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2350

Formaldehyde: Causes, Effects, and Relief from Formaldehyde Build-Up in the Home

B. Meyer, Ph.D.
University of Washington

My topic is formaldehyde sources and I doubt there is any need for introducing the subject. A large fraction of formaldehyde sources is in the outdoor environment; the single largest source is probably automobile exhaust gases. There is, however, a difference between indoor and outdoor formaldehyde. Outdoor formaldehyde is exposed to daylight, and it rapidly decays by photochemical reaction. Thus, even though we have large quantities of formaldehyde that are being released by automobiles, the bulk of it is promptly converted. In the outdoor environment sources are temporary in nature; there may be a burst of traffic during rush hours, but we have transient sources. In contrast, formaldehyde in the indoor environment does not rapidly decay and may linger until it is removed. Removal paths include ventilation, absorption on cold, wet walls, and in fact removal may be by breathing, i.e. by absorption in the respiratory system.

What about indoor sources? One indoor source of formaldehyde that is being frequently mentioned is smoking. According to the Surgeon General, cigarette smoke contains up to thirty parts per million (30 ppm) formaldehyde. But the Surgeon General also says that each puff of smoke is only forty milliliters of air. According to the Surgeon General most smokers only take about ten puffs of one cigarette. So, averaged out on a twenty-four hour time-averaged exposure basis, smoking, in the form of one pack per day in an average family-sized residential room, contributes less than a tenth of ambient formaldehyde levels, according to my calculations. Thus, smoking does give high concentration peaks of formaldehyde, but averaged out, even a chain smoker does not contribute very significantly to the total formaldehyde level in a house. Of course, I do not promote smoking, which I consider an unnecessary, unhealthy, and offensive habit, because it emits toxic substances, other than formaldehyde and which are actually much worse. We have particulates and all kinds of truly toxic suspended materials in that smoke that are carcinogenic.

Formaldehyde is only one of about three hundred chemicals that are deleterious to indoor air quality, so why does formaldehyde cause such a big fuss? It is a strange aspect of the history of civilization and a story which repeats itself all the time; it has to do with the success of technology and with the success of new products. Formaldehyde was discovered about 130 years ago by Butlerov in Russia. In 1920, a Czech scientist, Hanns John, mixed it with urea and discovered that he obtained resins (UFR). John's patent of 1920, in a nucleus, contains an amazing number of applications that have since reached maturity. Now urea-

formaldehyde resins are currently the main source of formaldehyde in the indoor environment. However, there are other formaldehyde compounds present as well. Exterior grade plywood, CD-X plywood of the type we have in the Northwest, is bonded with phenolic resins. Many people, including myself, have found that phenolic resins as a group release on the order of one hundred times less formaldehyde than urea-formaldehyde resins. A CD-X plywood is usually identified as such with a stamp, and is recognizable because the glue line is dark. Formaldehyde release from this material is negligible unless the product is truly defective. [A similar plywood stamp is shown in Figure 1a. Figure 1b shows the stamp that identifies UF-bonded wood products that comply with the emission limits that are mandatory since February 11, 1985 for materials used in mobile homes.]

There is a lot of confusion between these adhesives. For example, a week ago I had a phone call from a lawyer in Pennsylvania. The unexpected death of six hundred piglets in a plywood barn had cause him to litigate for five years. The value of the six hundred piglets was estimated to be higher than $950,000. How did they establish that formaldehyde was the cause of the expensive problem in this pigsty? The answer was that apparently the veterinarian recognized plywood and thought the problem was due to formaldehyde. Nobody conducted any test during the five years of litigation. I suggested that the suspicious material should be tested. A $75 standard material test, called FTM-1, showed that the flakeboard was CD-X, and it had no measurable formaldehyde emission. This is only one of many dozen similar stories I could relate. Another adhesive is formaldehyde-resorcinol, a coldsetting adhesive, which is used to make laminated beams for swimming pools, hockey rinks, and public assembly halls. These products do not emit much formaldehyde either.

How does one identify products? Commercial wood panels contain identifying stamps that show the product specification code, the factory identification code, and the name of the certifying agency. By way of example, Figure 1 shows stamps by the Hardwood Plywood Manufacturing Association (HPMA). This organization can provide all the necessary details about the products they certify. HPMA is located in Reston, Virginia. In this case the panel was bonded with UF-resin.

