DOCUMENT RESUME

ED 310 771 IR 052 831

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TITLE	The Invasion of the Giant Spore. SOLINET Preservation Program Leaflet Number 5.
INSTITUTION	Southeastern Library Network, Inc., Atlanta, Ga.
PUB DATE	1 Nov 87
NOTE	20p.
PUB TYPE	Reports - Descriptive (141)
EDRS PRICE	MF01/PC01 Plus Postage.
DESCRIPTORS	Archives; Books; *Cleaning; *Climate Control; Hazardous Materials; *Library Facilities; *Library Materials; *Paper (Material); Physical Environment; *Preservation
IDENTIFIERS	Fungi; Health Hazards; Mildew; *Molds (Biology); Rare Books

ABSTRACT

This report addresses solutions to problems of fungus growth on library materials. The first of four sections--"What Is Mold? Where Does It Come From?"--defines mold, mildew, and fungi, and describes their optimum environment (i.e., generally in conditions with temperatures above 70 degrees and relative humidity above 78%). The second section--"What Does Mold Do to Books and Paper, and to People?"--discusses some effects of fungi such as mold and mildew, including: (1) an increase in the rate of book and paper deterioration by accelerating the aging process and the formation of acids; (2) mold and mildew stains that destroy text and images; (3) a weakening and softening of books and paper, making them difficult to handle; and (4) adverse effects on human health. The third section--"The Repulsion of the Giant Spore, or How To Rid One's Collection of Mold"--makes up the greater part of the report. It prescribes methods for inhibiting the growth of or killing fungi, with emphasis on nontoxic, nonchemical environmental control measures for both prevention and cure. Other nonchemical (e.g., freezing, gamma radiation, and ultraviolet light) and several chemical (i.e., fungistatic and fungicidal) treatments are also detailed. The fourth section--"Concluding Recommendations"--advises that fumigating collections with toxic or hazardous chemicals is rarely necessary for dealing with mold and mildew problems, and provides a checklist to consult before instigating chemical treatments. (29 references) (SD)

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THE INVASION OF THE GIANT SPORE

SOLINET Preservation Program
Leaflet Number 5
by Sandra Nyberg
1 November 1987

It's a quiet, peaceful day. You stroll complacently through the aisles of books, contemplating the neat rows of colored cloth and leather. A bit of sunshine glimmers through the distant stacks. A little tune is wandering through your thoughts. Suddenly, a shiver runs down your spine. You stop. Something is wrong; you sense danger. Slowly you turn and peer down the rows of books, half afraid of what you will find. You cautiously step forward, and there it is, lurking in the dark, slowly creeping down a row of books. It slithers from one volume to the next, maliciously victimizing innocent and helpless books. The air is filled with a vaguely unpleasant odor. Books become untouchable -- they are slimy, they are furry, they are distinctly icky. Who knows, it may spread to the carpet, the walls, the curtains, the chairs, even your office; it may take over the whole library! It's the attack of the awful mold!

Before you panic, calm down. Although it won't be easy, mold can be stopped. You can protect yourself from it. This leaflet will provide you with some effective weapons to use against mold. Before we come to the weapons, though, we need to analyze our foe. What is mold? Where does it come from? What does it do to books and paper?

I. What is Mold? And Where Does It Come From?

Mold is a type of fungus. It grows on surfaces in masses of branching threads which resemble dense cobwebs. The fertile threads, those which produce spores, often stand up from the surface into the air to release their spores. Spores are carried by air currents or by adhering to insects or animals. Active mold can be any color, depending on the species and the substrate upon which it is growing. Mildew is another type of fungus,

similar in structure to mold, but distinct as one species of fungus is distinct from another. The terms "mildew" and "mold" are not interchangeable; they are most often used in the common names of various fungi. Fungi is a kingdom of organisms, with a single division, Mycota. The fungi have traditionally been classified with plants but are now considered a distinct group of organisms. Unlike plants, which produce their own food, fungi absorb nutrients from dead or living organic matter. Fungi also lack photosynthetic pigments. There are over 100,000 known living species of fungus, some of which are beneficial to mankind. Mycologists estimate that there may be as many as 200,000 more unidentified species of fungus. Yeasts, molds, mildews, rusts, and mushrooms are types of fungus.

