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Remediation of Manufactured Methamphetamine in Clandestine Laboratories. A Literature Review

Clyde V. Owens, **Mark M. Mason**, and **David Marr**

U.S. Environmental Protection Agency, Air Pollution Prevention and Control Division, Indoor Environment Management Branch, Office of Research and Development, Research Triangle Park, NC 27711

Abstract

The purpose of the current literature review was to identify, collect, review, and organize all available information concerning clandestine laboratories used to produce methamphetamine through an analysis of routinely collected data sources. There were numerous peer reviewed journals, electronic databases, websites, and commercial vendors relevant to the remediation process of methamphetamine laboratories. Our intention in this review was to produce background information as well as a reference guide relating to the critical problem of methamphetamine production nationally and internationally in addition to generating future research projects associated with the topic. This literature review determined there has not been a national standardized analytical method recognized as a reference guideline for the remediation of clandestine laboratories for production of methamphetamine.

Keywords

Contamination; methamphetamine; clandestine; decontamination; environmental monitoring; production; and remediation

1. Introduction

The clandestine production of methamphetamine is a growing concern nationally and globally. Until the early 1990s, methamphetamine for the US market was made mostly in laboratories run by drug traffickers in Mexico and California [1]. Since then, authorities have discovered increasing numbers of small-scale methamphetamine laboratories all over the United States, mostly in rural, suburban, or low-income areas [2]. Clandestine laboratories have been found in a variety of structures, including private dwellings, townhomes, apartments, motels, and vehicles. For example, Indiana state police found a record 1,808 laboratories in 2013, although this number of laboratories may have been a result of increased police activity [3].The sophistication of these laboratories varies widely, from individuals at home following online instruction to large elaborate set-ups. Illicit manufacturing of methamphetamine in clandestine laboratories poses numerous hazards to public health, the environment, and property, including hazards from fire and explosions as well as the production of dangerous chemical byproducts. Studies conducted by National Jewish Medical and Research Center (NJMRC) have shown that contamination by methamphetamine is a major hazard associated with clandestine laboratories. A single cook may result in residual methamphetamine surface contamination ranging from 0.1 μg/100cm^2 to as high as 16,000 μg/100cm^2 [4]. With recent increases in property foreclosures, the question has been asked whether these former meth labs can be adequately remediated for reoccupation. Appropriate characterization, decontamination, and remediation of former meth labs are needed to restore these structures for reoccupation.

Currently, each state has listed research requirements to develop their own health-based procedures addressing characterization, decontamination, and remediation criteria issues. The U.S. Environmental Protection Agency (EPA) Office of Research and Development (ORD) and National Institute of Standards and Technology (NIST) have agreed to generate research products that will address science-related questions associated with meth lab remediation. The EPA has developed voluntary guidelines and established a program to support the voluntary guidelines [7]. NIST is currently initiating a research program to develop new methamphetamine detection technologies and validating those procedures for detection testing.

The purpose of the literature evaluation was to identify, collect, review, and organize all available information concerning the remediation of clandestine laboratories used in the illicit production of methamphetamine. Several objectives exist to support the purpose of this literature review:

- Identify relevant sources of information by searching the scientific literature in online databases, as well as guidance documents relating to the remediation of former meth labs.
- Collect available information relating to the types and identities of chemical substances 1) used during the illicit production of methamphetamine; 2) generated as byproducts of methamphetamine production; 3) used during site decontamination and remediation, and 4) generated as byproducts of site decontamination and remediation.
- Collect available information relating to the methods used to sample, identify, and quantify chemicals in the indoor environment of a former meth laboratory.
- Collect available information relating to the gaseous, particulate, and residual concentrations of chemicals in former meth lab buildings.
- Collect available qualitative and quantitative information relating to the effectiveness of decontamination and remediation methods of buildings formerly used as meth labs and locations used to store methamphetamine related chemicals.
- Organize the information that is retrieved so it can be a useful resource to generate research products that address science-related questions associated with meth lab remediation.

1.1 Scope of the current literature review

Our review process started from summarizing the online databases TOXLINE, PubMed, NIOSHTIC-2, and Academic Search™ Premier to identify relevant sources of information related to “methamphetamine” (CAS #537–46-2). The initial search included over 8,000 articles which were imported into reference managing software called EndNote®. A tiered process was used to identify, review, and manage potentially relevant articles. The first step was to produce a manageable list of citations to review using keyword filters to identify citations most relevant to the topics. Key terms included: *contamination, clandestine, decontamination, environmental monitoring, production, and remediation*. Search terms varied slightly depending on terminology used in individual databases relating to the remediation of former methamphetamine labs. The relevant articles included reports produced by international, federal, state, local health and environment, or law enforcement agencies, as well as additional information provided by nongovernmental organizations (NGOs) involved with the remediation of clandestine methamphetamine labs.

In addition, the websites of drug agencies such as the Drug Enforcement Agency (DEA), Alcohol Tobacco and Firearm (ATF), and National Jewish Medical and Research Center were searched for relevant reports. DEA explained that the agency does not remediate methamphetamine laboratories. \However, their involvement includes removal of any controlled substances from the property and securing the site. The NJMRC was referred as the top research agency for clandestine meth laboratory remediation where Dr. John Martyny has provided a significant number of reports and publications in the field. After identifying documents with relevant information, all pertinent information was collected and subjected to a thorough quality control (QC) review to ensure accurate reporting. The following QC review criteria included: information selected for inclusion was evaluated against project objectives; source data quality rankings were verified; included information was checked back to original sources. Much of the available information in this review is of limited scope and variable quality in terms of gold standard research. Many different viewpoints have been advanced on improvements in methamphetamine remediation; however we determined no population-based studies or large trials which provided insight into the burden of methamphetamine remediation. While providing limited insight into some of the potential issues relating to remediation, only limited conclusions can be determined from this review.

2. Chemical for methamphetamine production

From the literature review, there was not a single source identified that provided a comprehensive list of chemicals associated with methamphetamine manufacture. Some chemicals were cited by nearly every source, while others were only mentioned a few times across all documents. Methamphetamine manufacture has proven to be highly adaptive, as witnessed by the multiple shifts in production methods following regulations of specific precursor chemicals. The widely available book *The Secrets of Methamphetamine Manufacture*, currently in its eighth edition, may support this statement. The book cites the hurdles that federal regulations pose and then quickly clears those barriers by proposing new production methods to circumvent the most recent regulations [5]. Therefore, acknowledging the great number of chemical permutations possible, the following list does not claim to be a comprehensive account of every chemical that could be involved in methamphetamine manufacture. The list does attempt to include, however, the most common chemicals used in the production of methamphetamine.

