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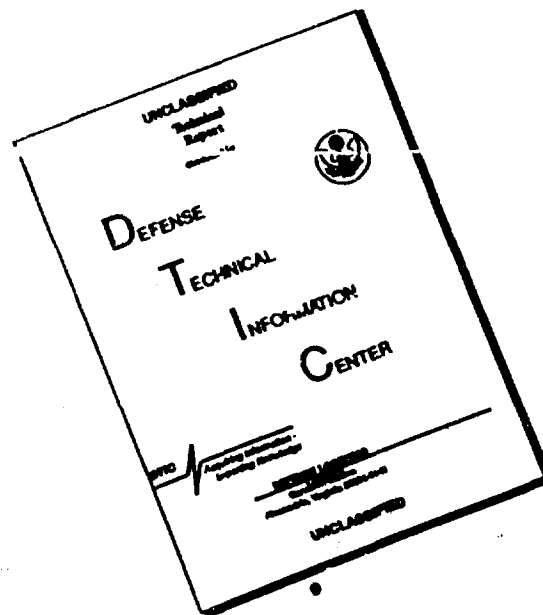
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STEALTH MATERIALS TECHNOLOGY:

PART I: Low Observable Technology and Background

PART II: Stealth Composites and their Applications

PART III: Materials Analysis, Comparison, and Testing

PART IV: A Specific Analysis of Boron Nitride

By

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University of Illinois at Urbana-Champaign
April 28, 1993

**Safety, Health, and Environmental Hazards
Associated with Composites: A Complete Analysis.**

By

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This study was prepared as a research project for:

Industrial Engineering 357
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Dr. Roger L. Brauer

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Abstract

The need to address safety, health, and environmental hazards associated with composites and their use is a key aspect of continued growth and development within the composites industry. The complex challenges facing each facet of this field require in-depth analysis and simplifying organization so that the scope of the problems can be characterized and appropriate solutions can be proposed. The ultimate goal is legal, technical, managerial, and financial compatibility with constantly improving performance capability. The solution is the development of a composite plan tailored to specific needs.

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I. Introduction

The dynamic expansion of the composites industry is a reflection of the rapid development and widespread application of organic composites in both the military and private sectors. The unique characteristics of these relatively new materials provide virtually unlimited application potential. In order to keep pace with the global expansion, the composites industry must overcome the challenges of design, manufacturing, and maintenance. Several critical factors that must be addressed are the safety, health, and environmental hazards associated with composites. Hazard reduction and risk control within the composites industry is of utmost importance in maintaining the continued viability and efficiency of this rapidly emerging industry. The goal of this paper is to provide a fundamental basis for a general hazard analysis of composites and several solution proposals.

II. Background

In order to effectively address a potential problem, the relevant parameters must first be defined. In the case of the composites industry, the safety, health, and environmental hazards associated with the manufacture, use, maintenance, and repair of these materials are of utmost importance. Essentially, a hazard is "a condition or changing set of circumstances that presents a potential for injury, illness, or property damage" (Brauer 79). Additionally, it can be defined as "the potential or inherent characteristics of an activity, condition, or circumstance which can produce adverse or harmful consequences" (Brauer 80). Yet, there is a fair amount of controversy over the extent of the potential health hazards of composite materials.

The nature of composites development has been such that the new advances in materials and processing have outpaced adequate analysis and research. Many of the new products present a variety of health, environmental, safety, and disposal problems not previously encountered. Additionally, the development, implementation, and modification of composites has usually been done by specialists, often working under proprietary or military secrecy. Furthermore, the diversity of constituents,

substances, methods of production, and use environments has vastly increased the complexity of the analysis problem. The synergistic effect of these conditions is a lack of definitive information to ascertain real from alleged hazards (Luce 2). By consolidating information from industry, on both the technical and managerial levels, along with governmental regulations and military information, a general hazard analysis can be made. However, continued research and analysis are needed.

Composites Technology

Modern materials technology has fostered the outstanding achievements within the field of composites. The unique characteristics of composites, derived from two or more distinct components (the reinforcement and the matrix), allow the physical and mechanical properties to be tailored to fit a specific performance need (Lee 19). Consequently, composite materials have not only replaced conventional materials in many areas, but spawned new designs previously limited by material constraints. Because of the widespread scope of materials that can be classified as composites, a hazard analysis must be broad enough to encompass the entire industry while maintaining flexibility for specific areas. The focus of this report will be on polymer composites as the representative materials, although the principles will be universal.

The development of new composite materials is concentrated on three primary areas: the constituents, the product, and the processing. Each of these areas presents a potential hazard scenario that must be addressed in order to ascertain the overall risk. Driven by moral and legal obligations, hazard determination has become paramount in today's work setting. Society is no longer willing to accept the benefits of technology without careful observation of the human and environmental effects, both on a short and long term scale (Lee 20). Working on this premise, each aspect of composite development can be scrutinized with a control oriented mindset.

