

SURVEYS FOR SENSITIVITY TO FIBERS
AND POTENTIAL IMPACTS FROM FIBER
INDUCED FAILURES

A. J. Butterfield
The Bionetics Corporation

The surveys for sensitivities to fibers and potential impacts from fiber induced failures begins with a review of the survey work completed to date and then describes an impact study involving four industrial installations located in the Virginia - southeast area. The observations and results from both the surveys and the study provide guidelines for future efforts.

The surveys have been performed by a number of teams working more or less together. Figures 1 and 2 summarize the status of surveys conducted to date.

The survey work was done with three broad objectives:

1. Identify the pieces of potentially vulnerable equipment as candidates for test.
2. Support the transfer function work by gaining an understanding of how fibers could get into a building.
3. Support the economic analysis by understanding what would happen if fibers precipitated a failure in an item of equipment.

The surveys completed to date have covered both commercial and public service installations. Figure 1 begins with hospitals where the Hill-Burton Act sets the requirements for a hospital to receive federal aid. The Hill-Burton specifications define a minimum level of air filtration for operating rooms, cardiac care units, and intensive care units in terms of a triple filtration system: a pre filter; a secondary filter; and the last stage as a high efficiency (HEPA) filter. The rest of the equipment in a hospital correlates to electronic items in general use throughout the rest of the country. Hospitals live with a lint environment; therefore hospital equipment tends to have good covers. Life critical equipment appears well protected.

For air traffic control, the surveys included the tower and area traffic control centers outside of Boston plus the Washington National Tower. The radars, the control rooms, the IFR rooms, and

SURVEYS COMPLETED

<u>LOCATIONS SURVEYED</u>	<u>BY</u>	<u>COMMENT</u>
HOSPITALS: * MASSACHUSETTS GENERAL TUFTS MEDICAL CENTER HOLY CROSS (MD) RIVERSIDE (VA)	ADL ADL ORI BIONETICS	● LIFE CRITICAL EQUIPMENT PROTECTED BY HIGH EFFICIENCY AIR FILTERS
AIRPORT/AIR TRAFFIC CONTROL: * BOSTON LOGAN TOWER WASHINGTON NATL. BOSTON AREA CONTROL	ADL ORI ADL	● FLIGHT-CRITICAL EQUIPMENT IS WELL PROTECTED
AIRPORT SERVICES: PASSENGER AREAS (MASS) RESERVATION SYSTEM (MASS)	ADL ADL	● AIR CONDITIONING PROVIDES THE PROTECTION
AIRLINE OPERATIONS (MASS) HANGARS (MASS)	ADL ADL	● VULNERABLE ITEMS IDENTIFIED

* AREAS COMPLETED: NO FURTHER SURVEYS

Figure 1

SURVEYS COMPLETED

<u>LOCATIONS SURVEYED</u>	<u>BY</u>	<u>COMMENT</u>
TELEPHONE EXCHANGES: CENTRAL OFFICES (MD) MILITARY BASE (MD)	ORI BRL	● VULNERABLE ITEMS IDENTIFIED
POST OFFICE (MASS)	ADL	● SOME VULNERABLE ITEMS
TRAFFIC LIGHT CONTROL *	BIONETICS	● WELL PROTECTED
RADIO STATIONS (MASS)	ADL	● STUDIOS PROTECTED ● TRANSMITTERS, OPEN
MANUFACTURING INDUSTRY: DIGITAL ELECTRONICS (MASS) ELECTRONIC AND METAL MACHINING (VA) TELEVISION RECEIVERS ASSEMBLY (VA) LIGHT TRUCK ASSEMBLY (VA) TEXTILE FIBER (VA)	ADL BIONETICS ↓	● PROTECTED BY FILTERS ● INDUSTRIAL INSTALLATIONS SELECTED FOR AN IMPACT STUDY

Figure 2

all the pieces of equipment necessary to handle an airplane in the air have air conditioning with good filtration and in most cases, each item of equipment has a good enclosure or case.

The passenger areas of a terminal must control jet engine fumes. Each terminal handles the problem differently. Dallas - Ft. Worth uses positive pressure; Boston uses activated carbon. The surveys found air conditioning with extra filtration or some means that would tend to minimize the ingestion of carbon fibers. Reservation systems generally have open electronic equipment and depend upon the air conditioning system for protection.

