

## CONCLUSIONS

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I would now like to summarize. Referring to figure 1, we have developed and exercised a risk analysis method. You should recognize, and I want to emphasize, that our risk estimates are very preliminary. Sensitivity analysis has not been done. Only civil transport aircraft accidents have been considered as a source of accidentally released graphite fibers. We intend to study the question of the potential release of graphite fibers from accidents with general aviation, including helicopters, which is the remaining category of civil aircraft to be considered. Let me add that we do not anticipate a large increase in risk due to this additional source. In fact, I doubt very seriously that it is going to increase by even a factor of two. We have already completed a survey of fire accidents in general aviation. We find that the total empty weight of general aviation aircraft that are involved in fire accidents, which represents an upper boundary on the potential carbon fiber released from general aviation, is approximately one-fifth of the empty weight of civil transport aircraft involved in fire. Unless there are some unusual circumstances when we consider a large number of small sources, we may already have at least an order of magnitude estimate on the total risk by studying air transport aircraft alone.

### CONFERENCE SUMMARY

A RISK ANALYSIS METHOD HAS BEEN EXERCISED  
 RISK ESTIMATES ARE VERY PRELIMINARY  
 SENSITIVITY ANALYSIS HAS NOT BEEN DONE  
 ONLY TRANSPORT AIRCRAFT ACCIDENTS HAVE BEEN CONSIDERED AS A SOURCE

DATA BASE IS STILL SPARSE - FURTHER STUDY NEEDED IN THE FOLLOWING AREAS  
 FIBER RELEASE FROM LARGE FIRES  
 POWER GENERATION AND DISTRIBUTION VULNERABILITY  
 EQUIPMENT VULNERABILITY (WITH REALISTIC FIBER LENGTH SPECTRA)  
 INDUSTRIAL FACILITY VULNERABILITY  
 COSTING TECHNIQUES

SOME ELEMENTS ARE STILL UNDER DEVELOPMENT. I.E.:  
 FIRE PLUME - DISPERSION MODELS  
 FIBER LIFE - REDISPERSION DATA

Figure 1

With reference to our data base, further study is needed in a number of areas. For example, both ORI and A. D. Little assumed that from 5 to 25 percent of the carbon fiber in an aircraft would be released in a crash. However, in Dr. Bell's presentation, he points out that, in the case of fire accidents, approximately 1 percent or less of the fibers might be released. In the case of fire followed by an explosion, 10 percent of the weight of carbon might be released as free fibers. Therefore, we should note that considerable conservatism has been included in the current A. D. Little and ORI analyses. As we acquire further data, we may see a further reduction in the risk profiles from this one area alone.

We do not have enough information on power generation and distribution vulnerability. Ansel Butterfield pointed out in his presentation that power distribution was a key item in assessing cost impacts on factories. We at NASA are heavily dependent upon the activity of the Department of Energy who has responsibility for evaluating carbon fiber effects on power distribution systems. We need to evaluate equipment vulnerability with a more realistic fiber length spectrum. Most of the fiber chamber testing has been done with rather moderate length fibers. Israel Taback showed you the effect on vulnerability of short, medium and long fibers for a very limited sample of equipment. The available vulnerability test data is primarily based on a range from six to ten millimeters. We note that the mean exposure level goes up drastically when short fibers are used in the tests, which, by itself, infers that the probability of damage is less but there may be more fibers. We need to continue studying industrial facility vulnerability to identify key areas for further tests. We need to look at the different approaches to costing in order to have better confidence in the cost impacts of our risk estimates.

Some elements are still under development. Up to now, we are using some simple fire plume models, and they may be adequate in the long run. However, we recognize that a combined fire plume dispersion model, that would also allow computation of the amount of fiber that may be consumed in the actual fire, may show a further reduction in potential damage. To date, the only large outdoor test data we have is the China Lake experiment and it appears that we have had a large amount of fiber burned up in that particular experiment.

