TRANSFER FUNCTIONS

Israel Taback

The Bionetics Corporation

There are various interfaces, such as filters, doors, window screens, and cabinets, which affect the concentration, exposure, or deposition on the two sides of an interface. The dimensionless ratio of these quantities as they challenge and breach the interface is called the transfer function.

Before transfer functions are discussed, it is useful to review the overall problem of doing a vulnerability assessment. I will talk in general about single fiber lengths, but when overall vulnerability assessment is done, we must remember that the fibers released from the source are of various lengths and, in general, would have a distribution as illustrated in figure 1. It is believed that the shorter ones will be numerous and the longer ones relatively infrequent. This would be designated as a source characteristic. At a specific location away from the source, that distribution can very well change, depending upon how those various fibers fly, the fall rates, and perhaps some of the fiber lift char-

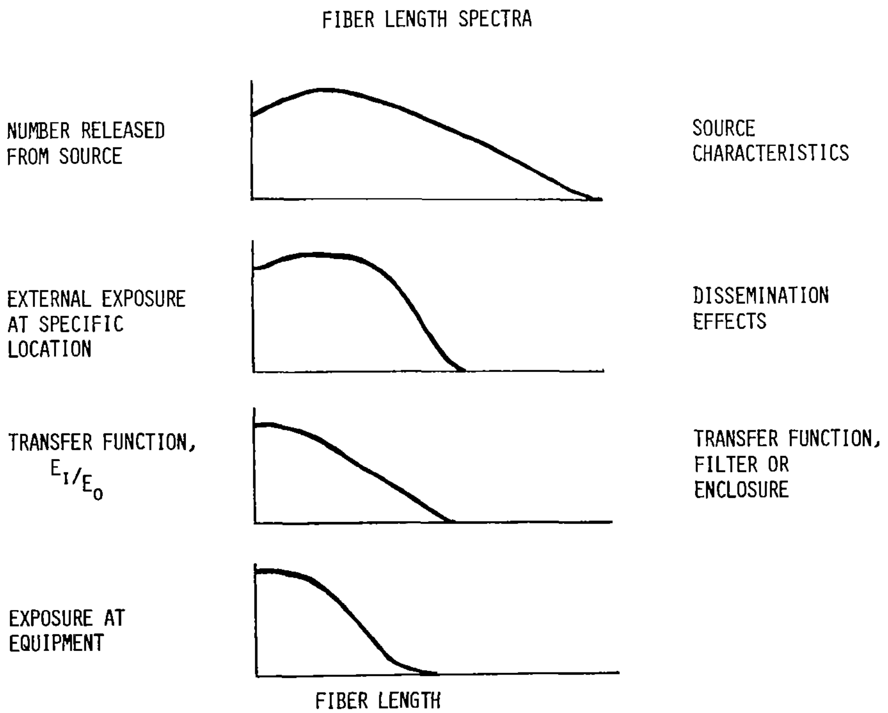


Figure 1

acteristics. The phenomena would be included in dissemination effects. We then get to the external exposure outside a piece of equipment. The transfer functions between the external and internal world must be evaluated, and we find that the transfer functions for the shorter particles are larger than the transfer functions for the larger ones. To get the exposure for a piece of equipment, all of these factors are evaluated at a fixed fiber length. The installed vulnerability of the specific equipment is evaluated by determining its local exposure at a fixed length and then integrating its vulnerability over the complete length spectrum.

Figure 2 illustrates a number of typical values for filter transfer functions. This work was done with fibers about 7 millimeters in length. These are a limited number of samples, there are more in the literature. The first one illustrated is one that is used quite often in ground support equipment. It is a multilayer aluminum mesh called Air Maze (trade name), tested dry. In its normal mode, this material is used coated with a sticky liquid. We tested it dry in order to get some idea of what would happen if the filter were poorly maintained. The figure illustrates the transfer function at a velocity of 100 feet per minute, which is approximately the velocity at which the filter is used.

FILTER TRANSMISSION

(MEDIUM LENGTH FIBERS)

	AIR VELOCITY IN FEET/MIN		
	100	400	800
MULTI LAYER ALUMINUM MESH, AIR MAZE R-82, UNCOATED (DRY)	1%	2%	4%
MULTI LAYER ALUMINUM MESH, AIR MAZE R-82, COATED (WET)	0.1%	0.2%	0.5%
3/8-INCH-THICK OPEN FOAM POLYURETHANE	0.1%	0.9%	1.4%
WINDOW SCREEN	1%	10%	15%

Figure 2

Transmissivity factors of the order of 1% may occur, and as the air velocity through that filter is increased, we find that the percentage passed through that filter also increases. These tests were done at 100, 400, and 800 feet per minute. When this same filter is coated, which is the condition in which it is normally used, it has transmissivity of the order of tenths of a percent at all velocities. Its transmissivity is still a function of air velocity. Another commonly used filter is open foam polyurethane. This filter was 3/8-inch-thick open foam. Again the transmissivities ranged from about a tenth of a percent to 1.4 percent. We also tested one very interesting interface, a window screen, which is not normally regarded as a filter.