Airline operations equipment includes the computers and the communication elements by which an airline schedules its airplanes, schedules its maintenance, and schedules its own internal operations. These functions receive their protection from air conditioning since most of the equipment tends to be open. Potentially vulnerable items have been identified and are candidates for test. Reviews of this particular area found power failure as the principal problem. Most have some kind of emergency power system; and Boston generally has to call on emergency power about four times a year. Hangars are open. In the servicing of aircraft, equipment can become exposed; however, sensitive pieces of equipment have protective covers which tend to minimize the ingestion of fibers. The lists have now defined those items which are open and do need testing.

For telephone exchanges (Figure 2), the other big user of electronics, the surveys included central offices and one military base. Here, the range of equipment runs from fairly old to the most modern of electronics. Some exchanges have better protection than others. The surveys have identified a composite list of potentially vulnerable equipment. Some of the patch boards and pass-through circuitry that the telephone company uses appear potentially quite sensitive. Some of that equipment finds its way into airport equipment rooms and control towers. In such a case, should the integrity of the tower be violated, it would probably be the telephone items in the ground communication equipment that would suffer first.

The post office uses digital equipment in cancelling and sorting mail. Some show reasonable protection; however, the facility surveyed had elevator shafts, roller doors, and windows such that fibers could enter. The impact would be a return to hand sorting if the equipment were down for an extended period of time.

Traffic light controllers show a similarity to telephone equipment; they range from simple items to sophisticated equipment. The combination of air flows, filtration and design features eliminates these items as a problem.

Radio stations have their studio areas divided into small rooms for isolation. This limits the ingestion of fibers; however, a fair amount of dust does get into the electronics. The field survey found one transmitter that was an open building; newer transmitters are moving away from open construction.

The digital electronics manufacturer protects the manufacturing areas by air filtration and operates the building at a positive pressure. Control computers are installed in a room-within-a-room. If they lost their air conditioning system and their air filtration, the economic impact would be the cost of cleaning any open equipment. At the present time, survey efforts are considered completed for hospitals, air traffic controls and traffic light controllers.

The last four industries were surveyed in detail to look at the possible effects of a fiber release incident. In addition to the general objectives which guided all the survey efforts, the impact study carried the three special objectives as listed in figure 3. This particular effort received cooperation and hospitality from four major industrial installations located in the Virginia - southeast area. The basis for their selection was diversity in product coupled with a dependence upon electrical equipment throughout the manufacturing sequences.

IMPACT STUDY - INTENT AND OBJECTIVES

A DETAIL IMPACT STUDY WOULD PROVIDE:

- | | |
|---|------------------------------------|
| (1) VERIFICATION OF DATA OBTAINED | - USEABLE DATA |
| (2) AN INITIAL SCOPING OF ANY POTENTIAL COST-RISK | - FIRST ESTIMATES |
| (3) IDENTIFICATION OF DATA IMPROVEMENTS
REQUIRED FOR AN ACCEPTABLY COMPLETE
COST-RISK VALUE | - DIRECTIONS FOR
FURTHER EFFORT |

INDUSTRIAL INSTALLATIONS STUDIED:

- (1) MANUFACTURE OF MACHINED METAL AND ELECTRONIC COMPONENTS
- (2) ASSEMBLY OF MONOCHROME AND COLOR TELEVISION RECEIVERS
- (3) ASSEMBLY OF LIGHT TRUCKS
- (4) MANUFACTURE OF SYNTHETIC TEXTILE FIBERS AND YARN

Figure 3

As listed in figure 4, the study used six steps to make the detailed estimate of impact. The first step was aimed at understanding what went on inside that factory. The second step sought out the vulnerable equipment and looked at what would happen in the event of a failure. The third step clothed the failure incidents with dollar costs. Step four drew from the information on ventilation to define transfer functions that would show the kind of barriers in the way of a carbon fiber entering the building. Step five became a scenario for a carbon fiber release incident plus the use of established mathematics to estimate a probability for failure. Step six multiplied the values from step five and step three to get the impact summary. This study is presently on-going, therefore one plant will serve as an example to show the method and then be compared to the other three.