The spores of fungi that become mold or mildew are always present in the air and on objects. When the temperature and moisture in the environment are suitable for germination, the fungus spore bursts and grows into a thread-like filament called a hyphae. Using the object it is growing on as a food source, the hyphae form a mass, called a mycelium, and within a short time begin to produce spores. At maturity, spore sacs burst and release spores, which eventually land on other material and begin the reproductive cycle again.

In libraries, optimum conditions for mold and mildew development exist when temperature is above 70 degrees Fahrenheit and relative humidity is above 70%. However, some common molds can grow at temperatures as low as 50 degrees Fahrenheit and in relative humidities as low as 45%. It is also possible for molds to begin growing in conditions of high relative humidity and temperature and then continue growing in environments with significantly lower relative humidity and temperature.

II. What Does Mold Do To Books and Paper, and to People?

Basically, mold and mildew eat library materials. Books and paper provide a source of nutrition through such components as cellulose, starch adhesives, and starches in sizing. The mold and mildew excrete digestive enzymes that allow them to eat starches and cellulose, grow, and produce more spores. Cellulose in paper is difficult to digest, so many molds prefer the starch in cloth-coverings on books and in paper sizings. In book collections, mold is often noted on the bindings long before it grows on textblocks. Molds grow rapidly, although they generally grow at a slower rate when relying on only cellulose for food.

Conditions that promote mold and mildew growth (high humidity and warm temperatures) will also, in and of themselves, increase the rate of book/paper deterioration by accelerating the aging process and the formation of acids. Furthermore, mold and mildew can irreversibly stain books and paper. Such stains

destroy text and images. Books and paper can also be seriously softened and weakened by mold, making them difficult to handle.

Mold and mildew can have an adverse effect on people. Those with allergies, asthma or other respiratory problems should stay away from infested areas, as many fungi will seriously irritate and inflame lungs. Some fungi can cause skin and eye irritation and infections. Prolonged exposure to germinating molds in closed areas (which exist in many library collections) can damage the lungs, mucous membrane, cornea, respiratory tract, stomach, intestines, and skin.

III. The Repulsion of the Giant Spore, or How To Rid One's Collection of Mold.

Before describing processes that will kill mold, I want to stress the fact that the ONLY way to get rid of mold permanently and to keep mold from your collections is to control the environment within non-hazardous ranges of temperature and humidity. You may use chemicals to kill mold, but the only safe and effective way to keep it from coming back is to modify the environment which contributed to the development of mold. So before I discuss methods of killing mold, I will describe the environment necessary for the prevention of mold formation.

III.A. What is a Mold-Preventive Environment?

There are a number of factors which influence the growth of mold: environmental humidity and moisture content of materials, temperature, air circulation, light, and the chemical composition of potential substrates. Each of these is discussed here in relation to the environments which will inhibit or promote mold growth.

III.A.1. Humidity. The most important environmental factor to control is the amount of moisture in the air and consequently in books and paper. Books and paper naturally contain a certain amount of water. They are hygroscopic, so that when relative humidity goes up, they absorb water to achieve equilibrium. At 50% relative humidity, the moisture content of paper is approximately 7%; at 70% relative humidity, it is approximately 10%. Moisture enables mold to absorb nutrients from book and paper substrates, so the more moisture a book contains, the greater are the chances for fungus spores to germinate at room temperature. The potential for mold or mildew development on wet books is one important reason for quick freezing of books damaged by water.

Relative humidities above 70% can easily lead to mold growth; for safety, it is generally recommended that libraries keep their relative humidity below 65%. Relative humidity below

40%, however, can cause books and paper to become fragile from dryness. Hence the acceptable range is 45% to 65%. It is possible, however, that some molds can begin growing at 70% relative humidity or higher and then continue growing at relative humidities of less than 70%. Because of this, new acquisitions should be checked for mold and treated, if necessary, prior to storing them with the rest of the collection.

Consistency is also important within the 45% to 65% range. As books and papers absorb or release water into the atmosphere with changes in relative humidity, they also change their shapes. They expand or contract, although different parts of a book will do so at different rates, as will different types of paper. For example, a vellum binding may expand quickly as it absorbs water, but the paper inside will expand more slowly, and the adhesive used in binding may expand at an intermediate rate. Fluctuations in humidity, when necessary due to, for example, seasonal changes, should be slow and carried on over time. Generally, it is recommended that relative humidity remain at 50% with a maximum change of plus or minus 5% per month.