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• 1,1,2-Trichloro-1,2,2-trifluoroethane (Freon 113) • Acetaldehyde • Acetic acid • Acetic anhydride • Acetone (fingernail polish remover) • Ally chloride • Allylbenzene • Aluminum • Ammonia (farm fertilizer) • Ammonium acetate • Ammonium formate • Ammonium hydroxide • Benzaldehyde • Benzene • Benzyl chloride • Chloroform • Ephedrine (cold tablets) • Ethanol (ethyl alcohol) • Ether (ethyl ether, engine starter) • Ethyl acetate • Formamide • Formic acid • Hexane (Coleman fuel/naphtha) • Hydriodic acid (liquid) • Hydrochloric (muriatic) acid (pool supplies)	• Hydrogen chloride • Hydrogen iodide (gas) • Hydrogen peroxide • Hydrogen sulfide • Hypophosphorous acid • Iodine (flakes/crystals/prills) • Iodine (tincture) • Isopropyl alcohol (isopropanol, rubbing alcohol) • Lead acetate • Lithium (batteries) • Lithium aluminum hydride • Magnesium • Mercuric chloride • Methanol (methyl alcohol, (gasoline additive) • Methyl ethyl ketone (2-butanone) • Methylamine • Methylene chloride • Monomethylamine • MSM (cutting agent) (nutritional supplement) • Nitroethane • Nitromethane • N-Methylformamide • Norpseudoephedrine • Palladium	• Perchloric acid • Phenyl-2-propanone • Phenylacetic acid • Phenylpropanolamine • Phosphine • Phosphoric acid • Phosphorus pentachloride • Potassium chromate • Potassium dichromate • Potassium permanganate • Propiophenone • Pseudoephedrine (cold tablets) • Pyridine • Raney nickel • Red phosphorus (matches; road flares) • Sodium • Sodium carbonate • Sodium cyanide • Sodium dichromate • Sodium hydroxide (lye, caustic soda) • Sulfuric acid (drain cleaner, auto battery acid) • Thionyl chloride • Thorium oxide • Toluene (brake cleaner) • Trichloroethane (gun cleaner) • Xylene

Methamphetamine production generally falls into one of three manufacturing methods, frequently referred to as the Phenyl-2-propanone (P2P), Red Phosphorus, and Birch Reduction methods. Although the three methods have many chemicals and steps in common, some processes and chemicals are unique to each. In the list below, each chemical is associated with only one or two of the three methamphetamine manufacturing processes:

P2P:	**Red Phosphorus:**	**Birch Reduction:**
• Acetic acid • Acetic anhydride • Benzaldehyde	• Ephedrine • Hydriodic acid (liquid) • Hydrogen iodide (gas)	• Anhydrous ammonia • Coleman fuel • Ephedrine

P2P:	Red Phosphorus:	Birch Reduction:
• Lead acetate • Mercuric chloride • Nitroethane • Phenyl-2-propanone • Phenylacetic acid • Pyridine • Thorium oxide	• Hypophosphorous acid • Iodine (tincture) • Pseudoephedrine • Red phosphorous	• Lithium metal • Pseudoephedrine • Sodium metal

2.1 Methamphetamine byproducts from production

Methamphetamine production generates a significant amount of gaseous, liquid, and solid toxic waste that adds to the hazards already in place from the chemicals used to produce methamphetamine. Many sources cited a variation of the statistic that for every pound of methamphetamine manufactured, between five and seven pounds of toxic waste are produced. Depending on the manufacturing method used in the laboratory, different chemical byproducts are created during the production process in addition to methamphetamine. Below is a list of manufacturing byproducts commonly associated with each type of production method:

P2P:	Red Phosphorus:	Birch Reduction:
• Carbon dioxide • Formic acid • Lead • Mercury	• Potentially flammable extraction process sludges • Phosphine gas • Hydriodic acid • Hydrogen chloride gas • Phosphoric acid • White or yellow phosphorus	• Potentially flammable extraction process sludges • Hydrogen chloride gas • Lithium hydroxide • Sodium hydroxide

2.2 Methamphetamine precursors used in production

Because the common precursor chemicals are becoming regulated more strictly, many manufacturers are resorting to making their own precursors. Cox et al. (2009) conducted a study to determine the byproducts associated with making methamphetamine by creating a known precursor (l-phenylacetylcarbinol [*l*-PAC]) to ephedrine and pseudoephedrine [6]. The additional byproducts released include:

- 1-Phenyl-propan-1,2-dione (corresponding amine: N1,N2-dimethyl-1-phenylpropan-1,2-diamine)
- 2-Hydroxy-1-phenyl-propan-1-one (corresponding amine: 1-(methylamino)-1-phenylpropan-2-ol)

2.3 Site decontamination and remediation

Below is a list of chemical substances and products that have been used in the process of site decontamination and remediation. From the literature review, no individual cleaning agent was endorsed by any of the respective agencies captured in this report. Also, a few reports questioned the validity of some of the included products as successful cleaning agents. However, those listed have been mentioned at least once as products used for meth lab remediation:

• Acetic acid	• Fiberlock Shockwave
• Alconox	• Formula 409
• Baking soda	• Household bleach
• Clorox Bleach	• IAQM Structural Decon
• Clorox Clean-Up	• Isopropyl alcohol
• Crystal Clean	• Kilz (primer/paint)
• Crystal Simple Green	• Liqui-Nox
• DepHyze 3D, Carpet Cleaner, and Ultra Clean	• Methanol
• EasyDECON	• Pine Sol
• Simple Green	• Septi-Zyme
• Trisodium phosphate (TSP) detergents	• Vinegar
	• Windex

2.4 Methamphetamine byproducts of decontamination and remediation

From the literature review, only a few sources contained information on chemical substances identified as byproducts of decontamination and remediation. Some products used for meth lab decontamination specifically cited their biodegradable, non-toxic properties. One study noted that hydrochloric acid, sulfuric acid, or other types of acid may react with bleach and cause dangerous vapors to form. The focus for many of the reports was generally on the efficacy of a product in rendering methamphetamine undetectable as opposed to noting what other chemicals could be generated during the remediation process.

3. Characterization methods for methamphetamine

3.1 General characterization techniques

The general methods used or recommended to characterize the level of contamination in a former meth laboratory mainly involve the use of best practices. The agencies and organizations that discussed general methods recommended the following:

- Using a certified or licensed industrial hygienist, contractor, or specialist to take samples.
- Using standard sampling procedures and laboratory analysis.
- Having the samples quantified by a certified laboratory.
- Collaborating with the local health department, including submitting a work plan for approval.

Because contamination from the production of methamphetamine can spread throughout a building, some agencies recommended multi-room sampling. However, many stated that pre-decontamination sampling is not necessary. Several states have specific rules and regulations that must be followed. Their guidance documents provided detailed methods and procedures for characterizing the level of contamination in a former meth laboratory in [Table 1].