Advanced polymer composites are comprised of high performance fibers within a resin matrix. By design, they have a high strength-to-weight and stiffness-to-weight ratio, giving them outstanding mechanical properties. This also makes them ideal for weight critical applications. In

fact, carbon fibers have a density two-thirds that of aluminum with strengths over three times greater than steel (Lee 19). Additionally, the worldwide volume production of plastics (polymers) has surpassed that of steel. Because of their qualities, composites are becoming increasingly prevalent in both peripheral and structural applications. The broad thermal use range, fire resistance, and corrosion resistance of composites gives them major advantages over other material competitors. Yet, in order to assure the continued use and application of composites in the marketplace, they must be cost effective with regards to risk control, hazard reduction, and production efficiency.

III. Outline and Analysis of the Hazards

Given a foundational basis of the composites industry, four specific areas in which potential or actual safety, health, and environmental hazards exist will be addressed. In general, these four classifications are:

1. Materials and Constituents
2. Worker Safety
3. Environmental Ramifications
4. Waste Disposal

Each particular classification relates to a specific area of concern, with the appropriate hazards and conditions outlined within each. It should be noted that "Areas of Concern" will be subsequently addressed once the classifications are complete.

Materials and Constituents

Most precursors for composite materials in the past were traditional chemicals and substances combined to form either a new matrix, fiber, or overall composite material. Usually, the safety, health, and environmental precursor information was fairly well established, although the cumulative effect was not always fully known. Nevertheless, predictions or extrapolations could be made. Unfortunately, more definitive information

is not only needed, but required for this expanding industry. The development of radically new and advanced materials has exacerbated the problem even further. Given the fact that matrix materials are generally diverse and reactive by design, the characterization of new composites based upon their constituents and processing techniques is critical.

Epoxies, including new phase toughened resins, along with polyimides, PAI's, and BMI's form a high percentage of the matrix resin market. Also, thermoplastic resin use, such as PEEK, PPS, and PEI, is becoming more widespread as new materials and processes evolve (Ballinger 2). Likewise, important fiber materials such as glass, carbon/graphite, aramid (Kevlar), and boron are prevalent in the industry. Each of these materials, depending upon the manufacturer, presents a unique hazard potential. The virtually limitless derivatives of these complex mixtures make generalized characterization quite difficult. The rapid evolution and turnaround of resin and fiber systems does not permit lengthy evaluation. Therefore, current hazard analysis techniques and exposure models must be feasibly modified so that an improved average hazard assessment can be made (Ballinger 2). Again, this average would be highly specific to a particular material genre.

Although far from complete, the following material descriptions highlight several representative hazards associated with more common substances used within the industry. The information should be interpreted by weighing the acute versus chronic and local versus systemic ramifications of exposure. The relative toxicology as it relates to carcinogens, mutagens, and teratogens must also be contemplated.

Epoxy - Epoxy based resins account for approximately half of the composite matrix systems. Because of this, the broadest base of information for resins lies in this area. Most unreacted epoxy resins have a low order of acute toxicity with low absorption. Skin irritation or sensitization may result from extended exposure (Ballinger 2).

Polyurethanes and Urea-/Phenol-formaldehyde - These resin systems contain isocyanate in the uncured urethane resin and formaldehyde in the U/F and P/F resins. These present both acute and chronic toxicity as well as carcinogenic and

teratogenic potential. All skin contact should be avoided (Ballinger 2).

Styrene - Although not often associated with composites, the polymer production process of styrene foam components yield styrene vapor that is extremely toxic and should be minimized.

Methyl ethyl ketone (MEK) and acetone - These solvents are used for clean-up in the composites industry. Although they are well-known chemicals, their use represent health, storage, and disposal hazards that directly affect the composites industry. Respiratory and skin irritation along with nausea are exposure results (Luce 2).

Methylene Chloride - Another common composites chemical, it may cause overt damage and carbon monoxide poisoning (Luce 2).

Epoxy-aromatic amine prepreg/glass - This prepreg system releases toxic chemical fumes during combustion. Lung damage and contact dermatitis are exposure effects (Luce 2).

Aliphatic amines - These chemicals can cause eye and skin irritation along with hypoallergenic reactions (Luce 2).

In general, most unreacted resin systems present respiratory and eye irritation hazards (Ballinger 3). These examples of hazardous constituents and peripheral substances demonstrate the diversity of the hazards that must be dealt with. This partial listing is a mere fraction of the truly expansive list.

In addition to the resin hazards, fibers are also a source of hazard concern. Although the vast majority of fibers are outside the respirable diameter range, they may cause mechanical irritation of the eyes and respiratory areas (Ballinger 3). The fibers that do become airborne generally have low concentrations and toxicity. Particulate exposure from dust is of primary concern when dealing with composites fibers. Often times, the dust is comprised of cured binder with a low fiber percentage.

In addition to potential fire hazards, preliminary studies have shown that composite dusts produce greater lung irritation than "nuisance dust" but less than quartz dust (Ballinger 3). Again, eye and respiratory irritation are probable hazards.

