RISK ANALYSIS APPROACH

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I would like to introduce the presentation of this activity at Langley by presenting an outline which you can use as a road map of the work that you are going to hear about for the rest of the day. Our program objective is identified in figure 1. We have said it several times already, but basically it is to quantify the national risks associated with accidental release of carbon fibers (CF) from civil aircraft having composite structures. Because of the sparsity of CF on current civil aircraft, we are looking ahead 15 years. As a part of determining the national risk, we will be looking for potential equipment damage on civil aircraft and, therefore, we will assess the need, if any, to protect civil aircraft from accidentally released carbon fiber.

CARBON FIBER HAZARD RISK ASSESSMENT

PROGRAM OBJECTIVES

- QUANTIFY RISK ASSOCIATED WITH ACCIDENTAL RELEASE OF CARBON FIBERS FROM CIVIL AIRCRAFT HAVING COMPOSITE STRUCTURES
- ASSESS THE NEED FOR PROTECTION OF CIVIL AIRCRAFT TO ACCIDENTALLY RELEASED CARBON FIBER

Figure 1

What requirements do we have on a risk assessment? First, as shown in figure 2, we must develop an accident scenario and associated probabilities. This involves integrating both known data and judgements from experts in a logical framework. We must explicitly state the assumptions and the source of the data so that we can assess the conservatism of the data inputs and of the judgements. Second, we must estimate public risk in a very systematic manner. Once an estimate is made, we can then determine the significance of any assumptions by sensitivity analysis, and we can quantify the uncertainty in the risks through evaluation of our assumptions, data, inaccuracies in the data, and the technical judgements that have gone into the analysis. This systematic framework also allows us the opportunity of evaluating risk reduction strategies. We have already mentioned one such strategy, the alternate materials program, which is a strategy to develop alternates to current graphite epoxy composites where the mechanism of release of graphite fibers from the composite is modified or the airborne characteristics of the fibers are changed in a favorable way. Other strategies such as protection of a substantial portion of the electrical equipment in the U.S. might be offered (as a ridiculous option) but some acceptable option could be developed. The final requirement on our risk assessment is that we perform the analysis in such a manner that we can make comparisons of the benefit of carbon fiber with the risk and that we can assess the risk against other risks of which we are familiar in other areas.

RISK ANALYSIS

DEVELOPS ACCIDENT SCENARIOS AND ASSOCIATED PROBABILITIES

- INTEGRATES KNOWN DATA AND JUDGEMENT FROM EXPERTS IN A LOGICAL FRAMEWORK
- EXPLICITLY STATES ASSUMPTIONS

ESTIMATES PUBLIC RISK IN A SYSTEMATIC MANNER

- DETERMINES SIGNIFICANCE OF ASSUMPTIONS BY SENSITIVITY ANALYSIS
- QUANTIFIES UNCERTAINTY
- PERMITS EVALUATION OF RISK REDUCTION STRATEGIES

PERMITS COMPARISON WITH BENEFITS AND OTHER RISKS

Figure 2

Let us look now at the scenario that we have adopted as of interest for the accidental release of carbon fiber from civil aircraft. Figure 3 illustrates the scenario that we see is important for the air transport aircraft. We are hypothesizing accidents of civil aircraft, usually near major airports, where the efflux from the burn of an aircraft containing composite has an opportunity to be distributed downwind and to contaminate the airport terminal facilities and air traffic control and ground control approach systems. This efflux has an opportunity of being carried into shopping centers, banks, local businesses, and into the homes of private individuals, where household appliances could be affected by the released graphite fibers. We have to be concerned with public service areas, such as telephone exchanges and hospitals, as well as manufacturing and transportation facilities. Of course, one item ties all of these together. This network is the power distribution system of the various utility systems.