- Alaska Department of Environmental Conservation
- Arizona State Board of Technical Registration
- Arkansas Department of Environmental Quality

- California Department of Toxic Substances Control
- Colorado Department of Public Health and Environment
- Connecticut Department of Public Health
- Hawaii Department of Health
- Idaho Department of Health and Welfare
- Indiana Department of Environmental Management
- Kentucky Division of Waste Management
- Michigan Department of Community Health
- Minnesota Department of Health/Minnesota Pollution Control Agency
- Montana Department of Environmental Quality
- Nebraska Department of Health and Human Services
- New Hampshire Department of Environmental Services
- New Mexico Environment Department
- North Carolina Department of Justice
- Oregon Department of Human Services
- Tennessee Department of Environment and Conservation
- Utah Department of Health
- Washington State Department of Health
- West Virginia Department of Health and Human Resources

Other states provided guidance that could not be enforced. Some states referred to EPA's 2009 *Voluntary Guidelines for Methamphetamine Laboratory Cleanup* or to guidance documents of other states [7].

- Illinois Department of Public Health
- Kansas Department of Health and Environment
- Missouri Department of Health and Senior Services
- North Dakota Department of Health
- Ohio Department of Health
- Oklahoma Department of Environmental Quality
- South Dakota Department of Environment and Natural Resources
- Virginia Department of Environmental Quality
- Wisconsin Department of Health Services
- Wyoming Department of Health

The only international guidance document found to contain characterization methods was produced by the National Collaborating Centre for Environmental Health (NCCEH) at the British Columbia Centre for Disease Control [8]. NCCEH states that the guidelines are derived from meth lab cleanup guidance produced in the United States, specifically Colorado, North Carolina, and Minnesota. According to OSHA's 2009 *Best Practices for Protecting EMS Responders during Treatment and Transport of Victims of Hazardous Substance Releases,* OSHA is preparing a guide addressing cleanup work at clandestine meth labs [9, 10].

3.2 Air sampling methods

Many agencies recommend air sampling [Table 1], specifically for volatile organic compounds (VOCs), to characterize the level of contamination in a former meth lab. Photo ionization detection (PID) was the most common method used or recommended. Flame ionization detectors (FID), SUMMA canisters, and passive charcoal badges were additional methods used or recommended for VOC sampling. Some agencies recommended sampling before cleanup to characterize the level of contamination, as well as after cleanup to ensure ambient concentrations are below standards. Some states (e.g., Alaska, Arizona, Arkansas, California, Connecticut, Colorado, Hawaii, Minnesota, Montana, New Hampshire, New Mexico, Tennessee, Utah, and Washington) recommend or require that mercury vapors be sampled at sites where the P2P method was used to produce methamphetamine.

Man et al. reviewed and assessed five chemical sensing technologies: capacitive sensors, conductance-based sensors, ionization sensors, gravimetric sensors, and optical sensors [11]. The authors concluded that no sensing technology alone can completely detect all relevant airborne chemicals emitted from clandestine meth labs. They suggested creating a heterogeneous sensing unit that incorporates sensors based on several different sensing technologies. The authors noted that PID appears to be the optimal all-around sensing technology due to its fast response time, low detection limits, ability to detect nearly all of the target analytes, and relatively small size. The drawbacks to PID can be partially addressed by using chemically selective pre-filters. The authors also said that Fourier transform infrared (FTIR) is another technology that could be used to detect emissions released from meth labs. Some of the emerging technologies (e.g., acoustic wave, microcantilever, electrical conductance-based and capacitance-based nanosensors, chemiresistor sensors, and chemicapacitors) are still under development but have potential for future use.

In several NJMRC studies, air samples were collected for VOCs, general hydrocarbons, anhydrous ammonia, phosphine gas, inorganic acids (hydrogen chloride, hydrochloric acid, and phosphoric acid), iodine, metals, and methamphetamine [12-18]. The center used the following methods:

- Airborne methamphetamine, iodine, and inorganic acid samples were collected using personal sampling pumps.
- VOCs were collected using SUMMA canisters.

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- Hydrocarbons were collected using vacuum canister collection and thermal desorption tube sampling.
- Real-time analysis for hydrochloric acid and phosphine was performed using an ITX Multi-Gas Monitor.
- Real-time analysis for anhydrous ammonia was performed using colorimetric detector tubes.
- Metal samples were collected using 37 mm sampling cassettes and 0.8 mm mixed cellulose ester membrane filters.

A certified lab analyzed the NJMRC samples using the following methods:

- Total airborne methamphetamine: NIOSH Draft Method 9106
- Hydrocarbons and VOCs: EPA Methods T0–15 and T0–17
- Phosphine: NIOSH Manual of Analytical Methods 6002
- Inorganic acids: NIOSH Manual of Analytical Methods 7903
- Iodine: NIOSH Manual of Analytical Methods 6005
- Ammonia: NIOSH Manual of Analytical Methods 6015
- Metals: NIOSH Manual of Analytical Methods 7300

The California Department of Toxic Substances Control (DTSC) evaluated emissions from methamphetamine manufacturing via the ephedrine/red phosphorus/hydriodic acid method. DTSC conducted two experiments: the first used a Solid Phase Micro Extraction (SPME) device, the second used active (vacuum) filtration [19]. Home Air Check promotes using their monitors to test for total VOCs in the air [20]. Bridger Photonics promotes the use of their Monolithic Laser Technology (tunable pulsed lasers in the mid-infrared region) to detect methamphetamine emissions in the air from a distance [21].

3.3 Surface sampling methods

Almost all agencies recommend wipe sampling to detect methamphetamine residue (Table 1). Some agencies also recommend surface sampling for mercury and lead, if the P2P method was used. Both discrete and composite samples are used. Wipe samples can be collected from nonporous surfaces, including floors, walls, ceilings, fixtures, furniture, counters, appliances, sinks, showers, toilets, and ventilation systems. EMSL Analytical recommended testing where a wall or floor meets a colder/warmer exterior, because methamphetamine tends to crystallize at temperature transition interfaces [22]. Wipe sampling involves using squares of a gauze material that have been wetted, typically with methanol for a methamphetamine sample, to enhance collection efficiency. Agencies provided varied guidance on wiping strategies:

- Wipe in concentric squares of decreasing size.
- Wipe in two perpendicular directions.
- Wipe in an overlapping “Z” pattern and then in an overlapping “N” pattern.

- Wipe side to side in an “S” motion.
- Wipe in a side to side/top to bottom manner.
- Wipe with a “rolling-up” motion (i.e., start at an outside upper edge and wipe around, along, and down the edge towards the central portion of the surface area).

Some agencies also recommend collecting vacuum samples from carpets, upholstered furniture, ceiling tiles, ventilation systems filters, and other surfaces not amenable to wipe sampling (e.g., brickwork and rough concrete). Most agencies with regulations require quantitative post-cleanup confirmatory testing to ensure that standards for cleanliness are met. Many of the companies promoting their services stated that quantitative testing is the only legally defensible option. Some agencies stated that sampling prior to decontamination is not cost effective. However, the agencies acknowledged that qualitative screening techniques may be useful, especially during the preliminary site assessment stage, including identifying the cook area and high traffic areas (i.e., hallway between cook area and bathroom), and suggested focusing remediation activities on those areas. Some agencies use Simon test reagents or rapid-detection immunoassays during initial site assessments to provide real-time detection of methamphetamine. However, these tests are not sensitive enough to determine whether cleanup standards have been met.

