

# Health effects of urea formaldehyde foam insulation: evidence of causation

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Studies of health effects of urea formaldehyde foam insulation (UFFI) were critically reviewed by means of accepted rules for evidence of causation. Three categories of health effects were examined: reported symptoms, primarily of the upper respiratory tract, lower respiratory tract disease and cancer. Most of the studies purporting to demonstrate health effects of UFFI failed to meet minimal methodologic criteria for evidence of causation. Evidence from the adequate studies provides little support for the hypothesis of a causative role of UFFI in health problems.

Dans la question des effets sur la santé de la mousse isolante d'urée-formaldéhyde (MIUF), les auteurs passent en revue les travaux déjà publiés à la lumière de critères reconnus de causalité. Ils se penchent sur trois ordres de faits: les symptômes d'origine respiratoire haute, les maladies des voies respiratoires basses et les cancers. Dans la plupart des cas, les travaux qui démontraient des effets nocifs de la MIUF ne respectent pas les critères méthodologiques minimaux de causalité. Quant aux travaux irréprochables sous ce rapport, ils ajoutent peu d'appui à l'hypothèse que cette mousse serait nuisible à la santé.

Urea formaldehyde foam insulation (UFFI) has been used as an insulating material in North America since the mid-1960s and in Europe for several decades. It is estimated that 100 000 homes in Canada and 500 000 homes in the United States are insulated with the material.<sup>1</sup> Because of reports in the scientific literature and the mass media of possible health effects of UFFI, ranging from respiratory tract irritation to cancer, UFFI was banned in Canada in 1980 and in the

United States in 1981. However, there remains considerable debate regarding the scientific evidence of health effects.<sup>2,3</sup>

There are several reasons for this lack of consensus. Establishing a causal relation between UFFI and health problems is a complex task. UFFI is not a single chemical entity; rather, it consists primarily of polymers of urea and formaldehyde in combination with various amounts of up to 50 other chemicals, depending on the manufacturer and the conditions of installation.<sup>4</sup> In addition, UFFI has been suggested as a causal agent in a variety of health problems, including upper and lower respiratory tract and gastrointestinal tract symptoms, asthma and chronic bronchitis, dermatitis, psychologic symptoms (including insomnia and depression), nasal cancer and lymphoma.<sup>5-8</sup> Finally, accepted rules for evidence of causation in epidemiologic investigations require the presence of several conditions — as outlined by Bradford-Hill<sup>9</sup> and used in the US surgeon general's report on smoking and cancer<sup>10</sup> and elsewhere<sup>11</sup> — including temporality, strength and consistency of association, specificity of outcome and coherence.

In this review we consider evidence of health effects of UFFI and of formaldehyde released from the material. Although we recognize that the chemical constituents of UFFI may vary, we do not consider health effects of specific components other than formaldehyde. Health problems in three broad areas are examined: reported symptoms, primarily of the upper respiratory tract, chronic lower respiratory tract problems, including asthma and bronchitis, and cancer. We evaluate evidence of a causal role of UFFI using the rules advanced by Bradford-Hill.<sup>9</sup>

## Formaldehyde release

The chemistry of the polymerization of urea and formaldehyde provides two mechanisms for release of formaldehyde into the environment: release in the initial reaction of excess free formaldehyde, some of which is eventually polymerized in a postcuring phase, and subsequent decomposi-

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tion of the polymer.<sup>4</sup> These two reactions proceed at varying rates, depending on temperature, humidity and acid content of the foam. Study of formaldehyde levels in homes has indicated that formaldehyde release decreases over time, with half the original level being reached in 5 to 50 weeks.<sup>12</sup>

What is the evidence that UFFI releases excess formaldehyde vapour to indoor air? Most studies have been carried out only in homes where UFFI-related health complaints have been reported. Dally and colleagues<sup>13</sup> found a median formaldehyde concentration of 0.1 parts per million (ppm) in 14 UFFI-insulated homes where there were health complaints. Breysse<sup>14</sup> reported that 73% of 39 UFFI-insulated homes in the state of Washington had formaldehyde concentrations exceeding 0.1 ppm. Because formaldehyde may be released from many sources inside the home, particularly particle board, carpeting and gas appliances,<sup>15</sup> these studies, which lacked control groups, yield no direct evidence that the recorded formaldehyde levels were due to release from UFFI.

