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DISINFECTION 101

KEY PRINCIPLES OF CLEANING AND DISINFECTION FOR ANIMAL SETTINGS

The Center for Food Security & Public Health

Iowa State University®
College of Veterinary Medicine

INTRODUCTION

Diseases are a constant threat to the health of animals. Surfaces contaminated by feces and body fluids contribute directly and indirectly to the transfer of microorganisms to other animals and locations. Contaminated housing areas, equipment, tools, vehicles, footwear and other fomites all pose risks.

The cleaning and disinfection process – often referred to as C&D – inactivates or destroys these organisms. Decreasing pathogen levels on surfaces reduces the potential for exposure and minimizes disease risks, which protects the health of animals and those working with them. The C&D process should be used routinely for all types of animal settings.

Properly performing C&D processes decreases pathogen levels on surfaces and reduces exposure risks. It also improves the health and well-being of animals, particularly in high density settings.

- C&D is an essential component of biosecurity on farms and in other congregate animal settings (e.g., animal shelter facilities, exhibitions and shows).
- C&D in veterinary clinics is a crucial measure for infection control and preventing disease spread.
- C&D is critical for disease containment and elimination during disease outbreaks and also serves as a layer of protection against novel or emerging diseases.

However, the C&D process is often not done correctly. When efforts are ineffective, the destruction of disease-causing organisms can be inadequate, resulting in exposure to disease agents and further spread of microorganisms.

Successful C&D involves understanding the key principles and steps for the process, choosing the best method, and recognizing any limitations. This document addresses this information as well as factors to consider when setting up a C&D program, common failures in disinfection programs, and how to address health and safety issues.

THE DESTRUCTION OF MICROORGANISMS

BIOCIDE

The general terms “biocide”, “germicide”, or “microbicide” refer to a substance or product that destroys or inhibits the growth or activity of living organisms. This includes disinfectants, sanitizers, antiseptics, and sterilants. **But, these antimicrobial products vary in their ability to destroy microorganisms!**

Designations are often used to convey a specific action of the product against a particular group of microorganisms.

- The suffix –***cide*** or -***cidal*** (e.g. bactericide, virucidal, fungicide, sporicidal, tuberculocidal) reflects a killing action on a particular microorganism class.
- The suffix –***static*** (e.g. bacteriostatic, virostatic, sporostatic) is used if the product only inhibits the growth or replication of the organism.

Depending on the goal for the C&D process, these designations can be critical!

CLEANING, SANITIZING, DISINFECTING – WHAT'S THE DIFFERENCE?

When discussing C&D, it is important to recognize there are different processes that can be used to destroy microorganisms. These terms are often used interchangeably, but their level of destruction varies.

Cleaning involves the *physical removal* of visible contamination from surfaces. **Soaps and detergents** bind to oils, soil and organic material so it can be rinsed away. Some cleaners can disrupt the lipid components (e.g., cell membrane or viral envelope) of certain pathogens.

Sanitizing significantly *reduces bacterial contamination* on surfaces to levels considered safe from a public health standpoint. It does not eliminate all microorganisms. Sanitizers are most commonly used for food contact surfaces.

Disinfection *destroys or irreversibly inactivates most pathogens* (e.g., bacteria, viruses and fungi) *on surfaces (i.e., inanimate objects).** It is generally not effective against bacterial spores. Efficacy will vary with disinfectant product or method.

Sterilization *destroys or eliminates all forms of microbial life,* including bacterial spores. This involves the use of higher levels of physical (e.g., extreme heat) or chemical (liquid or gas sterilants) processes and is generally used for medical devices/equipment.

*NOTE: Antiseptics are products applied to the *surface of living organisms or tissues (e.g., skin)* to destroy or inhibit the growth of microorganism.

Some chemical products may act as a sanitizer, a disinfectant, or possibly a sterilant, depending on concentration or contact time used.

For example, the table below shows the required dilutions and contact times for a commonly used hydrogen peroxide disinfectant.

Table 1: Differences in dilution and contact time for an example hydrogen peroxide disinfectant.

Use	Concentrate dilution ratio*	Liquid measurement (concentrate/gallon water)	Contact Time needed*
Sanitizing	1:128	1 oz/gallon	3 minutes
Daily disinfection	1:64	2 oz/gallon	5 minutes
Bactericidal, fungicidal, virucidal	1:16	8 oz/gallon	5 minutes

KEY PRINCIPLES OF C&D

Regardless of the setting or item, there are five key principles to keep in mind for a successful C&D program.

1. **Clean surfaces before disinfection.** Before any disinfection method is used, surfaces have to be cleaned. Cleaning removes dirt, organic matter, (e.g., feces or manure, body fluids), and other debris that can hide organisms during the disinfection process. This material can also inactivate several disinfectants, making disinfection ineffective.