The Minnesota Pollution Control Agency (MPCA) evaluated the consistency of wipe sampling by submitting wipe samples with known concentrations of methamphetamine to six analytical laboratories [23]. The results were “discouraging” and highly variable. MPCA recommended the following to improve reporting consistency:

- Publishing a standard analytical procedure.
- Developing a proficiency testing sample.
- Requesting a NIST-traceable methamphetamine standard for routine quality control procedures.

The National Institute for Occupational Safety and Health (NIOSH) has developed three methods (9106, 9109, and 9111) to quantify the amount of methamphetamine on cotton gauze wipe samples. Backup Data Reports are provided [24-26].

- Method 9106 is a solid phase extraction method using gas chromatography/mass spectroscopy (GC/MS). A limit of detection (LOD) of 0.05 μg/sample was achieved in either scan or selected ion monitoring (SIM) mode [24].
- Method 9109 is a liquid-liquid extraction method using GC/MS. An LOD of 0.1 μg/sample was achieved in scan mode. The LOD was 0.07 μg/wipe, and the limit of quantitation (LOQ) was 0.22 μg/wipe for methamphetamine [25].
- Method 9111 uses liquid chromatography (LC)/MS/SIM to quantify methamphetamine wipe samples. The LOD was 0.05 μg/sample and the LOQ was set at 0.15 μg/sample [26].

The California Department of Toxic Control Substance (DTSC) tested the sampling recovery on four different surfaces commonly found in contaminated buildings (i.e., glass, flat painted drywall, semi-gloss painted drywall, and fabric) using NIOSH Method 9106. The results showed that glass plate and semi-gloss painted drywall have an excellent percent recovery (>90%). Flat painted drywall has acceptable recovery (51%). However, fabric showed only a 17% recovery. DTSC estimated the LOQ to be 0.05 μg/wipe [27]. Throughout its studies, NJMRC took surface wipe samples from walls, counters, floors, carpets, and clothing to test for methamphetamine. The samples were analyzed in a certified lab according to NIOSH Method 9106 [4, 12-17]. During one study, vacuum samples were also collected from carpeted areas using a Eureka Sanitare Commercial vacuum cleaner fitted with a Mitest Dust collection device [13]. These samples were also analyzed for methamphetamine using NIOSH Method 9106. In a series of studies to evaluate the effectiveness of decontamination methods, NJMRC sent all samples to DataChem Laboratories for analysis [18, 28-31].

Patrick et al. conducted a study at three previously decontaminated residential clandestine meth labs in the state of Washington to examine residual methamphetamine concentrations [32]. The authors collected a total of 159 discrete random methamphetamine wipe samples, which were analyzed by EPA Method 8270 for semivolatile organic chemicals. Overall, 59% of random samples and 75% of contact point samples contained methamphetamine in excess of the state decontamination standard (0.1 μg/100 cm^2). At each site, methamphetamine concentrations were generally higher and more variable in rooms where methamphetamine was prepared and used.

Many companies promote their products for characterizing the level of contamination deposited on surfaces in former meth labs. Some of the products are quantitative and others detect the presence of methamphetamine at a certain concentration. The following are some examples:

- MethChek® (Eighty Four, PA) is a semi-quantitative immunoassay wipe kit used to identify methamphetamine residue on surfaces at or above relevant state cleanup levels [27, 33]. MethAlert® is a colorimetric test that detects the presence of methamphetamine residue on surfaces from 15 to 5000 μg/100 cm^2. OSHA discusses the use of MethAlert and MethChek during investigations to help first responders, health officials, and remediation workers quickly detect the presence of methamphetamine on various surfaces [9, 10].
- Duffy et al. describes a colorimetric wipe, NarcoWipes (Saint Victor, France), which was specifically designed for evaluations at clandestine meth labs [34].
- Meth-Test (Houston, TX) is an aerosol-based drug field test kit for the detection and identification of methamphetamine which contains a modified Simon reagent [35].
- AZ Meth Detection Service (Litchfield Park, AZ) will take readings for methamphetamine residue in a person's home using an ID2 LE electronic methamphetamine reader [36].
- Medimpex (Bucks County, PA) sells the METH-X Pen Test, which can be used to identify methamphetamine residue on any surface [37].

- Safety Elements (Akron, OH) sells a "test by mail" kit where users take their own wipe samples and send them back for laboratory analysis using NIOSH and CDC approved methods [38].

Other companies (Chicago Crime Scene Cleanup, Extreme Scene Clean, Meth Lab Cleanup Company) promote their in-home testing services [39-41].

4. Methamphetamine residual chemical concentrations prior to production

4.1 Chemical Concentrations prior to production

Two sources sampled for methamphetamine prior to production:

- VanDyke et al. took wipe and vacuum samples prior to conducting two red phosphorous methamphetamine cooks in a residence [13]. Pre-cook wipe samples ranged from 1.5 to 23 µg/100 cm^2. Pre-cook vacuum samples ranged from 2.65 to 5.5 µg/100 cm^2. The samples indicated that methamphetamine had either been used or manufactured in the home prior to their simulated cooks.

- NJMRC took wipe samples at some of the marked locations prior to the cooks. All of the samples were found to have no detectable methamphetamine present [12].

4.2 Chemical concentrations during production

Several agencies cite the NJMRC studies, which state that the methamphetamine cooking process can release as much as 5,500 micrograms of methamphetamine per cubic meter (µg/m^3) into the air and deposit as much as 16,000 µg/100 cm^2 onto surfaces. In 2003, NJMRC conducted a study to determine the potential chemical exposures to law enforcement and emergency services personnel responding to clandestine meth lab seizures [17]. Two of the goals of the study were to: 1) determine primary chemical exposures of concern and 2) determine which phase of the response poses the highest risk by measuring chemical concentrations. The results of the air samples indicated that:

- Methamphetamine concentrations ranged from not detected (ND) to 5,500 µg/m^3.

- Phosphine concentrations ranged from ND to 4,842 µg/m^3.

- Iodine concentrations ranged from ND to 37 mg/m^3.

- Hydrochloric acid concentrations ranged from ND to 16.9 mg/m^3.

- Hydrogen chloride concentrations ranged from trace to 30.4 mg/m^3 and peaked at 56.2 mg/m^3.

NJMRC conducted a follow-up study to specifically determine the potential chemical exposures to law enforcement and emergency services personnel responding to clandestine meth labs using the anhydrous ammonia method [12]. Three controlled cook events were performed, using different levels of ventilation.