The question of fiber life and redispersion was covered in Dr. Elber's presentation. We have to establish what would happen if a small percentage, say one percent of the released fibers, continue to be redispersed from an accident site for a period of time. That effect has not been included in our risk assessment estimates to this point.

Now I am going to go out on a limb and make a judgement about the risk. Our preliminary estimate indicates that the public risk due to accidental release of carbon fiber from air transport aircraft is small. You may judge it in your own way, but I believe that the risk is small with respect to the national benefits that can be obtained from carbon fibers. We should recognize that there is a balance of payment issue involved in terms of foreign sales of commercial aircraft and a significant fuel import and cost savings offered in the application of graphite composites. We do need further work to increase our confidence in this estimate. To reemphasize our schedule, we anticipate completing our "final" risk assessment in 1 year. These conclusions are summarized on figure 2.

#### CONFERENCE CONCLUSIONS

PRELIMINARY ESTIMATES INDICATE THAT THE PUBLIC RISK DUE TO ACCIDENTAL RELEASE OF  
CARBON FIBER FROM AIR TRANSPORT AIRCRAFT IS SMALL

FURTHER WORK IS REQUIRED TO INCREASE OUR CONFIDENCE IN THESE ESTIMATES

Figure 2



## PANEL RESPONSE TO QUESTIONS

Question: Regarding exterior exposure...where can you draw a line between this area as being contaminated and an area outside that for which you need not be concerned?

Response: Israel Taback

If you do it on a computer there's no limit; that is, if you really believe the exponential model, then all the way down to where you drop one fiber on a piece of apparatus, there is some probability of doing some damage. In the real world when the probability of damage gets so small compared to the normal failure rates of equipment, then I think you have to forget it - the equipment would be normally repaired anyhow and the damage would not be noticed. It's a rather difficult question really; as you saw for some of the exposures the failure rates go down as the areas go up, so as you try to extrapolate the total damage you really don't know where to end the computation. Eventually, we know the computations will converge. The answer to your question however, is that with the concept that a single fiber can do damage, you must at least numerically extrapolate it all the way out to where fibers can land.

Question: Question related to describing risk in terms of criticality (i.e. loss of communications say in White House) rather than in terms of dollars.

Response: Bob Huston

We are currently only trying to quantify the risk in terms of cost for the civil community. However, we do need to assess the cost to protect any kind of activity that we think is critical.

Israel Taback

I just wanted to remind the audience that there was a third study underway with respect to other measures of risks, which is being done by George Washington University. We don't have those results in yet but we are going to look at that study to see what other measures should be used in evaluating the risk.

Dr. Karen Credeur

My comments would be to echo these two comments, and also to say that Dr. Kalelkar pointed out in his talk that he will be looking at secondary costs and perhaps some of those secondary costs will get into just the issues you're talking about.

Question: Question regarding relationship of vulnerability to deposition and exposure.

Response: Dr. Wolf Elber

I think in most cases that we've looked at, if you go through an analysis, you'll find that first of all deposition is usually proportional to exposure so that they are related--in most cases they are proportional, so that if we measure the vulnerability in terms of exposure even if inside the box might be deposition critical, we're getting a number which is proportional to the critical term.

Question: There is a substantial amount of fiber that is manufactured overseas. A logical way of shipping it into the United States might be by air and therefore has the case of an accident involving raw unprepregged or raw carbon fiber as a cargo been considered?

Response: Dr. Credeur

We are considering exactly that scenario for a worst case.

Question: Question related to vulnerability of civil aircraft.

Response: Bob Huston

One of our objectives is to look at the need for protection to civil aircraft. We have right now Boeing, Lockheed, and Douglas working with us analyzing all of their air transport aircraft to see if there is a need for protection to air transport aircraft. That is being evaluated right now, not as a part of the input to our risk assessment, but as a separate issue.