2. **Use the right disinfection product or method for the situation.** Disinfection methods can involve the use of a chemical or physical process. Both disrupt the cell walls or membranes, viral envelopes, or replication processes of microorganisms, resulting in their destruction or inactivation. But, no single product (or process) works for all situations. Products or methods needed for a disease situation will likely be different than those used on a daily basis. Higher concentrations or longer exposure times may be needed to destroy resistant organisms but may increase health and safety risks or damage surfaces.

3. **Read the product label.** In the U.S., products used to destroy microorganisms must be registered with the Environmental Protection Agency (EPA). The information on product labels must include the organisms the product can kill or inactivate, instructions for use (e.g., where the product can be used, the proper concentration for use, the necessary contact times), and any health and safety issues. Always read and follow the label instructions for effective disinfection.

4. **Give it time to work.** Disinfection does not occur immediately. The process needs time to work, and times vary for each product or process. Surfaces must remain wet or exposed for the full contact time for best results. Contact time is critical for success!

5. **Keep everyone safe.** All disinfection methods have health and safety considerations for people, animals or the environment. Read the product label for any safety measures required. Personal protection should be worn when mixing and applying disinfectants. Surfaces should be rinsed before the placement of animals.

BASIC C&D PROCEDURE

In animal settings, C&D should be performed on a regular basis, during, and after infectious disease situations. All surfaces in contact with animals, including the C&D equipment used, should be included.

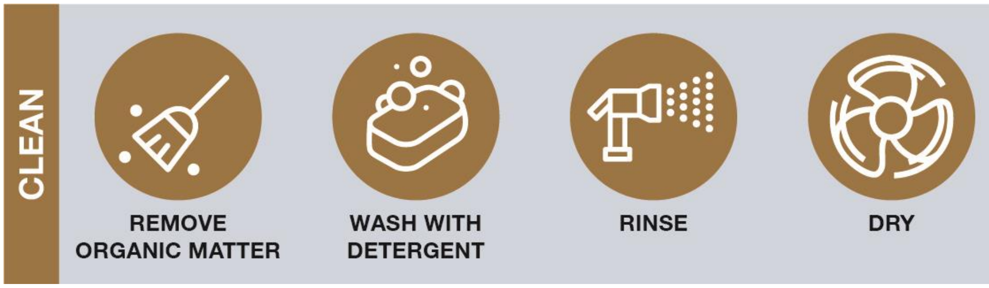
USE A SYSTEMATIC APPROACH

When performing C&D procedures, use a systematic approach to make sure all areas or items are addressed. Work in small sections. Proceed from the cleanest area to the dirtiest, from the highest level (e.g., ceiling) to the lowest (e.g., floor). Marking tape can be used to indicate where C&D steps have or have not taken place. Disinfect floor drains last.

Regardless of the situation, item, or area, the C&D process follows two distinct phases. Both are needed for optimum results. Without cleaning, disinfection does not work.

- **Cleaning** removes visible organic material that can interfere with the disinfection process.
- **Disinfection** inactivates or destroys most remaining pathogens on inanimate objects.

THE CLEANING STEPS



There are four steps for proper cleaning. The goal is to remove manure, bedding, feed, body fluids, dirt and other debris that can interfere with the disinfection process. This material can hide organisms from the disinfection action. Additionally, disinfectants may react with this material instead of microorganisms, this can reduce the level of active ingredient available to attack microorganisms.

Remove Organic Matter.

Any visible dirt, manure, or other debris should be removed by wiping, brushing, scraping, sweeping, scooping, or other methods. In large production facilities, heavy equipment, such as skid steers or manure scrapers, may be needed to handle large quantities of material. This step is sometimes called dry cleaning. The goal is to remove as much visible debris as possible. **This step may take considerable time and effort, depending on the object, size of the area, or level of contamination. But it is essential for optimum disinfection!**

Wash Surfaces.

Often called wet cleaning, washing the item or area with soap or detergent and water removes material adhered to surfaces. Certain soaps or detergents can destroy some microorganisms.

Mechanical scrubbing or scraping helps to loosen dirt and debris. Areas with deep cracks, pits, pores, or other surface irregularities may require scrubbing with a coarse or wire brush. Presoaking or use of a degreaser may be necessary to remove oils or bodily fluids. Hot water and steam can be effective for cleaning cracks, crevices, and the inside of pipes.

High pressure sprayers may be effective to remove heavy accumulation of urine and feces or for cleaning porous surfaces (e.g., concrete). However, in cases of highly infectious or zoonotic pathogens, high pressure systems should be avoided or used with caution to avoid further dispersal of the pathogen or risk to the applicator.