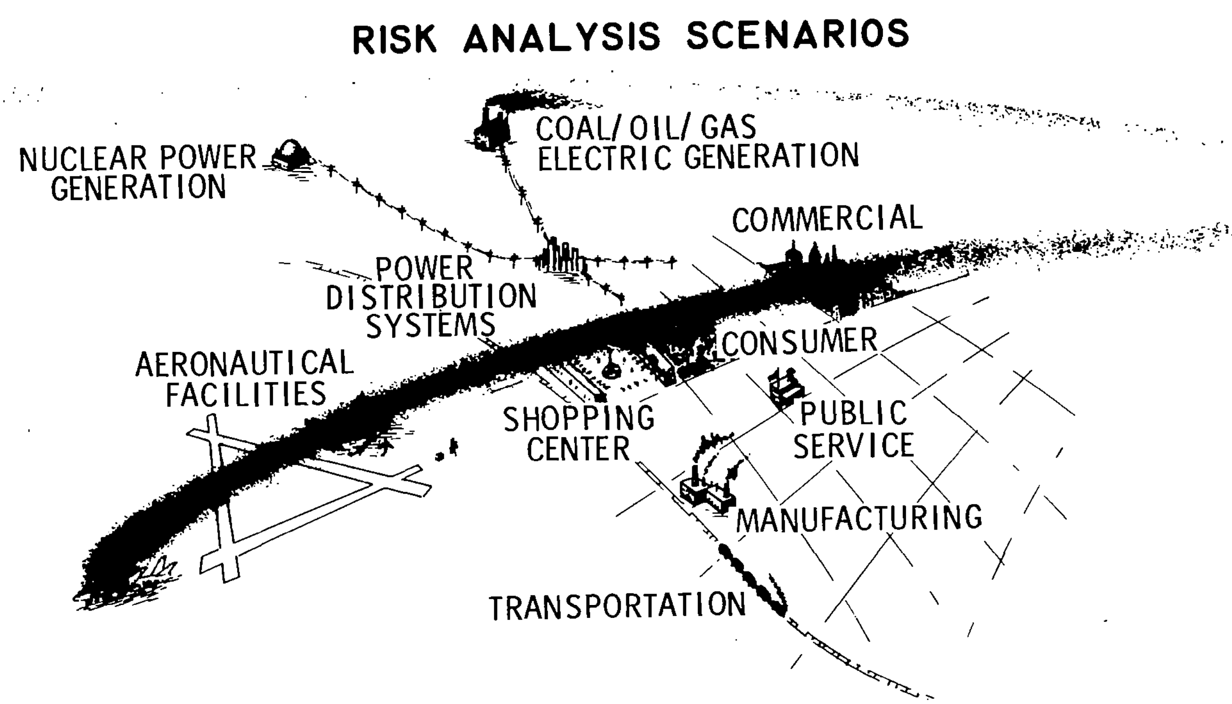

Figure 3

Another dimension of the risk analysis is illustrated by the risk analysis flow chart shown in figure 4. Six elements are associated with the physical phenomena of the accidental release. I will go through this in a little more detail, step by step, and since this conference is organized along the lines of this chart, I will only mention that basically I am referring to the source of carbon fiber, the potential dissemination of carbon fiber, the life of the released fiber (which may result in a potential redissemination that might cause a problem at a later time), the transfer of

CF from the exterior of enclosures to the interior, and the vulnerability of equipment associated with the various areas of importance identified in the risk analysis scenario. In the final step, we must relate the demographic data with the density of equipment in homes and businesses to determine cost impacts.