Israel Taback:

There is one thing that is in work that I don't think we emphasized previously - that was our concern about general aviation aircraft as well as the larger scheduled commercial aircraft. We are evaluating some of the electronic components that are in the lighter aircraft to see what the extent of risk might be for airplanes parked on the apron. To date, what we've tested hasn't failed, but I suspect that some day we will run into a box that does, then we'll evaluate it.

Question: Is there a size effect below which you would not worry about the vulnerability of electronics?

Response: Israel Taback

Yes, there is a critical size, but I'm afraid it varies with the electronics. First, you always have to worry because of the fact that if you put a lot of fibers into a piece of apparatus, you may bridge the gap with more than one fiber. On the basis that those probabilities are much lower than the bridging of a gap with a single fiber; however, you must usually worry about the relative length of the gaps and the single fibers. For most commercial apparatus where people aren't worried about space, these gaps typically range from a sixteenth of an inch to a quarter of an inch. In military equipment and in space work, where you kind of build the devices from the outside in and room is very important, many of the circuit traces on circuit boards may be as little as ten thousandths of an inch apart, and you must then worry about very short fibers.

Question: Question related to vulnerability sensitivity to fiber length.

Response: Israel Taback

I can only give you a guess at the present. I think the longer fibers would not be a problem for any internal equipment because it's very hard for them to get through filters or even window screens. Short fibers of millimeter length are probably of no concern because they are too short. My guess is that equipment will generally be most vulnerable to fibers ranging in length from 1 to 4 millimeters.

Question: Question related to dispersion sensitivity to fiber length.

Response: Israel Taback

The dispersion doesn't vary much with length. These fibers tend to fall parallel to the ground; and independent of length, they have the same fall velocity.

Question: Question related to fall velocity of fibers.

Response: Bob Huston

They always fall at terminal velocity, if that's what you mean.

Israel Taback

Well I wouldn't say always. I think when the fibers get long enough so that they are essentially not straight lines, so that they have some curvature to them, they'll fall at various velocities with a spectrum of fall rates. As long as they're short and stiff

they seem to be stable in a horizontal attitude and fall at a rate which is independent of length.

Question: Question related to whether or not electrical utilities and substations were considered in the risk assessment.

Response: Dr. Fiksel

In our description of vulnerable facilities I attempted to summarize the categories we looked at and we failed to show the fact that we did look at gas and electric utilities. Those were included.

Question: Is the length of the released fiber related to the length of the fiber in manufacture and would manufacturing techniques affect the lengths of released fibers?

Response: Dr. Vernon Bell

I believe the only evidence we have seen that that might be so, first of all, is in the burning and explosion of woven composites where you have crossovers during the weaving process and there may be weaknesses built into the fiber, thus causing it to break up prematurely into short fibers. The other exception seems to be the long fibrous particulate strips which came off in the outdoor spoiler fire at China Lake where the long strips seem to be quite closely related to the lengths and dimensions of the composites in the spoilers' skins.

Question: Have you done any tests on chopped fibers?

Response: Dr. Vernon Bell

No, we have not. We have sure thought about it because many applications will involve chopped fibers. The fiber is already cut to size once you have burned the resin off. There are some problems with mounting such a type of composite and holding the fibrous residue before you can impact in some fashion. But we are still thinking about doing that.

Question: Have you tried to compare the incident with the incinerator incident of several years ago?

Response: Bob Huston

The answer is no, but we have thought of it and we would like to get the appropriate data. We believe that if we could get the appropriate data from the incinerator incident that we could make a good attempt at predicting what happened.



Question: The statement was made that you did look at the power generation--distribution systems. Could you give us some idea of the . . (vulnerability estimates). . in terms of transfer function or the sensitivity of this type of equipment?

Response: Dr. Fiksel

I do not have the detailed figures in my head, but I could show them to you afterwards. We considered several different types of equipment, including the switch room and switching apparatus.

Dr. Kalelkar

As far as outdoor equipment is concerned, the clumps and the larger pieces are the ones to be more concerned about. As yet, those have not been incorporated in our analysis.