Rinse.

After washing, it is important to thoroughly rinse surfaces with clean water to remove material and any cleaning product residue. Soaps or detergents can inactivate some disinfectants. Surfaces should be carefully inspected to ensure they are clean. If dirty surfaces or residual oils are seen, rewash the affected areas.

Dry.

The item or areas should be allowed to dry completely before the disinfection process; excess water, especially on porous surfaces, will unintentionally dilute any disinfectant solution applied. If this is not possible, allow a minimum of 5-10 minutes for water to drip away. Heating the building, circulating the air with blowers or fans, or high-pressure air from a compressor can aid in the removal of excess moisture to speed drying. However, **if highly infectious or zoonotic pathogens are suspected, fans or high-pressure systems should be avoided** to avoid unintended spread of pathogens.

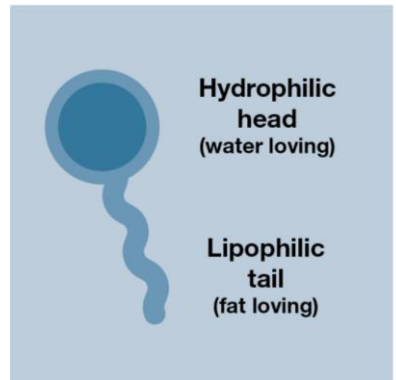
The cleaning step may take considerable time and effort, depending on the object, size of the area, or level of contamination. But it is essential for successful disinfection! It has been estimated that cleaning alone may remove over 90% of bacteria from surfaces. The removal of organic matter helps to ensure that the subsequent disinfection stage has a greater impact on the remaining microorganisms.

Disposal of Debris

Any material removed during the cleaning step should be considered contaminated, and handled and disposed of in a manner that prevents any spread of microorganisms (e.g., burning, burial, or composting). Disposal will need to comply with any federal, state, and local requirements.

How Cleaning Works

Soaps and detergents are surfactants, or **surf**ace **act**ive age**nts**. Surfactant molecules reduce the surface tension of water, which means they increase the ability of water to penetrate, disperse and remove organic material from surfaces. This is accomplished by their bipolar chemical structure. Each molecule has a polar hydrophilic, or water-loving, head and a nonpolar lipophilic, or fat-loving tail.



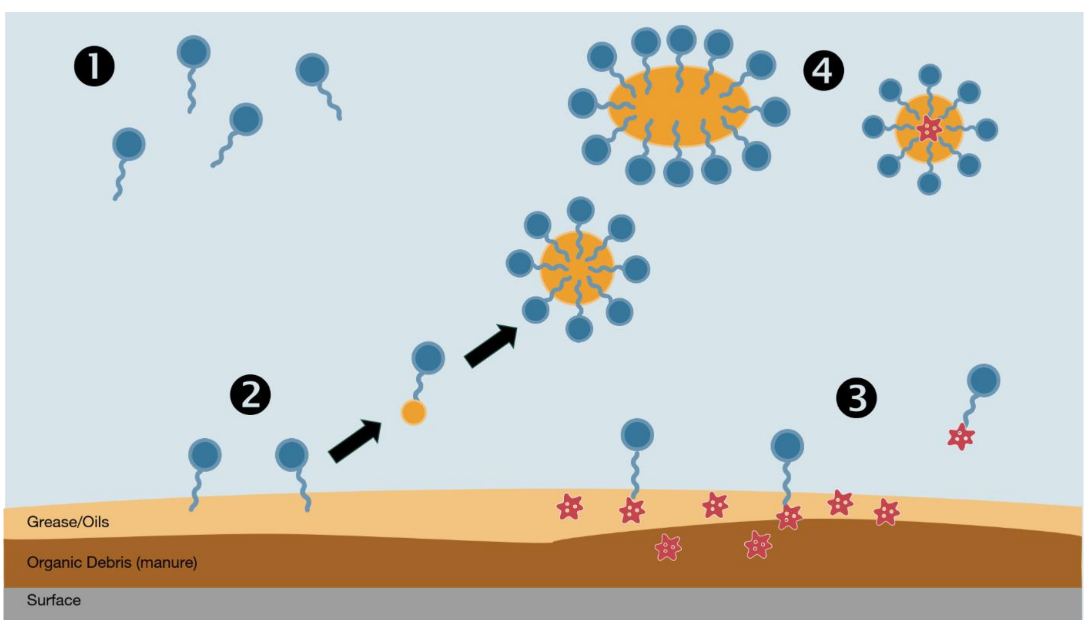
The cleaning process in action (see diagram below)

❶ In solution, the surfactant (detergent) molecules have both water-soluble and oil-soluble properties.