RISK ANALYSIS FLOW

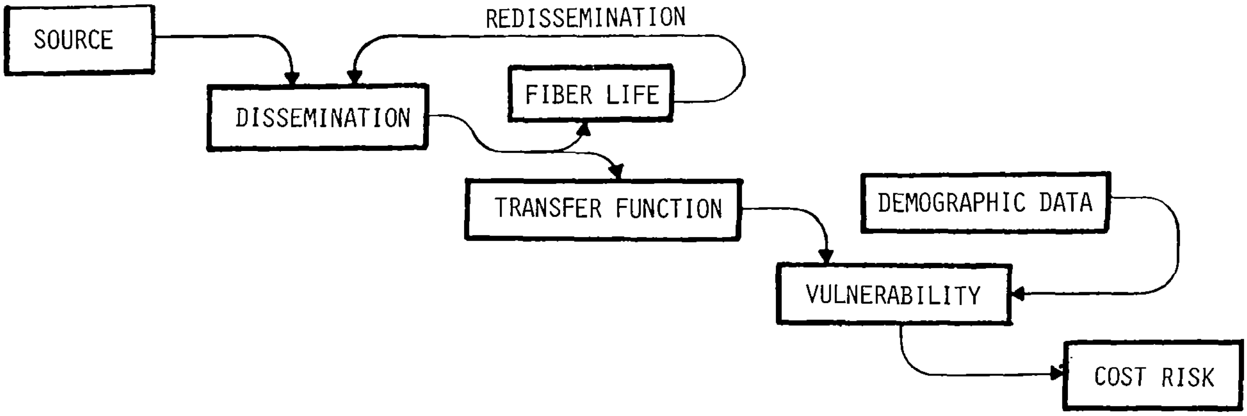

Figure 4

Looking at the element of source, figure 5, this first area covers the release of carbon fibers. Within the context of a risk assessment, we must determine the quantity of released fibers and their character. In order to determine the quantity of released carbon fibers, we must first project the use of carbon composites in the future. You have seen some projections earlier. We must then estimate the most likely locations and magnitude of accidents as well as the type of accident. It is important, in determining the release of graphite fiber, to know whether the accident was a crash burn, or a burn explode, or a total demolition at contact. We have National Transportation Safety Board (NTSB) data on accidents, but we are currently investigating, in depth, the details of all U.S. built jet transport accidents on which to base a better analysis. Fiber release is influenced by a number of factors: fire size and temperatures, the length of the fire, the nature and the character of composite material, and where it is used in the aircraft. Finally, the character of the released fibers must be determined. The character of the fibers includes the mass of fiber released, the form (single fibers, clumps, clusters, and strips), and the length and diameters of single fibers.

Figure 5

Given that fibers are released as single fibers or in other forms, the fibers will be carried off by the fire plume, as shown in figure 6. They will be carried up and away from the location of the fire or, if by an explosion, projected away from the source of the fire and then dispersed downwind from the accident scene. This dispersion can be characterized in several ways; one way is by looking at footprints of concentration of fibers, or by exposure. Some of the key elements involved in the dispersion estimates include the fire plume development, which depends upon the weather, the amount of fuel burned, and the rate of burn. The items that affect the dispersion of the cloud of fibers downwind from the fully developed fire plume include the weather and the fall rate or settling rate of the released fiber.

The footprints are presented in terms of exposure, as defined in figure 7, since exposure has been found to be the key parameter in the probability of failure of electrical equipment.

One element that must be included in our final risk assessment and has not been included to date is the long term effects of released fibers, which conceivably could be redisseminated by winds or through mechanical agitation. Let me say simply that in addition to the potential for

Figure 6

DEFINITIONS

C	CONCENTRATION	$\frac{\text{NUMBER OF FIBERS}}{\text{METER}^3}$
E	EXPOSURE	$\frac{\text{NUMBER OF FIBERS}}{\text{METER}^3}$ X SECONDS
		$E = \int C \, dt$
$\bar{E}$	CRITICAL (MEAN) EXPOSURE	PROBABILITY OF DAMAGE $= 1 - e^{-E/\bar{E}}$
T. F.		TRANSFER FUNCTION, RATIO OF QUANTITIES ACROSS AN INTERFACE, FOR EXAMPLE: $E_{\text{INSIDE}}/E_{\text{OUTSIDE}}$

Figure 7

redissemination, we would expect that the character of released fiber might change with time. Figure 8 shows an hypothesis about the change in character of the length spectrum with time. A later speaker will discuss this in more detail.