Question: There has been very little mention of ground transportation vulnerability in the risk assessment. The implication is that ground transportation is not vulnerable. Is that true?

Response: Dr. Leon Pocinski

We did not include it in the calculations we showed, primarily because of the tremendous impact on our thinking of a recent strike of the metro system in Washington. This strike ended up causing some inconvenience to the public, but not much else.

Dr. Fiksel

In our study, the major ground transportation systems that we had identified as being vulnerable were the modern mass transit systems which have electronic controls, such as the Washington subway. There is also a subway system in Boston, where we did include some estimates for vulnerability of the control apparatus.

Question: Is it possible that we can expect soon to have some sort of standardized test plans so the manufacturer can say "Here is my gadget or what have you. I would like to get it tested." Can I then take the results of that (to determine the source potential of the part) and feed it into all these models and what have you?

Response: Dr. Vernon Bell

Yes, at one time the military services had a little gadget which they hoped to use for detection of carbon fibers that were on the loose. I'm not sure what the status of that is. I think it is available. Whether it's been developed sufficiently to pass on, I'm not sure. We do have an activity going within the NASA program, in particular with Jet Propulsion Laboratory, who is trying to come up with a small, fairly portable device which could hopefully be used to not only detect and count but also perhaps measure the sizes of fibers. It was not intended for that purpose and it's still in the very early stages, but, if we're very fortunate, perhaps it could lead to something of that nature.

Bob Huston

Let me also point out that in the alternate materials program there is an intent to provide a standardized burn test, so that material A and material B, tested at two different places, give comparable test results.

Question: Question for Dr. Bell. Correct me if I have this wrong. The woven fabric panels worked very good from a burn only and burn plus a moderate explosion but in a severe explosion they looked worse than the unidirectional and cross ply laminates.

Response: Dr. Vernon Bell

For the woven fabric, the woven material seemed to resist burn and burn plus small impact reasonably well. However, the case of the burn and the high impact or explosion seemed to lead to more individual fibers.

Question: Question related to the fiber lengths used in the vulnerability testing.

Response: Israel Taback

Regarding the fiber lengths, I tried to give you some idea on the slide - they range from about 3 at the low end to about 12 millimeters at the high end. I designated them as being small, medium, and large. Those tests were performed, quite a number of them, here at Langley Research Center. We have a small test chamber. They were performed by carefully injecting fibers that were cut to size into a room at the best uniform concentration we could and testing the equipment in as close to the use condition as we could. That is, if it had a ventilating fan, that was on; if it was thermally ventilated, that's the way it was tested.

Question: What were the sample sizes?

Response: Israel Taback

Actually its the test numbers that I think you're interested in. After any failure the equipment was cleaned and repaired if it needed a repair. The normal number of tests was of the order of six and ranged to as much as perhaps 20 or so on one specific type of equipment.

Question: Was vulnerability testing conducted with a spectrum of fiber lengths?

Response: Israel Taback

At present, we have never used a mixed spectrum. The fibers have been cut to specified lengths and then tested one length at a time.

Question: You mentioned the maximum anticipated cost for an accident worst case situation as 12 million dollars possibly. Looking at the Tenerife situation where the damage cost of one of the airplanes involved was substantially less than the insurance associated with the problem, I am wondering if it would be worthwhile to plot on your last plot, where you show the effect of tornadoes and other weather conditions, etc, the total cost of an airplane accident so that you might get a barometer for the insurance rate increase and also possibly show better the real effects of graphite fibers.

Response: Dr. Kalelkar

In other words, you would like to see the incremental addition in loss of carbon fiber being utilized in connection with an airplane accident. Certainly we can do that and you will see something like that before we get finished with our study. However, I want to point out to you that from the point of view of the people who suffer the risk, the people who fly in an airplane that gets in an accident do so on a voluntary basis, but the people who get hit by the carbon fiber in the aftermath of such an accident take on that risk on an involuntary basis, so that the comparison has to be made rather carefully. From the point of view of people who live miles away from that accident, the only reason that accident affected them is because of carbon fiber composites and, from their perspective, they wouldn't be that interested in the differential between the carbon fiber cost and the total cost.