Figures 5 and 6 illustrate Step 1. These diagrams show a modern factory powered by four large transformers. All four work together in one room. The factory operates three independent lines with each line producing one component. The electronic component is sophisticated; the line has all the classical elements of a modern electronic fabrication facility. They make their own circuit boards and use numerical controlled equipment to drill the holes in the circuit boards. The circuit assembly process uses automated techniques; digital controlled devices place the resistors and capacitors into the circuit boards; and hand stuffing completes the

IMPACT STUDY METHOD AND EXAMPLES

THE STUDY REQUIRED 6 STEPS TO GENERATE IMPACT PRODUCTS

1. DIAGRAM THE FACTORY IN TERMS OF: PRODUCT FLOW; VULNERABLE EQUIPMENT; AND IN-PLACE PROTECTIONS.
2. IDENTIFY POTENTIALLY VULNERABLE ITEMS OF EQUIPMENT IN TERMS OF: IMPACT OF A FIBER-INDUCED FAILURE; AND THE KINDS OF LOSSES WHICH COULD OCCUR.
3. ESTIMATE THE POTENTIAL COST ASSOCIATED WITH EACH POTENTIAL FAILURE.
4. ESTIMATE AN EXPOSURE TRANSFER FUNCTION FOR EACH ITEM OF EQUIPMENT.
5. ESTIMATE THE PROBABILITY FOR SUCH A FAILURE BASED UPON A DEFINED RELEASE INCIDENT AND BEST VALUES FOR \bar{E} .
6. CALCULATE THE IMPACT PRODUCTS (PROBABILITY X COST ESTIMATE)

Figure 4

IMPACT STUDY METHOD AND EXAMPLE

STEP 1, VULNERABILITY CONSIDERATIONS FOR A METAL MACHINING AND ELECTRONIC COMPONENT FACTORY.

POWER SUPPLY: 4 AIR-COOLED TRANSFORMERS LOCATED IN ONE ROOM

ELECTRONIC COMPONENT LINE:

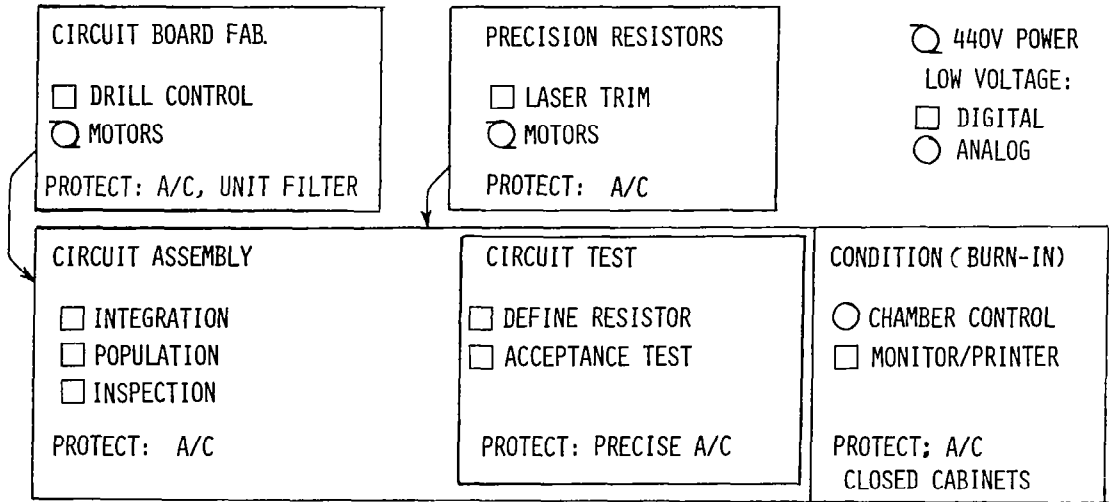
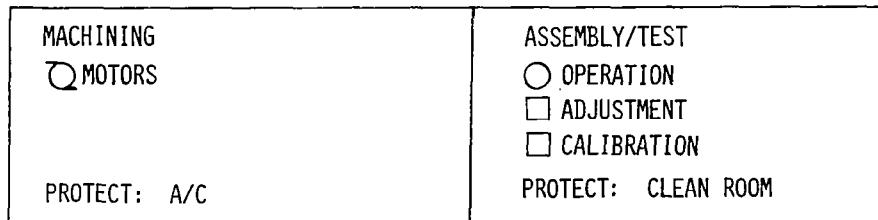


Figure 5

IMPACT STUDY METHOD AND EXAMPLE

STEP 1, CONT'D VULNERABILITY CONSIDERATIONS

PRECISION MACHINING LINE:



AUTOMATED MACHINING LINE:

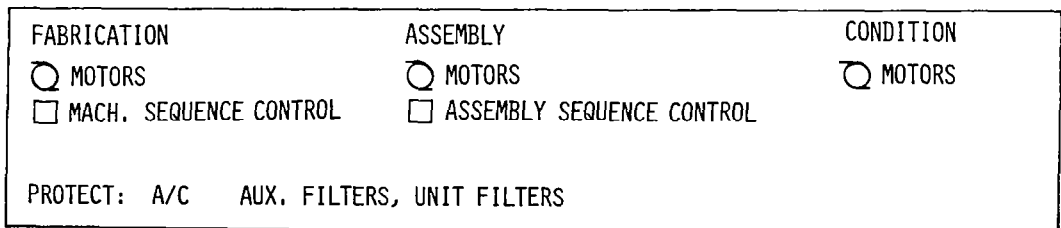


Figure 6

population. Digital equipment performs inspection sequences. This particular circuit is balanced by very precise, laser trimmed resistors. The values of the resistors are defined using digital equipment; the resistors are trimmed using digital equipment. The assembled units are conditioned by a thermal cycle burn-in as with any high quality electronic component.