III.A.2. Temperature. Most molds thrive at warmer temperatures. When combined with high levels of humidity, temperatures of 70 to 75 degrees Fahrenheit will cause mold to develop. Temperatures below freezing will not kill mold, but they do make it dormant. Few molds will be active at temperatures of less than 50 degrees Fahrenheit. Mold can also grow in conditions up to 140 degrees Fahrenheit. High heat will kill mold, but it will also severely damage library materials.

For patron comfort, temperatures of 70 degrees Fahrenheit plus or minus 2 degrees are acceptable in libraries, provided relative humidity is kept at 50%.

III.A.3. Air Circulation. In conjunction with humidity and temperature control, adequate air circulation will help prevent mold growth. Air circulation helps control moisture levels through evaporation.

Installing a heating/ventilation/air conditioning (HVAC) system with humidity control can solve all three problems of humidity, temperature, and air circulation at the same time. Such systems are not easy to install, simple to maintain, or inexpensive. But they provide the most effective means of preserving your collections. Not only do suitable HVAC systems assist in mold prevention, but they also stabilize the environment and hence eliminate the distortion of materials due to fluctuating temperature and humidity. Furthermore, maintenance of a stable environment slows down processes of deterioration caused by acid, light, and pollution. An HVAC system's control of the environment can also help in controlling insect infestations.

If you cannot install or improve an HVAC system in your library, there are a few alternatives which, although not as effective, will help. Fans can be installed to improve air

circulation. They are best placed near outside walls and close to floor level. Portable dehumidifiers can be used, particularly for localized problems. Although you can invest in several units, portable dehumidifiers tend not to be as effective in large spaces as a centralized HVAC system with humidity control. Fans and vents in attics will increase air circulation by pulling air through the building. This is particularly useful when it is necessary to leave windows open. Desiccants (such as silica gel) can be used to absorb moisture in humid environments. They should not, however, be used where young children are able to reach them because ingestion may be dangerous. Desiccants are most useful for localized problems, especially those that can be contained in a small, enclosed space.[1]

III.A.4. Light. Sunlight, and in particular ultra-violet radiation, generally inhibits mold growth. The Virginia State Library observed a direct connection between the rate of mold growth and the presence of light during several outbreaks in its collections between 1978 and 1980. It was found that more light correlated with slower growth rates. The relationship between light and mold growth is discussed further in section III.B.1.c. Sunlight and ultra-violet radiation, however, cause serious fading of library materials and can speed up chemical reactions leading to the formation of acids in paper; hence prolonged increases in the exposure of library materials to light are not recommended.

III.A.5. Chemical Composition. Mold growth can also be affected by the chemical composition of the book or paper substrate. Many fungi prefer slightly acidic material. They will also interact with non-cellulose matter within paper, such as iron particles, leading to staining and further deterioration. The chemical composition of most library materials is not something which can easily or even should be changed. But it does make some parts of collections more susceptible to mold growth than others.

III.A.6. Miscellaneous Environmental Modifications. There are several modifications that can be made to the building or its internal environment which will assist in preventing mold outbreaks.

a. Don't shelve books directly against an outside wall. Due to temperature and humidity differences between inside and outside environments, moisture may develop along walls. Allowing

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[1]Silica gel is a buffering substance, absorbing or releasing moisture into the environment to maintain a chosen level of relative humidity. It is frequently used in exhibit cases. See Lafontaine, Silica Gel, for procedures to condition and use silica gel.

air to circulate against the walls will enable the moisture to evaporate.

b. Keep the quantity of indoor plants to a minimum and don't allow indoor planted areas.

c. Waterproof basements and walls below ground level. And use water-sealant paint on floors and walls.

d. Place or adjust outside gutters and drains so that water does not collect near the outside walls. Check gutters and drains regularly to avoid clogs. Place lawn sprinkler systems so that they do not soak outside walls.

e. Regularly inspect your collection for mold or mildew. This will allow you to catch any infestation before it becomes large. And continue to monitor potentially hazardous areas until the environment can be stabilized in an appropriate state.

III.B. What Can You Do If You Have a Mold Outbreak?

There are a number of things you can do when faced with mold in your collection, but first you need to determine what has caused the mold to grow. Check the humidity and temperature. Chances are good that, for a large infestation, the cause at least partially lies there. When the Denver Public Library found mold in its off-site storage facility in 1984 (it was visible on approximately one-third of the books there), relative humidity was 60% and temperature was 78 degrees Fahrenheit. Also look for a source of water, such as an unnoticed leak, a broken window, moisture along outside walls. A third place to check is the heat-exchange coils in the heating/air conditioning system; they are a prime area for fungus growth and spore distribution. Clean them with a normal fungus-killing household cleaner. You need to pinpoint whatever caused the mold to develop and then fix it, because until you solve that problem, mold will continue to grow, no matter how often you treat the affected material.

