lbs	29	62.64	7.5	Med

Seymour Johnson Assessment. The list of hazardous materials for Seymour Johnson AFB had a different format from either Davis-Monthan or Shaw Air Force Bases. Within the main list from Seymour Johnson was another list of Emergency Planning and Community Right-to-know Act (EPCRA) reportable chemicals. Of the 28 materials listed, seven materials, acetone, formaldehyde, hydrazine, methanol, methyl ethyl ketone, sulfuric acid, and 1,1,1-trichloroethane were also listed in the Davis Monthan hazardous materials list.

The majority of the materials listed were from the entomology shop, the hospital, the corrosion control (equipment painting) facility, and supply. All 28 materials were assessed using the Dow method with nine chemicals classifying as high hazard potential, ten as medium hazard potential, and seven as low hazard potential. Two chemicals, dichoromethane and digoxin could not be rated because no information was available on toxicity or heat of combustion. Table 10 only displays the assessment results for the chemicals in the medium or high hazard potential classification. The rankings for all 28 chemicals are in Appendix B.

Comparison of Assessments and Comments.
There is a disparity between the number of chemicals found in the medium and high hazard potential categories for Davis-Monthan, Shaw and the Seymour Johnson Air Force Base. If all three bases were representative of average Air Combat Command bases, the assessments would be expected to produce similar

Dow Chemical Company. Fire and Explosion. Dow's Safety and

TABLE 10: MEDIUM AND HIGH HAZARD POTENTIAL CHEMICALS FROM SEYMOUR JOHNSON'S EPCRA REPORTABLE CHEMICAL LIST

Location	Material	Quantity	Hazard Class	F	T
Hospital	Cyclophosphamide	.5 lbs	M	L	M
	Selenium Sulfide	1 lbs	M	L	M
Entomology	Chloropyrofos	89 lbs	M	L	M
	Diazion	31 lbs	H	H	H
	Warfarin	55 lbs	M	L	M
Corrosion Control	Strontium Chromate	5 lbs	M	L	M
	Toluene	550 lbs	H	H	H
	Methyl Isocyanite	28 lbs	H	H	H
Supply	Dichloro-benzene	12,100 lbs	H	M	H
	Isobutyl Alcohol	91 lbs	H	H	M
	Methyl Isobutyl Ketone	350 lbs	M	L	M
	Naphthalene	1500 lbs	M	M	M
	Sulfuric Acid	874 lbs	M	L	M
	1.1.1-trichloroethane	868 lbs	M	L	M
	Xylene	110 lbs	H	H	M
Combat Monitors	Acetone	315 lbs	H	H	L
Photo Lab	Formaldehyde	16 lbs	H	H	M
3400	Methylene Chloride	490 lbs	H	H	H
FIG	Hydrazine	250 lbs	M	L	M

L = Low   M = Medium   H = High

lists of chemicals in the high and medium hazard potential classifications.

One of the main differences is in the reporting of pesticides. Davis-Monthan listed one pesticide, Seymour Johnson listed six materials in the entomology area, and Shaw listed 49 chemicals, but listed no quantities.

Another difference is in reporting of chemicals in supply. Seymour Johnson listed seven hazardous materials in the supply area, while neither of the other bases reported a similar number of materials in that area.

Regardless of the differences, the Dow method was able to produce a listing of high hazard potential areas on these three bases. Because the method can produce the ranking of areas, it is now possible to improve the prevention plans by planning additional resources for higher hazard areas.

For the three bases assessed, the purpose of the assessment is to comply with the SARA Title III which will result in improving the prevention, countermeasures and control of chemical releases through improved planning. Consideration of existing prevention equipment needs to be considered in discussing the hazard potential and the future installation of prevention equipment needs to be addressed in prevention plans for those areas without equipment.

General Application of Assessment Results. The Dow method does not reflect the hazard reducing potential of existing release prevention methods, such as secondary containment, and planners will have to take the effect of these methods and other factors into account when preparing plans (Unterberg 1988:89). Topography will be an important factor in planning, it will determine flow of a spill. Dikes, berms, location of water sources, safety showers, fire hydrants and fire extinguishers will all need to be considered in planning. Hazard prevention equipment will need to be installed in areas with hazard potential or the hazards will have to be moved to the equipment (Unterberg 1988:89).