At air velocities of about 100 feet per minute (which is about a mile an hour), it had a transmissivity of 1% and then rose very rapidly at higher speeds to about 10 to 15%. One other filter was tested with material of rather long lengths, compared to the lengths of the fibers just discussed. It is another piece of polyurethane filter, and the results are shown on figure 3. It has a trade name, Scott Foam, and is 3/4" thick. It did not react the way the other filters did in terms of its response to various air velocities.

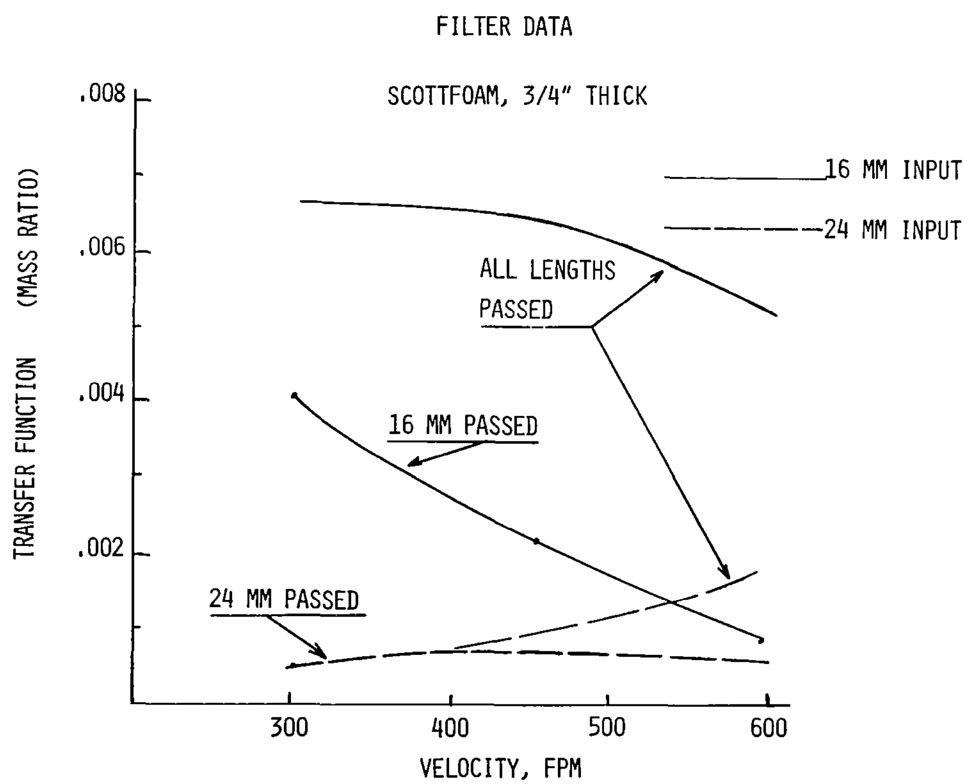
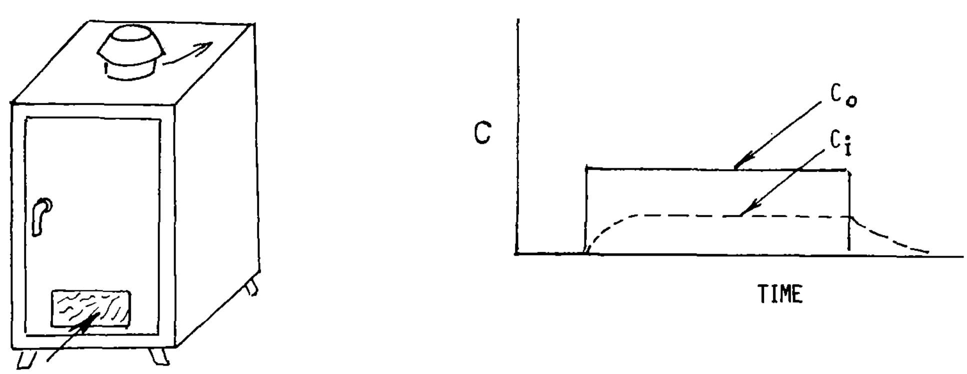


Figure 3

When the 16-millimeter material was passed through the filter, the amount of 16-millimeter material which came through the filter varied with air velocity from about 0.004 (note this is not percent, this is in mass ratio) to a value about 0.001 at high velocity. On the other hand, if you look at the mass transfer ratio without regard to the length of the material passed (the upper solid line), this was relatively invariant with velocity through the filter and, in fact, decreased as the velocity through the filter increased. The ratio of all lengths passed was about 2 to 3 times the amount of material that was passed at the 16-millimeter length. Very much smaller ratios were secured for the 24-millimeter material, and again there was a difference between the total amount of material passed, regardless of length and the material that was passed at the original length. These numbers, by the way, seem to be somewhat typical of most of the filters that we have tried. A transfer function of approximately a few tenths of one percent seems to be a number that we come across many times.