In contrast, the National Testing Survey<sup>16</sup> in Canada used four samples of homes: 651 UFFI-insulated homes randomly selected by means of a list of callers to an information centre for owners of homes with UFFI, 1146 UFFI-insulated homes randomly selected from a federal registry associated with a government subsidy toward the cost of home insulation, 378 control homes without UFFI selected from the same registry, and 100 UFFI-insulated homes in which residents had reported health problems or that residents had left. Both indoor and ambient outdoor air levels of formaldehyde were determined, and considerable care was taken to ensure the reliability of the measurements. The average formaldehyde level in the two random samples of homes with UFFI was 0.049 ppm, compared with 0.034 ppm in the homes without UFFI. The level exceeded 0.1 ppm in 9.9% and 5.1% of the two random samples of homes with UFFI, compared with 2.6% of the control homes. The average formaldehyde level in the homes where health problems had been reported was 0.139 ppm; the level exceeded 0.1 ppm in 47%. In a study in the United Kingdom of 128 homes with UFFI and 50 control homes, mean formaldehyde levels of 0.093 ppm and 0.047 ppm respectively were found.<sup>17</sup>

Cohn<sup>12</sup> summarized data from a variety of sources to determine formaldehyde level as a function of time since installation in 827 UFFI-insulated homes where health problems had been reported, 337 UFFI-insulated homes where no such problems had been reported, and 103 control homes. The mean formaldehyde level in the control homes was 0.027 ppm. No significant difference in formaldehyde level was found between the two groups of homes with UFFI, and the average level ranged from 0.25 ppm 6 weeks after insulation to 0.1 ppm 1 year after and 0.05 ppm 3 years after.

From these studies it is apparent that UFFI

contributes some free formaldehyde to the indoor environment. The level decreases slowly with time and after 1 to 3 years is of about the same order of magnitude as the level of formaldehyde from other sources. However, in a small minority of homes formaldehyde levels exceeding 0.1 ppm may persist after a period of months or years. Although these levels cannot be ignored (since residents, particularly the very young and very old, may spend considerable time indoors), they are about 10 times lower than those in some occupational settings.<sup>1,11</sup> These differences should be borne in mind when extrapolating health risks from the occupational to the domestic environment.

### Reported symptoms

Most of the evidence of health risk from UFFI is based on self-reported symptoms. Harris and colleagues<sup>5</sup> sent a questionnaire to 100 occupants of homes with UFFI who had reported health problems to a centre in Denver; 48 people responded. Symptoms were included only if they had been present for more than 1 month and had begun after installation of the material. A variety of symptoms, generally those commonly associated with formaldehyde toxicity,<sup>11</sup> were reported: dyspnea (46% of respondents), headache (44%), rhinitis (44%) and eye irritation (40%); cough, colds, rash and malaise were reported by fewer respondents. Formaldehyde levels were not measured. In a similar study of symptoms in residents of 84 homes in Connecticut, the formaldehyde levels ranged from 0.5 ppm (the limit of detection) to 10 ppm, with a mean of 1.8 ppm.<sup>18</sup> Symptoms were reported by 224 residents in 74 of the homes; however, in 37% of the homes, symptoms were reported when there was no detectable formaldehyde. The symptoms in the homes with detectable formaldehyde were similar to those in the Denver study: eye irritation (49% of residents), headache (46%), upper airway irritation (37%) and gastrointestinal tract symptoms (22%).

Similar data were reported in a study in Wisconsin in 261 occupants of 100 homes, mobile homes or offices in which formaldehyde from foam insulation or particle board building materials was present.<sup>13</sup> The median concentration of formaldehyde in the six homes studied was 0.1 ppm; however, symptoms were not reported separately for the homes. Breysse<sup>14</sup> reported similar results from surveys of 44 residents with symptoms in UFFI-insulated homes in the state of Washington. Formaldehyde levels ranged from 0.1 to 1 ppm; in 73% of the homes the level exceeded 0.1 ppm.