Before any additional equipment is considered, planners and operators should attempt to minimize the hazardous materials and their inventories. The hazard potential can be eliminated or reduced by eliminating the use of the chemical, substituting a non-hazardous chemical, reducing the quantity of material stored. Mitigation of the hazard potential through prevention and detection devices is the final means for lowering hazard potential.

IV. Conclusions, Recommendations and Further Research

Results showed that the modified Dow method could be used to determine hazard potential on the three Air Force bases examined. One question of this study was to determine if performing hazard assessments would improve the base plans for prevention of accidental chemical releases. Since the bases examined do have high hazard potential areas, and identification of these areas is important to allocate resources, then hazard assessments can improve the prevention plans at these bases. However, it is important to note, the hazard evaluation is only as accurate as the hazard identification. Since this study used the spill prevention control and countermeasures (SPCC) plans as the hazard identification the results are a reflection of the inventory in those plans. The disparity between the SPCC plans may mean some hazards still need to be identified.

Recommendations.

The Air Combat Command should publish a list of medium and high hazard potential chemicals for its bases after performing hazard assessments of using SPCC plans from every base. Bases can then use that list to rank their known hazards and search for hazards that may have been overlooked. The ranking of hazards should be added to SPCC plans or

HAZMAT plans. Along with the listing of hazards by potential, equipment and procedures to eliminate or mitigate those hazards should also be included.

Further research.

Additional research needs to be done in spill prevention plans and formats to incorporate results from hazard assessments. In addition to identifying extremely hazardous substances, plans should also list the potential hazards from each substance. Further research could be done to modify the Dow method presented here to include credits for prevention equipment and penalties for additional hazards created downstream. The Dow method used here does not take into account primary and secondary containment or fire prevention to mitigate the hazard potential. It also does not take into account the possible effects downstream from a spill. In the case of prevention equipment, a high potential hazard may be lower. In the case of possible downstream problems caused by a spill, a low hazard may have very high hazard potential. Both cases need to be taken into account when preparing prevention plans.

Appendix A: Hazard Assessment of Davis-Monthan AFB

Location	Material	Quantity	Unit	MF	F	T	Hazard Class
106A	Lube Oil	275	gal	16	40	2.2	L
Taxi-way	Jet Fuel	356065	lbs	16	53	2.7	L
		322500	lbs	16	53	2.6	L
		222000	lbs	16	50	2.6	L
		239000	lbs	16	52	2.6	L
		280000	lbs	16	52	2.6	L
USMCR	Lube Oil	220	gal	16	37	2.1	L
65	Chlorine	300	lbs	29	63	7.5	M
		1800	lbs	29	63	7.5	M
128A	Hydrazine	30	gal	24	48	7.1	M
	Hydraulic Fld	55	gal		0	0	
	Lube Oil	110	gal	16	35	2	L
133	Lube Oil	220	gal	16	37	2.1	L
	Hydraulic Fld	110	gal		0	0	
183	Lube Oil	55	gal	16	32	1.9	L
221	Lube Oil	220	gal	16	37	2.1	L
	Antifreeze	55	gal	4	7.2	1.8	L
222	Lube Oil	165	gal	16	37	2.1	L
Munitions	Lube Oil	55	gal	16	32	1.9	L
	Brake Fluid	55	gal	4	7.2	0	
Hospital	Formalin	5	gal	21	42	4.8	L
	Cyclohexamine	55	gal	10	27	2.9	L
	Nitrous Oxide	4440	cu ft		0	1.7	L
US Customs	Hydraulic Fld	110	gals		0	0	
	Lube Oil	220	gals	16	37	2.1	L
	PD 680 Solvent	20	gal	16	32	1.9	L
1542	Methanol	110	gal	16	32	1.9	L
	Lube Oil	55	gal	16	32	1.9	L
	Hydraulic Fld	55	gal		0	0	
1740	Jet Fuel	55	gal	16	32	1.9	L
	Hydraulic Fld	110	gal		0	0	
1740	Lube Oil	385	gal	16	43	2.3	L
Aero Club	Lube Oil	220	gal	16	37	2.1	L