- Airborne methamphetamine concentrations ranged from 2.4 to 42 μg/m^3 during the early stages of production. The highest concentrations were produced during the salting-out phase (7.6 to 680 μg/m^3).
- Anhydrous ammonia concentrations ranged from 4 to 3,348 parts per million (ppm). As time weighted averages, the concentrations ranged from 130 ppm to over 437 ppm.
- Hydrochloric acid concentrations ranged from ND to > 0.7 ppm.
- NJMRC also conducted a study to determine the potential chemical exposures to law enforcement and emergency services personnel responding to clandestine meth labs using hypophosphorous acid and phosphorous flakes [15]. Two controlled cooks were performed—one using hypophosphorous acid and the second using phosphorus flakes.
- Airborne methamphetamine concentrations were < 0.19 μg/m^3 during the early stages of production, and ranged from 680 μg/m3 to 4,000 μg/m^3 during the salting-out phase.
- Phosphine concentrations ranged from ND to 13 ppm.
- Hydrogen chloride concentrations ranged from ND during the early stages of production to 400 ppm.
- Iodine concentrations ranged from ND to 0.005 ppm.
- VOC concentrations ranged from 0.89 ppm (methyl cyclohexane) to 11 ppm (C7 hydrocarbon A).

Martyny et al. also studied the chemical exposure associated with the clandestine manufacture of methamphetamine [4]. Sampling was conducted at clandestine laboratories as they were being raided and at controlled cooks conducted in houses to be destroyed.

- Airborne methamphetamine concentrations ranged from 2.6 to 5,500 μg/m^3.
- Phosphine concentrations ranged from 0.1 to 13 ppm.
- Hydrogen chloride concentrations ranged from 0.02 to 20 ppm, with a peak of 155 ppm.
- Airborne iodine concentrations ranged from 0.001 to 0.15 ppm.
- Anhydrous ammonia concentrations ranged from < 66 to 410 ppm.

VanDyke et al. documented the contamination resulting from two simulated red phosphorous methamphetamine cooks conducted in a residence and the associated exposures up to 24 hours after the cook [13]. Day 1 involved controlled manufacture of two batches of methamphetamine. Day 2 involved documenting residual chemical concentrations and methamphetamine contamination 12 to 24 hours after the cook. The authors report that airborne methamphetamine is present as very small particles (<1 μm) both during and up to 24 hours after a cook.

- Total airborne methamphetamine concentrations ranged from 99 to 760 μg/m^3. Most of the methamphetamine aerosol was of respirable size.
- Airborne hydrochloric acid concentrations ranged from 0.029 to 0.42 ppm.
- Average iodine concentrations ranged from 0.0046 to 0.12 ppm.
- Average VOC concentrations were below 1 ppm.

4.3 Chemical concentrations following production

All of the NJMRC studies also conducted wipe sampling for methamphetamine residue.

- The 2003 study reported methamphetamine wipe samples ranging from ND to 16,000 μg/100 cm^2 [17].
- The 2004 anhydrous ammonia study reported methamphetamine wipe samples ranging from 0.08 to 160 μg/100 cm^2 [12].
- The 2005 anhydrous ammonia study reported methamphetamine wipe samples ranging from 0.067 to 23 μg/100 cm^2. Methamphetamine was also found on the clothes of the participants (ND – 28 μg/wipe), and on toys (0.18 – 6.4 μg/sample) and baby clothing (6.4 – 500 μg/sample) present in the cook area [15].
- Martyny et al. reported surface methamphetamine concentrations ranging from 0.1 to 860 μg/100 cm^2 produced during controlled cooks [4]. Concentrations as high as 16,000 μg/100 cm^2, with most results over 25 μg/100 cm^2 from samples taken at former labs.
- VanDyke et al. reported surface methamphetamine concentrations ranging from 6.1 to 230 μg/100 cm^2 [13].

The Salt Lake Valley Health Department reported in a presentation that the average methamphetamine concentration on surfaces in 18 former meth labs was 33 μg/100 cm^2. The concentrations ranged from 0.03 to 771 μg/100 cm^2 [42]. VanDyke et al. quantified contaminant concentrations up to 18 hours after the simulated cooks [13].

- Total airborne methamphetamine concentrations ranged from 70 to 210 μg/m^3. Normal household activities (e.g., walking, vacuuming) resuspended the contamination.
- Airborne hydrochloric acid concentrations ranged from <0.02 to 0.065 ppm.
- Average iodine concentrations ranged from 0.002 to 0.005 ppm.
- Average VOC concentrations were below 1 ppm.

Two of the NJMRC studies also reported concentrations of iodine in former meth labs.

- Airborne iodine concentrations ranged from ND to 0.023 mg/m^3 [17].
- Airborne iodine concentrations ranged from ND to 0.002 ppm [4].

Two additional sources reported phosphine concentrations found at former meth labs.

- Betsinger et. al stated that a forensic scientist was exposed to phosphine (2.7 ppm) during an investigation of a meth lab [43].
- According to a NIOSH report, phosphine gas was found at concentrations greater than 0.3 ppm in a former meth lab where three people died from phosphine exposure [44].

4.4 Chemical concentrations prior to decontamination and remediation

Boulder County Public Health presents the following residual methamphetamine concentrations (as a percent above the standard) in verified labs [45].

- Night stand: 5,600%
- Ceiling fan: 5,000%
- Microwave: 4,800%
- Bath exhaust grill: 3,200%
- Hotel table: 1,840%
- Kitchen stove: 1,580%
- Floor: 1,020%
- Return air vent: 900%
- Living room table: 860%

In a presentation, MPCA reported the contamination found in six former meth labs [23, 46]. The agency studied the horizontal and vertical distribution of methamphetamine on surfaces and the infiltration of methamphetamine into building materials. Surface wipe concentration of methamphetamine increased as distance from the floor increased. MCPA also reported that methamphetamine residues in the paint. NJMRC found that 60% of the methamphetamine remained in the paint following wipe sampling [18]. MPCA also sampled methamphetamine concentrations in carpets at one of the sites that had been used as a meth lab for two years. Great variability in methamphetamine deposition occurred within a carpeted room. Concentrations ranged from 1,231 to 19,603 µg/ft^2 [46]. SafeHouse Solutions presented three case studies, where methamphetamine concentrations as high as 56 µg/100 cm^2 were found 18 months after the last cook occurred [47]. The case studies also detailed how methamphetamine contamination can spread from the original cook site (> 29 µg) to adjacent units (> 9 µg). During congressional testimony, Dr. John Martyny reported that residual methamphetamine concentrations as high as 300 µg/100 cm^2 can found up to 6 months after the last cook [16].

