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# *White Paper* *on* *Corrosive Drywall*

American Industrial Hygiene Association<sup>®</sup>

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<b>TABLE OF CONTENTS</b>	<b>PAGE</b>
<b>1.0 Executive Summary.....</b>	<b>3</b>
<b>2.0 Introduction.....</b>	<b>4</b>
<b>3.0 Origin.....</b>	<b>5</b>
<b>4.0 Chemistry.....</b>	<b>5</b>
<b>5.0 Effects.....</b>	<b>7</b>
<b>6.0 Inspection.....</b>	<b>8</b>
<b>7.0 Materials Testing.....</b>	<b>10</b>
<b>8.0 Air Monitoring.....</b>	<b>11</b>
<b>9.0 Exposure Reduction.....</b>	<b>12</b>
<b>10.0 Remediation.....</b>	<b>13</b>
<b>11.0 Post-Remediation Verification.....</b>	<b>15</b>
<b>12.0 Worker Protection.....</b>	<b>16</b>
<b>13.0 Waste Disposal.....</b>	<b>16</b>
<b>14.0 Competencies for CDW Services.....</b>	<b>17</b>
<b>15.0 Findings.....</b>	<b>17</b>
<b>16.0 Recommendations.....</b>	<b>21</b>
<b>References.....</b>	<b>24</b>

## **1.0 Executive Summary**

Contaminated drywall imported from China has been found to emit sulfide vapors, impacting the air quality in tens of thousands of homes as well as in larger buildings. In this White Paper, AIHA summarizes the available science and identifies critical gaps in the current understanding of the problem that must be addressed.

The presence of corrosive drywall (CDW) can generally be recognized based on visual inspection and the building's construction history. Blackening of certain metal surfaces provides a consistent marker for the potential presence of CDW. Corrosion damage to electrical and mechanical systems has occurred, and property values can be significantly diminished.

The one available medical study evaluating occupants of homes with CDW identified short-term irritation effects possibly associated with CDW emissions in subjects predisposed to irritation of the mucous membranes based on their medical history (e.g., asthma, dry eyes).

Federal and state response guidance and commercially available remediation services have proceeded ahead of a complete understanding of critical issues. Since emissions from CDW represent a complex, variable mix of sulfides in the parts per billion levels, setting chemical air quality standards is not feasible. Available air quality monitoring methods are generally not sufficiently sensitive for either assessing exposure to CDW emissions or verifying remediation efforts.

CDW can be identified in a bulk sample analysis by a positive laboratory test for elemental sulfur. Elevated strontium content is also a marker for potential emissions. Both elemental sulfur and strontium can be measured by laboratory analysis of drywall samples. A hand-held X-ray fluorescence meter (XRF) can be used as a field tool for identifying potential CDW locations within a structure.

Several attempts to control emissions while leaving CDW in place have not been successful. Air cleaning and moisture reduction, however, may reduce indoor air contaminants and corrosive effects pending removal of CDW.

To effectively control emissions from CDW, remediation should (a) remove all corrosive drywall; (b) eliminate visible demolition dust; (c) eliminate residual CDW odors from remaining surfaces; and (d) restore electrical and mechanical systems to a safe, reliable, and code-compliant condition. Various remedial approaches have been attempted, ranging from removal of all drywall (both CDW and non-CDW) and all electrical and mechanical systems to selective removal of only CDW and affected components. However, none of these strategies has been demonstrated conclusively to eliminate emissions on a permanent basis.

Residual odors emitted by remaining surfaces have been addressed by airing the structure and its contents up to several months. Various treatments are in use to expedite

this process, although none has been scientifically validated. Remediation strategies that ensure cost-effective restoration of CDW-impacted structures to pre-existing condition are needed. This is especially critical for homes where mitigation budgets are limited.

Competencies necessary for individuals assessing and remediating CDW are also discussed.

Additional work is needed to resolve CDW issues: (a) research on underlying chemistry, emission dynamics, health risks and corrosion damage; (b) development of protocols for air quality monitoring, assessment, and remediation; and (c) issuance of guidance for worker protection. AIHA's findings and recommendations will be updated as new information becomes available.

## **2.0 Introduction**

This AIHA White Paper on the corrosive drywall problem was developed by the Corrosive Drywall Project Team comprising members of the Construction and Indoor Environmental Quality Committees. While critical scientific issues remain unresolved, a review of the available evidence is presented, along with preliminary recommendations.

*Note: The acronym "CDW" in this text refers to corrosive drywall (contaminated sheetrock producing sulfide emissions). Although the term "Chinese Drywall" is in common use, not all drywall imported from that country is corrosive.*

Some U.S. homes and larger buildings built or renovated starting in approximately 2001 have been found to contain CDW, with the majority of complaints reported from Florida, Louisiana, and Virginia. Noxious odors (e.g., smell resembling a burnt match), visible corrosion of copper and silver items, and health concerns have been associated with the installation of drywall imported from China.<sup>(1)</sup> It is likely that CDW is present in tens of thousands of detached homes and multifamily residences constructed or renovated after 2000, along with an unknown number of commercial and public buildings.

The Consumer Product Safety Commission (CPSC) has received more than 3000 complaints alleging CDW damage.<sup>(2)</sup> Several hundred homes reported by larger builders to have been restored by extensive replacement of building materials, followed by an extended airing-out period. Approximately 2000 homes are involved in litigation, with initial decisions awarding remediation funding to some plaintiffs.<sup>(3)</sup> The majority of affected homeowners and builders are waiting for the availability of funding and a cost-effective remediation protocol to resolve their situation.