Appendix A: Hazard Assessment of Davis-Monthan AFB

Location	Material	Quantity	Unit	MF	F	T	Hazard Class
1750	Lube Oil	55	gal	16	32	1.9	L
2402	Hydraulic Fld	30	gal	16	29	0	
4212	Ammonia	500	lbs	4	7.9	6.2	M
	Photo Chems	115	gal		0	0	
	Bleach	25	gal		0	0	
4437	Lube Oil	110	gal	16	35	2	L
Hobby Shop	Lube Oil	85	gal	16	32	1.9	L
	Antifreeze	255	gal	4	7.9	1.9	L
	Antifreeze	300	gal	4	7.9	1.9	L
	Acetylene	255	cu ft	29	157	3.8	H
Bulk Store	Lube Oil	110	gal	16	35	2	L
4705	Lube Oil	715	gal	16	37	2.1	L
	Sulfuric Acid	100	gal	4	7.2	6.8	M
4705	Hydraulic Fld	275	gal		0	0	
	Antifreeze	110	gal	4	7.9	1.9	L
	Benzene	35	gal	16	32	1.9	L
VDP Lot	Lube Oil	1650	gal	16	37	2.1	L
	Antifreeze	165	gal	4	7.9	1.9	L
	Benzene	110	gal	16	32	1.9	L
Armament	Oil	165	gal	16	37	2.1	L
	Solvent	220	gal	16	32	1.9	L
AGE	Lube Oil	330	gal	16	37	2.1	L
	Hydraulic Fld	330	gal	16	29	0	
	Gasoline	110	gal	16	32	1.9	L
358 FS Sup	Lube Oil	110	gal	16	35	2	L
	Hydraulic Fld	55	gal		0	0	
	Methanol	55	gal	16	32	1.9	L
Refuel Maint	Jet Fuel	15000	gal	16	55	2.7	L
	Diesel	3600	gal	16	40	2.2	L
	Mogas	3600	gal	16	40	2.2	L
	Lube Oil	55	gal	16	32	1.9	L

Appendix A: Hazard Assessment of Davis-Monthan AFB

Location	Material	Quantity	Unit	MF	F	T	Hazard Class
	Antifreeze	170	gal	4	7.9	1.9	L
Fire Trk	Lube Oil	110	gal	16	29	1.8	L
	Antifreeze	120	gal	4	7.9	1.9	L
Fire Dept	Halon	6000	lbs	0	0	2.3	L
Fuels Sup	Jet Fuel	80000	gal	16	58	2.8	L
	Diesel	2400	gal	16	40	2.2	L
	Gasline	1200	gal	16	37	2.1	L
	Lube Oil	55	gal	16	32	1.9	L
Cryogenics	TriChloroe thane	55	gal	4	7.2	5.4	L
Rail Eng Mnt	Lube Oil	55	gal	16	32	1.9	L
	Glycol	55	gal	4	7.9	1.9	L
Battery S	Sulfuric Acid	4	gal	4	4	3.8	L
Pneudraulics	Hydraulic Fld	50	gal		0	0	
Welding	Acetylene	900	cu ft	29	157	3.8	M
Power Pro	Sulfuric Acid	25	gal	4	4	3.8	L
	Lube Oil	220	gal	16	37	2.1	L
	Diesel	330	gal	16	32	1.9	L
	Glycol	110	gal	4	7.9	1.9	L
Storage Yd	Sulfuric Acid	135	gal	4	7.2	6.8	M
	Glycol	275	gal	4	7.9	1.9	L
	Trichloro-triflouroe htane	270	gal	4	7.2	5.4	M
	Lube Oil	3080	gal	16	40	2.2	L
	Hydraulic Fld	22	gal		0	0	
	Methanol	275	gal	16	40	2.2	L
	1,1,1 Trichloro-ethane	330	gal	4	7.2	5.4	M
	MEK	110	gal	16	46	2.4	L
	Chlorine	5400	lbs	29	89	9.4	M
	Acetylene	3700	cu ft	29	157	3.8	H
	Freon	1500	lbs	0	0	1.2	L