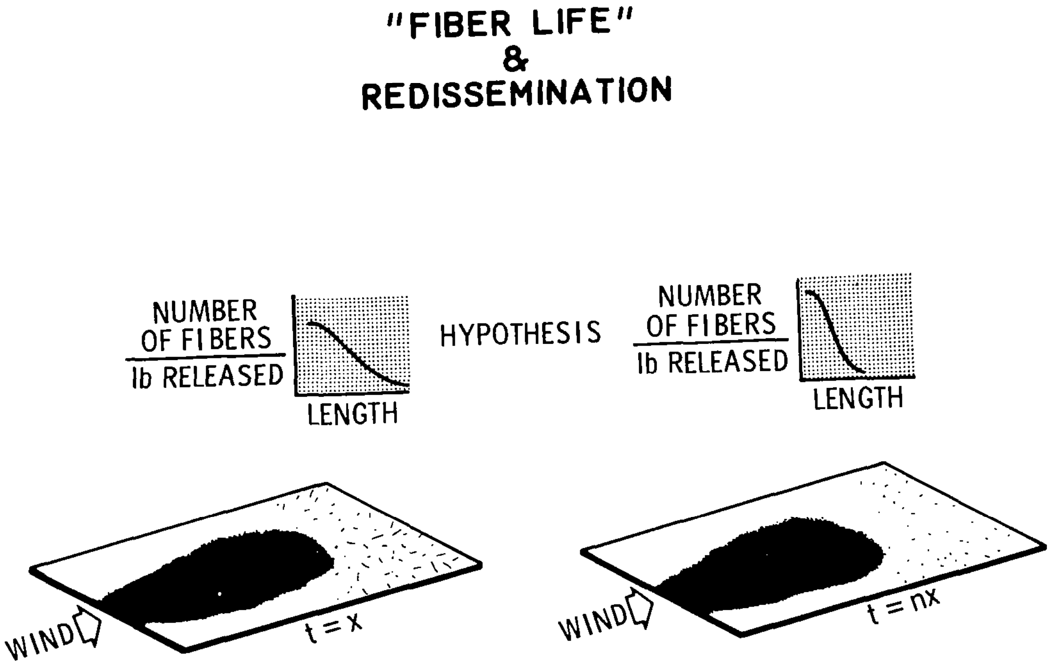

Figure 8

Eventually, the released carbon fiber will reach homes, businesses, and factories, and we must estimate what interior fiber concentration or exposure will result. Figure 9 illustrates the expected effect, though a number of factors influence the actual values of what we call transfer function. Some of the factors that affect the transfer function include the use or nonuse of air-conditioning, the condition of windows (opened or closed) in buildings, natural ventilation, the fall rate of fibers, and generally the nature of air circulation and what kind of filtration, if any, is used in buildings.

Once fiber concentrations are carried to electrical equipment, the electrical conductivity of the fiber can result in a hazard to susceptible equipment. The probability of failure for a couple of assumed examples is illustrated in figure 10 and has been experimentally determined to follow the exponential relationship cited on the definition chart (figure 7).