In assessing vulnerability, the electronic component has coated circuit boards and is not considered vulnerable. The electronic equipment depends upon air conditioning filters and cabinet filters for protection. Therefore the electronic component line and the air cooled transformers show a degree of vulnerability.

Figure 6 diagrams the other two lines, one is a machining line for an electromechanical unit built to close tolerance. The machining is done in a separated area and the equipment operates in the spray from the cutting fluids. Assembly has to be done under very closely controlled environmental conditions. This particular unit has to be operated, adjusted, and calibrated, all using digital test equipment. On the automated machining line, computers do the sequencing and controlling of the steps during both machining and assembly. In looking at the kinds of protections, the computers in the automated line are also working in the spray from the cutting machines or in the dust from the lubricants used during assembly. Filters which remove mist or stray lubricant will not pass fibers. The filtration within clean rooms employs HEPA type filters which do not pass fibers. These two lines do not show a vulnerability to fibers.

The comparison to the other three factories must consider the diversity intended in the selection for product and mode of operations. Figure 7 compares the characteristics of the four factories.

The assembly of televisions included a limited amount of fabrication, mostly plastic molding, together with a number of moving belt assembly lines. Each television chassis size has a dedicated assembly line which can accommodate different cabinetry and different small features from set to set. The assembly of light trucks employs one large integrated line which can accommodate every option that can go into a pickup truck from vehicle to vehicle. The production of textile fibers requires a dedicated line which runs continuously seven days a week around the clock. This plant has another product, nylon with a conductive carbon coat. This material is used for control of static electricity in carpets.

In comparing the factories, the first two are "all under one roof" type of operations. The truck assembly plant is about 50 years old and has a main assembly building plus warehouses and a separate building to house the air compressors and steam boilers. The fiber producer employs separate buildings for processing lines, for spinning of yarn and for the coating of nylon.

IMPACT STUDY

COMPARISON OF INDUSTRIAL INSTALLATIONS: CHARACTERISTICS

	MACHINING ELECTRONIC	ELECTRONIC ASSEMBLY	AUTOMOTIVE ASSEMBLY	TEXTILE FIBER
<u>PRODUCT</u>	<ul style="list-style-type: none"> • 3 AUTOMOTIVE COMPONENTS 	<ul style="list-style-type: none"> • TV RECEIVERS (BLACK/WHITE AND COLOR) 	<ul style="list-style-type: none"> • LIGHT TRUCKS 	<ul style="list-style-type: none"> • ACRYLICS • CONDUCTIVE-COATED NYLON
<u>HOW PRODUCED</u>	<ul style="list-style-type: none"> • FABRICATION AND ASSEMBLY IN DEDICATED LINES • IDENTICAL UNITS 	<ul style="list-style-type: none"> • LIMITED FABRICATION PLUS ASSEMBLY • NUMBER OF MOVING-BELT LINES. SET BY CHASSIS (~ TUBE SIZE) 	<ul style="list-style-type: none"> • INTEGRATED MOVING-BELT ASSEMBLY LINE • UNITS DEFINED INDIVIDUALLY 	<ul style="list-style-type: none"> • DEDICATED LINES FOR EACH TYPE FIBER • CONTINUOUS OPERATION
<u>FACTORY</u>	1 BUILDING	1 BUILDING	1 BUILDING PLUS	MULTIPLE BUILDINGS

Figure 7

Figure 8 compares some of the pertinent features of the four industrial installations. The power systems showed both points of diversity and elements of commonality. Transformers were located in different places, many of them indoors, some clustered together, some of them outdoors; and they employed different means for cooling; but there was one commonality. All installations used a 13.2 kV inlet, all had air cooled high voltage switches. In the case of the television factory, the cooling was secondary air flowing around sealed cases. The automotive plant and the fiber plant had the air cooled switches enclosed in outdoor type cabinets, louvered inlets, vents at the top of the case, over-hanging roof for rain protection. Outside air circulates through this type of cabinet.