Worker Safety

Worker Safety is basically a generalistic term for a very diverse and complex set of hazards within the work environment. The composites industry encompasses workers ranging from initial fiber and resin handlers through product disposal personnel. Not only do the occupations vary, but the materials, processes, applications, and locations as well. For example, the conditions in large, specialized aerospace composite manufacturing facilities, similar to the military depot level, vary drastically from those at smaller businesses and the field level (Ballinger 3). Yet, in each case, safety, health, and environmental hazards must be minimized.

Worker protection must be emphasized in the work environment by making prudent design, processing, and materials choices. Additionally, in our ever increasing litigious society, existing and emerging regulations must be accounted for. A vivid example of the need for worker safety and industrial hygiene lies in the area of composite sanding. It is not uncommon to see employees in industry sanding graphite material without dust masks and proper gloves. Graphite particulates end up infecting tissue that has not been properly protected, causing health problems that could have been avoided. Although employees should take a vigorous interest in their personal safety and hygiene, it is ultimately the responsibility of the company to protect the health and safety of the employee (Luce 5). Further analysis of four major areas of concern as they relate to composites workers will be discussed later.

Environmental Ramifications

In light of the ever-increasing pressure to be ecologically and environmentally responsible, the composites industry must ensure its practices are within the established realms of societal norms and legalistic

expectations. The end goal must be environmental compatibility without sacrifice of performance capability. Industry and government wide "environmental stewardship" is not only obligatory, it makes good sense in terms of public opinion and support (Warner 6). The total energy consumption of the composites industry is another promising element in an area previously overlooked.

According to Boeing, the target areas for reduction of environmental hazards are "chlorofluorocarbon materials, cleaning solvents, finishing technologies, chromate materials, electronic manufacturing technologies, waste minimization opportunities, and new facility planning" (Warner 6). A more specific analysis of polymer resins, carbon fibers, and prepregs shows that wash water effluent is the primary environmental impact medium involved in composite matrix production (Lee 23). Minimal particulate waste and virtually no air emission is present. However, carbon fiber production yields several volatiles such as HCN, which warrants strict pollution control (Lee 23). In terms of prepreg production, the most significant hazard is ventilation, as the process generally produces little pollution. The use of acetone and other solvents in the production and cleaning must also be carefully monitored to ensure proper handling and disposal.

The energy required to produce composites is becoming an increasingly important factor governing applications. In a comparative energy study between aluminum and a representative composite, composites proved to be approximately 30 percent more efficient in terms of production energy required per strength-to-density ratio (Lee 22). It should be noted that this value is based upon the raw material production. The energy required for finished parts is not comparable because of the methodology diversity. Nevertheless, as energy costs increase and the availability of constituent chemicals and materials decreases, composites continue to become more attractive. However, the relative production costs must always include the more difficult qualitative costs of workers' compensation and lost product cost, regulation and safety compliance, and environmental control. The bottom line is that environmental hazards have the potential to play a large role in the overall viability of the composites industry.

Waste Disposal

As with any industry involving a large volume of hazardous and potentially harmful materials, waste disposal is a very important and radically increasing expense area. Although some sources say the waste disposal of composite materials is "not presently perceived as a problem", complacency in this area could be disastrous. The materials generated by the composites industry generally fall within two categories: toxic, and non-toxic waste, whether it be liquid, gaseous, or solid. Waste stems from all aspects of the composite life, extending from production through disposal. Hazardous waste production falls under already strict governmental control. Often times the waste problems are generated by non-direct production means. For example, solvents are used to clean much of the equipment after the composites have been manufactured. As such, they become contaminated with resin and catalyst residue, requiring stringent storage and disposal procedures (Davis 5).

In order to confront the problem, its magnitude must first be understood. Using generalized information, prepreg cutting produces approximately 15 to 20 percent scrap in the formation of laminate lay-ups (Lee 24). Because of limited applications, this is regarded as waste. In the future, this level of waste within a growing volume production industry, cannot be tolerated. New scrap use and disposal methodologies must be developed. One alternative is recycling. Currently, the recycling of composites lags far behind that of the aluminum and steel industries. Composite recycling methods still need to be developed. One important difference is that after-use composites are not easily recycled. The thermosetting nature of most currently used polymers makes them incompatible for alternative use and forming. However, the increased use of thermoplastics may change this problem. Burning, pyrolyzing, and grinding of composites and fibers are alternative recycling venues. In conclusion, waste disposal hazard reduction depends upon environmental responsibility and recycling evolution.

Areas of Concern

As previously discussed, a safety, health, and environmental hazard analysis of composites must be parameterized in order to simplify or organize the wide variety of contributing information. Four major classifications have already been discussed as they pertain to the industry hazards, but continued analysis requires a further distinction. Essentially, the field of composites and the hazards associated with them can be classified into four primary areas of concern:

1. Production
2. Primary Use
3. Maintenance and Repair
4. After Use and Disposal

Each of the areas of concern will be approached using previously detailed information as it pertains to the topic of concern. By focusing on these specific areas, the intricate groundwork for solutions to hazard generated problems can be laid. Just as the constituent materials are bonded together in a composite whole, so too are the safety, health, and environmental solutions an integrated product of constituent responses.