One typical enclosure, sketched on figure 4, that we encountered in some of our survey work was evaluated for its overall transfer function. This is a rather typical traffic control box somewhat similar to the kind that exist on many street corners. It contains electronic equipment which controls traffic signals. That equipment not only controls the traffic signals, but also has

TRAFFIC CONTROL ENCLOSURE TRANSFER FUNCTION



VOLUME, $V = 1$ METER^3

FLOOR AREA, $A = 2/3$ METER^2

FLOW RATE, $Q = 1/30$ METER^3/SEC

FILTER T.F., $F = .002$

FIBER SETTLING VELOCITY, $V_S = .02$ M/S

STEADY STATE:

$$\text{T.F.}_C = \frac{C_i}{C_o} = \frac{F}{\left[1 + \frac{V_S A}{Q}\right]} = .0014$$

$$\frac{\int C_i \, DT}{\int C_o \, DT} = \text{T.F.} = .0014$$

Figure 4

within itself a conflict sensor, such that in the event of an electric fault, it will put all the lights on that corner onto red. One electronic failure in this box, generally, is not of large concern with regard to causing accidents. The volume of this box is about one cubic meter, and the floor area is 2/3 of a square meter. The enclosure is ventilated by a flow into the box of about a 30th of a cubic meter per second, so that it takes about 30 seconds to ventilate the entire box.

We have tested the specific filter that is used in these boxes, at least in the city of Newport News, and find that these filters have a transfer function of about 0.002. The fibers that were considered here are single fibers, and their fall velocity is of the order of about 0.02 meters per second. If one hypothesizes that there is a square pulse of concentration outside the box and looks at the inside of the box, the concentration inside the box comes up slowly with time and reaches a steady-state value.

At the end of the pulse, the concentration drops off at a rate that is shown in the figure consistent with the ventilation rate of the box. If the internal concentration is computed with respect to the external, it turns out to be a function of the filter factor divided by one plus a correction term. This term consists of the fall velocity times the area of the box divided by the flow rate into the box. This fall rate, this settling term as it is called, is the settling that would occur if the internal mixing in the box was fairly uniform so that the concentration throughout the box was constant.

The overall-steady state transfer function for concentration turns out to be 0.0014, somewhat smaller than the filter function of 0.002. The transfer function for exposure is the ratio of the integrals for concentration with time. For the external exposure, the integral takes the form of a square pulse. For the internal exposure the integration must include the effect of buildup and the effect of drop-off. In performing the integration, the two effects balance, and the transfer function for exposure is exactly the same number as computed for the steady-state ratio of concentrations.

There is one interesting thing about this filter, as well as all others. (I'll present this in inches and you can turn it into meters). If the height of that filter were about 6 inches and there was a little bit of a gap at the top of the filter (which we have observed in many installations) of perhaps an eighth of an inch, one would find that perhaps ten times as many fibers entered that box due to the poor installation of the filters. The most important factor with regard to the number of fibers that may be ingested into this box may not be the filter itself but how well it is inserted into its holder.

The next illustration, figure 5, is for a typical room. It is hard to recognize in meters but it is a 9- by 12-foot room with an 8-foot ceiling. The infiltration factor which I have assumed is 0.1. The flow rate into the room is such that the ventilation time for the room would be of the order of about 3 hours. That is fairly realistic. It could be as little as 2 and as large as 6 depending on how well built the house was. We assumed that the room has an air conditioner with a filter having a transfer function of 0.005 with a flow rate such that it could ventilate the room in about 8.6 minutes.

The equation in the upper right of the figure gives the same relationship that was shown in the previous figure; that is, the ratio of the internal to the external concentration. Again, the integral is really the same ratio that would be secured in the steady state (if indeed the pulse lasted long enough to achieve steady state). The ratio is always correct regardless of the length of the pulse.