The 440 volt power equipment showed a diversity which reflected the product of the plant. The television plant has to heat plastics, the automotive plant has to weld, the fiber plant has to control the speeds of the line. They achieve control by driving a motor generator to produce a variable frequency. Variable frequency 440 volt induction motors along the line will then all run in step.

440 volt motors appear as the common denominator for all industry. They are running in the spray and mist of a machining operation; they are hanging from the ceilings to drive an overhead conveyor; they are buried under the floors to drive moving

IMPACT STUDY

COMPARISON OF INDUSTRY INSTALLATIONS: FEATURES

FEATURES	MACHINING ELECTRONIC	ELECTRONIC ASSEMBLY	AUTOMOTIVE ASSEMBLY	TEXTILE FIBER
<u>POWER SYS.</u>	4 TRANSFORMERS 1 LOCATION INDOORS	16 TRANSFORMERS 6 LOCATIONS INDOORS	9 TRANSFORMERS 9 LOCATIONS MOSTLY INDOORS	9 TRANSFORMERS 9 LOCATIONS OUTDOORS
<u>COOLING:</u> TRANSFORMER SWITCH CT. BKRS.	AIR AIR AIR	OIL AIR AIR	OIL AIR AIR	OIL AIR AIR
440V POWER MAJOR USE	● MOTORS	● MOTORS ● HEATERS	● MOTORS ● WELDERS	● MOTORS ● FREQUENCY CONVERTER
<u>BUILDING</u> VENTILATION	AIR COND.	AIR COND.	● WINDOWS ● HEATERS	MOSTLY OPEN
FILTERS	ALL AIR	RECIRCULATE	PAINT AREA ONLY	NONE

Figure 8

belt conveyors; and they are mounted over chemical vats to drive process lines. At the present time, tests have shown that 110 volt motors are not a problem, and 220 volt motors should be the same. However, 440 volts is in the range which can create a sustaining arc; and considering the wide usage, the vulnerability of 440 volt motors must be defined by test.

The ventilation systems reflect the needs of the product. Precision assembly and the fabrication of electronics benefit from closed buildings with filtered air conditioning. The assembly of automobiles has a dust-critical operation during spray painting. The heat and vapors from a chemical process dissipate more readily from an open building.

Figures 9 and 10 illustrate Step 2 which employs an adaptation of the fault tree concept. This step first identifies any possibly vulnerable item of equipment and then describes what would happen in the event of a fiber induced failure. The results of the failure are then presented in terms which would permit establishing a cost.

For instance if a power transformer were to fail, it would probably stop some of the lines, but offices would not go dark and the maintenance people could work. In such a case, the considerations would become: Would it be necessary to furlough people?

IMPACT STUDY METHOD AND EXAMPLE

STEP 2, IMPACT SUMMARY

EQUIPMENT ITEM	MAIN TRANSFORMER (13.2KV SUPPLY)	DRILL CONTROL	LASER TRIM
IMPACT; FIBER- INDUCED FAILURE	HALT MANUFACTURE	STOP OPERATION SPOILED BATCH	STOP OPERATION SPOILED UNITS
LOSS CONSIDERATIONS	WORK FORCE TIME LOST PRODUCT START UP RECOVER SCHEDULES	SPOILED BATCH TROUBLESHOOT LOST TIME STARVED LINE	SPOILED UNIT TROUBLESHOOT LOST TIME STARVED LINE

Figure 9

IMPACT STUDY METHOD AND EXAMPLE

STEP 2, CONT'D IMPACT SUMMARY

EQUIPMENT ITEM	INTEGRATOR POPULATOR INSPECTION	RESISTOR DEF. ACCEPTANCE MONITOR	CHAMBER CONTROL
IMPACT; FIBER- INDUCED FAILURE	REDUCED CAPABILITY SPOILED UNITS	REDUCED CAPABILITY PRODUCT DELAY	DELAY SPOILED BATCH
LOSS CONSIDERATIONS	SPOILAGE TROUBLESHOOT LOST TIME DELIVERY RATE	TROUBLESHOOT RE-TEST LOST TIME DELIVERY RATE	SPOILED BATCH TROUBLESHOOT RE-TEST DELIVERY RATE

Figure 10

Would machine stoppage spoil product? Would start-up require clearing the machines and reprogramming some computers? And, finally, in the case of a plant which supplies another assembly line, would they have to recover their schedule?