❷ The lipid loving tails attach to oil, grease, dirt, and debris. The hydrophilic heads interact with water molecules.

❸ Surfactant molecules can also attach to other lipid-based substances, such as the cell walls of bacteria or the lipid envelopes of viruses.

❹ As surfaces are scrubbed and debris loosened, it becomes surrounded and trapped by surfactant molecules (i.e., form a micelle), which allows the pieces to be washed away during rinsing.



Good to know: Surfactant classifications

Surfactants vary in chemical structure, particularly the chemical charge of the head portion of the molecule (the hydrophobic tails are often chemically similar). This charge affects the detergency (or cleaning power) and the antimicrobial efficacy of the cleaning product. Most commercial detergents are a combination of anionic (negatively charged) and non-ionic (neutral charge) formulations.

The chemical composition of surfactants (e.g., anionic, cationic) can enhance or interfere with the disinfection process. The cleaning product used must be compatible with the disinfectant selected. Some disinfectant products may be formulated with a detergent component. Cleaning products may also incoporate other chemical components, such as enzymatic agents, such as proteases (which break up proteins), lipases (which break up fats), and amylases (which attack starch), to further aid the cleaning process.

The following table summarizes characteristics of surfactant types and highlights the detergency or antimicrobial efficacy of each.

Table 2. Types and characteristics of various surfactants.

Surfactant Type	Chemical charge (depending on pH of solution)	Detergency (cleaning power)	Antimicrobial efficacy	Examples
Anionic	Negative charge	**+++**	+/-	Soaps, sodium lauryl sulfate
Nonionic	Neutral charge	**+++**	-	Polysorbates
Cationic	Positive charge	+	**+++**	Quaternary ammonium compounds (QAC), such as benzalkonium chloride
Amphoteric	Variable based on pH	++	**+++**	Betaine, alkyl methyl oxide

THE DISINFECTION PROCESS

The second phase of the C&D process is disinfection. This is needed to inactivate or kill remaining microbes, and may involve either physical or chemical processes.

Disinfectant Preparation

Disinfectant selection: The selection of a disinfection method or product will depend on several factors, including the targeted microorganism, the surface or object being treated, environmental conditions and health and safety concerns. Additional information on disinfectant selection is found later in this document.

Read the product label: Always prepare disinfectants according to product label instructions. Products differ in formulation. Some products are ready to use, others require dilution. Fresh solutions are best and should be prepared daily or as specified on the label. Only use EPA-registered products. One U.S. gallon of diluted disinfectant is ordinarily applied to approximately 100-150 square feet (9-14 m^2) of surface area.

Use the proper concentration: The safest, most effective concentration will be listed on the product label. The concentration needed may vary depending on the surface type or target microorganism. Stronger solutions are not always better. Higher concentrations can damage surfaces or lead to health or safety issues. Under-dilution may not be effective against the microorganisms of concern.

Check the amount of active ingredient in stock and prepared solutions: Chemical disinfectants can degrade or lose potency over time. Check the product for an expiration date. Commercial test kits are available for most products to determine if chemical degradation has occurred or if diluted ("use") solutions contain the necessary amount of active ingredient.

Prepare safely: Prepare disinfectant solutions in a well-ventilated area. Personal protective equipment (e.g., gloves, eye protection) should be worn. Always pour the chemical into water, not water into the concentrate. Some disinfectants can have strong chemical reactions when water is added.

Disinfectant Application

The application of chemical disinfectants most often involve spraying, fogging, misting, wiping, or mop-on methods. Small, portable items can be soaked in a container of disinfectant solution. The application instructions for a particular product will be listed on the label.

Fumigation may be used in some situations, but it is inefficient or ineffective in buildings with ill-fitting doors and windows, or damaged roofs. It also requires higher levels of PPE and often times specific training. The use of fumigation is uncommon except under select circumstances.

As with cleaning, disinfectant application should occur in a systematic manner (e.g., top to bottom, front to back, working in small sections) to ensure all areas are treated adequately. It is essential to pay close attention to corners, deep cracks, crevices, pits, pores, or other surface irregularities. These areas can serve as reservoirs for pathogens. Floor drains should be the last areas disinfected.

Contact Time

Regardless of the disinfection method chosen, it is critical to ensure the full contact time is achieved. **This is a commonly overlooked step, and often leads to disinfection failure!**

The disinfection process is not instantaneous; the process needs time to work. Contact times vary depending on the product or method used, the concentration, the type of surface being treated, and the ambient temperature. Some may require 1-5 minutes, but 10 minutes or more is common; some may require hours, especially for resistant pathogens.