Exposure concerns associated with emissions from indoor sources in the past have been resolved by applying the results of basic research to the development of practical methods for assessment and control. As CDW researchers verify its chemistry, dynamics, and effects, CDW assessment and remediation procedures useful to field practitioners

should be developed. Efforts to deal with past indoor environmental issues are instructive for the development of cost-effective solutions to the CDW problem.

### **3.0 Origin**

Drywall is an interior construction material usually consisting of gypsum pressed between two sheets of paper. Gypsum is calcium sulfate dihydrate, with the chemical formula  $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ . Gypsum has been used as an inexpensive and fire-resistant building material for thousands of years. Drywall is manufactured using both natural gypsum ore and byproduct (synthetic) gypsum. Mined gypsum ore may be mixed with mineral salts, carbon-containing materials (e.g., oil shale), and elemental sulfur.<sup>(4)</sup>

Gypsum is processed at a manufacturing plant (crushed, water added, heated) to form drywall. The drywall manufacturing process basically involves rock dryers (in the case of mined gypsum), calcination (i.e., the heating of raw, mined gypsum), water heaters for making slurry (plaster), and kilns for baking the extruded wallboard. Fiber, plasticizers, foaming agents, and other agents may be added to resist moisture and increase fire resistance.<sup>(4)</sup>

CDW seems to have originated from a Chinese mine where high-sulfur gypsum was mixed with oil shale. From approximately 2001 to 2007, substantial quantities of this product were shipped to ports in the eastern United States.<sup>(5)</sup> A recent CPSC study documents sulfide emissions for specific Chinese drywall products.<sup>(6)</sup> North American drywall samples were not corrosive.<sup>(7)</sup>

### **4.0 Chemistry**

The most salient differences between the problem Chinese drywall and North American drywall are higher elemental sulfur content and the emission of gaseous sulfides (including hydrogen sulfide and various organosulfides). In most cases, CDW contains greater amounts of elemental strontium. The presence of elemental strontium is useful as a marker but unrelated to production of volatile sulfides. CDW has been identified as having a higher organic content than other drywall.<sup>(8)</sup>

Possible etiological mechanisms for the production of reduced sulfur gases have been proffered, but the precise mechanism has not been confirmed. It has been hypothesized that the source is gypsum from a Chinese mine that was mixed with naturally occurring sulfur minerals and organic materials (e.g., oil shales) which, in the presence of elevated temperature and moisture (both present during the manufacturing process and after installation), reacted to produce sulfide gases.<sup>(1,9)</sup> One investigator reports that the presence of carbon monoxide at normal background concentrations contributes to this reaction.<sup>(6)</sup>

Another theory is that the drywall contains sulfur-reducing bacteria that cause iron and sulfur compounds to produce sulfides. This does not appear to be consistent with available evidence (e.g., one experiment found emissions to continue after CDW samples were sterilized).<sup>(1)</sup>

Several other theories have been advanced regarding the possible origin and nature of corrosive drywall. These include:

- (a) Gypsum was mixed with fly ash.
- (b) Gypsum was manufactured from fertilizer waste and thus radioactive.
- (c) Gypsum contained asbestos.
- (d) Gypsum was manufactured with polluted water.
- (e) Drywall odor is produced by adhesives or fungicides.

Data consistent with these theories have not been presented.

Emissions from CDW represent a complex and variable mixture of chemicals at very low concentrations. Laboratory tests have established that hydrogen sulfide, carbon disulfide, carbonyl sulfide, and dimethyl sulfide are emitted.<sup>(6)</sup> Preliminary testing by the Fraunhofer Institute identified 17 other compounds with emission rates exceeding normal drywall. The majority were organosulfides, which tend to produce odor, corrosion, and irritation at low concentrations. These were:

- methanethiol
- propanethiol
- 2-(ethylthio)-propane
- butyl ethyl sulfide
- 2-methyl-3-furanthiol
- diisopropyl disulfide
- isobutyl isopropyl disulfide
- diethylthiophene
- ethyl isopentyl disulfide

The other contaminants were trace volatile organic compounds, which included:

- 2,3-butanedione
- 3-methylbutanal
- 1-hexen-3-one
- hexanal
- 2-acety-1-pyrroline
- 1-octen-3-one
- octanal
- (z)-2-nonenal<sup>(9)</sup>

While it has been suggested that hydrogen sulfide is responsible for much of the

observed corrosion, ambient hydrogen sulfide concentrations in CDW-impacted homes have been found to be comparable to both outside air and non-CDW homes,<sup>(8)</sup> and it is generally observed that the characteristic, rotten egg odor of hydrogen sulfide is not detected in CDW homes. The “burnt match” odor intermittently present in most CDW-impacted homes appears to be more consistent with a mixture of organosulfides.

A CPSC study has characterized emission rates for various types of drywall. Hydrogen sulfide emitted from some Chinese products was 100 times greater than non-corrosive samples. Specific organosulfide compounds in the emissions were not measured.<sup>(6)</sup>

For assessment and control, it is critical to understand how emissions vary seasonally with weather changes, structural location, etc. The impacts of ventilation, HVAC operation and other environmental contaminants, along with distribution patterns of contaminated air, are also important. While emissions appear to increase with temperature and moisture,<sup>(10)</sup> information on other emission factors has not been made available. These characteristics include minimum conditions required to initiate emissions and off-gassing duration.