Why do urea-formaldehyde resins tend to release more formaldehyde vapor than other products? The reason is chemical: Urea and formaldehyde react with each other forming monomethylolurea (FU) and water:

Equation I $$F + U = FU + H_2O$$

and this reaction can continue to form long polymers. Since there is an equilibrium, this reaction can go backward as well as forward. Adding water to the product can force the reaction backwards. This makes urea-formaldehyde resins very effective slow-release fertilizers. The water is produced during the

a.

HARDWOOD PLYWOOD MANUFACTURERS ASSOCIATION		
FORMALDEHYDE EMISSION 0.2 PPM CONFORMS TO HUD REQUIREMENTS	SIMULATED DECORATIVE FINISH ON PLYWOOD	FLAME SPREAD 200 OR LESS ASTM E84
LAY UP 16 3.6MM THICK HP-SG-84	hpma ® MILL SPECIALTY GRADE	GLUE BOND TYPE II ANSI/HPMA HP 1983

b.

HARDWOOD PLYWOOD MANUFACTURERS ASSOCIATION		
FORMALDEHYDE EMISSION 0.3 PPM CONFORMS TO HUD REQUIREMENTS	hpma ® MILL	FLAME SPREAD 200 OR LESS ASTM E84
		SIMULATED DECORATIVE FINISH ON **PARTICLEBOARD**

Figure 1

chemical reaction. This is one of the reasons why we have formaldehyde problems. However, in 1920 when John patented UFR, chipboard was not yet invented. Instead, John made window glass out of UF-resin. This was used for over a decade in greenhouses because UF glass transmitted UV sunlight far better than window glass.

In particleboard, UF-resins form a very thin uneven layer with a large surface area. A similar situation exists in urea-formaldehyde foam insulation (UFFI). UFFI is 96% open cell. The material has a very low density, it consists of very thin resin bubbles, and obviously the surface area is tremendous. In UF-bonded wood products wood chips are sprayed with liquid resin dissolved in water. A typical particleboard or medium density fiberboard, or similar type of wood product, has about 8% urea-formaldehyde resin by weight (8 wt%) where the ratio of urea-formaldehyde is 1 to 1.2. This UF ratio is extremely important.

It used to be that people took four-fold excess formaldehyde to make sure the reaction would proceed. This left excess formaldehyde in the product. In a particleboard or medium density fiberboard, only about 10% of the wood surface is actually wetted by the glue. Essentially, those products are reconstituted artificial wood. We have a material that consists primarily of wood and 10% glue. However, the most important culprit in this system is water. Water occurs in the reaction Equation I. and all wood contains moisture. The moisture content of wood is in equilibrium with air moisture. One reason why it is so nice to have wooden walls in the home is because wood has the capability of absorbing moisture. At 50% relative air humidity, wood contains about 9.2 wt% water. If it becomes steamy in a room, say, if any air conditioner breaks down in a full meeting room, such as ours here today, air humidity rapidly approaches 100% humidity. Under such conditions, wood can absorb up to 25 wt% moisture. Thus, wood is an excellent buffer for indoor air moisture, and is a very beneficial material if it is used correctly.

Particleboard contains 80% wood, 10% water, and 10% resin. For its manufacture, adhesive resin is applied to the wood chips and the mixture is formed into a sheet, put in a press and heated. In the hot press the water in the wood converts to steam and penetrates into the interior of what is called the mat, carrying with it formaldehyde vapor that is left over from the reaction. In finished wood products that are pressed at 150° C for 7 to 15 minutes, moisture and left-over formaldehyde are in the core. Thus, particleboard contains about three times more formaldehyde in the core than in the surface layer. A current, state-of-the-art board contains less than 10 milligrams of formaldehyde in 100 grams wood product. An old fashioned board or a defective board may very well contain 100 milligrams. It is part of my laboratory research to look into methods for measuring boards, identifying defective products, diagnosing the source of problems, and, hopefully, help find better products.