For some of the other items (Figure 10), the situation is a little different. The considerations include spoiled batches and the time required to trouble shoot or repair; meanwhile there would be lost time for the operators. A prolonged down time of a piece of equipment could starve the rest of the assembly line or at least reduce the capability for production.

Figure 11 compares the potentially vulnerable equipment within the four factories. For power, the common use of air cooled switches both indoors and outdoors appears vulnerable. For the 440 volt equipment, some work reported by the Navy has shown that 440 volt buses with air ventilation can create a sustaining arc and burn up; a similar situation may exist in large 440 volt motors with open windings. In the textile fiber plant, the frequency converter appears potentially vulnerable.

For low voltage analog types of equipment, the vulnerability of temperature controllers has been recognized. The television plant has two areas of concern. A television set has to be aligned and tuned to the frequencies of the commercial stations. This requires

IMPACT STUDY

COMPARISON OF INDUSTRY INSTALLATIONS: POTENTIALLY VULNERABLE EQUIPMENT

ELEMENT	MACHINING ELECTRONIC	ELECTRONIC ASSEMBLY	AUTOMOTIVE ASSEMBLY	TEXTILE FIBER
POWER	AIR-COOLED SWITCHES		AIR-COOLED SWITCHES	OUTDOOR SWITCHES
440V EQUIPMENT			<ul style="list-style-type: none"> ● VENTILATED BUS ● OPEN WINDINGS 	FREQUENCY CONVERTER
LOW VOLTAGES ANALOG	TEMPERATURE CONTROLLER	<ul style="list-style-type: none"> ● TEST SIGNAL SYSTEM ● TV RECEIVERS 	WELD TIMERS	TEMPERATURE CONTROLLER
LOW VOLTAGE DIGITAL	<ul style="list-style-type: none"> ● DRILLS ● TRIMMERS ● INTEGRATORS ● POPULATORS ● TEST STATIONS 	<ul style="list-style-type: none"> ● INTEGRATOR ● POPULATOR 	<ul style="list-style-type: none"> ● WELDER UNITS ● TELETYPE PRINTERS 	

Figure 11

an oscillator to generate the test signals and circuitry to support operations on the assembly lines. At any time during assembly, a number of television sets operate with their cases open; under such conditions there is some vulnerable product. The assembly of automotive sheet metal relies on spot welding; the welding timers operate exposed with uncoated circuit boards. These units must be considered vulnerable.

Low voltage digital equipment has an identified vulnerability. The automotive industry appears to be expanding the use of digital controlled robotic manipulators within the welding operations. In addition, teletype printer stations throughout the factory provide the means for achieving integration across the entire assembly process.

Figure 12 compares the potential impact of a fiber induced failure within types of vulnerable equipment. The failure of a power switch would halt manufacturing in one plant, halt assembly in another and, in the textile plant, it would shut down one or more lines. The 440 volt equipment has the same capability for impact. Low voltage equipment does not show quite the potential for impact; however, line stoppage is still a significant expense.

IMPACT STUDY

COMPARISON OF POTENTIAL FOR IMPACT

POTENTIAL FAILURE OF	MACHINING ELECTRONIC	ELECTRONIC ASSEMBLY	AUTOMOTIVE ASSEMBLY	TEXTILE FIBER
POWER: TRANSFORMER OR SWITCH	HALT MANUFACTURE	-	HALT ASSEMBLY	STOPS ONE OR MORE LINES
440 VOLT EQUIPMENT	-	-	HALT ASSEMBLY	STOPS LINE
LOW VOLTAGE ANALOG	SLOWS PRODUCTION	SHORT TERM LINE STOP	SHORT-TERM LINE STOP	SLOWS PRODUCTION
LOW VOLTAGE DIGITAL	SHORT-TERM LINE STOP	SLOWS PRODUCTION	SLOWS PRODUCTION	-

Figure 12

As shown in figure 13, the first step in the estimation of a cost requires defining how a factory would respond to a failure; and there seemed to be no common way these factories would respond. The factory supplying another assembly line would probably have to recover the delivery schedules. A factory that maintained an inventory supply may elect to defer any catch-up of production. A continuous operating plant does not have much flexibility for improving delivery or recovering lost production. The loss terms were converted to costs expressed as lost labor hours, number of product lost, and estimates of materials involved. The conversion to dollars used data that came from such sources as Chamber of Commerce publications, Industrial Association publications and to the extent practical, data from the Bureau of the Census. A national estimate for an economic impact on industry must find a way to use census data.