Production

Production hazards can stem from a multitude of problems. At the most basic level, improper building design can lead to ventilation, product handling, storage, and disposal problems. Because many of the materials have unique handling requirements, a generic floor plan or basic design will not provide optimal, possibly not even adequate conditions. Likewise, even with an adequate building design, improper placement of equipment and materials within can lead to unnecessary hazards.

Materials handling, as previously discussed, is a large source of production associated hazards in the composites industry. The proper storage, transportation, delivery, distribution, and application of materials is paramount to hazard reduction and loss control. The diversity of the

variables involved in this process make realistic control extremely complex throughout a broad spectrum of scenarios.

Another important aspect of production hazards is the actual equipment itself. Regardless of whether the equipment is a large production autoclave, or a small hot press, many similar hazards are present, although they vary in magnitude. Some of the relevant composites production equipment includes: autoclaves, hot presses, filament winders, extruders, molds, lay-ups, spray-guns, compression molders, and sheet molders. The type and variety are endless, although each specific apparatus has an important set of potential hazards. Some hazards may be eliminated, while others must be dealt with.

Because of the increased volume demand for composite applications, many previously labor-intensive tasks are being replaced by new manufacturing technologies, such as automated materials handling, robotics, and computer aided manufacturing (Ballinger 4). Although this new technology may reduce some hazards associated with composite production, it also introduces several others as well. Mechanical motion, maintenance, repair, and operation of many of these new production media present entirely new hazards.

Often times prepregs are stored prior to final completion. This practice also presents problems, especially the need to cool or refrigerate systems so that final curing does not take place. The temperature extremes and storage degradation are just two more hazards that comprise the overall production concerns. Finally, once the composite is completed, storage and delivery involve potential safety hazards.

Primary Use

Safety in use under adverse conditions, in addition to mechanical performance, is of fundamental importance for structural materials (Lee 23). The primary use of composites can be defined as their pre-designed end use. Because of the previous pre-dominance of metals in superficial and structural applications, composites were initially viewed as metal replacements with better desired qualities. Yet, because of materials advancement and a changing designer mindset, composites are now viewed as primary materials of choice in many applications. Furthermore,

advanced composites are allowing realization of designs previously impossible because of materials limitations. To be completely effective, composites must minimize the hazards associated with their normal use.

In general, composites have better fire resistance and crash stability than their aluminum counterparts with regards to safety. Additionally, both the combustion heat release and thermal conductivity values of composites are much less than the metal counterparts. These characteristics are extremely important in the aerospace industry.

The fire safety hazards of polymer composites for aircraft interiors are flammability, smoke, and toxicity (FST) (Lee 23). In order to meet increasingly stringent regulations, especially in the commercial aircraft industry, composite smoke and toxicity must continue to be improved. Fillers, additives, and flame retardants are current steps towards FST improvement. In typical aerospace fire conditions, the burn through characteristics of polymer composites are better than aluminum. Only polymer resin combustion takes place because of the high flammability temperatures of the carbon fibers (Lee 23). Boeing also sites other potential fire hazards such as lightning strike and High Intensity Radiation Field (HIRF) effects which require further research in order to make composites more suitable for the aerospace environment (Warner 3). In automotive and marine applications, gasoline fire hazards can also be reduced with judicious composite selection.

Because of the high kinetic energies usually involved in the transportation industry, composites are continually proving the value of their energy dissipation capabilities as they pertain to crash strength and stability. Through effective design of fiber orientation, composites absorb more impact energy than a metal structure (Lee 23). In order to minimize potential safety and health hazards in transportation, continued refinement of composites design is critical.

Maintenance and Repair

Often times, the necessity for maintenance and repair of composites is overlooked in the relentless pursuit for production and primary use improvement. Yet, because of their unique composition and wide variety of applications in many environments, maintenance and repair hazards

and problems can be enormous. One key parameter that has pervaded many hazard sources is the diversity of constituent materials in composites. The complex mixtures and various compositions necessitate the storage and inventory of many different substances (Warner 5). Each individual manufacturer requires a specific material which cannot be substituted with materials from another Original Equipment Manufacturer (OEM) (Warner 5). Thus, to repair different products, a vast assortment of specific resins, chemicals, fibers, and prepregs are needed. Compounding the problem lies in the fact that many of these specific materials are perishable or deegratory over time. The safety, health, and environmental hazards associated with this assortment of materials are obvious. The more substances involved, the greater the potential hazard.

Handling and manipulation composite components in the repair process are also sources of potential hazards. Composite failure can lead to imprecise and explosive deformation, breaking, and cracking. Fire damage and impact damage can lead to significant alteration of the constituents and their relative make-up. Airborne, protruding, or splintered fibers are sources for potentially dangerous hazard conditions.

The actual repair process is usually performed under conditions significantly different from their initial production. Accordingly, lay-up, processing, and curing are tasks which present a multitude of safety, health, and environmental hazards. Inadequate tooling, ventilation, lighting, waste disposal, and support are just a few of the maintenance and repair hazard sources.