Now, how does formaldehyde from the wood product get into the room? Figure 2 shows the ventilation rates that were common during the last 160 years. Ventilation regulations started around 1800 when it was recognized that certain diseases, like tuberculosis, are transmitted through the air by suspended particulates, and people recognized the need for increasing ventilation. In the early part of this century, work places had very high levels of ventilation, because people perceived ventilation to be beneficial, and comfort at work was perceived as increasing productivity. In 1936 Professor Yaglou at Yale University discovered that one does not really need all that fresh air to avoid illness and bad odor. Since 1973 we have been living in yet a different world. Today, energy conservation is the main concern, and we are talking about "minimum acceptable indoor air quality standards." The problem with current regulation is not that the five cubic feet per minute (5 cfm) minimum level is inadequate, but the fact that an air ventilation system with a given 5 cfm rating does not necessarily deliver 5

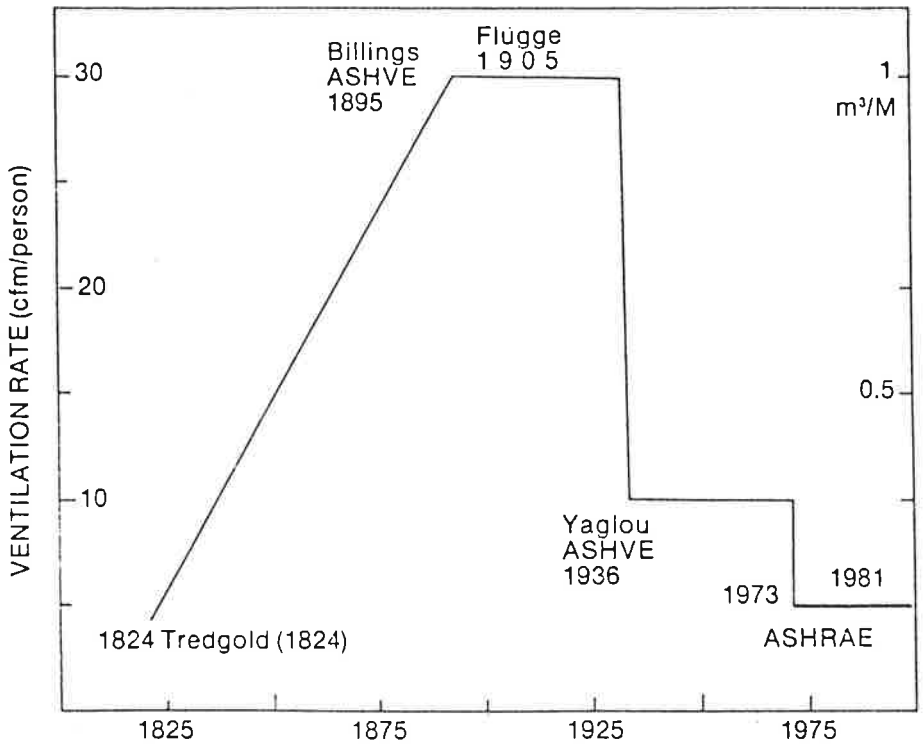

Figure 2: Ventilation Standards from 1820 to 1985
(from Meyer, Indoor Air Quality)

cfm at every air stratifier. Thus, it can happen that some areas have adequate fresh air supplies, while other areas may have no measurable air supply at all. If a formaldehyde emitter is present in such a place, formaldehyde will accumulate. Industry has recognized this problem since 1962, as evidenced by particles in the professional literature. In the middle 1960's there was a conference in East Germany for specialists about formaldehyde in the indoor environment, because some Czech and Polish factories made boards that gave indoor levels of up to 20 ppm in school rooms. The same happened in West Germany in 1975, and again this past year. However, these recent problems are no longer due to lacking technology, but are caused by grossly defective products. Therefore, on October 9, 1984, the German government published a proposal for a federal law providing for a 0.1 ppm formaldehyde level which had been voluntarily accepted by most industries since 1978. Indeed, in Europe one can buy products that are guaranteed to keep air levels below 0.1 ppm in appropriately built and ventilated places.