4.5 Chemical concentrations following decontamination and remediation

Several agencies have quantitative cleanup standards that must be met following decontamination and remediation. According to EPA's 2013 *Voluntary Guidelines for Methamphetamine Laboratory Cleanup*, the state methamphetamine standards range from 0.05 to 0.5 µg/100 cm^2, with 0.1 µg/100 cm^2 being the most common standard [7]. Some states also have standards for VOCs in air (less than 1 ppm), pH on surfaces (6–8), lead on surfaces (2–4.3 µg/100 cm^2), and mercury in air (0.05–0.3 µg/m^3). Hannan et al. emphasized the need for the development of a national exposure standard [48]. The Salt Lake Valley Health Department reported in a presentation that after the first round of decontamination of 34 properties, the average methamphetamine residue concentration was 2.4 µg/100 cm^2 (range: 0.01–59 µg/100 cm^2) [42]. The department stated that additional decontamination is often required to remove the remaining residue. A presentation by SafeHouse Solutions, which promotes the use of DepHyze decontamination products, presented the same results [47]. Patrick et al. conducted a study to determine the residual methamphetamine concentrations on interior surfaces in three decontaminated residential meth labs [32]. The authors reported the following median methamphetamine concentrations:

- *Site 1*. 0.05 µg/100 cm^2 (lab activity: 2 months; time between sampling and decontamination: 31 days)
- *Site 2*. 0.65 µg/100 cm^2 (lab activity: 6 months; time between sampling and decontamination: 5 days)
- *Site 3*. 0.04 µg/100 cm^2 (lab activity: 6 months; time between sampling and decontamination: 210 days)

Miskelly et al. evaluated the recoveries of pseudoephedrine and methamphetamine from glass, stainless steel, and a range of impermeable surfaces using GC-MS of derivatized samples [61]. When surfaces were cleaned prior to drug deposition, wiping with methanol-dampened filter paper could recover 60 – 90% of the methamphetamine immediately after deposition, and could recover at least 50 – 60% of the methamphetamine still present after 2 days.

4.6 Chemical concentrations prior to and following decontamination and remediation

NJMRC conducted several studies to determine decontamination effectiveness prior to and after decontamination and remediation.

- *Clothing*. Prior to being washed, mean methamphetamine concentrations ranged from 19.5 to 271 µg/100 cm^2. Washing different types of cloth (denim, cotton, and bunker gear) resulted in mean concentrations ranging from 0.2 to 3.4 µg/100 cm^2 [30].
- *Building materials*. Prior to being washed, mean methamphetamine concentrations ranged from 0.1 to 37 µg/100 cm^2. Washing the different surfaces (drywall, plywood, metal, and glass) with Simple Green resulted in mean concentrations ranging from 0 to 8.5 µg/100 cm^2 [29].
- *Oxidizing agents*. Prior to being washed, mean methamphetamine concentrations on drywall ranged from 15.3 to 20.2 µg/100 cm^2. Washing with different oxidizing agents (Formula 409, Clorox Clean-Up, and EasyDECON) resulted in mean concentrations ranging from $<$ 0.05 to 8.9 µg/100 cm^2 [31].
- *Encapsulation with paint*. Prior to being painted, mean methamphetamine concentrations on plywood and drywall panels ranged from 16.4 to 34.6 µg/100 cm^2. Painting the panels with latex, Kilz® (encapsulating paint), or oil-based

paint resulted in mean concentrations ranging from 0 to 5.1 µg/100 cm^2 [28]. In a follow-up study, NJMRC determined the natural decline in the methamphetamine concentrations due to evaporation after painted drywall was decontaminated. The original mean concentrations were 5.2 µg/100 cm^2 (washed twice) and 13.6 µg/100 cm^2 (unwashed). After 47 days, the concentrations were 2.5 and 5.5 µg/100 cm^2, respectively. In a second experiment, the original mean concentrations were 3.3 µg/100 cm^2 (washed three times) and 14.3 µg/100 cm^2 (unwashed). After 5 months, the concentrations were 0.62 and 3.2 µg/100 cm^2, respectively [18].

MPCA reported sampling results prior to and following heating, ventilation and air conditioning (HVAC) cleaning at one site that had been used as a meth lab for one month [23, 46]. The agency noted that the methamphetamine contamination was twice as high in the cold air returns than in the heat registers of the same room.

- Pre-cleaning methamphetamine concentrations ranged from 273 to 1,487 µg/ft^2 in cold air returns and from 90.3 to 213.2 µg/ft^2 in heat registers.
- Post-cleaning methamphetamine concentrations ranged from 23.8 to 196.5 µg/ft^2 in cold air returns and from 24.6 – 80.2 µg/ft^2 in heat registers.

EFT engineered a methamphetamine decontaminant called Crystal Clean. The company presented the results from three case studies to prove the effectiveness of its product.

- *Case study #1*. Prior to treatment with Crystal Clean (Lakewood, CO), methamphetamine concentrations ranged from < 0.02 to 32.22 µg/100 cm^2. All samples were less than 0.02 µg/100 cm^2 (ND) following treatment [49].
- *Case study #2*. Prior to treatment with Crystal Clean, methamphetamine concentrations ranged from < 0.02 to 5.29 µg/100 cm^2. All samples were less than 0.02 µg/100 cm^2 (ND) following treatment [50].
- *Case study #3*. Prior to treatment, methamphetamine concentrations ranged from 0.06 to 1.24 µg. Treatment with trisodium phosphate did not eliminate methamphetamine contamination to acceptable concentrations (< 0.03–22.4 µg/100 cm^2). A second treatment with Crystal Clean removed methamphetamine contamination (< 0.03–2.05 µg/100 cm^2) [51].

5. Effectiveness of decontamination and remediation

5.1 General effectiveness of decontamination and remediation

Many local and state agencies present guidance for conducting remediation at former meth labs using best management practices.

- Several of the agencies with cleanup standards require decontamination and remediation to be repeated until the standards are met.
- Some require post-remediation sampling to show that the concentrations are below the standards. Others say that as long as their procedures for

decontamination and remediation are followed, final clearance testing is not necessary.

- Some agencies require that the decontamination plan be reviewed and approved.
- Some require that a certified or licensed industrial hygienist, contractor, or specialist conduct and certify that the decontamination and remediation was successful. Others allow the property owners to conduct the cleanup themselves.

Some agencies give the property owner the option of demolishing the contaminated property, especially when decontamination costs are higher than the value of the property. Another option is to remove the interior of the structure (e.g., carpeting, ceiling tile, paneling, wallpaper). Most sources indicate that this is an effective method of remediation. General recommended decontamination and remediation procedures include the following:

- Conduct gross removal including porous/absorbent materials (e.g., furniture, carpets and pads, drapes, bedding, and clothing).
- Steam clean items if they are extremely valuable or under extraordinary circumstances (e.g., irreplaceable antique furniture).
- Air out the site to reduce air contamination levels prior to, during, and after decontamination and remediation.
- Heat up the site prior to decontamination and remediation to evaporate residues. However, some agencies do not think this method is effective since it could mobilize and redistribute chemicals.
- Neutralize acids and bases.
- Clean/wash all surfaces (e.g., ceilings, walls, and floors).
- Conduct high efficiency particulate air (HEPA) vacuuming of nonporous and semiporous materials.
- Paint/encapsulate all porous surfaces (e.g., ceilings, walls, and counters). Some agencies recommended encapsulating as an additional measure, after cleanup standards are met through washing.
- Clean ventilation systems and replace the air filters.
- Clean or replace plumbing and septic systems, depending on the level of contamination.