Additionally, one peripheral aspect of maintenance is the hazard associated with the painting and stripping of composite materials. According to a Boeing study, paint stripping is an expensive routine for the airlines because normally used solvents generally degrade the resin systems (Warner 5). Due to the obvious safety concerns, normal paint strippers are prohibited on composites, forcing the need to sand the surfaces. Yet, sanding over the product lifetime could reduce the mechanical performance (Warner 5). Plastic blasting, similar to sand blasting, has been proposed as a possible solution, but it also presents several additional safety, health, and environmental hazards (Warner 5).

After Use and Disposal

Once a composite has reached the end of its primary use life, the safety, health, and environmental hazards do not cease. In fact, the long term viability and continued growth of the composites industry hinges upon responsible after use treatment and appropriate disposal of materials. As previously stated, the past trends toward thermosetting resins for composite materials allow little alternative application or regeneration of composites. Also, of particular concern to military, is the need to preserve the secrecy of some composite materials. As a result, this security concern precipitates demilitarization of expended composite products as well as technological sanitation of wreckage or damage materials. The end result is another phase of potential hazards within the after use/disposal loop. The hazards inherent in the waste disposal and recycling arenas, both previously discussed, are important concerns for the composites industry. Given a renewed "cradle to grave" mentality, the expenditures in this area could be astronomical. The trends in disposal methods have and will continue to change dramatically as the following table displays:

	<u>Pre-1984</u>	<u>'84-'90</u>	<u>Post-'90</u>
Land Disposal	90 %	60 %	50%
Recycling	5 %	10 %	30 %
Treatment/Incineration	5 %	30 %	65 %

(Luce 5)

Additionally, the disposal costs are expected to radically increase as more and more waste is banned from disposal in landfills. Examples of landfill bans include:

- 1982 - Contaminated liquids
- 1985 - Bulk liquids
- 1986 - Solvent and dioxin waste
- 1988 - Wastewater treatment sludge
- 1990 - Characteristic waste TRIC

(Luce 5)

Not only are the direct disposal costs of end-use composites and production materials of interest, but the handling, storage, and transportation costs as well. Each particular area must be addressed with the goal of hazard minimization, cost efficiency, and long-term sufficiency.

IV. Solution Proposals

With a basic knowledge of the safety, health, and environmental hazards of composites already outlined, the ultimate quest for hazard minimization and loss control can begin. Diligent planning, sharp attention to detail, and rational calculation must be the hallmarks of any solution proposals. In general, there are several "universal principles" that apply to hazard control with relative priorities assigned to each. Accordingly, all subsequent solution contingencies will depend, in order of importance, upon the following:

1. Recognize the hazards
 - Eliminate the hazard
 - Reduce the hazard
2. Define/select preventative measures
 - Provide safety devices
 - Provide warnings
 - Provide safety procedures and equipment
3. Assign implementation responsibility
4. Measure the effectiveness

(Brauer 82)

Within this framework, a broad spectrum of solution alternatives to composite hazards exist.

Subjectively and relatively speaking, there seems to be a general lack of cohesive and continuous safety, health, and environmental hazard information. Given the diversity and complex structure of the industry, generic safety and risk management programs are not always adequate. The goal of this report is to outline and refine new methodologies to allow

the industry to grow into the future. The process includes legal and regulatory aspects, engineering and managerial areas, as well as time-dependant cost-benefit analysis. The ultimate goals are to ensure the health of workers, expand the job market, and bolster environmental responsibility, while increasing international competition in the production of performance products.

Applicable Laws, Regulations, and Standards

The number of laws and regulations directly or indirectly affecting the composites industry is phenomenal, with the development and implementation of many more on the way. The sheer volume represents a control philosophy founded mainly on industry, governmental, and military rule compliance. In a study done by Zoyd Luce, it was surmised that composite manufacturers believe:

- Too many regulations exist
 - Existing regulations frequently are contradictory
 - Governmental agencies are generally uncooperative with industry
- (Luce 2)

Contradicting the general feelings of industry are those of the public. In recent times, the public has increasingly voiced concern over too little regulation and environmental concern on the part of industry.

Consequently, a controversial dilemma exists. The solution lies in the fundamental premise that attention to safety, health, and environmental hazards is mandatory for continued economic and product growth. This does not necessitate complete regulation, although future internal and external environmental, worker, and waste regulations will be more stringent. Instead, a consolidation of approaches is needed.

A comprehensive look at many of the currently applicable laws, regulations, and industry standards reveals many benefits while simultaneously pointing towards several other solution alternatives. It should be noted that the diversity of operations within the composite industry requires more in-depth research of the particular areas. The Code of Federal Regulations (CFRs) and the U.S. Code list several of the

applicable governmental regulations, while many other standards and practices are outlined by state laws, governmental agencies, and various associations.

The following list is not entirely inclusive.