Formaldehyde levels generally decrease with age, as seen in Figure 3. However, the decrease depends on ventilation. If there is no ventilation, then the levels go down slower than if there is ventilation. In a normal product, formaldehyde levels drop to half in about a year if one has old fashioned type of ventilation, i.e. about one air change per hour. In a

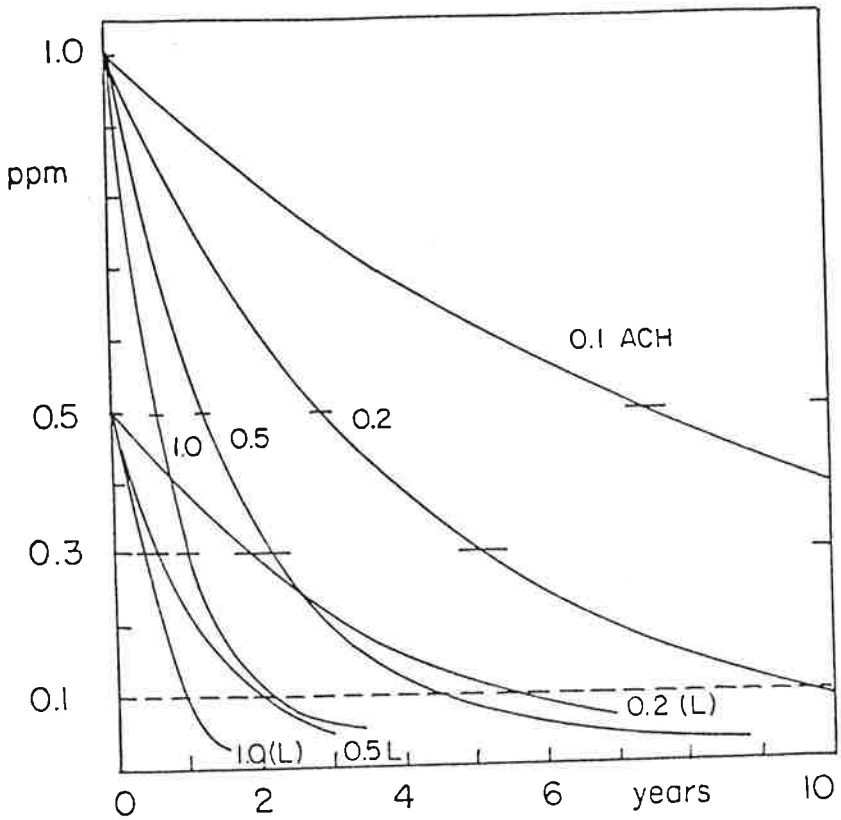

Figure 3: Formaldehyde Release as a Function of Age of Product and Ventilation Rate

superinsulated house with 0.2 air changes per hour (ACH), it will take ten years to get to half the original level.

Another factor is the quantity used. UF-bonded particleboard has been used increasingly to the extent that, today in a modern mobile home, the floor, furniture, and walls are all made with UF-bonded products. In a standard mobile home, for each square meter of material, there is less than a cubic meter of air. As a result, a modern mobile home may have up to a pound of unreacted formaldehyde in the wall which, one way or another, eventually will emanate from the products.

Another factor is temperature. As any other chemical, formaldehyde has a vapor pressure that depends on temperature. The vapor pressure correlation between formaldehyde and particleboard has been confirmed very carefully. In fact, one can predict formaldehyde emission at 45° C (116° F) with 6% accuracy. The temperature effect is especially noticeable in mobile homes in hot climatic regions. We have done extensive work on that and we can now model formaldehyde levels to plus or minus 5%. We have looked at daytime temperature variations in Portland, Oregon; Florida and Oklahoma. And we are able to reproduce observed indoor formaldehyde levels on the basis of the

climatology of the area, because mobile homes generally are quite poorly insulated. Furthermore, the temperature -- and the formaldehyde levels -- change not only seasonally, but also with daytime. I have here a tracing from an Oak Ridge National Lab study for HUD that shows wall temperatures in winter. When the outdoor temperature was 10° F, the east wall heated up to almost 90° F because of sun radiation. The west wall goes through a similar cycle as a function of daytime. Calculated formaldehyde levels and observed formaldehyde levels are so close that I think, in summary, we can say there is an established relationship between temperature and formaldehyde indoor levels. The striking fact is that formaldehyde emission increases rapidly with temperature. In fact, increasing the temperature from 75° F to 90° F increases formaldehyde four-fold.