## **5.0 Effects**

Individual compounds in emissions from CDW are at low parts per billion (ppb) levels.<sup>(9)</sup> Effects of exposure to sulfide mixtures in this range are poorly understood. While a CDC toxicological evaluation suggested that air contaminant concentrations associated with emissions from CDW are below levels demonstrated to present a health hazard,<sup>(11)</sup> some occupants continue to attribute a variety of symptoms to CDW in their homes.

Only one medical study has evaluated the health of persons residing in CDW homes.<sup>(12)</sup> These physicians report some occupants had short-term irritation effects possibly associated from CDW emissions and that all subjects experiencing these were clinically pre-disposed to mucous membrane irritation at exposure levels below that known to impact the general population. Those patients’ medical histories included chronic rhinitis, atopy, asthma and/or dry eye syndrome. The physicians considered these findings preliminary and recommended further research. No studies are currently underway to evaluate this significant public concern

It has been hypothesized that sulfides may be synergistic, producing an irritant response in conjunction with other contaminants normally present in indoor air. For example, formaldehyde, which is typically present in all homes at sub-irritant levels, could affect the mucous membranes and cause headaches when combined with low concentrations of sulfides.<sup>(13)</sup>

The presence of CDW consistently causes blackening of susceptible metal surfaces, such as uninsulated copper wiring and piping, due to a reaction of metals with

sulfide gases, forming metallic sulfides (surface sulfidation) that under some circumstances could lead to system failure.<sup>(3)</sup>

Opinions vary widely with respect to electrical and mechanical damage caused by emissions from CDW. Some experts have suggested that corrosion of electrical components is not problematic and that insulated wires are not affected. They recommend that only blackened tips and ground wires be replaced. Other experts opine that corrosion damage is significant, insulated low voltage wires are susceptible to damage, and that replacement of the entire system is justified.

With respect to mechanical systems, some experts recommend replacement of blackened air conditioner coils and piping. The CPSC, however, addresses only sprinkler and gas systems. Defendants in the federal Multi-District Litigation (MDL) suggest that cleaning corroded pipes is sufficient. On the other hand, plaintiffs have advocated replacement of all mechanical components, and the Court has ruled in their favor.<sup>(3)</sup>

Electronic circuit boards with silver components susceptible to corrosion are found in appliances, sound systems, monitors, and alarms. While some failures have been attributed to CDW, assessing potential corrosion to electronic circuit boards is difficult. Expert recommendations range from replacement of all appliances to replacing only smoke and CO detectors.

Because of concerns for odor, health effects, and corrosion damage, property values of CDW-impacted homes are reported to be reduced.<sup>(14)</sup>

## **6.0 Inspection**

Guidelines for home inspection to identify affected properties have been issued by CPSC,<sup>(1)</sup> the State of Florida,<sup>(15)</sup> ASTM (draft),<sup>(16)</sup> the Florida State Task Force for Chinese Drywall Removal,<sup>(17)</sup> and the Multi-District Litigation.<sup>(3)</sup> These are collectively summarized as follows:

- (a) The guidelines generally focus on drywall installed after the year 2000.
- (b) All of the guidelines include the use of visual inspection of metal surfaces to locate black tarnishing.
- (c) Two guidelines prescribe follow-up tests to confirm that blackening is sulfide corrosion.
- (d) Two guidelines require documentation of electrical or mechanical failures.
- (e) All guidelines stated above suggest collection of drywall samples for evidentiary purposes and testing to determine chemical composition of the drywall.
- (f) Three guidelines mention odor evaluation without prescribing a systematic evaluation procedure.



- (g) All guidelines stated above suggest documentation of drywall labels but do not provide a key for classifying these drywall products based on corrosivity.

None of the guidelines consider the use of blackening patterns, construction history, or panel dimensions to suggest the location of CDW panels in homes with mixed drywall. Air testing, exposure assessment, and remediation planning are not addressed.

The CPSC guidance suggests that visible corrosion is not specific to CDW. This fails to consider that metal blackening is rare in newer homes and that non-CDW sources of sulfide contamination can be readily identified by odor patterns (e.g., “rotten egg” smell from sulfur water or sewer gas).

A comprehensive inspection protocol should be developed for CDW assessment with consideration of the following:

- Questions for the homeowner and builder on (a) construction history, (b) electrical or mechanical failures, and (c) environmental observations over time.
- Odor evaluation (i.e., “burnt-match” odor is suggestive but is not always present with CDW; “rotten egg” odor is suggestive of water with naturally occurring hydrogen sulfide or sewer gas)
- A systematic inspection to identify locations of black corrosion and potential sources of sulfide contamination
- Information correlating drywall labels with corrosivity.

Comprehensive inspection should enable a home or building to be classified as either:

- (a) **NO CDW PROBLEM**  
*Drywall installed prior to 2001 or no black corrosion observed and no CDW-type odor detected*
- (b) **CDW THROUGHOUT**  
*Black corrosion observed in most electrical outlets*
- (c) **LOCALIZED CDW**  
*Black corrosion limited to specific areas*

A multi-family or multi-tenant building ideally should be assessed in its entirety. Units without CDW may be impacted by adjacent areas.

Information from the assessment can also be used to support the development of mitigation strategies. Assessment findings should enable the following:

- (a) Identification of areas with and without corrosive drywall
- (b) Identification of electrical and mechanical components requiring replacement

- (c) The prioritization of response measures
- (d) Remedial scope and procedures

The assessment may also support qualitative estimation of relative exposure.