Dr. Karen Credeur

There's another point, and that is that sometimes when you get into insurance costs and liability suits, you get into the question of costing human life. That question gets into a lot of problems, as some of you may have seen on 60 Minutes some time in the last few months.

Questions: I assume that DOT is following your work and will use your data. How are you interfacing with DOT-automotive, and what are they doing?

Response from the floor: William Leavitt, Department of Transportation

What we're doing is getting acquainted with the problem of expected loadings of cars, vulnerability of the ground transportation system, etc. Hopefully we will get to a point that we can use all the risk techniques that have been developed here and by others that Bob mentioned and feed our inputs into this set of models, if you will. We are probably a year behind Bob's effort.

Bob Huston

Let me say that we are working together. Let me also make a general statement, that may or may not be obvious. In my original list of activities, I mentioned the various DOD laboratories that are supporting us and, of course, we are aware of some of the technical things that they are doing. We've had contact with the Department of Energy. They have some contracted activity. The National Bureau of Standards is doing some work for us and at least one of their people is here today. We hope to mutually support these efforts.

The risk assessment methodology that was presented this morning for commercial aircraft is not going to be terribly different from that for automobiles. Therefore, once the Department of Transportation can define the automobile parameters as inputs to the source data, I think they can generally use the remaining methodology.

Question: Is there any indication as to when the automobile industry will be planning to start utilizing carbon fibers, and secondly is there any indication of where, by virtue of the liability associated with fibers?

Response from the floor: William Leavitt, Department of  
Transportation

The best input we have so far, and most of this has been from Ford, is that they are looking forward to a flange. In particular, the thing that people are talking about is an air conditioning mounting flange in the next couple of years. Bill Burlant has told me that his best guess would be something like five pounds of composites by 1985 or 1990. In other words, it is not very much as things stand right now. If the picture would change, if someone came through with a real breakthrough in terms of cost or in terms of techniques for fabricating the automotive type component, it could be a different ball game. I should also mention that Ford has what they call an experimental lightweight car that has a lot of carbon fiber composites - I think it is 400 pounds: leaf springs, drive shafts, hoods, door reinforcements, a lot of gadgets inside. This is completed. They plan to show it at the SAE show in February in Detroit. But right now it looks like there isn't going to be much carbon fiber composite loading.

Comment from the floor: Four or five pounds per car times the number of cars produced per year is more pounds than are projected for aircraft.

Comment from the floor: This subject has come up in two composite sessions that have been held by the Society of Manufacturing Engineers. In each case, the manufacturer points out very clearly that they are doing a great deal of experimenting with composites in cars, hoods, doors, drive shafts, and push rods. Although this experimentation is very interesting from a test stand point, the key parameters that are affecting the automotive industry are (1) fifty dollars a pound, which is several orders of magnitude higher than the automobile people wanted to pay right now, and (2) gasoline mileage requirements for the year 1985 and subsequently are driving them in the direction of composites, so they are kind of straddling that horse. I don't think we are going to see a large introduction of composites in cars in the very near future.

Question: Is the soot produced by the incomplete combustion of the matrix an electrical problem?

Response: Richard Pride

In the Dahlgren shock tube, we have exposed two of the amplifier units that are on display in the back of the room to approximately one hour of smoke and soot, not from the epoxy matrix, but from the incomplete combustion of the JP-1 fuel, and had no problems whatsoever from that source.

Bob Huston

Dick Heldenfels mentioned yesterday morning at least one incident involving an aircraft that burned and apparently there were some electrical problems downwind of that aircraft. There was no carbon on that aircraft. Apparently there is a potential problem (from other than carbon fibers).