As shown in figure 14, the transfer function took the simplest practical approach. The A. D. Little Company, during previous work, had devised an equation for the transfer function based on filter efficiencies and the relative ventilation flow rates throughout the factory. This equation was considered adequate for the purposes of this study. The transfer function appears as a product with one term which describes the factory and the other term which describes the cabinet that houses the electronics.

IMPACT STUDY METHOD AND EXAMPLES

STEP 3, ESTIMATION OF A COST

- DEFINE AN APPROPRIATE RESPONSE-TO-FAILURE ACTION.
- ESTIMATE THE CORRESPONDING IMPACT FOR EACH ITEM OF EQUIPMENT AND EACH LOSS CONSIDERATION IN TERMS OF: LABOR HOURS; PRODUCT; MATERIALS.
- CONVERT TO DOLLARS USING AVAILABLE PUBLISHED DATA.

Figure 13

IMPACT STUDY METHOD AND EXAMPLES

STEP 4, TRANSFER FUNCTION, ASSUMPTIONS:

- ACCEPT THE ADL EQUATION BASED UPON VENTILATION PARAMETERS AND FILTER EFFICIENCIES.

$$\text{TRANSFER FUNCTION} = \left(\frac{Q + \frac{(1 - N_I) M}{R}}{Q + M + N_R} \right) (1 - N_C)$$

RELATIVE FLOW RATES:

Q = INFILTRATION
M = MAKE UP
R = RECIRCULATION

FILTER EFFICIENCIES:

N_I INLET FILTER
N_R RECIRCULATION FILTER
N_C CABINET FILTER

- ASHRAE DUST SPOT EFFICIENCIES CORRELATE TO FIBER EFFICIENCIES:

ASHRAE %	FIBER %	ASHRAE %	FIBER %
10-35	90	45-80	98.5
35-40	97	80-90	99
40-45	98		

Figure 14

Other work reported by the A. D. Little Company indicated that air conditioning filters showed a correlation between the efficiency for stopping fibers and the efficiency as rated by the ASHRAE dust spot method. As interpolated from the published data, the values shown represent the efficiencies for removing fibers as correlations to the efficiencies measured by dust spot ratings. The assumption is limited to just those kinds of filter materials used in industrial installations.

Figure 15 outlines the assumptions used to calculate the probability for a failure. The equation shown assumes the failure is precipitated by a single fiber. The values selected for \bar{E} become the best estimates extracted from existing test data. The outside exposure of 10^5 fiber seconds per cubic meter represents an estimate for a median fiber release incident.

Figure 16 shows the kinds of results appearing after preliminary calculations. Relative to the transfer functions, the value shown for the transformer/13 kV switch represents the basic air conditioning system. The populator has air conditioning plus a cabinet filter. Acceptance test represents a room-within-a-room with precise temperature control. The chamber control reflects air conditioning plus a tight cabinet.

IMPACT STUDY METHOD AND EXAMPLE

STEP 5 ESTIMATE A PROBABILITY FOR FAILURE

- PROBABILITY OF FAILURE = $1 - e^{-E_i/\bar{E}}$

E_i = EXPOSURE

\bar{E} = AVERAGE EXPOSURE TO CAUSE A FAILURE (TEST DATA)

- ASSUME A FIBER RELEASE INCIDENT RESULTING IN AN OUTSIDE EXPOSURE OF 10^5

THEN, $E_i = T.F (10^5)$

STEP 6 IMPACT PRODUCT

(PROBABILITY) X (COST ESTIMATE)

Figure 15

IMPACT STUDY METHOD AND EXAMPLE

CALCULATION ASSUMING AN EXPOSURE OF 10^5

<u>ELEMENT</u>	<u>TRANSFER FUNCTION</u>	<u>\bar{E}</u>	<u>PROBABILITY OF FAILURE</u>	<u>FAILURE EST. COST</u>	<u>IMPACT PRODUCT</u>
TRANSFORMER (13 KV SWITCH)	3.2×10^{-2}	10^5	6.4×10^{-2}	$\$ 8 \times 10^4$	$\$ 5.2 \times 10^3$
POPULATOR (COMPUTER)	3.0×10^{-4}	10^6	1.2×10^{-4}	$\$ 4 \times 10^2$	$\$ 4.9 \times 10^{-2}$
ACCEPTANCE TEST	2.2×10^{-5}	10^6	1.4×10^{-5}	$\$ 4 \times 10^2$	$\$ 5.5 \times 10^{-3}$
CHAMBER CONTROL	6.2×10^{-4}	10^7	6.2×10^{-6}	$\$ 4 \times 10^4$	$\$ 2.5 \times 10^{-1}$

Figure 16

For the \bar{E} values listed, the chamber control reflects a general knowledge of typical units. The 10^6 values correlate to test results on typical computers employed in such installations. The value listed for the transformer/13 kV switch is an engineering estimate. The values shown for the probability of failure include the effects of a multiple installation where a failure in any one unit could produce the estimated cost.