TRANSFER FUNCTION

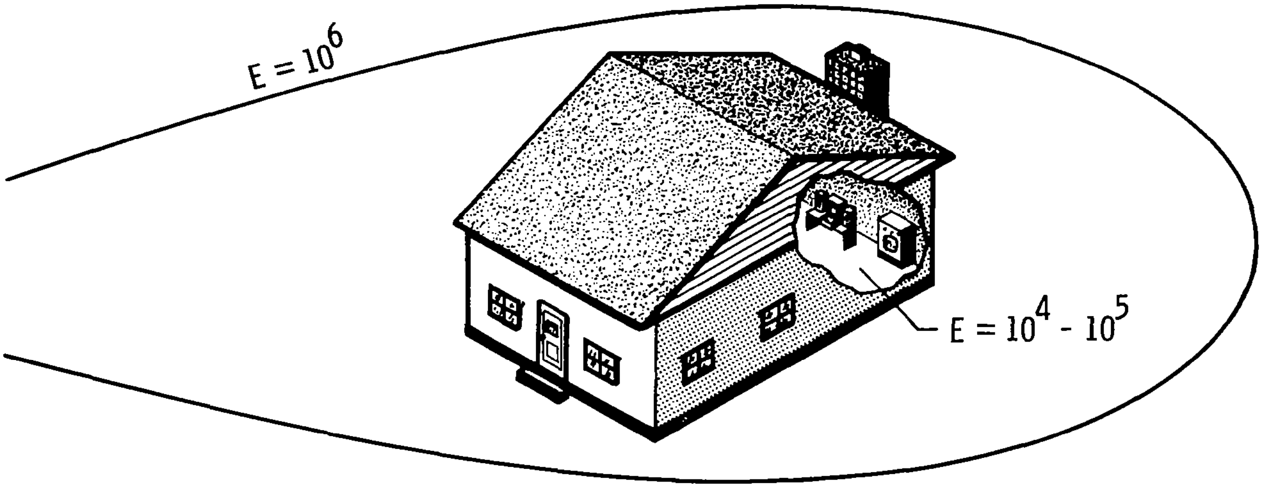

Figure 9

VULNERABILITY OF EQUIPMENT

ASSUMED CRITICAL EXPOSURE LEVELS ($\bar{E}$)

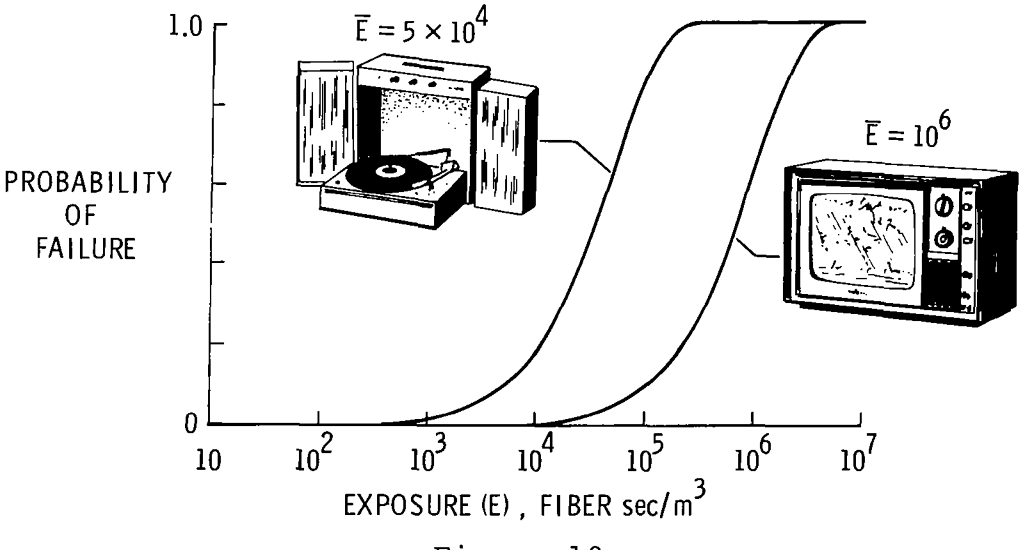

Figure 10

For the risk assessment, we must categorize susceptible equipment into classes and categories appropriate for investigation in risk models. This means that we must determine the susceptibility and vulnerability of a wide range of equipment in the very diverse areas covering household, business, and industrial electrical equipment. Let me point out that the values shown here are simply selected for illustration and the subsequent speaker will show some data on a range of civilian equipment that might be involved in a carbon fiber problem. Let me also point out that this is plotted in a little different form from that you sometimes see; that is, the probability of failure is represented on a log plot, which gives you an S-shaped curve in contrast to the exponential form on a linear plot that most researchers in this area utilize.