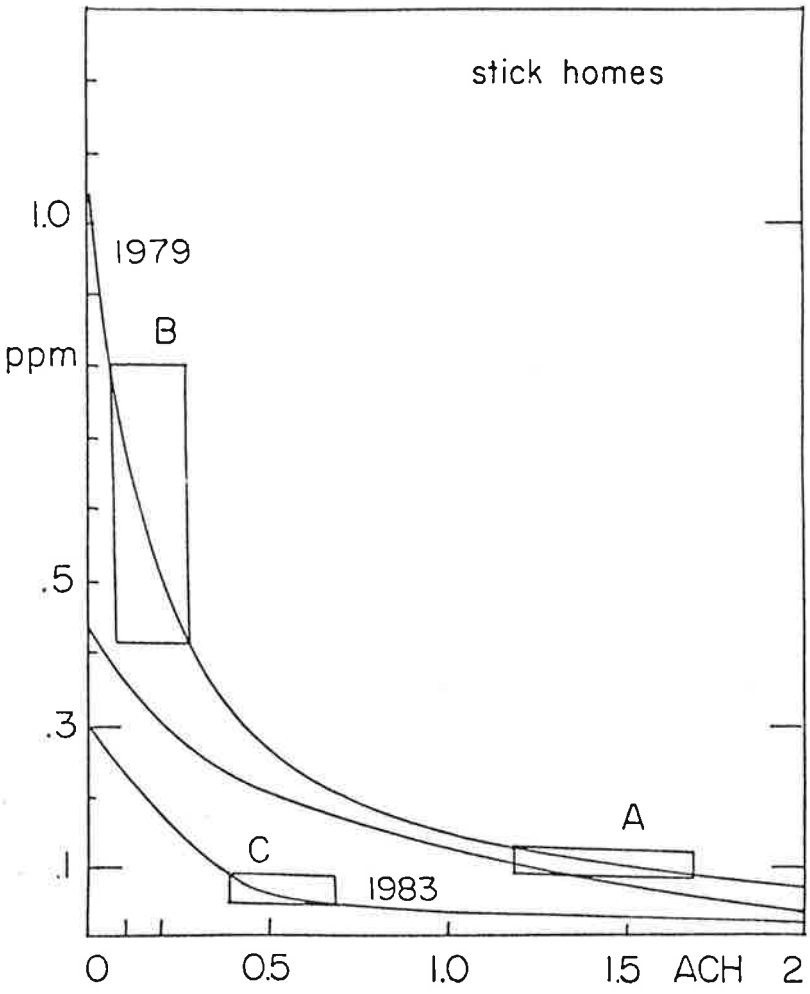

Figure 4: Influence of Ventilation Rate on Indoor Formaldehyde Concentration
A = situation before 1974
B = after energy conservation measures
C = currently common situation

Another factor is moisture variations. In a first approximation, the moisture content of wood depends only on air humidity and not on temperature. Thus, particleboard and UFFI are essentially sponges.

And yet another factor is ventilation. Certainly, ventilation reduces indoor air pollutant concentrations, but this effect is less than linear. There is a preconception among a lot of people that if we double ventilation, we reduce indoor pollution to one-half. Checking Figure 4 and we see that this is not so. Doubling ventilation may change the formaldehyde level by only about 20%.

In summary, one has formaldehyde problems in mobile homes because of the huge quantities of the material, and the only rational approach to reduce formaldehyde is to use a better material and better design. Please notice that I do not feel it necessary to advocate UF-free materials. Europeans have used UFFI since World War II. They still use it, and they have no problems except for truly defective resin episodes. The reason is that European wall cavities are ventilated. Also, Europeans use particleboard in roofing. Particleboard can withstand water if it can run off. One can make window sills of particleboard and it will work well as long as the moisture can drip off. In contrast, in a kitchen with defective ventilation that is not well fitted, there will be trouble. Thus, proper design means cavity ventilation.