Surfaces must remain exposed (e.g., wet with disinfectant solution) for the full contact time. This can be a challenge during high temperatures. Some chemical disinfectants, particularly alcohols, evaporate quickly. Reapplication may be necessary to ensure the required contact time. Ensure cracks, crevices, and joints remain exposed for the entire contact time.

Rinse Away Disinfectants

After the appropriate contact time has elapsed, all items or areas should be thoroughly rinsed with clean water. Most chemical disinfectants can be harmful to animals and must be rinsed away before the reintroduction of animals. This is especially important around feed and water equipment. Some products can also damage certain surfaces, such as rubber or metals, if not completely rinsed away. However, some products may have residual action and can remain on surfaces to continue to work.

Drying/Down Time

After rinsing, treated areas or items should be dried completely (ideally overnight). Applying disinfectant solutions uniformly over large areas (e.g., ceilings, walls, floors) can be very difficult. Adequate downtime helps to further reduce or eliminate any remaining microorganisms. The area should remain free of any animals or activity during this time.

OTHER C&D CONSIDERATIONS

Biofilms

Biofilms, an invisible, complex aggregation of bacteria, may remain on surfaces. Biofilms are highly resistant to disinfection. The use of detergents, mechanical scrubbing, brushing, and scraping can help remove biofilms.

Personnel Health and Safety

Personal protective equipment (PPE) should always be worn when preparing and applying disinfectants. Recommended PPE for a particular product will be listed on its label. At a minimum, this should include eye protection and gloves. Water-resistant disposable outwear (e.g., coveralls, boots) should be strongly considered. Respiratory protection (e.g., masks, possibly respirators) should be worn when preparing powdered formulations or for products with strong odors. Personnel should always wash their hands after C&D procedures – even if gloves were worn.

One-Step Disinfectant Cleaners

Some disinfectant products may be formulated with a detergent component as a one-step product. Organic matter still needs to be removed for these products. Most are labeled for use on cleaned surfaces, so the cleaning step is still needed. Some require washing of surfaces - **after disinfection** - particularly for situations where animal restocking or exposure will occur.

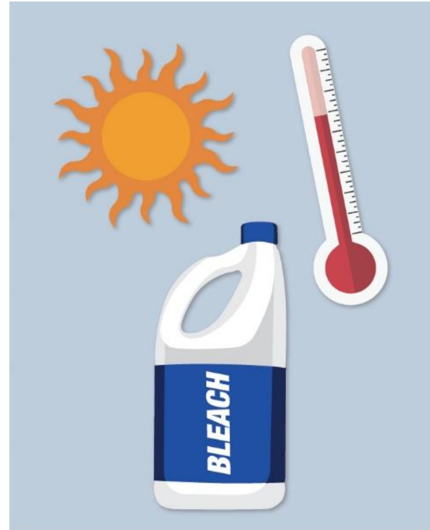
C&D in Cold Temperatures

Many disinfectant products are affected by temperature, and may be ineffective during cold weather conditions. Solutions may also freeze on surfaces when outdoors. Possible solutions for C&D in cold temperatures include heating surfaces or buildings to prevent freezing, using heat blankets around liquid containers, or adding antifreeze agents (e.g., propylene glycol); some disinfectants may be compatible, others are not. Always read the product's label instructions for use in cold conditions.

DON'T FORGET THE C&D EQUIPMENT

After completing the C&D procedure, any equipment used during the process (e.g., shovels, hoses, pressure sprayers, pumps, any heavy equipment or vehicles) should also be properly cleaned and disinfected. Some disinfectants can be corrosive or damaging, and should be rinsed away. Disposable C&D supplies (e.g., paper towels) should be discarded. Any unused disinfectant concentrate or solutions should be properly stored or disposed of in accordance with the label instructions.

DISINFECTION METHODS IN ANIMAL SETTINGS



Disinfection describes the use of a chemical or physical process to inactivate or eliminate microbial organisms *on inanimate objects or surfaces.* These processes destroy or irreversibly inactive most pathogens, but are **generally less** effective against bacterial endospores.

- **Chemical disinfection** involves the use of various chemical classes of products, each with different chemistries, microbial spectrums (or efficacies), and health and safety concerns.
- **Physical disinfection methods** includes drying or desiccation, the application of heat (or thermal inactivation), or the use of irradiation methods (most commonly ultraviolet light).

While an ideal disinfectant is one that is broad spectrum, has low toxicity to humans and animals, is non-corrosive, and is relatively inexpensive. Few products or methods meet all of these criteria.

HOW DISINFECTION WORKS

Disinfection processes target several sites and cause structural and functional damage to various macromolecules (e.g., proteins, lipids, nucleic acids) of microorganisms. This results in the disruption of cell walls or membranes, viral envelopes, or replication processes and destroys or irreversibly inactivates most pathogenic microorganisms.