Your second response should be to isolate affected materials. If a small quantity of books is moldy, seal them in air-tight plastic bags. If the infestation is large, quarantine the area. You should wear rubber or plastic gloves and a dust or filtration mask whenever handling moldy materials. Isolating moldy books and papers serves two purposes: it minimizes the spread of mold, and it protects those persons who may have allergies or respiratory problems from harm.

Third, do what you can to increase air circulation and lower humidity. Open windows, provided it is not raining outside and the relative humidity outside is lower than that inside. Set up fans to increase air circulation. Set up dehumidifiers or re-

adjust the HVAC system to lower the relative humidity. If you have a thermostat-controlled cooling system or one which simply lowers the temperature of outside air prior to ventilating it through the building, turn it off. This kind of "air conditioning" or cooling system does not provide humidity control and will in fact increase internal relative humidity because cold air cannot hold as much water as warm air. Furthermore, the moist heat-exchange coils in this system may be providing a fertile ground for the growth of mold, the spores of which are then distributed throughout the building via its ventilation system.

Every library and archives should have at least one tool for measuring relative humidity -- a hygrometer, sling psychrometer, or hygrothermograph. Used regularly and properly, these tools can alert you to increases in relative humidity before mold growth begins so that you may effectively modify the environment to prevent mold. During an outbreak, nygrometric tools should be used regularly (two to four times a day) to monitor the environment and the effectiveness of your modifications, and to make readjustments as necessary.

After you have readjusted the environment, you can look at available means for killing mold and cleaning the collections. There are both chemical and non-chemical means to kill mold. Effective treatments can be fungistatic or fungicidal. Fungistatic treatments are those that prevent the mold spores from germinating, but do not kill the mold. Freezing is one such method. Fungicidal treatments kill the mold and its spores. No safe large-scale treatment, however, imparts lasting, or residual, mold control. That is why it is so important to change the environment so that it inhibits mold growth. Furthermore, there is some evidence that books and papers treated with fungicides may be more susceptible to mold after treatment than they were prior to the outbreak.

In order to judge the effectiveness of the following chemical and non-chemical treatments, a number of questions should be asked about each. Is the treatment fungicidal or fungistatic? Can it damage books or paper during application or by leaving behind harmful residual chemicals? Is the treatment toxic to humans and how is such toxicity accounted for during application? Does the treatment act effectively in a short period of time, with low cost and reasonable implementation procedures (transportation, quarantine needs, equipment, etc.)?

III.B.1. Non-Chemical Treatments.

Non-chemical treatments to kill mold consist of procedures which do not involve the application of chemicals to the books or paper in solid, liquid, or vapor form. Usually, this involves

some temporary modification of the environment. Non-chemical treatments are preferred to chemical treatments by many because they don't interfere with the chemical composition of the materials, they do not leave residues in treated materials, and they are non-toxic to humans. Many non-chemical means have been discussed and experimented with; I mention the more commonly known of them here.

III.B.1.a. Freezing involves placing the moldy books in an atmosphere of below freezing temperatures. It is a fungistatic, not fungicidal treatment. It may present an option for halting the spread of mold while you evaluate other methods for killing the active mold.

III.B.1.b. Gamma radiation has been used to sterilize surgical equipment and food. Experiments in irradiation of books to kill mold have been conducted by Johns Hopkins Medical Institutions and by the State Central Archives of Czechoslovakia. Although it does kill mold and does not leave residues, there is evidence that gamma radiation softens leathers and adhesives and breaks down the internal structure of paper. The folding endurance of paper decreases with higher levels of radiation. Mold can be killed at lower levels of radiation when heat is applied; heat, however, can also decrease paper strength. Studies indicate that the effects of individual radiation exposures add up, hence repeated disinfection of books and papers with radiation is not recommended. Special chambers and corresponding operator training are necessary for irradiation, sources which are not easily accessible or necessarily affordable for most libraries. Because of the possibility of damage and the difficulty of accessing equipment, gamma radiation as a fungicide for books is not commonly used or recommended.