Clean Air Act (CAA) and Clean Water Act (CWA)
 Consumer Product Safety Act (CSPA)
 Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), Superfund
 Emergency Planning and Right-to-Know Act (SARA Title III)
 Federal Hazardous Substances Act (FHSA)
 Federal Water Pollution Control Act (FWPA)
 Flammable Fabrics Act (FFA)
 Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA)
 Hazardous Materials Transportation Act (HMTA)
 Hazardous and Solid Waste Amendments to RCRA
 Occupational Safety and Health Act (OSHA)
 Occupational Safety Communication Act (OSCA)
 Parks and Waterways Safety Act (PWSA)
 Pipeline Safety Act (PSA)
 Resource Conservation and Recovery Act (RCRA)
 Safe Drinking Water Act (SDWA)
 Superfund Amendments and ReAuthorization Act (SARA)
 Toxic Substances Control Act (TSCA)

Important Federal Agencies

Department of Commerce (DOC)
 Department of Health and Human Services (HHS)
 Department of Labor (DOL)
 Department of Transportation (DOT)
 Environmental Protection Agency (EPA)

Partial Standards Listing

OSHA Hazard Communication Standard	ASRAE Standards
ASTM/ANSI Standards	NIOSH-RTECS/NFPA
SAE/SME Standards	ASME/AIAA Standards
Military Standards	ACGIH Recommendations

Source: Brauer

As Zoyd Luce pointed out in his study, "Just as ignorance of the law is no excuse, compliance with the law will not keep a company out of trouble" (Luce 4). Even though OSHA dictates safety and health standards in the workplace, and several other Acts control the many other aspects of composites, creativity and informed decision making is required across the board. This involves everyone from the bottom to the very top.

One especially important piece of legislation is CFR 1910.1200 OSHA Hazard Communication Standard, which addresses an entire organization. This standard dictates five primary requirements for employers. These include:

1. Identify All Toxic Chemicals
2. Maintain Material Safety Data Sheets (MSDS)
3. Properly Label All Chemicals - NFPA Diamond
4. Develop a Management Plan to Handle All Contingencies
5. Train All People

Although this regulation has been regarded as "a paper trail" by many, the underlying relevance of its principles is important to a comprehensive plan.

It has been said that the most complex things in life can be best expressed by the simplest of expression. It is this type of risk control philosophy that has the greatest applicability within the complexities of the composite industry. Using this assumption, the solution process can be further refined.

Short and Long Term Concerns (Cost-Benefit)

The established composites industry is relatively young by industrial standards. Advanced composites and widespread application have only been prevalent for roughly the past forty years. Yet, the growth projections are very optimistic. In the near term, safety, health, and environmental hazard control programs represent a sizable and often overbearing expenditure. The myriad of rules, regulations, and contingencies can be translated into high overhead costs and unwanted profit-margin reductions. Yet, compared to the potential long-range costs,

which can reach astronomical proportions, an investment in safety and health can be a wise one.

Short term solutions to the hazard problem, once commonplace, are no longer acceptable. Past "band-aids" have included illegal dumping, storage, or emissions, as well as improper inventory, control, and records. Additionally, total reliance on external support and disposal have been relatively painless short term approaches. In the industrial and social climate of today, these solutions are no longer feasible. Instead, the composites industry must adopt a plan quite similar to an investment. Although the initial outlay is difficult, the future long-term results compound daily towards a substantial qualitative and quantitative dividend. As such, the long-term solution must be the approach taken by the composites industry.

More specifically, these short and long term decisions can be characterized by engineering and administrative choices or controls. Engineering controls can be classified as:

- Mechanical, visual, and thermal environments
- Materials handling system alternatives
- Safety and human factors problems

(Brauer 194)

Superficially, it would seem that engineering controls would be the more costly in a short term prevention program. Consequently, engineering options should only be applied when the hazard source or problem is specifically defined, thereby ensuring successful application for the investment (Luce 2). Also of note, engineering controls may be applied only when they meet regulatory guidelines (Luce 2). Although building design is not an engineering control, building modification is. Several innovative engineering controls have been implemented in the manufacturing and production industry environments. Unfortunately, many of these ideas are not applied outside the sponsoring company (Ballinger 3). Improved equipment design and layout are also engineering controls that have proved quite effective. Elimination of hazards through mechanical or automated means (engineering controls) serves both as an effective short and long term solution, yet they generally result in high

short term costs. For large firms this would be a wise investment. However, the capital expense might prove too great for smaller businesses.

Both an alternative and compliment to engineering controls is administrative controls. Essentially, administrative controls involve work practices, managerial options, and selection/training of workers (Brauer 194). Some representative examples are protective equipment, industrial hygiene, employee feedback, labelling, process specification, physical assessment, and supplemental education (Ballinger 4). Both on a short and long term scale, administrative controls have proved to be effective. Yet, there is controversy over whether or not administrative controls alone are sufficient alternatives for engineering controls. This argument is heightened by the locational variations within the industry. For example, maintenance and repair controls at a field or small business level would vary greatly from those at a large industrial site. Although unique for each case, the effective combination of both engineering and administrative controls with varying degrees is the best long term solution. Cost-benefit analysis should yield the relative proportions of each. The bottom line should be hazard minimization with realistic economic justification. The answer is a systematic and rational decision approach to existing and proposed operational changes.