Biocide Mechanisms of Action

There are four mechanisms of action for this process.

- **Oxidizing mode of action.** Biocides with an oxidizing mode of action remove electrons (oxidation) from a substance -in this case - nucleic acids, lipids, proteins and carbohydrates of microorganisms. Altered structures result in disruption of cell membranes and cell function. Oxidizing agents have a dramatic effect on DNA and RNA, causing strand breakage and disruption of replication, transcription, and translation processes. Oxidizing biocides are widely used and include halogen-based products (e.g., chlorine, iodine) and peroxygen products (hydrogen peroxide, peracetic acid)
- **Cross-linking or coagulating mode of action:** Some biocides primarily act by cross-linking or coagulating the amino acids of proteins, (and sometimes nucleic acids bases) to disrupt the structure and function of many microorganisms. Disinfectants in this category are aldehydes; alkylating agents, such as ethylene oxide; phenols, and alcohols
- **Other structure-disrupting agents:** Several biocides primarily damage lipid membranes. They may directly disrupt membrane proteins or cause increased permeability. The result is leakage of cytoplasm components and cell lysis. Biocides in this category include surfactants (including QACs), biguanides, and organic acids.
- **Transfer of energy:** A final mechanism of biocidal action involves the sudden transfer of energy that results in disruption of structure and function. These processes rapidly denature nucleic acids, lipids, and proteins. They include the application of heat and radiation (e.g., ultraviolet light).

CHEMICAL DISINFECTION

Chemical disinfectants are most commonly used and include a wide range of products classified by the chemical nature of their active ingredients. There are more than 275 different active ingredients used as the primary component of a disinfectant or part of a combination formulation (e.g., products containing multiple active ingredients). Products may be sold as wipes, ready-to-use (RTU) sprays or liquids, or concentrated liquids or powders.

Each chemical class has unique characteristics, microbial spectrums, compatibilities and effectiveness under certain conditions (e.g., presence of organic material, temperature, water hardness) and health impacts and hazards. Therefore, selection of a disinfectant product involves consideration of its specific characteristics and uses.

Most chemical disinfectants readily inactivate vegetative bacteria (gram-positive, gram-negative) and enveloped viruses. Fungal spores and non-enveloped viruses are generally less susceptible. *Mycobacteria*, bacterial endospores, and protozoal oocysts are highly resistant to most disinfectants. Prions, the etiologic agents of bovine spongiform encephalopathy, chronic wasting disease, and scrapie, are exceptionally resistant to chemical inactivation.

Regulation of Chemical Disinfectants

In the United States, chemical disinfectants are regulated by the U.S. Environmental Protection Agency (EPA) through the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA). Chemical disinfectants are considered “antimicrobial pesticides” - or substances used to control, prevent, or destroy harmful microorganisms (e.g., bacteria, viruses, or fungi) on inanimate objects and surfaces.

FIFRA requires a pesticide to be registered (or exempted) before it may be sold or distributed in the United States. Data on its chemistry, efficacy, toxicity to humans, animals and plants, and other parameters must be tested and submitted to the EPA. Labeling information and designations are determined by this data.

Product registration can occur under:

- Section 3 (regular label) or
- Section 18 (emergency exemption)

FIFRA further requires that all label use directions and safety precautions must be followed. The use and application of a registered disinfectant in a manner inconsistent with its labeling may not only result in an ineffective application, but may be a “misuse” of the product and subject to potential enforcement action.

Product labels will list an **EPA Registration Number** to show that the product has been reviewed by the EPA and can be used with minimal risk when the label directions are properly followed. For maximum success in preventing disease spread in a clinic, shelter, or livestock operation, only **EPA registered products should be used.**

While the EPA registers products and approves them for use, it is important to also be familiar with local or state regulations for other restrictions. Individual States (e.g., California) may have additional regulations on permitted products. Contact your local or state environmental agency for more information.

CHEMICAL DISINFECTION CLASSIFICATION BY CHEMICAL CLASS

Disinfectants are classified by their chemical nature. Each class has its unique characteristics, hazards, and efficacy against various microorganisms. Environmental conditions, such as the presence of organic matter, pH or water hardness can also impact the action of a disinfectant. Variations in formulation or combination solutions may have differing characteristics. Before using any chemical disinfectant, **thoroughly read and follow the label instructions**.

The following section provides an overview of characteristics of the primary chemical disinfectant classes (in alphabetical order): acids, alcohols, aldehydes, alkali agents, biguanides, halogen-based compounds (e.g., chlorine, iodine), oxidizing agents, phenols, and quaternary ammonium compounds (QACs).

Disclaimer: The use of trade names does not in any way signify endorsement of a particular product. They are provided only as examples.