Appendix A: Hazard Assessment of Davis-Monthan AFB

Location	Material	Quantity	Unit	MF	F	T	Hazard Class
	Ammonia	600	lbs	4	7.9	6.2	M
	Halon1211	6000	lbs	0	0	2.3	L
Propulsion	Oil	220	gals	16	37	2.1	L
	Jet Fuel	55	gal	16	32	1.9	L
333 FS Sup	Lube Oil	110	gal	16	35	2	L
	Hydraulic Fld	110	gal		0	1.8	
	Methanol	55	gal	29	57	1.9	L
Engineering	Ammonia	300	lbs	4	7.9	6.2	M
357 FS Sup	Lube Oil	110	gal	16	35	2	L
	Hydraulic Fld	55	gal		0	0	
	Methanol	110	gal	29	57	1.9	L
7222	Lube Oil	885	gal	16	37	2.1	L
	Hydraulic Fld	120	gal		0	0	
	Antifreeze	200	gal	4	7.9	1.9	L
	Jet Fuel	55	gal	16	32	1.9	L
	Benzene	120	gal	16	32	1.9	L
Supply	Lube Oil	220	gal	16	37	2.1	L
	Acetone	110	gal	16	65	3.1	M
	Naptha	220	gal	16	29	1.8	L
	Trichlorethane	110	gal	4	7.9	5.7	L
	Sulfuric Acid	15	gal	4	4	3.3	L
Paint Shop	Naptha	55	gal	16	29	1.8	L
	Naptha	110	gal	16	29	1.8	L
7329	Acetylene	1350	cu ft	29	157	3.8	H
7340	Lube Oil	55	gal	16	32	1.9	L
Reclaim	Lube Oil	925	gal	16	35	2	L

Appendix A: Hazard Assessment of Davis-Monthan AFB

Location	Material	Quantity	Unit	MF	F	T	Hazard Class
	Hydraulic Fld	165	gal		0	0	
Washrack	Trichloroethane	40	gal	4	7.9	5.7	L
	Trichloroethane	110	gal	4	7.9	5.7	L
	Acetone	55	gal	16	60	2.9	L
7408	Lube Oil	385	gal	16	43	2.3	L
	Jet Fuel	110	gal	16	32	1.9	L
Welding	Acetylene	2475	cu ft	29	157	3.8	M
Propulsion	Lube Oil	330	gal	16	37	2.1	L
7448	Jet Fuel	4945	gal	16	52	2.6	L
	Lube OIl	935	gal	16	43	2.3	L
Mat Lab	Lube Oil	55	gal	16	32	1.9	L
	Hydraulic Fld	55	gal		0	0	

Appendix B

Hazard Assessment: Shaw AFB, South Carolina

Location	Material	Quantity	MF	F	T	H.C.
1207	Hydrazine	42.5 lbs	24	51.84	7.5	Med
1619	Hydrazine	412 gal	24	90.72	10.88	Med
Pool 1	Chlorine	50 lbs	29	62.64	7.5	Med
Pool 2	Chlorine	50 lbs	29	62.64	7.5	Med
Pool 3	Chlorine	50 lbs	29	62.64	7.5	Med

Hazard Assessment: Seymour Johnson AFB, North Carolina
EPCRA Reportable Chemicals List