Finally, we must combine the physical models with our demographic model in such a way as to obtain a suitable measure of risk. One such measure is the risk profile illustrated in figure 11 which gives the annual probability of exceeding a given dollar damage as a function of the dollar damage. Since you are going to see a few of these over the next couple of days, I thought it might be appropriate to give you a simple example. Basically, at a point on the abscissa representing, for example, a million dollars, or whatever number you want to choose, the ordinate gives the probability of exceeding the million dollars in a given year. This representation might be unfamiliar to some who have not studied risk analysis in the past but it has been used as a typical measure in analyses that have been done in the areas of nuclear power and liquid natural gas transportation.

Let me now outline our approach to the risk analysis program. (See figure 12.) A central portion of our effort is to develop an adequate data base for a credible analysis. In many areas, before we can actually generate data, we must perform what we call pathfinder studies to determine what data should be obtained. These pathfinder studies, for example, involve looking at specific types of electrical equipment, determining in what manner they might be exposed to carbon fibers, and determining what kind of test is needed. We have the capability to assess the vulnerability of electrical equipment by exposing the equipment in a fiber chamber but in some cases we have found that other methods can be used. They will be discussed in a later presentation. When you first study a new area, you must quantify the new area. We have found that it is necessary to go out and physically survey hospitals, telephone exchanges, and factories in order to determine in what area we need to make measurements. The data and pathfinder studies are being used in our analysis