For additional product names, consult The National Pesticide Information Retrieval System (NIPRS) –a searchable database of federally active (registered) Section 3 pesticide products.

Tables are available from CFSPH that summarize the key characteristics and antimicrobial spectrums of each chemical class of disinfectants.

- Characteristics of Selected Disinfectants
- Antimicrobial Spectrum of Disinfectants

Acids

Acidic disinfectants include inorganic (e.g., hydrochloric acid, sulfuric acid) and organic (e.g., acetic acid, citric acid) compounds.

The antimicrobial action of acids occurs through the dissociation of free hydrogen ions, which alters the pH of the microorganism's environment. Acids also destroying the bonds of nucleic acids and precipitate proteins.

Microbial spectrum:
The antimicrobial activity of acids is highly pH dependent. Acids are:

- Generally effective against vegetative bacteria and can be bactericidal when the pH drops below 3.
- Enveloped viruses are particularly sensitive to extremes of pH, and therefore susceptible.
- Fungi may be susceptible with extended contact times (e.g., 30 minutes).
- Acids are not effective against *Mycobacteria* or non-enveloped viruses. One exception is the foot-and-mouth disease (FMD) virus, which is particularly sensitive to acids (e.g., citric acid).
- The efficacy against bacterial spores is variable, but limited, and often requires high concentrations. For example, a 2.5% hydrochloric acid solution is a reasonably effective sporicide that has been used to disinfect animal hides potentially contaminated with anthrax spores before tanning.

Specific acid compounds:

- **Acetic acid** is usually sold as glacial acetic acid (95% acetic acid) which is then diluted with water to make a working solution concentration of 5%. Household vinegar is a 4-5% solution of acetic acid (by volume). Acetic acid is typically applied by spraying, misting or immersing an item in a diluted solution. Acetic acid has poor activity in organic material. Acetic acid has been routinely used by the USDA (under a FIFRA quarantine exemption) to wipe down the coats of horses arriving from FMD virus positive countries.

- **Citric acid** has been used alone or as an additive to detergents in other countries to inactivate the foot-and-mouth disease (FMD) virus. In October 2012, the EPA approved the use of citric acid (under a FIFRA quarantine exemption) to control FMD and African swine fever in the U.S. The rate of application was amended in May 2013.
- **Other acids:** Some acidic compounds (e.g., formic, citric, lactic, malic, glutaric, and propionic acids) are added to anionic detergent or other disinfectant formulations to enhance antimicrobial properties. Strong inorganic acids (e.g., hydrochloric acid, sulfuric acid) have been used to disinfect farm buildings, but are typically too hazardous for use as a disinfectant.

Characteristics of acids:
Acids are generally slow acting, especially against viruses. They can be highly corrosive to metal surfaces (e.g., galvanized) and concrete. Acid efficacy can be affected by the presence of organic matter, pH, and water hardness.

Uses:
Some acids are EPA-registered as pesticides or exempted under FIFRA, while others are not. (NAHEMS FAD PReP 2014) Acids have a defined but limited use as disinfectants.

- Inorganic acids, such as nitric, hydrochloric, sulphuric, phosphoric, are often used as cleaners (e.g., anionic detergents) to remove lime scale or milk stone.
- Organic acids, such as citric, lactic, mallic, glutanic, propionic, are often incorporated into disinfectant formulations to enhance antimicrobial properties (e.g. viruses, fungi).
- Acetic acid has been routinely used by the USDA (under a FIFRA quarantine exemption) to wipe down the coats of horses arriving from FMD virus positive countries.
- Citric acid has been used alone or as an additive to detergents to inactivate the FMD virus. A FIFRA emergency exemption was approved by the EPA in October 2012, for the use of citric acid to control FMD and African swine fever in the U.S.
- A 2.5% hydrochloric acid solution is a reasonably effective sporicide that has been used to disinfect animal hides potentially contaminated with anthrax spores before tanning.

Health and safety:
While typical dilutions are considered non-toxic and non-irritating, concentrated solutions of acids can cause chemical burns, and can be toxic at high concentrations in the air. During preparation, acids should ***<u>always</u>*** be poured into water (not the water into the acid) to avoid violent boiling or splashing of concentrated acid. Personnel should wear eye protection and rubber gloves when mixing, applying, and rinsing acidic disinfectants. Acids may result in potential aquatic hazards, if released into the environment, due to their low pH levels.

Alcohols

The most commonly used alcohol-based disinfectants are ethyl alcohol (i.e., ethanol) and isopropyl alcohol (i.e., isopropanol).

Their hydroxyl functional group (-OH) interacts with the membrane proteins and lipids of microorganisms resulting in disorganization, membrane damage, and lysis. These products also alter the pH of the environment. Some alcohols are EPA-registered as "antimicrobial pesticides" under FIFRA, while others are not.