Many companies promote their products or services for decontaminating and remediating former meth labs. Although most say their methods are effective, only some companies agree to take post-decontamination samples to prove the effectiveness of their methods. Only one presented data to prove the effectiveness.

- EFT stated that Crystal Clean is a “revolutionary decontaminant for safe and cost-effective cleanup of structures and materials contaminated by meth.” The company presents the results from three case studies [49-51].

Florida Meth Lab Cleanup and Meth Lab Cleanup Company state that baking, encapsulating/sealing, and using common household detergents are all unsuccessful methods for remediation [41, 52]. Both companies promote removal over neutralization.

5.2 Effectiveness of decontamination and remediation on surfaces

As previously discussed, several agencies stated that the most practical and reasonable strategy for measuring the effectiveness of decontamination is to test for residues of methamphetamine on surfaces after decontamination. However, many agencies do not require post-decontamination testing. Patrick et al. determined the cleanup effectiveness in three decontaminated residential meth labs by evaluating the magnitude, distribution, and variability of residual methamphetamine concentrations on interior surfaces [32]. Each site had been decontaminated by a certified contractor in accordance with state regulations. The qualitative wipe sample results from the contractors showed concentrations below the state decontamination standard. However, when Patrick et al. sampled, the authors found that more than a third of the random wipe samples (35% at Site 1, 96% at Site 2, and 45% at Site 3) and more than half of the contact point wipe samples (58% at Site 1, 100% at Site 2, and 63% at Site 3) exceeded the state of Washington standard. The authors concluded that all three former meth labs had unacceptable concentrations of residual methamphetamine at the time of sampling despite having been decontaminated by a state-certified contractor.

MPCA reported the results of a site remediation. The site was used as a meth lab for less than a month. Extensive sampling was done before and during the cleaning and sealing to characterize methamphetamine deposition on different materials, surface textures, and finishes, and to compare post-cleaning and post-sealing sampling. The agency reported that double-cleaning followed by a water rinse is effective in substantially reducing methamphetamine contamination, although sealing is often required to further reduce methamphetamine contamination to 1 μg/ft^2.

California DTSC analyzed the ability of commonly used commercial cleaning detergents/ solvents (Septi-Zyme, Clorox Bleach, Crystal Simple Green, Pine Sol, Liqui-Nox, TSP detergent, and Arm and Hammer baking soda) to chemically breakdown methamphetamine [53]. The results were reported qualitatively using GC/MS. Only Clorox Bleach caused the methamphetamine to breakdown (90%). These preliminary results indicate that bleach may be an effective cleaning agent to chemically breakdown residual methamphetamine.

NJMRC determined the decontamination effectiveness of three different kinds of oxidizing agents (EasyDECON, Formula 409, and Clorox Clean-Up) on painted contaminated drywall. The results varied depending on the cleaner that was used [31].

- EasyDECON (hydrogen peroxide/quaternary ammonia complex) was 100% effective (Lakewood, CO). The oxidation of methamphetamine to another compound was complete and no methamphetamine was detected after the initial treatment.
- Formula 409 (quaternary ammonium compound) was the second best decontamination compound with a 90 to 95% reduction of methamphetamine contamination (Oakland, CA).

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- Clorox Clean-Up (hypochlorite solution) was the least effective (57–64% reduction) decontamination cleaner (Oakland, CA).

NJMRC determined the decontamination effectiveness of washing specific building materials with Simple Green (Garden Grove, CA). The results varied depending on the surface that was being decontaminated. Surfaces that were smooth (metal and glass) were easily cleaned using a single washing with the detergent (100% reduction). Surfaces that were more porous (plywood and drywall) were not as easily cleaned. More than 50% of the methamphetamine present on these surfaces was removed from a single wash. Subsequent washes were able to remove another 30%, indicating a maximum reduction of approximately 80% for porous materials [29]. NJMRC determined the decontamination effectiveness of three different kinds of paints (latex, Kilz® [encapsulating paint], and oil-based) on drywall and plywood [28].

- Spray painting with either the Kilz® or oil-based paint completely covered the methamphetamine. A 100% reduction was observed for both. Almost all the samples were below the detection limit of 0.050 µg/100 cm^2. Four months later there was still 100% reduction on the painted plywood.
- Painting with a roller and a latex paint did not completely encapsulate the methamphetamine. An 80% reduction was observed.

NJMRC also found that the amount of methamphetamine in painted drywall decreased by up to 80% over time [18]. The Agency for Toxic Substances and Disease Registry (ATSDR) conducted health consultations for two sites used as clandestine meth labs.

- The Wisconsin Department of Health and Family Services (DHFS), under a cooperative agreement with ATSDR, investigated the health concerns and cleanup of an illegal, clandestine drug laboratory in a 20-unit apartment building in Menomonee Falls, Wisconsin. DHFS concluded that the abatement plan, which included wipe sampling of the hallway and doorway and thorough cleaning and coating of all surfaces, was sufficient to ensure the safety of future occupants [54].
- The Michigan Department of Community Health (MDCH), under a cooperative agreement with ATSDR, evaluated exposure pathways associated with a meth lab in Harrison, Michigan. MDCH followed up with the building management to ensure that the remediation recommendations were implemented. Based on current exposure conditions, MDCH concluded that the remediation appeared to be sufficient. No post-remediation sampling was conducted to verify the effectiveness of the cleanup because post-remediation sampling is not required [55].

The Idaho Department of Health and Welfare stated in its guidelines that washing a surface three times with household cleaning products will reduce meth lab contamination by 80% [56]. The department did not state how effectiveness was determined. The New Hampshire Department of Environmental Services (DES) stated in its guidance that a single cleaning event may not reduce concentrations to below cleanup standards if the pre-cleaning concentrations are above 10 µg/100cm^2 [57]. DES reported that 70–90% of the contamination is removed with each wash-and-rinse cleaning event, and that decontamination solutions containing a weak oxidizer like dilute bleach or hydrogen peroxide have been shown to be effective. DES did not state how effectiveness was determined. The South Dakota Department of Environment and Natural Resources (DENR) stated in its guidance that interior surfaces should be scrubbed twice using a standard detergent solution, such as Simple Green or trisodium phosphate, then rinsed with clear water [58]. However, methanol cleaning has been shown to be more effective in some situations, such as on countertops and stoves that will not be painted during remediation. DENR did not note how effectiveness was determined.

Corsi et al. evaluated the efficacy of wallboard remediation techniques for homes contaminated with methamphetamine by: 1) enhancing desorption by elevating temperature and relative humidity while ventilating the interior space, and 2) painting over affected wallboard to seal the methamphetamine in place [60]. The results indicated that elevating temperatures during remediation and latex painting of impacted wallboard will not significantly reduce freebase methamphetamine emissions from wallboard.