## **7.0 Materials Testing**

Laboratory testing has correlated emissions with the elemental sulfur and strontium content of drywall.<sup>(1,10,18)</sup> Drywall evaluation by practitioners can be accomplished by either analyzing the material for indicators of contamination (strontium or elemental sulfur) or by enclosing in a container with copper and observing whether blackening occurs. Measurement of strontium in the field can be accomplished by XRF.<sup>(1,19)</sup>

For a method to be conclusive, it must consistently test positive for corrosive drywall and test negative for non-corrosive drywall. While collecting individual samples for laboratory analysis may be useful to provide evidence for litigation, each sample represents only one panel, making this impractical for mapping corrosive panels in a building constructed with more than one type of drywall (due to cost constraints, time limitations, and the destructive nature of bulk sampling).

Commercial testing now being offered to determine if drywall is corrosive includes:

- (a) Laboratory analysis of drywall for elemental sulfur or strontium<sup>(20)</sup>
- (b) Fourier Transfer Infrared Spectroscopy (FTIR) looking for a characteristic CDW footprint<sup>(21)</sup>
- (c) Chamber test of a drywall piece for reduced sulfur emissions<sup>(22)</sup>
- (d) Examination of copper placed in a container with a piece of drywall for black corrosion
- (e) A bacterial endotoxin test, assuming CDW emissions are bacterial in origin (research referenced in Section 4.0 is inconsistent with this hypothesis)
- (f) Evaluation of “physical properties and organic content” (protocol not specified by laboratory)<sup>(23)</sup>

Scanning drywall in the field with a hand-held XRF instrument provides a screening tool for identification of CDW using elemental strontium concentration as a marker.<sup>(24)</sup> CPSC has suggested a strontium content of 1200 parts per million (ppm) as an indicator that CDW is corrosive. While the agency’s data are generally consistent with this, there are two exceptions. First, a few non-corrosive drywall products exceed 1200 ppm strontium, which could occasionally result in the removal of more drywall than necessary without additional testing. The other exception is reduced XRF readings caused by drywall coatings. When drywall is measured in situ, paint or other surface coatings have a muting effect on the strontium concentration. To minimize the probability of underestimating the strontium concentration, the field measurement should be multiplied

by a correction factor (e.g., XRF reading of an exposed edge divided by measurement through coating).<sup>(19)</sup>

XRF findings may be limited by access (e.g., cannot test behind cabinet or under drywall mud). Protocols are being developed that (1) analyze the full spectrum of XRF peaks for correlation with specific drywall products, and (2) measure the amount of sulfide corrosion on metal surfaces.

## **8.0 Air Monitoring**

Any air monitoring protocol used for quantitative field assessment should specify standard monitoring conditions, sampling strategy, collection, and analytical procedures, interpretation criteria, and potential interferences. For routine use by field practitioners, a protocol must be simple, quick, and inexpensive. A protocol must be validated to be considered conclusive.

Potential uses for air quality monitoring related to CDW emissions include:

- (a) Determining whether corrosive drywall is present – *This is better determined by inspection.*
- (b) Locating corrosive drywall panels – *Air monitoring is generally not sufficiently site specific.*
- (c) Evaluating occupant exposure – *Dose/response cannot be generalized, but relative exposure may be instructive.*
- (d) Prioritizing response – *Consider addressing more concentrated emissions first.*
- (e) Designing remediation – *While specifications can be based on inspection only, pre-testing can provide comparison for tracking work progress.*
- (f) Verifying remediation – *Air testing by an appropriate method is critical.*<sup>(25)</sup>

With respect to air quality monitoring of CDW-impacted homes, chemical tests involving hydrogen sulfide and VOCs have not been conclusive because emissions from CDW represent a complex and variable mixture of contaminants at very low concentrations, many of which are unstable. While researchers have been able to detect air pollutant concentrations unique to CDW using state-of-the-art laboratory techniques, this cannot be accomplished in the field using currently available methods.

The cleanroom and electronics industries recognized the problems associated with monitoring a variable mixture of pollutants and developed technology to measure the overall corrosivity of air (also known as air reactivity). Air corrosivity provides a surrogate measure of air quality by tracking the combined impact of corrosive chemicals, which is similar to the measurement of combustible gas.<sup>(26)</sup> Corrosivity monitoring has been widely used to protect semiconductor manufacturing and electronics equipment in industrial plants and museum archives.<sup>(27)</sup> Because tolerance for corrosive pollutants in

those environments is less than normal background, accepted criteria for cleanrooms are not applicable to residential monitoring.

Air corrosivity can be measured on copper or silver probes (also known as coupons) left at a site and then measured for either corrosion gain or metal loss. Where CDW is being assessed, other sources of sulfides have to be considered (generally limited to sulfur water or sewer gas). Non-sulfide sources of corrosion (e.g., bleach) are also potential interferences.<sup>(25)</sup> Because this method detects only current corrosivity, it may not account for past or future off-gassing (e.g., emissions may occur only during periods of elevated temperature or humidity).

Air corrosivity data cited by the CPSC and the MDL was used only to verify the source of corrosion. These organizations did not consider air corrosivity measurements as a surrogate measure of air quality. CPSC reported air reactivity of non-complaint homes all to be in the mild range (about 20–100 angstroms per 30 days), while levels in CDW-complaint homes ranged from moderate (approximately 300 angstroms per 30 days) to severe (approximately 2000 angstroms per 30 days).<sup>(8)</sup> These data suggest that measuring air corrosivity may provide a practical method to assess exposure in CDW homes. However, setting health-based criteria to protect susceptible individuals from a complex mix of pollutants is not possible.