In both control scenarios, monitoring and analysis of the respective areas ensures effectiveness. With regards to engineering controls, industrial hygiene monitoring reveals exposure levels (Ballinger 4). Medical monitoring of exposed personnel is also helpful in determining the adequacy of the controls (Ballinger 4). On the other hand, administrative control sufficiency may be analyzed through standardized testing, surveys, employee feedback, hazard communication, and industry uniformity. By monitoring some of these areas, the value of the relative investments may be determined, and the results applied to future "purchases".

Solution Approaches

As previously stated, the hazard spectrum is complex, but the solution system should be simple. The best overall solution approach is one in which the mandates of law are fulfilled within a comprehensive program comprised of multi-phase, integrated management, risk control

(risk management and loss control), and TQM solutions. The idea is simple: use the best characteristics of existing plans to make a new one specifically designed for composites. Metaphorically, generate a "composite" plan.

Phase Type Plan

The fundamentals of a phase type plan involve distinct periods of action towards the final goal of hazard reduction and risk control. Several current models exist, although each has limitations. The focus here, will be on description and highlights. Phase I should be fundamental.

Phase 1:

- Inventory ALL chemicals used
- Obtain Material Safety Data Sheets (MSDS)
- Analyze each constituent and product for health hazards
- Review utilization of hazardous chemicals (TLV/PEL/STEL)
- Determine type of protective measures needed

Phase 2:

- Inform employee about hazards of chemicals used
- Inform of MSDS existence and location
- Label chemicals and explain label meaning

Phase 3:

- Employer must issue proper protective equipment

Phase 4:

- Monitor employee under work conditions
- Examine employee for effects

(Luce 3)

The overall effectiveness of the phase type plan hinges upon the synergistic effect and complete institution of each phase. The building block process is critical for success.

Integrated Management Approach

The integrated management approach to the safety, health, and environmental hazards of composites is focused upon reduction or minimization of legal constraints. In order to promote industrial responsibility as opposed to governmental dictation, this solution plan emphasizes the importance of using existing assets and rational decision making. This type of solution would generally be more applicable to larger operations within the industry, although many of the principles are universally applicable.

Essentially, the integrated management approach follows the following steps:

1. Facilitate safety, health, and environmental professional interfacing through organization consolidation
2. Cross-train these professionals
3. Assign regulation knowledge responsibility to a professional
4. Review and assess constituent and product materials
5. Conduct on-site waste program feasibility study
 - Emphasis:
 - Self-sufficiency
 - Waste minimization compliance
 - Liability reduction
 - Decrease in long-term costs
 - Reduce transportation costs
6. Focus on plan choice; Either in-house or external waste plan
 - Elevate program visibility
 - Provide position and authority to person in charge
 - Ensure accountability and responsibility
 - Form a direct liaison with agencies
 - Stress recycling/waste minimization
 - Analyze all programs and offices
 - Nurture public relations
 - Emphasis employee regulatory compliance
 - Perform in-house audits
 - Generate strong academic and institution ties
 - Advocate industrial and association awareness (Luce 5)

Risk Management and Loss Control: Risk Control

Risk can be defined as the possibility or potential for undesirable or negative consequences when an event occurs. Quantitatively, risk is a product of the frequency and severity of an event (Brauer 527). Risk management is a logical and systematic approach to reducing undesirable, negative losses. Applied to the composites industry, loss infers an ultimate financial loss due to many underlying causes. Accordingly, loss control is a management effort to minimize the amount of loss by controlling the terms or conditions of loss (Brauer 527). According to Brauer, risk management incorporates five procedures:

1. Risk identification
2. Risk analysis
3. Elimination or reduction of risks
4. Financing risks
5. Administering the process (Brauer 528)

The fifth step in the risk management process involves several sub-functions including: setting acceptable risk levels, assigning resources, monitoring progress, and assessing results.

Much of the information and many of the processes are similar to those found in system safety. Basically, system safety involves both engineering and management approaches to safety optimization within the realistic bounds of time, cost, and effectiveness (Brauer 37-2). The highlights of this method are its inductive and preventative focuses. Failure Mode Analysis, Fault tree diagrams, and the Hazard Totem Pole are specific strategies of system safety that have been successful in the past. By incorporating risk management and loss control plans along with system safety strategies, composites manufacturers can chose an appropriate approach to accident prevention and ultimately hazard and loss minimization.

Total Quality Management

Total Quality Management (TQM) is the newest management approach being applied to the overall direction and control of many composites industry manufacturers and users. Unlike most of the previously discussed solution alternatives, TQM is a philosophy, not just a system.

Based on the work of Demming, TQM parallels many of the industrial principles and practices of successful Japanese industries. The basic philosophy is shared responsibility with a demand for overall quality. The concept is one that is both plausible and common-sense oriented. Yet, the ideas are clearly related in both quantitative and qualitative measures.