Three controlled studies of symptoms in random samples have been carried out. In a study conducted by the New Jersey State Department of Health, Thun and colleagues<sup>19</sup> found no overall differences in reported symptoms or physician visits between residents of 395 homes insulated

with UFFI and 395 matched control homes; however, the homes represented only 23% of the initial sample. There were substantially more symptoms, both before and after installation, in residents of a subgroup of 33 homes in which persistent odour had been reported. The authors acknowledged that there were ambiguities in their data but concluded that there was no evidence from their study of a "broad-based epidemic of allergic or irritative symptoms referable to UFFI". In a cohort study in 29 children in UFFI-insulated homes in Hamilton, Ont., and 58 matched controls, there were no significant differences in respiratory tract symptoms between the two groups.<sup>20</sup>

The data for both these studies were gathered before UFFI was banned in Canada and before there was any widespread concern about health problems. In contrast, a third study, initiated by the Canadian government after the ban, has recently been completed.<sup>21</sup> Questionnaires were mailed to residents of three groups of homes in the province of Quebec: 736 UFFI-insulated homes where symptoms had been reported, 408 UFFI-insulated homes where no symptoms had been reported, and 554 control homes. The response rates were relatively low, ranging from 45% to 75%. To disguise the intent of the survey, UFFI was not mentioned in the questionnaire. Information on 48 symptoms was requested. No attempt was made to distinguish between "real" and "placebo" symptoms. The results were in marked contrast to those of the two studies conducted before the ban: subjects who reported symptoms had a relative risk of symptoms of about 2.3 compared with the controls, while those who did not report symptoms had a risk of about 1.6 compared with the controls.

Although there have been other studies of formaldehyde levels or symptoms in public buildings<sup>22</sup> and in small numbers of homes,<sup>23</sup> our review of evidence of causation is based on these three larger studies.

### *Temporality*

Has it been established that exposure to the causal agent (UFFI) occurs before the effect (reported symptoms)? On the surface it appears that this condition is easily fulfilled, since the precise date of first exposure to UFFI can readily be established. However, the date of onset of symptoms is less well established: in all three studies it was contingent upon recall by the respondents, and there is evidence that recall of health events is subject to bias.<sup>24</sup> This problem is compounded by the non-specific nature of the reported symptoms, many of which occur frequently in any population.<sup>25</sup> Finally, retrospective study of reported symptoms is prone to "attribution" bias:<sup>26</sup> subjects seeking a cause for their symptoms may attribute them to UFFI whether or not there is any direct evidence of this causal connection. Most investigators have attempted to control for these biases. For example,

Harris and colleagues<sup>5</sup> included symptoms only if they had been present for more than 1 month and had begun after installation of UFFI.

There is evidence of recall bias in the study by Thun and colleagues,<sup>19</sup> in which residents of UFFI-insulated homes with a persistent odour reported substantially more symptoms both before and after installation. The investigators advanced three hypotheses to explain this finding: the subjects were less healthy before installation than those in the other subgroups; they represented a subset of chronic over-reporters of odour and of symptoms; or they were hypersusceptible to formaldehyde, and their condition worsened following installation. Another explanation is that, for whatever reason, the subjects had more perceived symptoms at the time of the interview, and this perception influenced their recall of symptoms present before the interview. Each hypothesis is purely conjectural and is offered only as an illustration of the difficulty in establishing temporal association on the basis of retrospective recall, which is the method used in all studies of the association between UFFI and symptoms.

### *Strength of association*

To establish evidence of strength of association it is necessary to determine the relative risk of symptoms in residents of UFFI-insulated homes and control homes. Only studies based on random samples<sup>19-21</sup> permit such a calculation. In the study by Thun and colleagues<sup>19</sup> 9.9% of residents of both UFFI-insulated homes and control homes reported symptoms; thus, the increased risk of symptoms attributable to UFFI was 0. Those in homes with a persistent odour reported roughly three times as many symptoms, physician visits and admissions to hospital after installation than those in the other subgroups. However, approximately the same proportionate increase in symptoms and physician visits was apparent in this subgroup before installation, which again indicates an absence of increased risk attributable to UFFI. In the Hamilton study<sup>20</sup> the overall rate of respiratory tract symptoms in children exposed to UFFI was 69%, compared with 57% in the controls; the rates of lower respiratory tract symptoms were 31% and 40% respectively. Neither difference was significant.

The recent study by Nantel<sup>21</sup> showed increased relative risks of symptoms attributable to UFFI. However, the relative risks were also elevated for symptoms (irritability, vertigo, double vision and constipation) that have not been shown to result from formaldehyde exposure. This suggests that some other factor is responsible, such as other chemical constituents of UFFI, as suggested by Nantel, or attribution bias.