III.B.1.c. Ultra-violet light, as mentioned earlier, inhibits mold growth and may kill mold. It is not, however, recommended as a full-scale treatment for mold on books and papers because the amount of exposure necessary to kill mold would induce fading and accelerate aging. However, it has been suggested as a possible step in treating small, localized outbreaks. Active mold can be wiped or vacuumed from the book[2], and the book then placed outdoors, fanned open, in the sun, for a day or two. Do not leave books and papers outside overnight, as temperature changes may cause condensation to form. If the book is placed back into a suitable environment, the combination of removing the visible mold and allowing the book to dry out in the

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[2]Use a dry, clean rag or a brush to remove mold from books and papers. Rags moistened with ethanol can be used to wipe mold from bookbindings. A wet/dry vacuum cleaner with a 10% solution of sodium hypochlorite in the tank can also be used to clean mold from books. See section III.B.3.a.

sun may halt the further growth and spread of the mold. Books should not be placed outdoors if the relative humidity is above 65%. This process needs careful and continued monitoring, and may not be feasible for a mold outbreak affecting a large quantity of material.

III.B.2. Chemical treatments.

Using chemicals to kill mold involves the same concerns and criteria discussed earlier. And, although many chemicals can kill mold, environmental conditions still need to be modified and improved in order to prevent recurrence of the mold.

Unlike non-chemical treatments, there is a much greater awareness of toxicity to humans and residual damage to books when applying chemical fungicides. Several chemicals which are fungicidal are not used on book collections because of their toxicity and instability: included here are mercuric chloride, highly toxic and legally restricted in the U.S.; hydrogen sulfide, an explosive; and methyl bromide, which leaves an irreversible foul odor, softens adhesives, and is toxic.

Many chemical fungicides can impart limited residual control if applied directly to a document through aqueous means (instead of killing mold through exposure to toxic fumes, documents are soaked in solutions which contain fungicides). Aqueously-applied fungicides cannot be rinsed out of the documents, though, if any residual control is desired. Aqueous application of chemicals to books and paper is time-consuming and requires extensive knowledge of chemicals and their effects on paper and book materials. Only a conservator should aqueously apply chemical fungicides to material in library and archival collections. If the recommended or available fungicides are chlorinated substances, as many are, they will break down in paper over time to form the highly destructive hydrochloric acid. This breakdown is accelerated by impurities in most papers, such as iron and copper. Examples of fungicides which should be applied only by a conservator include salicylanilide, pentachlorophenol, and dichlorophene.

Only a knowledgeable conservator will know how to test the stability and effectiveness of aqueously-applied and/or chlorinated fungicides in the paper to be treated. Even if a fungicidal chemical is stable in the particular paper, it will need to be used in appropriate and often very low concentrations (for example, chlorinated chemicals are often applied in concentrations of Ø.1% of the paper's weight). Because they are time-consuming and require significant pre-testing prior to application, aqueous and/or chlorinated treatments are not feasible for large-scale infestations. Some will work, though, on single items. The high cost involved (especially labor cost)

tends to limit the use of aqueous treatments to rare materials, items whose intrinsic values make the expense worthwhile.

In contrast to the item-specific application of aqueous and/or chlorinated fungicides are several vapor treatments which may be applied on a large scale in libraries and archives as well as to just a few items. The aqueous treatments discussed above have the ability to impart some residual mold control, but none of the vapor treatments allow for residual control. However, these vapor treatments are easier to use, can be used for large or small infestations, and can be safely applied by non-conservators, under the appropriate conditions.

Below I describe the more commonly known and discussed chemicals used for killing mold in libraries and archives. When included in my description, implementation procedures for these chemical treatments are aimed only at application to general book or record collections. Consulting a conservator is recommended prior to treating large mold infestations in rare book or manuscript collections.

III.B.2.a. Thymol (isopropyl-meta-cresol) is a phenol. It is in crystalline form at room temperature, and sublimes to vapor when heated above 120 degrees Fahrenheit.

Thymol is toxic, and can be absorbed through the skin, by inhalation, or by inadvertent ingestion. The major hazard to those using thymol for fumigation is inhalation. Thymol has a pungent odor, however, which serves as a good warning to those working with it. Symptoms of overexposure include gastric pain, nausea, vomiting, and central nervous system overactivity. Very high levels of exposure could result in convulsions, coma, and cardiac or respiratory arrest. Long term effects from repeated exposure include liver and kidney damage, and dermatitis.