Another surrogate for tracking emissions from CDW is detectable odor. In many CDW-impacted homes, a unique, “burnt match” odor is detected intermittently. This does not resemble “rotten eggs” but is more consistent with a mixture of organosulfides. Since CDW odor may not consistently track corrosivity, odor monitoring should always be included in the initial and post-remediation clearance assessments. Because CDW odor is variable and its detection is subjective, a systematic monitoring process is needed. Development of an odor evaluation protocol should consider:

- (a) If site conditions have been changed (e.g., remediated), time should be provided for odor to stabilize before evaluating.
- (b) An evaluator should be able to distinguish odors detectable by the general population and be familiar with characteristic odors associated with sulfur compounds.
- (c) It is preferable to have more than one person evaluate the odor.
- (d) The evaluator could have a reference smell available at the site for comparison (e.g., damp piece of corrosive drywall in a sealed container).
- (e) The home should be pre-conditioned to increase the probability of odor detection (e.g., doors and windows shut; HVAC, fans, and air cleaners off; masking odors eliminated; relative humidity over 40%).
- (f) Odor detected upon initial entry should be recorded.
- (g) Olfactory fatigue should be addressed by having inspectors periodically go outside during the inspection.

CDW odor can be classified by strength (e.g., none, slight, strong). Locations where it appears to be present and absent should also be noted.

## **9.0 Exposure Reduction**

Although many experts now agree that CDW should be removed to protect occupants and control corrosion, other control strategies could potentially reduce occupant exposure and corrosion. Air cleaning (e.g., enhanced filtration) may prove to be a useful interim control.<sup>(25)</sup> Since sulfide emissions from CDW appear to increase with moisture, controlling relative humidity and/or drying wet materials may also prove to be beneficial. For example, introducing conditioned outside air to pressurize wall cavities with drier air might improve IAQ but would require additional dehumidification capacity and increased energy use.

Substituting corrosion-resistant electrical or mechanical components can also reduce damage pending control of emissions (e.g., adding coated air-conditioning coils).

## **10.0 Remediation**

Some CDW-impacted homes have been remediated by extensive materials and systems replacement. Costs have typically been around \$100 per square foot, and have necessitated occupant relocation up to several months.<sup>(3)</sup> Successes and failures have been reported anecdotally but not verified by conclusive test data. Research is needed to determine how to efficiently restore CDW-impacted buildings.

Efforts to eliminate emissions while leaving CDW in place have not generally been successful. For example, while fumigation may react with airborne and surface sulfides, sulfides will continue to be produced inside CDW and be emitted. Fumigation can also damage other material and contents, does not address corroded electrical and mechanical systems, and may create potentially harmful byproducts.

Coating CDW in-place (i.e. encapsulating) has also been attempted. This process does not address corroded electrical and mechanical components or residual odors on contents. Moreover, all surfaces may not be coated, and thus, a chemical residue is left in place.

Comprehensive tear-out removes all drywall and adjacent insulation based on the assumption that other porous materials are contaminated. Some protocols also remove wood and carpeting. In other cases, flooring is protected and remaining surfaces wiped with various solutions. Many of these projects also replace all electrical and mechanical systems, along with some or all appliances. Contents are moved to another location where they may be cleaned, treated, or aired out. Occupants are relocated for a period ranging from a few weeks to several months.

Selective removal is limited to drywall panels considered to be corrosive, any adjacent insulation, and corroded electrical or mechanical components. Removal of

additional materials may also be needed to provide access and to expedite repairs. This requires the same cleanup procedure as more extensive removal, along with the protection of areas with no CDW. Success of selective removal is dependent on locating all corrosive panels and retaining only electrical and mechanical components that are safe and reliable for reuse. Where CDW is localized, selective removal may allow remediation to be completed in less time at lower cost.

The use of CDW in multi-family, commercial, or public buildings requires additional considerations. Where the building is to remain occupied during remediation, work areas must be fully isolated and then protected from recontamination.

It is generally observed that CDW odor lingers after both comprehensive and selective removal. This phenomenon is commonly experienced in other situations where control of the primary odor source leaves low concentrations of the airborne contaminants adsorbed on porous surfaces (known as the “sink effect”). This residue eventually dissipates (i.e., off-gasses), a process that may be accelerated by treatment or increased ventilation.

Although airing out the building for several months after removal seems to resolve odor concerns, new corrosion has been alleged in some cases. This may be caused by failure to remove all demolition dust and/or failure to fully resolve residual off-gassing. Availability of a verified treatment procedure for eliminating residual odor could considerably shorten the post-remediation period.

Techniques used by the fire restoration industry to eliminate residual odor after smoke and soot are removed may be applicable to CDW remediation. One procedure involves wiping down surfaces with an alcohol/detergent solution then directing high-velocity blowers on these surfaces.

Contents and furnishings in homes with CDW may also retain surface odors. This may be resolved by removing them from affected areas, laundering or vacuuming surfaces, and then letting air out. The effectiveness of this process can be evaluated by sealing representative items and then checking for odor under the plastic. If CDW odor is detected, contents and furnishings should be recleaned or otherwise treated before being returned.

Guidance for addressing corrosion damage in CDW homes ranges from replacing only blackened components, such as air-conditioning coils and uninsulated wires, to full replacement of all electrical, HVAC, plumbing, security systems, and appliances.

CPSC has issued CDW remediation guidance calling for removal of all problem drywall, along with the replacement of all electrical components, fire safety systems, and gas service piping.<sup>(28)</sup> Its guidance notes that (1) the recommended approach is conservative, and (2) more cost-effective solutions may become available.