Examining the evidence of a dose-response relation, Nantel and associates<sup>9</sup> found no relation between formaldehyde level and severity of reported symptoms in 758 UFFI-insulated homes in the

province of Quebec. In the Connecticut survey,<sup>18</sup> symptoms were reported in 37% of the homes studied when there was no detectable formaldehyde. Perhaps the best evidence against a dose-response gradient is derived from the report by Cohn.<sup>12</sup> A careful analysis of formaldehyde level as a function of time since installation in 827 UFFI-insulated homes where symptoms had been reported and 337 UFFI-insulated homes where no symptoms had been reported showed no significant difference in formaldehyde level between the two groups. Some other agent in UFFI may be responsible for symptoms; however, no dose-response relation with any other constituent has been established.

Evidence of a dose-response relation was found in one study: Thun and colleagues<sup>19</sup> showed that presence of persistent odour was related to symptom rates. However, since this relation was also present for symptoms that occurred before installation, there was likely some form of respondent bias. In addition, reports by residents of odour were used instead of direct measurement of formaldehyde level, which may have led to confounding.

Examination of the formaldehyde levels found in the National Testing Survey<sup>16</sup> might also lead to a conclusion of a dose-response relation, since in homes where symptoms have been reported the levels generally range from 0.1 to 1 ppm, compared with about 0.05 ppm in homes selected at random. However, these differences do not account for the strong relation between formaldehyde level and time since installation. The fact that the studies in subjects who reported symptoms were generally conducted earlier than those using random samples may explain the observed differences.

Since formaldehyde emission rates vary depending on temperature and humidity, a single measurement may not accurately reflect time-averaged levels. In addition, people vary greatly in formaldehyde sensitivity.<sup>11</sup> Nevertheless, from the available studies there is little evidence of an association between UFFI and reported symptoms.

### *Consistency of association*

To what extent has the association been consistently observed across different studies? In the studies of homes where health problems were reported, there was consistency in the type of symptoms reported, primarily those associated with irritation of the upper respiratory tract. However, in view of the study by Thun and colleagues,<sup>19</sup> this consistency may not represent a causal association, particularly since the symptoms reported (with the possible exception of eye irritation) are common complaints of patients of family physicians.<sup>25</sup> Also, the recent studies appear to indicate that high rates are found even for symptoms not shown to result from formaldehyde exposure.

### *Specificity of outcome*

To what extent is the association limited to particular sites and types of disease? As Bradford-Hill<sup>9</sup> indicated, this condition should not be overemphasized since in some circumstances an environmental factor may have an effect on several organ systems. However, specificity may be a stringent requirement in the case of UFFI, since a variety of conditions have been attributed to formaldehyde exposure. Moreover, irritation of the upper respiratory tract can result from low concentrations of other chemicals in the home.<sup>1</sup> Thus, the condition of specificity of outcome is not met but may be irrelevant.

### *Coherence*

Coherence refers to a biologically plausible or consistent relation between cause and effect. Clearly the association between UFFI and upper respiratory tract symptoms is biologically plausible, the link being formaldehyde release. The acute effects of formaldehyde are well documented in both the experimental and the occupational literature,<sup>11</sup> and symptoms of formaldehyde toxicity are consistent with those reported by residents of UFFI-insulated homes. It is more problematic to determine whether other reported symptoms, such as malaise, insomnia and depression,<sup>5,7</sup> are biologically linked to the presence of formaldehyde vapour.

In sum, the available data directly relating UFFI to symptoms show little evidence of a causal association. The association remains biologically plausible but unproven.

### *Lower respiratory tract disease*

Although there are biologic reasons to believe that exposure to formaldehyde might exacerbate asthma, only one case of asthma from exposure to UFFI has been reported in the literature, by Frigas and colleagues.<sup>27</sup> This case was paradoxical in that the patient showed a response to UFFI dust but not to formaldehyde. The report has been challenged on methodologic grounds.<sup>28</sup> Frigas and colleagues<sup>29</sup> also reported a subsequent study in 20 subjects who presented with asthma suspected of being related to UFFI. In direct challenge testing none of the subjects showed a response consistent with UFFI- or formaldehyde-induced asthma.