One of the foundational TQM principles is diversified responsibility. Essentially, workers and managers are each given control for different areas, thereby creating an atmosphere that fosters responsibility on many levels. Additionally, the employer-employee relationship becomes more productivity oriented while enhancing quality and safety. The benefits of such a structure are a direct result of increased interaction, communication, and interdependency. Under this type of operating scheme, the initiative to reduce safety, health, and environmental hazards is spread throughout all phases of the industry. The TQM premise is that embracement of the philosophy will yield productivity, safety, and satisfaction within the composites industry. On a broader level, the successful implementation of TQM will make the global industrial scene better, from the military to small business to large industries.

Solution Approach - The Composite Plan

Although all of the previously described solution strategies contain applicable and valuable information, a composite plan specifically tailored to meet the future legal, technical, managerial, and financial challenges of composites is the best solution. The safety, health, and environmental complexities can best be addressed by a simple composite plan. The difference lies not only in the solution, but in the commitment.

Just like a composite, the "matrix" of the plan is knowledge. This is the common "binder" for all of the aspects. Similarly, the workers,

management, and laws are the "fiber" or strength of the composite plan. Together, like a composite material, they must include cost-efficiency, high performance, and high quality. The plan must be a commitment, a passion, a process, and a philosophy in one. Thus, the solution is simple; use the relevant portions of each program and discard the superfluous.

Knowledge involves identification of all constituent and product materials. It incorporates MSDS's, hazard reviews, exposure limitations, risk assessments and protective measures. Proper labelling and warnings, combined with training, hazard communication, and education are also imperative. Professional, management, and employee interface, consolidation, and cross-training provide further means of improving overall knowledge. Furthermore, regulation awareness and compliance, followed by interdepartmental cooperation, academic integration, and public relations are also key. Finally, relative costs, productivity parameters, efficiency studies, effectiveness reviews, and trend projections are necessary components of the knowledge matrix.

The fiber, the very strength of the composite plan is the people and the law. Management strategies and worker diligence depend upon a firm commitment to the cause at hand. Processes and guidelines, which can be tailored for size, task, and location, will provide orientation and direction for the "fiber". However, the ultimate responsibility for safety, health, and environmental hazard reduction stems from the people involved.

It has been said that 98% of the problem is mental. If so, the composites mindset must be on safety, health, and the environment with the goal of growth in size, quality, and performance. Justification for a new mindset, as well as implementation for a composite plan is crystal clear. An EPA study estimates that 80 billion tons of hazardous waste are produced each year, with the composites industry being a contributor (Brauer 405). For the three year period of 1986-1988, workers' compensation and human scrap losses accounted for \$77.1 billion, with the composites industry again being a contributor (Olson 2). Finally, the cost of proposed environmental clean-up has been projected into the hundreds of billions of dollars. Contrastingly, the implementation of effective solutions has led to a 10% annual reduction of hazardous waste per employee since installation of a 1986 Boeing target plan (Warner 6). Similarly, a study revealed that composite aircraft components for one plane yielded a 224

ton lifetime jet fuel savings per aircraft, with a drastic reduction in high-altitude pollutant emission (Lee 24). Thus, energy consumption and ozone depletion are reduced and the potential for success is high.

The following are composites areas in need of further exploration with regards to safety, health, and the environment:

Organic solvent substitutes
In-plant solvent recycling
Batch solvent distillation
High efficiency distillation
Supplier based solvent recovery
Solvent incineration
Air assisted airless spray guns
Prepreg fiber reinforcing
In-plant resin impregnation and resin rollers
Compression Molding applications
Resin Transfer Molding (RTM) and SRIM
Thermoplastic alternatives
Bulk and mini-bulk resin and waste storage
Delivery Mechanisms
Facility-based waste and pollution reduction
Confined space composite work
Ventilation, filtration, and recirculation systems
Fume incineration
Flammability, smoke, and toxicity (FST)
Repair and curing operations
Hand protection standardization
Respirator development and standardization
Public awareness and knowledge
Industry and academic ties
Military technology transfer
Recycling Operations

(Davis 6-19)

V. Conclusions

The virtual explosion of global composite material use is a reflection of the swift pace of material technology innovation. Composites continue to press the bounds of performance and processing within an ever-increasing applications market. Accordingly, the safety, health, and environmental hazards associated with the composites industry have also grown and become increasingly important. The challenges provided by the constituent and product materials, processes, uses, and disposal methods must be addressed. Analyzing the hazards from a safety, health, and environmental perspective within specific areas of concern facilitates organization and prioritization. Once the complexities are manageable, appropriate solution alternatives can be proposed. Based on this strategy, the solution to composite hazards lies with the implementation of a specific, yet simplistic Composite Plan. By highlighting the best aspects of each solution approach, a realistic solution based on human, legal, technical, and financial constraints is possible. The justification for a plan is solid, just as the commitment for it must be. The end result will be a viable and expansive composite industry for the present and for the future.

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