In assessing costs, clearing a failure within a computer does not incur a large penalty particularly if companion units do not fail (only one failure in a group). Loss of a half day of production during a thermal excursion has a significant cost impact. A power failure which halts manufacture has a major impact.

The consequence of a power failure persists into the impact product and result in the only significant value. The costs associated with a half day of production are offset by the low probability for a chamber control failure to cause a thermal runaway.

The findings from the study as listed in figure 17 show that failures within power equipment have the potential for causing the kinds of economic impact associated with the shut-down of a factory. Low voltage equipment can fail and cause a significant economic impact such as loss of a half days production. Fortunately, the

IMPACT STUDY FINDINGS

OBSERVATIONS FROM THE STUDY:

POWER: ONLY FAILURES WITHIN POWER EQUIPMENT SHOW A POTENTIAL FOR MAJOR ECONOMIC IMPACT.

LOW WIDE USAGE IN IMPORTANT APPLICATIONS.

VOLTAGE: FAILURES COULD HAVE SIGNIFICANT ECONOMIC IMPACT.

PROTECTIONS: FILTERS AND CABINETS IN-USE APPEAR TO PROVIDE ORDERS-OF-MAGNITUDE BUFFERING.

Figure 17

present protections of air conditioning and good cabinets moderate any chances for failure.

Figure 18 summarizes the results from the surveys relative to further effort. The areas of hospitals and air traffic control do not seem to have a problem. For other essential service equipment, the surveys have generated candidate lists of items for test. Industry cost modeling requires more data. Future work must look at high voltage and 440 volt equipment first. Test data must include a wider range of filter media, since industry uses a correspondingly wide range. There is a need for a correlation to other economic data such as provided by the Bureau of the Census. Therefore, surveys must continue toward developing a method for relating to the bulk of federal data. The DOE has a test plan to evaluate high voltage equipment and requires the coordinating of information such that areas of concern do receive evaluation by test. Finally the current test program for vulnerability and for filter transfer will require a continuing liaison toward updating candidate lists in the light of new data.

CONCLUSIONS AND RESULTS FROM THE SURVEYS
APPLIED TO FUTURE COST RISK ASSESSMENT EFFORTS

1. HOSPITAL AND AIR TRAFFIC CONTROL EQUIPMENT APPEAR TO HAVE GOOD PROTECTION.
2. SURVEYS OF ESSENTIAL SERVICE EQUIPMENT HAVE IDENTIFIED POTENTIALLY VULNERABLE ITEMS.
3. COST IMPACT MODELING FOR INDUSTRY NOT COMPLETE; DATA FROM SURVEYS AND TESTS NEEDED TO:
 - DEFINE VULNERABILITIES OF HIGH VOLTAGE AND 440 V EQUIPMENT
 - CHARACTERIZE FILTER EFFICIENCIES AND TRANSFER FUNCTIONS
 - ESTABLISH A CORRELATION TO OTHER ECONOMIC DATA
4. ACTIONS INDICATED:
 - PLAN AND CONDUCT ADDITIONAL SURVEYS
 - COORDINATE WITH DOE IN THE TEST PLANNING FOR HIGH VOLTAGE EQUIPMENT
 - EVALUATE RESULTS FROM ON GOING TESTS

Figure 18

Pertinent Questions and Answers

(1) Question:

Have any surveys looked at nuclear or other electrical generating stations for effects on control rooms or vulnerable equipment?

Answer:

No visits have been made to any electric power plants; the DOE is charged with that responsibility. In a review of the requirements for nuclear plants, their specifications consider seismic effects, and they also require the capability to seal the control rooms such that they become self-sustaining entities in the event of an emergency. Control of power plants does not appear as a problem.

There is no definitive data to show what happens when fibers get into an area that is concentration critical, here the presence of fibers can distort the electric field. These effects are part of the reasoning behind the DOE test program. There has been some work done by BRL, by the Navy, and by other agencies; they have identified the principal areas of uncertainty.

(2) Question:

What did the airport surveys find for landing aids such as glideslope transmitters and similar equipment?

Answer:

These items are usually located out along the runways in a sealed building or at least with filtered air. The electronics are mounted in closed or sealed cases. They do not appear as a problem.