Again, we find that the predominate factors that determine the ratio of internal to external transfer function consist of the filter factor, the filter infiltration factor, and three terms in the denominator: the settling velocity times the area of the room, the filter factor of the air conditioner and its flow rate, and both divided

TYPICAL ROOM TRANSFER FUNCTIONS

ROOM DATA

- V VOLUME = 23.3 M^3
- A FLOOR AREA = 9.72 M^2
- F_I: INFILTRATION T.F. = 0.1
- Q_I: FLOW RATE = .0022 M^3/SEC
- VENTILATION TIME = 3 HRS

AIR CONDITIONER DATA

- F_{AC} AIR CONDITIONER T.F. = .005
- Q_{AC} FLOW RATE = .04 M^3/SEC
- VENTILATION TIME = 8.6 MINS.
- V_S FIBER SETTLING VELOC. ≈ .02 M/S

AIR CONDITIONER RECIRCULATING:

$$\frac{\int C_I \, DT}{\int C_O \, DT} = \frac{F}{1 + \dfrac{V_S A + (1 - F_{AC}) Q_{AC}}{Q_I}}$$

$$= \frac{0.1}{1 + \dfrac{.19 + .045}{.0022}} = 10^{-3}$$

AIR CONDITIONER INTAKE:

$$\frac{\int C_I \, DT}{\int C_O \, DT} = \frac{Q_I \, F_I + Q_{AC} \, F_{AC}}{Q_I + Q_{AC} + V_S \, A}$$

$$= \frac{2.2 \times 10^{-4} + 2.2 \times 10^{-4}}{.0022 + .047 + .19} = 2 \times 10^{-3}$$

Figure 5

by the infiltration volume flow. There are really only two important terms here; one is the filter infiltration factor, and the second is the fall rate of the fiber. The characteristics of the air conditioner, as such, do not strongly affect the ratio of internal to external exposure. That ratio, the room transfer function, turns out to be about 10^{-3}. One can recompute this with the air conditioner bringing in air from the outside.

We still have an infiltration factor which is assumed to be the same, although it may change somewhat with the air conditioner running. The input-flow volume of the air conditioner and its filter factor appear, and when that is evaluated, it turns out that the fact that the air conditioner is taking in air and passing it through its filter has only raised the internal to external relationship by just a factor of two.

Of further interest is that if one shuts off the air conditioner entirely (that is, let the second term be zero), one gets the same answer as in the first case or about 10^{-3}. So although I did not choose these numbers they are typical of a room. For all three conditions of operating that air conditioner, there is not an enormous difference between the ratios of internal to external exposure (time integrals of the concentration).

Figure 6 lists the work we have planned on transfer functions.

PLANNED TRANSFER FUNCTION WORK

ADDITIONAL FILTER TESTS: SHORTER LENGTHS
COARSE, MEDIUM, FINE
USED FILTERS

SPECIAL FILTERS: AIRCRAFT AIR CLEANERS
AIRCRAFT WATER SEPARATORS

GENERIC CABINET T.F. TESTS

FILTER T.F. MODELING

VERIFICATION OF TYPICAL ROOM/EQUIPMENT PREDICTIONS

Figure 6

I suspect its elements are rather obvious; do more filter tests at lengths down to the order of 1 millimeter or shorter. We did want to test down to this value somewhat earlier in time, but have been limited until very recently, both in terms of being able to make fibers of that length in a practical way and in sensing those fibers in the laboratory. I believe we are now in a position of running our tests down to about 1 millimeter. Various filters of different fineness will be tested. Special aircraft filters will be tested because of the specific responsibility NASA has regarding aircraft.

Generic cabinet transfer function tests are planned. These tests are on cabinets with louvers and on appliance cases with air-flow which is fairly typical of that encountered in practice.

Filter transfer function modeling will be attempted in order to predict transfer functions, and although the computations shown on the previous figures seem to be straight forward, there is a need to verify the settling terms in those equations. These may be somewhat dependent upon the amount and the scale of the turbulence that might exist within a given enclosure, and it is planned to check this under one or two sets of conditions.

Figure 7 lists some preliminary conclusions. I believe that,

PRELIMINARY CONCLUSIONS

1. A BODY OF ANALYTIC AND TEST DATA EXISTS WHICH ALLOWS COMPUTATION OF TRANSFER FUNCTIONS TO BE MADE FOR SPECIFIC INSTALLATIONS.

2. ADDITIONAL TEST DATA AND MODELING IS NEEDED REGARDING GENERAL TYPES OF ENCLOSURES FOR PERFORMING THE NATIONAL RISK ESTIMATE.

3. VERIFICATION BY TEST OF COMPUTED TRANSFER FUNCTIONS FOR TYPICAL INSTALLATIONS HAS YET TO BE ACCOMPLISHED.

Figure 7

if we have any specific installation and understand its filter, the infiltration flow rates, and forced ventilation rates, there is no question that the transfer function can be computed. However, to generalize these relationships for particular industries, homes, and other facilities in the country, additional modeling work must be done so that the national risk can be computed.