CPSC guidance does not address the following:

- (a) Older drywall contaminated by demolition dust
- (b) Newer drywall established to be noncorrosive
- (c) Corroded air-conditioning coils and water service components (not a safety concern)
- (d) Electrical and mechanical components without corrosion, which may be safe and reliable for future use
- (e) Residual odor
- (f) Appropriate procedures for dust cleanup
- (g) Verification testing
- (h) Worker protection
- (i) Waste disposal

As these issues are not addressed, following the guidance does not ensure that homes will be restored to pre-existing condition.

A protocol distributed by the Building Envelope Science Institute (BESI) includes post-removal odor treatment with an elevated temperature “bake-out” and air quality monitoring for verification. However, BESI’s procedures specify products that have not been validated for these uses, and analytical methods and interpretation criteria are not specified. The BESI protocol requires submittal of detailed documentation for certification by the Institute.<sup>(29)</sup>

Court decisions in the MDL have also addressed remedial measures, awarding damages to cover the cost of removing all drywall, electrical and mechanical systems. The rulings do not specify procedures to accomplish and verify remediation. The Court allowed for selective removal of materials where CDW is localized within the overall structure.<sup>(3)</sup>

A comprehensive CDW protocol covering the entire assessment and remediation process has recently been proposed by one investigator.<sup>(25)</sup>

## **11.0 Post-Remediation Verification**

Verification of CDW remediation requires some form of testing to establish that air quality is acceptable and that the problem has been permanently resolved. As previously discussed, air quality standards for emissions from CDW cannot be set for specific pollutants, and thus chemical testing procedures available to field practitioners are not conclusive.

Following removal of contaminated material, it takes time for air quality to stabilize, as the concentration of contaminants is highly dependent on environmental conditions. Any post-remedial testing should thus not be conducted until a new equilibrium is established; however, research is needed to verify this time period. In addition, standard test conditions should be specified that promote higher ambient

concentrations and minimize non-CDW sources (e.g., windows and doors closed, air-conditioning off, no masking odors). The number and location of test sites must also be representative.<sup>(25)</sup>

At the present time, commercially available post-remediation testing does not meet any of these requirements. Chemical tests are sometimes performed before emissions stabilize, with pollutant measured at insufficient sensitivity to evaluate emissions from CDW. Odor evaluation is also attempted but generally without following a systematic procedure.

When a post-remediation protocol is developed and validated, it should be applied to all CDW remediation projects after completion. No testing should be initiated until all visible demolition dust has been eliminated. Where air corrosivity is not restored to normal background levels or CDW odor is still detected, additional cleanup and/or odor treatment must be undertaken. Any remaining electrical/mechanical components must also be established as safe, reliable, and code compliant.

Following reconstruction, the long-term effectiveness of remediation can be verified by inspection of new air-conditioning coils after their first cooling season. The follow-up inspection should verify that the coils remained free of black corrosion.

## **12.0 Worker Protection**

There are no specific OSHA standards governing work with CDW. The one exposure study conducted measured concentrations consistent with conditions prevalent during general demolition projects. This study evaluated vapors and dust but did not analyze particulate composition.<sup>(30)</sup> Additional research is needed to determine if the dust generated during CDW demolition presents any special concerns.

Some projects proceed with the assumption that exposures are potentially dangerous and include hazmat-type requirements (e.g., respirator program, fitted respirators, protective clothing). Other projects assume that CDW removal presents no more of a hazard than general demolition. In these cases, nuisance dust precautions are suggested (e.g., N95 dust masks). Classification as a nuisance dust would represent a significant cost saving over more stringent approaches. Guidance from NIOSH or OSHA is needed to resolve this issue.

## **13.0 Waste Disposal**

All drywall is made up of calcium sulfate (gypsum), which can produce hydrogen sulfide in anaerobic (stagnant) landfill water. The resulting odor is characterized as “rotten eggs” (hydrogen sulfide).<sup>(31)</sup> There is no evidence that CDW causes additional water contamination in landfills. Many remediation projects simply dispose of CDW debris as general construction waste.



While waste from other drywall may be recycled, reusing CDW debris would add some elemental sulfur to the resulting product.

#### **14.0 Competencies for CDW Services**

CDW assessment and remediation oversight requires expertise in a variety of disciplines:

- (a) Basic inspection, including identification of areas with tarnishing and documentation of site history, can be accomplished by an experienced industrial hygienist, engineer, home inspector, or construction tradesperson following detailed guidance.
- (b) Removal scope and project oversight should be directed by an experienced construction manager.
- (c) Detailed corrosion evaluation (e.g., identification of components that may be left in place) and design/oversight of electrical and mechanical replacement must be performed by a qualified engineer or licensed tradesperson.
- (d) Materials testing and air monitoring should be conducted by an industrial hygienist or an individual with comparable qualifications.
- (e) Evaluation of occupant health risks requires joint assessment by an industrial hygienist and physician.
- (f) Control specifications and verification should be the responsibility of an industrial hygienist or engineer or person with comparable qualifications.

Drywall contractors and general construction/maintenance workers have the basic skills needed to remove CDW. However, ability to eliminate dust during cleanup requires specialized experience or close supervision. Implementation of control measures to accelerate off-gassing may also require specialized experience. Because CDW remediation presents unique issues, provision of specialized training would be prudent for contractors and workers. If CDW is found to present unique health risks, the employer will need a respiratory protection program, potentially increasing the cost of remediation.