To use thymol effectively and safely as a fungicide, a sealed cabinet is necessary. Sources of instructions for building or modifying cabinets to use with thymol are included in the bibliography.[3] Conservators and others handling treated materials and thymol should wear neoprene or butyl rubber gloves and, when opening the chamber after treatment, should wear a respirator with an organic vapor cartridge. Care should be taken to limit human exposure to thymol to a minimum.

Studies have shown that paper will discolor (yellow) if treated with thymol and then exposed regularly to light. Some authorities have declared thymol to be fungistatic but not fungicidal in their tests.[4] Others, such as Barry Byers and Mary-Lou Florian, claim that it is fungicidal. The effectiveness probably varies with the type of fungus and the application

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[3]See Byers; Nagin and McCann; and Ritzenthaler.

[4]See Gustafson; Haines and Kohler; Kowalik "Some...".

procedure. The following procedure is that described by those who found the treatment with thymol to be fungicidal.

Before fumigation, wipe visible mold from bindings.[5] Fan books open and stagger flat paper on the shelves in the cabinet. Place thymol crystals in dishes in the cabinet and heat them with 15 to 20 watt light bulbs. The ratio of thymol to area is roughly 1 dish with 5 grams of thymol crystals and a corresponding light bulb for each 9 cubic feet (.25 cubic meters) of cabinet. The cycle is 2 hours of heating with light bulbs on, 22 hours with light bulbs off, for three consecutive days. The cabinet is kept closed for the entire cycle, to allow the vapor to penetrate. Upon completion, the cabinet is opened and books/papers are aerated for several hours. Some cabinet designs incorporate exhaust systems, which make aerating safer and easier at the end of the cycle.

Thymol can also be used in spray or mist forms, but is generally not because of the greater exposure on the part of the person applying the thymol. In such situations, ortho-phenyl phenol is usually substituted.

Many libraries and archives no longer use thymol because of health hazards. Those who are considering its use should read Deborah Nagin and Michael McCann's "Thymol and O-Phenyl Phenol: Safe Work Practices" from the Center for Occupational Hazards.

III.B.2.b. Ortho-phenyl phenol is a solid at room temperature. It is usually mixed with an alcohol, such as ethanol, for aqueous or spray applications. When applied as a vapor, it is much slower acting than thymol, but also much less of a health hazard. Many recommend that o-phenyl phenol be substituted for thymol in general use.

Although it is a phenol, like thymol, o-phenyl phenol is not absorbed through the skin. It may cause some skin irritation with prolonged contact. It can cause eye irritation, and inhalation of the powder can cause upper respiratory irritation. Repeated and long-term exposure could lead to kidney damage. Respirators with organic vapor cartridges should be worn when fogging or spraying with o-phenyl phenol, as should neoprene or butyl gloves when handling o-phenyl phenol and/or treated items. Care should be taken to wash hands when working with o-phenyl phenol, even if wearing gloves, to avoid inadvertent ingestion.

As with thymol, there is some debate among experts as to o-phenyl phenol's effectiveness as a fungicide. Some experts feel that o-phenyl phenol is not fungicidal as a vapor.[6] The two vapor applications described below may depend more on the controlled environment in the chamber than on the o-phenyl phenol for effectiveness.

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[5] See section III.B.3.a.

[6] See Haines and Kohler; Gustafson.

Three variations on o-phenyl phenol application are described below; two are vaporous and the third relies on a combination of spraying and vapor. Before use, as much of the visible mold as possible should be removed from the bookbindings.[7]

-- for a few books, place them in an air-tight plastic bag with o-phenyl phenol crystals. Do not allow the crystals to directly touch the books. Seal the bag, and leave it for 4 to 6 weeks. Vapor from the slow sublimation of the crystals should kill active mold.

-- for use in an airtight chamber, mix o-phenyl phenol with enough ethanol or trichloroethane to dissolve the crystals. Use 2 tablespoons of o-phenyl phenol for each square foot of the chamber. Seal the books inside with the o-phenyl phenol, and leave them for three weeks. Again, o-phenyl phenol vapor should kill the mold.