RISK ANALYSIS SCENARIOS

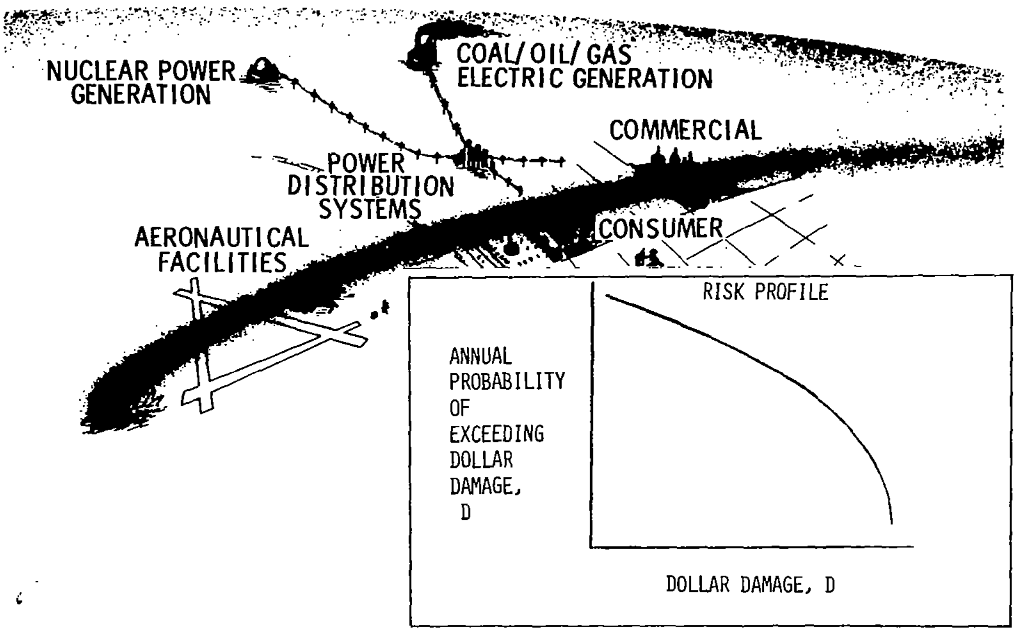

Figure 11

PROGRAM OUTLINE
ASSESSMENT OF RISK ASSOCIATED WITH ACCIDENTAL RELEASE
OF CARBON FIBERS FROM CIVIL AIRCRAFT

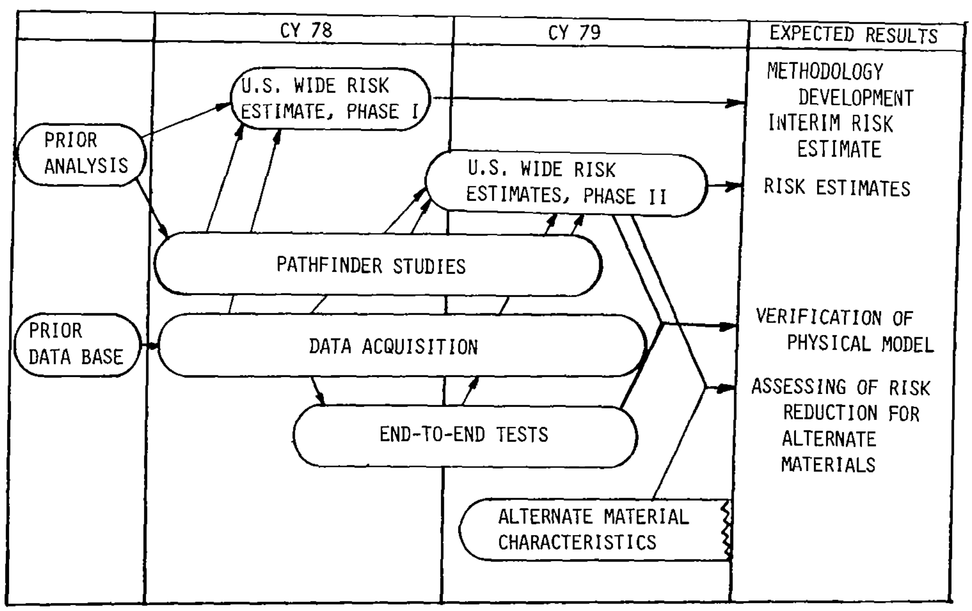

Figure 12

effort to determine the risk to the United States as a whole. Our first phase analysis effort has primarily been one to develop an adequate methodology in which we have confidence, and to make an interim risk estimate. This activity of our risk analysis has resulted in two studies that you will hear reported on tomorrow. We anticipate continuing these first phase studies through most of the rest of the calendar year. Our second phase efforts will include evaluating studies that we have currently underway and data that are expected to be generated in the near future. Our plans in each area will be covered by subsequent speakers. We will also be using data being developed by other government agencies, such as the studies of the Department of Energy in the power distribution area. Finally we anticipate performing some tests to allow us an opportunity for verification of the physical model used in the risk analysis. We are, at this time, in the initial development of what could be described as a contained end-to-end test which will be discussed by the last speaker of the day. We are also assessing the need for a full scale outdoor end-to-end test. One final item, our program allows for us to evaluate the material characteristics that are coming out of the alternate materials programs that Dr. Harris described in the second presentation of this conference. If necessary, we can assess the reduction in risk that might be associated with any particular alternate material.

We have a number of participants on the risk assessment program, as shown on figure 13. Without going into detail, I would like to just check off the list and try to indicate where the work is going on. The Fire Products Division of AVCO, in Massachusetts, is working with us on developing chamber test methods for fire testing materials to determine the characteristics of released graphite fibers. The Ballistic Research Laboratory (BRL), at Aberdeen, Maryland, has been working with us on vulnerability testing of equipment and on transfer function measurements. We have been quite heavily dependent upon that activity in the past for much of our data. The Bionetics Corporation, Hampton, Virginia, has been performing pathfinder studies and analysis that has led us to identify many areas in which additional data are needed. They have also identified areas where we can short cut some of the laborious paths that we have had to follow to analyze the risk. The commercial aircraft manufacturers, Boeing, Douglas, and Lockheed, have been assisting us by supplying information on potential uses of carbon composites in the future and in details of aircraft accidents. They are studying the airplane accidents of all jet airplanes that they have built. They have detailed data on these accidents in their files and are correlating that data with NTSB accident data so that we can have a better understanding of how much of an