Quality control is indeed the key to formaldehyde elimination. Today there is no longer any justification for formaldehyde emission above ambient levels, because we now have formaldehyde material standards. These standards are available from the National Particleboard Association (NPA) in Silverspring, MD or the Hardwood Plywood Manufacturers Association in Reston, VA. This standard was adopted in October, 1983, and since then most manufacturers rate their products internally. The remaining problem is that only a few people know about this standard.

As of today two tests have been accepted. FTM-1 is a voluntary standard laboratory test that requires eight pieces of material 2-3/4" x 5" x natural thickness of each material to be tested. The test procedure is described in the instructions that are available from the Hardwood Plywood Manufacturers Association and the National Particleboard Association. The second test, FTM-2 requires a full 4' x 8' sheet or even larger panels and requires several days of testing in large air chambers. [It has become mandatory February 11, 1985.] This test is also sponsored by the Formaldehyde Institute (FI) and is now a final part of the mobile home safety standard 24 CFR 3280.406. Both tests have been described in the Federal Register, which is available in most public libraries. The citation for FTM-1 is 48FR37169; for FTM-2 it is 49FR32012.

Once disclosure of formaldehyde emission rates is widely demanded and disclosed, the formaldehyde problem will cease to exist, because formaldehyde levels can now be reasonably predicted on

the basis of the material standards. There are good correlations available between laboratory scale measurements, FTM-1, and emission of full panels in air chambers, FTM-2, and good predictions for real-life systems are also possible.

The key to the recent progress has been improved UF resins and improved manufacturing methods. In some of the new processes, there is no extra cost involved. For example, there is a Swedish invention in which the wood particle is sealed so that the formaldehyde doesn't penetrate into the wood. The formaldehyde stays on the surface and as a result the glue doesn't soak into the wood. According to the patents by this company, one actually needs 10% less glue with these modern resins while maintaining mechanical strength. Thus, even though the glue is somewhat more expensive, the modern product, which is guaranteed to keep 0.1 ppm, is less expensive.

What is a reasonable formaldehyde level? Most of us do not desire unwanted odor in our homes. A Swedish group has done studies for ten years on formaldehyde levels. Their results are shown in Figure 5. Half of the people will notice formaldehyde every time if there are 0.1 ppm in the room. The absolute threshold is 0.05 ppm. At 0.4 ppm three-quarters of all people smell formaldehyde 100% of the time. A second method to set reasonable formaldehyde ceiling values is based on past experience with work standards. The Occupational Safety and Health Administration (OSHA) standard is 3 ppm for an 8 hour day. Eight hours times 3 ppm is 24. Thus, 1 ppm over 24 hours is equivalent to the OSHA limit for time-weighted average. Averaged over a week, the OSHA level corresponds to about 0.71 ppm. So if someone spends all his time in a home with an indoor environment at 0.71 ppm, this person would experience exposures equal to OSHA limits.

In estimating formaldehyde exposure, one must remember that both exposure duration and local concentrations may vary, even within

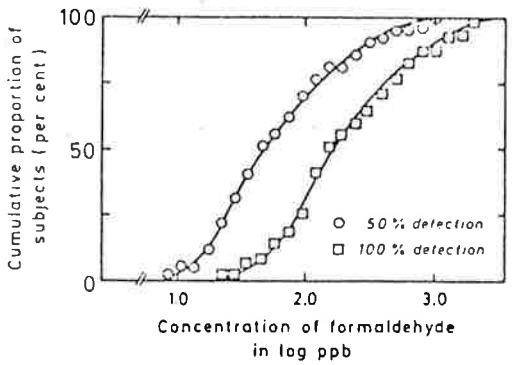

Figure 5: Formaldehyde Odor Detection: Cumulative Frequency Distribution for the Individual Detection; ED 50 and ED 100. (Berglund, 1984)