-- for treating large outbreaks, use a solution of 13% o-phenyl phenol in ethanol or 10% o-phenyl phenol in trichloroethane. An experienced commercial exterminator should be employed for implementation of this procedure. The solution is sprayed into the air in the enclosed area for several hours on each of three consecutive days (at a minimum), or for 6 treatments spread out over nine days (the former done at the Denver Public Library, the latter recommended by Dr. Robert McComb at the Library of Congress). Those persons who are spraying the o-phenyl phenol solution must wear protective clothing, gloves, and respirators. The entire building should be sealed and inaccessible to unprotected persons during treatment. Several hours after the final spraying, the windows should be opened and fans turned on.[8]

After all treatments, thoroughly aerate all materials. Precaution should be taken against inhalation of the o-phenyl phenol vapor. When sprayed, the o-phenyl phenol will be effective for 30 to 40 days, and will slowly evaporate during that time. The treated books should be quarantined from the public during that period, and otherwise handled only when wearing rubber gloves and a respirator with an organic vapor cartridge.

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[7]See section III.B.3.a.

[8]Turner's article describes the implementation of this procedure fully.

Spraying individual books with o-phenyl phenol solutions should only be done by a conservator with a fume hood. As mentioned earlier, spraying of large collections in situ should be done by qualified exterminators who have experience with fumigation for mold. They are best equipped to handle the spraying safely.

III.B.2.c. Ethylene oxide is among the most effective of mold fumigants for library materials. Because it is highly flammable, ethylene oxide is mixed with Freon (8.8:1.2 ratio) or carbon dioxide (9:1 ratio) and then applied in a vacuum chamber. The cycle is usually 12 hours long. Ethylene oxide has been used as a fumigant in libraries, archives, and museums since the early 1930s.

Ethylene oxide is also, however, extremely toxic and carcinogenic; its use is regulated by the Occupational Safety and Health Administration (OSHA). The permissible exposure level for humans is one part per million (ppm), as an 8 hour time-weighted average.[9] This is a level that very few of the vacuum chambers originally designed for ethylene oxide use can maintain. Studies have shown that even as many as 75 post-exposure air wash cycles still leave 4 ppm of ethylene oxide in some chambers. Ethylene oxide has a distinctive odor when present in the air in concentrations greater than 300 ppm. There is also concern that some materials, such as leather, retain ethylene oxide, which will volatilize into the air for several months after treatment.

Exposure to ethylene oxide irritates skin, eyes, and the respiratory system. Exposure can also cause dizziness, dullness, sinus congestion, vomiting, and nerve damage. Ethylene oxide is linked to leukemia, stomach cancer, brain cancer, and reproductive dysfunctions among men and women, including genetic damage and spontaneous abortion.

Most libraries and archives which had installed ethylene oxide fumigation chambers no longer use them. Some commercial exterminators or sterilizers may have suitably controllable chambers for use with ethylene oxide. However, it is difficult to move moldy books for treatment, the treatment is likely to be costly, post-treatment aeration is lengthy, and those using ethylene oxide chambers for sterilization may not be willing to treat books for mold. So, despite its effectiveness, ethylene oxide is seldom recommended or used any more for mold fumigation in libraries and archives.

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[9] See "Occupational Exposure to Ethylene Oxide" in the Federal Register, 22 June 1984, pp. 25, 734-5, 809. Summaries of OSHA regulations are also available from the Center for Occupational Hazards, 5 Beekman St., New York, NY 10038.

III.B.2.d. Paradichlorobenzene is a mild fumigant. It comes in crystalline form at room temperature, and should be used in an enclosed space. It is not a proven fungicide, but seems effective as a fungistat. Three weeks of exposure is needed for the application to be effective; less time is needed if the crystals are volatilized by heat, as were the thymol crystals described above.

Paradichlorobenzene seems to be most useful as a method for preventing mold growth, especially in small, enclosed spaces. It is hazardous if inhaled, ingested, or in contact with skin. Exposure can cause dizziness, headaches, skin and eye irritation, respiratory problems, and loss of coordination. Long-term effects include dermatitis and possible liver and kidney damage.

III.P.2.e. Carbon dioxide has been suggested by Richard Smith as a possible fumigant. As far as I can tell, no experiments have been undertaken to test its effectiveness. Carbon dioxide is a high pressure gas which would have to be carefully handled in a chamber. It is estimated that a fumigation cycle would take several days. Because it has not been practically demonstrated, carbon dioxide is not a recommended fungicidal treatment for books.

III.B.3. Miscellaneous Activities to be Carried out in Conjunction with Treatment.