Location	Material	Quantity	MF	F	T	H.C.
Hospital	Acetic Acid	564 lbs	14	32.8	4.2	Low
Combat Mon	Acetone	315 lbs	15	109	4.4	High
Entomology	Carbaryl	58 lbs	25	45	5.85	Low
Entomology	Chlorpyrofos	89 lbs	25	45	6.75	Med
Hospital	Cyclophospham ide	0.5 lbs	25	45	6.75	Med
Entomology	Diazinon	31 lbs	25	140	14.25	High
Supply	Dichlorobenze ne	12100 lbs	16	76.32	10.35	High
Refrigera- tion	Dichloro- methane	258 lbs	25	45	0	?
Hospital	Digoxin	0.5 lbs	25	45	4.5	?
Photo	Formaldehyde	16 lbs	21	114.7	9.4	High
FIG	Hydrazine	250 lbs	24	64.8	8.625	Med
Supply	Isobuyl Alcohol	91 lbs	16	87.4	11.25	High
Entomology	Malathion	427 lbs	25	45	5.85	Low
Supply	Methanol	295 lbs	16	34.56	12	High
3400	Methylene Chloride	490 lbs	16	98.58	12	High
Corrosion Control	MEK	2700 lbs	16	51.84	2.6	low
Supply	Methyl Isobutyl Ketone	350 lbs	16	43.2	6.9	Med
Corrosion Control	Methyl Isocyanite	28 lbs ***	29	165.9	9.5	Low ***
Supply	Naphthalene	1500 lbs	25	81	8.45	Med

Appendix B (cont.)

Location	Material	Quantity	MF	F	T	H.C.
Photo	Potassium Hydroxide	10 lbs	25	45	5.4	Low
Corrosion Control	Strontium Chromate	5 lbs	25	45	6.75	Med
Entomology	Pyrethrine	15 lbs	25	45	4.85	Low
Hospital	Selenium Sulfide	1 lbs	25	45	6.75	Med
Supply	Sulfuric Acid	874 lbs	4	7.2	6.75	Med
Supply	1.1.1-Trichloroethane	868 lbs	4	7.2	4.5	Med
Corr Con	Toluene	550 lbs	16	108.2	12.6	High
Entomology	Warfarin	55 lbs	25	45	6.75	Med
Supply	Xylene	110 lbs	16	95.68	6.83	High

*** Very small quantities of Methyl Isocyanite are found in the paint.

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Vita

Captain Raymond A. Sable was born in Lakenheath, Sulfolk, England, in the United Kingdom, in 1961 while his father was assigned as a non-commissioned officer in the United States Air Force. Captain Sable graduated from Fridley High School, Fridley, Minnesota, in 1979 and attended the University of Arizona, graduating with a Bachelor of Architecture in 1985. Commissioned on graduation, he was assigned to the 27th Fighter Wing, Cannon Air Force Base, New Mexico and reported on active duty in October 1985. In the Civil Engineering Squadron design section, Captain Sable held positions as project architect, project manager, wing architect, and chief of design. In 1988 he was reassigned to the 36th Fighter Squadron, Bitburg Air Base, Germany where he was chosen to become the Wing Environmental Coordinator. His responsibilities included creating and implementing environmental plans and preparing and training wing personnel to comply with United States and Federal Republic of Germany hazardous waste laws. He entered the School of Engineering, Air Force Institute of Technology, in May 1993 after attending the Air Force Squadron Officer School in route from Germany.

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13. ABSTRACT *(Maximum 200 words)*

This study investigates the possibility of determining the hazard potential of chemicals on Air Force bases using a relative ranking hazard assessment method. Hazard assessment includes identification of hazards and evaluation of the hazards. Title III of the Superfund Amendments and Re-Authorization Act of 1986 requires hazard assessments by all facilities with extremely hazardous substances to prepare release prevention plans.

The purpose of the hazard assessments is to provide information to improve the spill prevention, control and countermeasures plans and to identify the substances with the highest hazard potential. Using the results from the hazard assessments, bases cam prepare plans to reduce and remove substances with high hazard potentials.

Using a simplified relative ranking assessment method developed by Dow Chemical Company, assessments were performed for three Air Combat Command bases. The results from the bases' assessments showed several substances in the high categories.

This study recommends an assessment be performed for all bases in each command to identify the higher hazard potential substances. Identification of substances with high accident potential is also a good precursor to pollution prevention plans.

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