5.3 Effectiveness of decontamination and remediation in HVAC

MPCA reported sampling results prior to and following HVAC cleaning at one former meth lab. Wipe sampling within heat registers and cold air returns after HVAC cleaning showed a significant reduction in methamphetamine contamination with the removal of the matted dust. Air samples were collected to determine if HVAC cleaning redistributed methamphetamine contamination to the air. No quantifiable methamphetamine levels were detected in the air during and after the HVAC cleaning [46].

5.4 Effectiveness of decontamination and remediation on materials

NJMRC determined the decontamination effectiveness of washing three types of materials—denim, cotton. Samples were taken prior to being washed, and following each wash. The author concluded that the ability to remove methamphetamine contamination from clothing is relatively easy using a normal washing machine and detergent. Methamphetamine concentrations in the denim and cotton were reduced by 95% after a single wash and reduced by 99.8% after three washes [59]. MPCA tested the level of methamphetamine found in carpets, the pad, and underlying floor at one former meth lab [23]. The agency sampled prior to and following HEPA vacuuming, steam cleaning, and shampooing. MPCA concluded that even the best industrial steam/extraction cleaning could not reduce methamphetamine to acceptable levels.

6. Conclusions

This paper is the first review to gather all the related literature pertaining to remediation of clandestine laboratories producing methamphetamine. The reports and studies included in this review were obtained via Internet searches, from the reference bibliographies listed in research studies, educational publications, and professional journals. For the most part, the Internet searches yielded reports of methamphetamine use, methamphetamine production, and methamphetamine facility remediation programs throughout numerous U.S. states, as

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well as in other countries world-wide. While these data have provided much information on the extent of methamphetamine facility remediation-related trends, it is also important to note that many of the issues surrounding the methamphetamine situation cannot be answered solely through analysis of routine data sources, but require specific focused research. It was our intention that the review and categorization of the publications will facilitate further access to information for those researching and practicing methamphetamine facility remediation.

This literature review identified the need to address national methamphetamine remediation. Nationwide, more guidance is needed on detailed methods and procedures to remediate the level of contamination in a former methamphetamine laboratory. The US EPA prepared voluntary cleanup guidelines for homeowners, cleanup contractors, and, policy makers. However, it does not specify requirements, but rather suggests a way of approaching methamphetamine facility remediation. Although numerous states have adopted detection based cleanup standards for methamphetamine, none have tried to correlate these levels to known health effect-based concentrations. Routine data are still essential and a continued effort to collect good quality data at a national level will improve prospects for gaining information to support remediation efforts. This review could be used to help focus future research and also serve as an ongoing information resource for methamphetamine facility remediation and related issues.

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Highlights

- Methamphetamine manufacturing is a continuously growing United States epidemic.
- Review addresses the need for remediation of facilities used to produce methamphetamine.
- Numerous states address remediating homes with their own clean-up guidelines for re-occupancy.

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P2P:	Red Phosphorus:	Birch Reduction:
• Carbon dioxide • Formic acid • Lead • Mercury	• Potentially flammable extraction process sludges • Phosphine gas • Hydriodic acid • Hydrogen chloride gas • Phosphoric acid • White or yellow phosphorus	• Potentially flammable extraction process sludges • Hydrogen chloride gas • Lithium hydroxide • Sodium hydroxide

• Acetic acid • Alconox • Baking soda • Clorox Bleach • Clorox Clean-Up • Crystal Clean • Crystal Simple Green • DepHyze 3D, Carpet Cleaner, and Ultra Clean • EasyDECON • Simple Green • Trisodium phosphate (TSP) detergents	• Fiberlock Shockwave • Formula 409 • Household bleach • IAQM Structural Decon • Isopropyl alcohol • Kilz (primer/paint) • Liqui-Nox • Methanol • Pine Sol • Septi-Zyme • Vinegar • Windex

Table 1.

Characterization Methods

Agency/Group	General	Air	Surfaces
Local Agencies			
El Dorado County Environmental Management Department, CA	✓		
Fort Wayne - Allen County Department of Health, IN	✓		
Meth-Free Mesa County, CO	✓		
Orange County Methamphetamine Task Force, FL		✓	
Salt Lake Valley Health Department, UT			✓
Tri-County Health Department, CO	✓		
State Agencies			
Alaska Department of Environmental Conservation		✓	✓
Arizona State Board of Technical Registration		✓	✓
Arkansas Department of Environmental Quality		✓	✓
California Department of Toxic Substances Control		✓	✓
Colorado Department of Public Health and Environment		✓	✓
Connecticut Department of Public Health		✓	✓
Hawaii Department of Health		✓	✓
Idaho Department of Health and Welfare			✓
Indiana Department of Environmental Management			✓
Kentucky Division of Waste Management			✓
Michigan Department of Community Health			✓
Minnesota Department of Health/Minnesota Pollution Control Agency		✓	✓
Montana Department of Environmental Quality			✓
Nebraska Department of Health and Human Services			✓
New Hampshire Department of Environmental Services		✓	✓
Oregon Department of Human Services		✓	✓
Oregon Alliance for Drug Endangered Children			✓
South Dakota Department of Environment and Natural Resources			✓
Tennessee Department of Environment and Conservation			✓
Utah Department of Health/Utah Division of Administrative Rules/ Utah Occupational Safety and Health	✓	✓	✓
Washington State Department of Health			✓
Federal Agencies			
Agency for Toxic Substances and Disease Registry		✓	✓
National Institute for Occupational Safety and Health			✓
Occupational Safety and Health Administration			✓
International Agencies			
BC Centre for Disease Control			✓
Non-governmental Organizations			
Accutest			✓

Agency/Group	General	Air	Surfaces
AZ Meth Detection Service			✓
Bridger Photonics		✓	
CDEX, Inc.			✓
Chicago Crime Scene Cleanup			✓
EMSL Analytical			✓
Extreme Scene Clean, Inc.			✓
Florida Meth Lab Cleanup	✓		
Forensic Magazine			✓
Home Air Check		✓	
Medimpex United, Inc.			✓
Meth Lab Cleanup Company			✓
National Jewish Medical and Research Center		✓	✓
Neilson Research Corporation	✓		
Network Environmental Systems, Inc.	✓		
New York Environmental Technologies, Inc.	✓		
Safety Elements, Ltd.			✓
SKC, Inc.			✓
University of Arizona College of Public Health		✓	✓
Published Literature			
Martyny et al. 2007 [4]		✓	✓
Cox et al. 2009 [6]	✓		
Man et al. 2009 [11]		✓	
VanDyke et al. 2009 [13]		✓	✓
Patrick et al. 2009 [32]			✓
Duffy 2007 [34]			✓
Hannan 2005 [48]			✓