#### **15.0 Findings**

*The term “CDW” in this text refers to corrosive drywall (contaminated sheetrock producing sulfide emissions). Although the term “Chinese Drywall” is in common use, not all drywall imported from China is corrosive.*

##### **15.1 *Status***

Corrosive drywall was installed in tens of thousands of individual homes as well as larger buildings. While it has been suggested that the use of CDW dates back to as early as 2001, this has not been documented. Most of these structures are located in Florida, Louisiana, and Virginia (few investigations have been conducted in other areas

that may have received CDW). While some builders have replaced all drywall in homes, the effectiveness of these remedial strategies has not been validated. Many homeowners and builders are waiting for funding and verification of more efficient repair methods.

### ***15.2 Health Effects***

Individual compounds in emissions from CDW are at low ppb levels. Effects of exposure to sulfide mixtures in this range are poorly understood. While a CDC toxicological evaluation suggested that air contaminant concentrations associated with emissions are below levels demonstrated to present a health hazard,<sup>(11)</sup> some occupants continue to attribute a variety of symptoms to CDW in their homes.

Only one medical study has evaluated the health of persons residing in CDW homes.<sup>(12)</sup> These physicians report some occupants had short-term irritation effects possibly associated from CDW emissions and that all subjects experiencing these were clinically pre-disposed to mucous membrane irritation at exposure levels below that known to impact the general population. Those patients' medical histories included chronic rhinitis, atopy, asthma and/or dry eye syndrome. The physicians considered these findings preliminary and recommended further research. No studies are currently underway to evaluate this significant public concern.

### ***15.3 Corrosion***

Sulfide gases produced by CDW react with metal surfaces to form black corrosion. This has been associated with the failure of air-conditioning coils and damage to other electrical and mechanical components. Some investigators consider replacement of all susceptible electrical and mechanical components in areas with black corrosion as necessary. Investigator opinions vary as to whether components in areas free of black corrosion are acceptable for reuse.

### ***15.4 Other Impacts***

Property values can be adversely impacted where CDW emissions are suspected.

### ***15.5 Source***

CDW appears to have originated from a Chinese mine where high-sulfur gypsum was mixed with oil shale. Other explanations of contamination have not been validated. Some Chinese drywall is not corrosive.

### ***15.6 Chemistry***

Emissions are a complex, variable mixture of contaminants at the ppb level dominated by corrosive and odorous sulfides. Underlying reactions responsible for emissions have not been confirmed. Gaseous sulfides may be produced by reaction of

elemental sulfur in the presence of heat, moisture, and carbonaceous material. Sulfide production appears to be primarily chemical and physical, not microbiological.

### ***15.7 Dynamics***

While emissions appear to increase with temperature and moisture, other important dynamics have not been characterized (e.g., minimum conditions required to initiate emissions, duration of off-gassing, variation over time).

### ***15.8 Protocol Development***

No protocols are generally accepted for the assessment or control of CDW emissions. Remediation of some homes has proceeded without verified procedures. As funding becomes available from litigation settlements, loans, insurance, etc., verified procedures are needed to mitigate CDW within budgetary constraints.

### ***15.9 Materials Analysis***

Elemental sulfur content exceeding 10 ppm is consistently associated with emissions from CDW. Elevated strontium content is generally associated with CDW. Identification of all corrosive panels in the field by laboratory analysis is not practical.

Scanning drywall in the field with a hand-held XRF instrument provides a screening tool for identification of CDW using elemental strontium concentration as a marker.<sup>(24)</sup> CPSC has suggested a strontium content of 1200 ppm as an indicator that drywall is corrosive. While the agency's data are generally consistent with this, there are two exceptions. First, a few non-corrosive drywall products exceed 1200 ppm strontium, which could occasionally result in the removal of more drywall than necessary without additional testing. The other exception reduced XRF readings caused by drywall coatings. When drywall is measured in situ, paint or other surface coatings have a muting effect on the strontium concentration. To minimize the probability of underestimating the strontium concentration, the field measurement should be multiplied by a correction factor (e.g., XRF reading of an exposed edge divided by measurement through coating). XRF findings may be limited by access (e.g., cannot test behind cabinet or under drywall mud). Protocols are being developed that (1) analyze the full spectrum of XRF peaks for correlation with specific drywall products, and (2) measure the amount of sulfide corrosion on metal surfaces.

### ***15.10 Inspection***

Available protocols are not conclusive with respect to home classification. The presence of CDW can be confirmed by the observation of black tarnishing in the absence of other sources of sulfide contamination. Documentation of construction history, odor, panel dimensions, and drywall labels is also informative. Black corrosion is suggestive that corrosive panels are in the immediate vicinity. However, air-conditioning coils may

be affected by air drawn from remote CDW locations. Conversely, the absence of black tarnishing suggests that there is no CDW in the immediate vicinity. A negative finding can be based on a detailed inspection that finds no blackening. XRF scanning can identify locations of most CDW panels where corrosion is localized. Laboratory analysis of drywall and air testing prior to remediation are optional for basic assessment, although this data may be of value for risk assessment and litigation evidence.

### ***15.11 Air Quality***

Setting air quality criteria for emissions from CDW based on testing for specific chemicals is not feasible. Measurement of air corrosivity (i.e., proven technology used in the cleanroom industry) is a potentially useful air quality surrogate. Systematic evaluation of detectable CDW odor is needed to supplement air tests.

### ***15.12 Occupant Protection***

Interim means of reducing exposure (e.g., by air cleaning and/or moisture reduction) could be beneficial where remediation is deferred.