a home or within a family. Often, the homemaker is bothered more than the working spouse. In a remodeled kitchen exposed to the sun, a homemaker may experience ten times the formaldehyde dose of a working spouse who is seldom in the kitchen and is only in the home twelve hours. In mobile homes in severe climates the situation is yet more extreme, because of sunshine warming the walls during the day. In fact, there are conditions in mobile homes where weekly exposure averages are .44 ppm due to daytime conditions alone. These levels are high, even compared to occupational levels for plywood manufacturing plants, textile workers, etc. What can be done about these levels? One can conduct material tests, FTM-1, and use this test to identify defective products. In high emitting homes there is invariably a defective product. Once this is identified, one can notify the manufacturer. It is my experience that most manufacturers will be happy to replace defective panels. Instead, many people who discover formaldehyde odor in their home get emotional, call a lawyer and enter into exhaustive and expensive litigation before they have identified the source of their problem. I am not a lawyer, but it is obvious that lawsuits about formaldehyde injuries tend to be vague, tort-type situations. In contrast, if one has identified a defective material in one's home, something can be done more rapidly and any litigation will likely cost less in money and emotions. Today, 90% of the industry will replace defective products promptly, because current generation products emit only very little formaldehyde and can be used in most applications.

QUESTION: You said something that led me to believe UF is always necessarily destroyed by high temperature. Is that true or false?

ANSWER: It is a combination of high temperature and moisture. The question was is temperature necessarily destroying UF resin, and the answer is no. If the temperature goes above the boiling point of water, one should not use UF-bonded materials. For example, one should not insulate steam pipe with UF foam.

QUESTION: Do we have yet reliable, inexpensive field tests of emission rates from surfaces, or does this still have to be done in the laboratory?

ANSWER: There is no quick, reliable and cheap field test yet. There is a great need for developing better field methods for air measurement. I was chairing a Federal panel making recommendations on that subject four years ago, and it would cost a lot of money to get a quick air measurement method which is convenient and reliable. The NIOSH test is very good, but it requires glassware and skilled operators, as well as wet chemistry. Also, I feel that the interpretation of air levels is difficult, because of temperature fluctuations. The temperature that counts is not the temperature of the air, it's the temperature of the product that emits formaldehyde. For

screening it's very convenient to have an air level and it is my practical experience that if you have less than about 0.4 ppm that it is unlikely that you have a grossly defective product and you can handle it with ventilation. If you have less than 0.1 ppm then your ambient formaldehyde is probably going to make it very difficult to ever identify a bad product. However, the best solution, I'm afraid, is to cut out a sample and send it to a testing lab and have a material test done.

QUESTION: Where do you send this stuff to have it tested? Where is a good local place?

ANSWER: In choosing a lab, I would select one that can perform a validated test, such as the FTM-1. HUD has not yet established certification procedures. Thus, there are no testing labs that are certified yet. If you want a reliable test contact the National Particleboard Association, 18928 Premier Court, Gaithersberg, MD, 20879 and the Hardwood Plywood Manufacturing Association, P.O. Box 2789, Reston, VA, 22090.

QUESTION: Does the release of formaldehyde decline over time in a typical household?

ANSWER: Yes. Earlier I showed a typical decay curve. It depends on the rate of ventilation. Remember those curves coming down? Typically, a particleboard will go to about half of its value within about 18 months. If levels do not go down then, one has a defective product. If one can still smell UFFI then it is either not placed properly or it is a defective product. I have recently tested some UFFI's. I boiled a sample of UFFI in my lab for a week in a sealed ampule, submerged in water, and we measured very little formaldehyde. On the other hand, we had a sample from New York that dissolved totally in boiling water within 20 minutes. There is a tremendous difference in quality among commercial UFFI. Particleboard, MDF, and plywood are manufactured in a plant under controlled conditions. The problem with UFFI is that it is manufactured in the field, often by people who either don't know what they are supposed to know or they had a product that wasn't what it was supposed to be.

QUESTION: Are there many products that contain formaldehyde?

ANSWER: I should have given you a list of consumer products. As I stated, cigarette smoke contains up to 30 ppm per puff, but this averages out rather low over 24 hours. CPSC tested some dozen consumer products. The results are published in my recent book. Current carpets and carpet backing, to my knowledge, no longer contain formaldehyde adhesives, but there are carpet shampoos which contain formaldehyde that may be left in the carpet after cleaning. Fiberglass insulation batts may have papers which contain UF-resins. I didn't talk about furniture. Furniture used to be high emitting, but this has changed

dramatically during the past three months, and several large MDF manufacturers now produce board that is guaranteed to emit less than 0.3 ppm in the FTM-2 test. Once this board is built into cabinet work or furniture, it will emit less than 0.1 ppm.