III.B.3.a. Cleaning Books and Paper. Use a clean dry rag or a soft-bristled brush to brush mold from paper and books. Ethanol can be used to wipe away visible mold on bindings. It should not be applied to paper (texts) except by a conservator. Application should be done carefully as ethanol may change or remove color from some bindings. Visible mold can be wiped away before or after treatment and, with a large infestation, it may be necessary to do so at both times. When wiping off mold, be careful not to brush it into the air indoors or onto other objects; this can be accomplished by wiping books or papers off outdoors or under a fume hood. Used rags should be stored in sealed plastic bags until they can be washed in bleach for re-use. Visible mold can also be removed by vacuuming the books with a wet/dry vacuum cleaner. The tank should contain a mold-killing solution, such as 10% sodium hypochlorite in water. Remember to wear plastic or rubber gloves and filtration masks when handling moldy materials.

III.B.3.b. Cleaning the Room(s). While books are being treated, the area in which they were stored should be cleaned. Shelves, floors, walls, ceilings, and windows can be cleaned with a mold and mildew killing solution, such as Lysol, Chlorox, or X-14. Make sure that the area is properly ventilated while cleaning. Don't return treated books to the area until it has been cleaned. It may also be necessary, depending upon how

serious the infestation is, to clean carpets and drapery. Filters and heat-exchange coils in HVAC systems should be checked and replaced or cleaned with a mold-killing household cleaner.

III.B.3.c. Odor removal. Charcoal and/or baking soda can be used to remove the odor of mold, if the treatment has not done so. Simply place briquettes and/or bowls of baking soda in the area to absorb the odor. Do not wipe the books or paper with the charcoal or baking soda.

III.B.3.d. Monitoring. Continue to monitor the area and the treated books and papers after the fungicidal treatment has occurred. Changes in the environment should have been made (either before or during treatment) to reduce the possibility of future outbreaks; i.e., humidity and temperature control established, air circulation improved, leaks fixed or other sources of moisture removed. Nonetheless, careful watch should be kept over treated collections to prevent new outbreaks. Books seem to be somewhat more susceptible to mold after treatment.

IV. Concluding Recommendations

Most authorities agree that fumigating collections with toxic chemicals is rarely necessary for dealing with mold and mildew problems. Treating individual incoming items may occasionally be necessary, but storing collections in appropriate environmental conditions should prevent the need for fumigation. To quote Dr. Thomas Parker, of Pest Control Services, Inc.:

> fumigation will not control mold and mildew if the library materials are placed back into the same conditions from which they came. In most instances library materials that have been fumigated are then stored in areas which do not have an environment conducive to mold growth. The success of the fumigation is given as a reason for the control of the mold and mildew, when in fact, the new area in which the materials are stored is the governing factor as to why mold and mildew is now being controlled.[10]

Maintenance of proper environmental conditions will prevent mold growth. And if mold does occur, a relatively gentle form of cleaning along with improving the environment will solve the problem in most situations. I recommend that you try the following before instigating chemical treatment.

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[10]Parker, "Integrated Pest Management for Libraries," p. 21.

1. Determine the cause: check temperature and relative humidity levels; check to see if the material has been wet and, if so, why; check heat-exchange coils in air conditioning units.

2. Isolate materials: place individual items in sealed plastic bags; quarantine stacks; for large and heavy infestations, it may be necessary to restrict access to the building/room.

3. Modify the environment: readjust relative humidity to the best of the HVAC system's ability; set up fans to keep air circulating in the affected area; install portable dehumidifiers in the affected area if the HVAC system cannot be controlled; turn lights on in affected areas for as long as possible during periods of obvious mold growth. Continuously record temperature and relative humidity until they stabilize at an acceptable level.

4. Clean: wipe visible mold from books or papers with a clean dry rag or a soft brush; bookbindings can be wiped with ethanol or vacuumed with a wet/dry vacuum cleaner; clean shelves, walls, floors, air conditioning heat-exchange coils, air vents, etc. with Lysol, Chlorox, X-14, or other mold-killing solutions; if you are dealing with a small quantity of books, you can set them out in the sun to dry out, otherwise use fans following the ethanol/vacuum cleaning.

5. Monitor: keep watch on the affected area for several months beyond the mold outbreak and clean-up, even after the environment has been restored to conditions which inhibit mold growth.

Research and testing continue to assess the effectiveness of fungicides, to determine appropriate treatment procedures, and to identify molds and mildews and their characteristics. Studies may result in changes to existing procedures for mold control in the future. The SOLINET Preservation Program is able to provide advice and assistance in dealing with mold infestations in specific situations. Please call if we can help.

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