Four experimental studies have been carried out to investigate pulmonary function in subjects with lower respiratory tract symptoms suspected to be attributable to UFFI. Schenker and associates<sup>6</sup> found a high prevalence of eye irritation, upper and lower respiratory tract symptoms and neuropsychiatric symptoms in 24 adults who reported health problems suspected of being related to UFFI. However, results of base-line spirometry were normal in all the subjects, as was the average

change in forced expiratory volume in 1 second (FEV<sub>1</sub>) as a percentage of base-line forced vital capacity. In a study by Day and coworkers,<sup>30</sup> 15 subjects with symptoms that they attributed to UFFI and a control group of 9 healthy subjects were exposed in blinded testing to formaldehyde vapour at a concentration of 1 ppm and UFFI off-gas containing about 1.2 ppm of formaldehyde. The same rates of eye irritation and nasal congestion were found in the two groups, and no significant changes in pulmonary function were noted in either group. Frigas and colleagues<sup>31</sup> studied 13 patients suspected of having formaldehyde-induced asthma, of whom 5 lived in UFFI-insulated homes. In blinded challenge testing with formaldehyde gas at concentrations of 0.1, 1 and 3 ppm, no patient showed an immediate or delayed decrease in FEV<sub>1</sub>, nor was there evidence of exacerbation of symptoms attributed to formaldehyde. In the Hamilton study<sup>20</sup> no significant differences in pulmonary function were found between 29 children who lived in UFFI-insulated homes and 58 matched controls.

As yet there is no direct evidence that UFFI is a causative agent in lower respiratory tract disease. The lack of evidence does not, however, justify the conclusion that UFFI is not implicated. There is evidence of lower respiratory tract dysfunction induced by formaldehyde vapour in studies carried out in occupational settings<sup>32,33</sup> and in case reports of occupational exposure to high levels of formaldehyde.<sup>34,35</sup> However, the studies appear to have several methodologic problems. Moreover, Hendrick<sup>36</sup> subsequently commented that formaldehyde-induced asthma is likely uncommon and that unusually high levels are probably involved when it does occur. Although the possibility of pulmonary effects of UFFI cannot be entirely excluded, such effects are rare even in occupational settings, where formaldehyde levels are much higher.

## Cancer

There is recent experimental evidence that formaldehyde vapour can induce nasal cancer in rodents.<sup>37,38</sup> In Canada and the United States these animal data were extrapolated to provide estimates of cancer risk from formaldehyde released from UFFI in the home.<sup>12</sup> The best estimate of risk was 0; however, the upper 95% confidence limit was 51 per million population exposed, which appeared sufficient to justify concern that UFFI may cause cancer. In contrast, a series of epidemiologic studies in various occupational groups, including embalmers, pathologists and chemical workers, have consistently shown no overall increased risk of cancer and no cases of nasal cancer.<sup>39-45</sup> Because the risk of nasal cancer is extremely low, these cohort studies may have had inadequate power to detect an increased risk due to formaldehyde exposure. In one large case-control study a significantly elevated relative risk (2.8) was found for

workers exposed to formaldehyde.<sup>46</sup> However, when the data were adjusted for exposure to wood dust (a known nasal carcinogen) the relative risk, while still elevated, was no longer significant. These contradictory findings have led to considerable debate on whether formaldehyde may be a human carcinogen.<sup>47,48</sup>

One case of nasal cancer that developed in a woman shortly after she moved into a home insulated with UFFI has been reported.<sup>49</sup> This case has been discounted as evidence of a causal association because there was no latent period between exposure and appearance of the malignant disease.<sup>2</sup>

## Conclusion

Although UFFI emits formaldehyde under some circumstances, it is only one source of formaldehyde in the home. In addition, despite the ubiquity of formaldehyde in occupational settings for over 100 years, there is no definite evidence that the material causes adverse or irreversible problems such as asthma and cancer in humans.

It is evident from this critical review that the evidence linking UFFI to acute health effects meets few of the conditions required to conclude that there is a causal association. Although the substantial number of health problems reported by occupants of UFFI-insulated homes cannot be ignored, the few controlled studies in random samples carried out in an attempt to systematically investigate the problem have shown little or no evidence of health effects. Furthermore, there is little direct evidence relating UFFI to less reversible, more serious health problems.

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### The nature of disease

*We are accustomed to speak of "disease entities" as though they had an independent, individual existence and could be recognized as friends — or better, perhaps, as enemies. This is obviously one of those abstractions that do violence to the reality of the concrete situation, for there is no disease apart from the patient.*

—Thomas Addis (1881-1949)