GRAPHITE FIBERS RISK ANALYSIS

PROGRAM PARTICIPANTS

AVCO	SOURCE
BALLISTIC RESEARCH LABORATORY ABERDEEN	- VULNERABILITY, TRANSFER FUNCTION
BIONETICS CORPORATION	- PATHFINDER STUDIES
BOEING DOUGLAS LOCKHEED	- SOURCE, AIRCRAFT VULNERABILITY
DAHLGREN, NAVAL SURFACE WEAPONS CENTER	- SOURCE, END-TO-END TESTS
DUGWAY PROVING GROUND	- DISSEMINATION, FIBER LIFE - REDISSEMINATION
JET PROPULSION LABORATORY	- INSTRUMENTATION
A. D. LITTLE ORI GEORGE WASHINGTON UNIVERSITY	- ANALYSIS
NATIONAL BUREAU OF STANDARDS	- VULNERABILITY
SCIENCE APPLICATIONS, INC.	- DISSEMINATION
TRW	- DATA ANALYSIS

Figure 13

aircraft actually burns. We need to know what the opportunity is for a wing tip or an elevator to be involved in an actual fire. In addition, as part of the risk analysis activity and as a part of assessing the need for protection to civil aircraft, they are studying the susceptibility of electrical equipment in their current and future air transport aircraft to determine how vulnerable aircraft are and what protection may be needed. In the source area, the Dahlgren Naval Surface Weapons Center in Virginia has been testing a number of material specimens, as well as aircraft components, to determine released fiber characteristics. They are also participating in our end-to-end test activity that you will hear about this afternoon. The Dugway Proving Ground in Utah has been assisting us in calculations of dissemination and in prediction of the life and redissemination of fibers. The later data have been obtained from measurements at a site where fibers were released outdoors several years ago. The Jet Propulsion Laboratory has been looking at some innovative ideas for released fiber sensin instrumentation. We have a considerable problem with instrumentation. Dick Heldenfels mentioned earlier that you can look right at fibers and not see them. When fibers are in concentrations high enough that you can see them, such as you may have in a fiber chamber, you can hardly count them, and we actually have to count the fibers to determine the number of fibers released. The techniques to date have been primarily through manual counting. We are trying to develop some instrumentation that will allow us to do this a little faster. I should point out that Dugway Proving Ground has been instrumental in providing this type of counting. We have A. D. Little of Massachusetts, ORI of Maryland, and George Washington University assisting us in analysis. The National Bureau of Standards is assisting us in a study of household appliances. Many household appliances can be tested by a simpler method than a carbon fiber chamber. The National Bureau of Standards has been tasked in the national carbon fiber program, with responsibility for evaluating household equipment, and is assisting NASA by determining vulnerability. Science Applications Inc., of California, under contract to the Ames Research Center, is supporting our program by providing fire dynamics and plume models. Finally, TRW Inc. of California has been analyzing data for us from the large scale burn tests they performed for the Air Force at the Navy's China Lake, California, facility. I should note that we are using data generated by other programs, such as the alternate materials program. The Ames Research Center has some burn facilities at their installation and has been supplying us with data from these facilities. In addition, we will take advantage of data generated by other agency efforts in the federal program such as the Department of Energy's activity on carbon fiber effects on power system elements.

The agenda for the remaining presentations in the conference is presented in figure 14.

BRIEFING OUTLINE

SOURCE	
• CARBON FIBER AND COMPOSITE USAGE	- RICHARD PRIDE
• FIBER RELEASE MECHANISM	- DR. VERNON BELL
DISSEMINATION, FIBER LIFE, REDISSEMINATION	- DR. WOLF ELBER
TRANSFER FUNCTION, VULNERABILITY	- ISRAEL TABACK
END-TO-END TESTING	- RICHARD PRIDE
ANALYSIS	
• OVERVIEW	- DR. KAREN CREDEUR
• PATHFINDER SURVEYS	- ANSEL BUTTERFIELD
• ORI STUDY STATUS	- DR. LEON POCINKI
• A. D. LITTLE STUDY STATUS	- DR. ASHOK KALELKAR
	- DR. JOSEPH FIKSEL
CONCLUSIONS	- ROBERT HUSTON
QUESTION AND ANSWER PANEL	- SPEAKERS

Figure 14