### ***15.13 Remediation***

- (a) Remediation protocols have not been validated.
- (b) Several procedures used to treat CDW in-place do not appear to permanently resolve air quality concerns.
- (c) Relocation of occupants is generally necessary during CDW removal and cleanup.
- (d) An effective remedial process should remove demolition dust and eliminate residual odor from contents and remaining building materials.
- (e) Removal of all drywall, along with electrical and mechanical components, followed by airing out for a period ranging from a few weeks to several months is reported to have resolved corrosion and odor issues, but this has not been verified.
- (f) Remediation procedures that are verifiable and more cost-effective would facilitate resolution of CDW problems. In homes where CDW installation is localized, non-corrosive drywall and some electrical and mechanical components may be left in place where it can be established that air quality has returned to normal background and that electrical and mechanical systems are safe, reliable, and code compliant.
- (g) Off-gassing of residual odor may be accelerated by procedures used in fire restoration. Surface treatment of remaining surfaces is also reported to eliminate odor, although these products tend to leave chemical residues and their effectiveness has not been verified.
- (h) The interim CPSC Remediation Protocol is based on removal of all problem drywall, electrical systems gas piping, and fire safety systems, but it does not address how restoration is to be accomplished or how it can be verified.

- (i) Judicial decisions do not address specific remedial procedures but do allow for selective removal where CDW is localized.

#### ***15.14 Clearance***

There are currently no validated testing protocols to verify the effectiveness of CDW remediation. Air corrosivity and odor detection may provide useful parameters. Post-remedial verification should occur under standardized conditions after air quality stabilizes.

#### ***15.15 Worker Protection***

There are no published standards for worker protection during CDW demolition. A limited study suggests that exposures are similar to those experienced during general demolition. Research is needed to determine whether particulate composition justifies more protective measures.

#### ***15.16 Waste Disposal***

Environmental contamination from disposal appears to be similar to other drywall, and special handling is not needed. Recycling CDW is problematic.

### **16.0 Recommendations**

16.1 Scientific research is urgently needed to address the following areas of uncertainty:

- (a) Etiologic mechanisms for the release of sulfide gases
- (b) Emission rates and duration
- (c) Characterization of specific chemicals in emissions and their potential contribution to corrosion, odor, and irritation
- (d) How emissions change over time and under varying environmental conditions
- (e) Occupant health risks (requires clinical and epidemiologic study)
- (f) Operational implications of electrical and mechanical components with and without blackening
- (g) Worker exposure during demolition and cleanup

16.2 An inspection protocol is needed to conclusively determine whether CDW is present and to provide the basis for remedial specifications. Elements of this protocol should include:

- (a) A systematic procedure to evaluate susceptible surfaces for the presence of black corrosion

- (b) Guidance for documenting construction history, drywall labels and panel dimensions
- (c) Systematic odor evaluation
- (d) A checklist for collecting site information needed to develop a response strategy

16.3 A procedure for classifying drywall by portable XRF analysis should be verified.

16.4 Monitoring protocols based on air corrosivity and systematic odor evaluation should be developed.

16.5 Procedures for reducing exposure and corrosion pending remediation by air cleaning and moisture reduction should be verified.

16.6 For remediation, the scope of materials removal should be based on what is needed to achieve decontamination and repair objectives. Consideration should be given to replacing all drywall, insulation, trim, and susceptible electrical and mechanical components in areas with black corrosion. In areas without blackening, drywall should also be replaced where access is needed for electrical and mechanical repair, dust cleanup, or treatment of residual odor. In some cases, additional removal may be needed to facilitate cost-effective reconstruction. The scope of electrical and mechanical replacement should be determined by a qualified person, such as a licensed electrician. Components may be left in place where they are found to be safe, reliable, and code compliant.

16.7 Pilot studies are needed to develop cost-effective and verifiable restoration procedures. Elements of a remediation protocol should include:

- (a) Classification by area based on the presence or absence of black corrosion
- (b) Specification of materials to be replaced
- (c) A site-specific reconstruction plan
- (d) Relocation of occupants during demolition and cleanup
- (e) Isolation of work areas in larger buildings (e.g., not single family)
- (f) Removal or protection of flooring, furnishings, and contents
- (g) Removal procedures to minimize dust generation
- (h) A detailed cleaning process to ensure the elimination of demolition dust
- (i) Waste disposal (e.g., treat as general construction debris but do not recycle)
- (j) Treatment to ensure that residual odor is eliminated in remaining materials and returning contents

16.8 Post-remedial verification prior to reconstruction should document that:

- (a) Surfaces are free of demolition dust
- (b) Air corrosivity is consistent with normal background
- (c) CDW odor is not detected

- (d) Any remaining electrical and mechanical components are safe, reliable, and code compliant

16.9 Physicians should be consulted as to questions involving health status of individuals in CDW homes and in determining whether they may need to relocate prior to remediation. In making such a decision, physicians should consider available information related to CDW health risks.

16.10 Pending specific guidance from NIOSH/OSHA for CDW workers, respiratory protection for CDW demolition and cleanup workers should be provided based on an exposure assessment of the process to be performed.

16.11 Basic inspections can be performed by an individual with expertise and experience related to CDW emissions. Detailed corrosion evaluation and electrical/mechanical decisions must be made by qualified engineers or qualified tradespersons. Testing and exposure assessment should be performed by an ABIH-certified industrial hygienist or an individual with equivalent expertise. Consideration of health risks should be performed by a qualified physician. Remedial design and work oversight requires construction management expertise.

16.12 A study should be conducted to document the geographic distribution of problem homes and confirm the date when CDW was first installed.

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