Microbial spectrum:
Alcohols are considered fast-acting, broad-spectrum antimicrobial agents.

- Alcohols are capable of killing most bacteria within five minutes of exposure. They are also effective against acid-fast bacteria (e.g., *Mycobacteria*). Fungi can be susceptible at prolonged contact times.
- Virucidal activity varies with the product. Ethanol is considered virucidal, while isopropanol is not effective against non-enveloped viruses, especially small, non-enveloped viruses.
- Alcohols alone are not effective against spores, but may potentiate the sporicidal effect of some halogen-based products (e.g., iodines).

Uses:
Alcohols are used for surface disinfection, as topical antiseptics and hand sanitizing lotions. They are often incorporated into disinfectant formulations for increased efficacy, and have been used in combinations with phenols, quaternary ammonium compounds and chlorhexidine. Alcohols may be used to disinfect small areas or items (e.g., cell phones, keyboards, stethoscopes); however, they evaporate rapidly making extended exposure time difficult.

Characteristics of alcohols:
The activity of alcohols is limited in the presence of organic matter. Surfaces must be cleaned before application. This class of disinfectants can damage to rubber and plastic with frequent or extended use.

Health and safety:
Alcohols can be very irritating to injured skin. Alcohols are highly flammable; products must be stored in a cool, well-ventilated area and used with caution.

Noteworthy: The presence of water is necessary for alcohol efficacy; therefore, concentrations of 60-90% are recommended. Most rubbing alcohol (i.e., isopropanol) is 70% and hand sanitizers are typically 62%. Higher concentrations (95%) are actually less effective because some degree of water is required for efficacy (to denature proteins).

Aldehydes

Aldehyde disinfectants [R-CHO] include formaldehyde, glutaraldehyde, and ortho-phthalaldehyde (OPA). These alkylating agents denature proteins and disrupt nucleic acids causing irreversible inhibition of microorganism enzyme activity.

Microbial spectrum:
Aldehydes are highly effective, broad spectrum disinfectants. They are slow-acting but very effective against bacteria and enveloped viruses and somewhat effective against non-enveloped viruses, bacterial spores, and acid-fast bacteria. High concentrations of formaldehyde can destroy all microorganisms, including spores, (sterilization) and has been used extensively to inactivate viruses.

Uses:
Aldehydes are highly irritating, and acutely toxic to humans or animals with contact or inhalation. Formaldehyde is a known carcinogen. The use of aldehydes is limited to certain applications, and requires caution and higher levels of personal protective equipment and training.

Characteristics of aldehydes:
Aldehyde disinfectants are non-corrosive to metals, rubber, plastic, and cement. Health and safety concerns limit the use of these products to specific situations or warrant increased personal protection measures.

Health and safety:
Aldehydes are highly irritating and toxic to humans or animals by contact or inhalation. Solutions can cause irreversible eye damage and skin burns. They are harmful if absorbed through the skin and fatal if swallowed. Prolonged or frequent repeated skin contact may cause allergic reactions in some individuals.

Appropriate personal protective equipment, (e.g., fluid-resistant gloves and clothing, and eye/face protection) must be worn when using all aldehyde products. Fumigation measures require specialized equipment and training. When used as a mist or gas, respiratory protection is warranted.

Formaldehyde has been identified as a potential carcinogen. Occupational Safety and Health Administration (OSHA) standards limit the exposure time for personnel working with formaldehyde (29 CFR 1910.1048). The pungent fumes can be irritating to mucous membranes, contact can cause skin irritation, and ingestion can be fatal. Personal protective equipment must always be worn when working with this compound, and application must be confined to areas which are air-tight and completely sealed to prevent gas escape.

Specific aldehyde compounds:

Formaldehyde

- ***Formaldehyde*** can exist as a gas or liquid. A solution of 4-8% formaldehyde in water is considered an intermediate to high-level disinfectant. Its use is limited due to health and safety concerns. It has been used as a surface disinfectant and a fumigant to decontaminate rooms, buildings, wooden surfaces, bricks, electronic devices and mechanical equipment (e.g., hatchery equipment). When permitted under an exemption, gaseous formaldehyde may be used to decontaminate air spaces and equipment that must be kept dry (e.g., electronic devices or equipment).
- Formaldehyde combines readily with proteins, so efficacy is decreased by the presence of organic matter. The efficacy of formaldehyde is dependent on relative humidity and temperature; optimum conditions are humidity close to 70% and temperature close to 57°F (14°C).

Glutaraldehyde

- ***Glutaraldehyde*** is EPA-registered as a disinfectant in over 300 products at various concentrations. Many products containing glutaraldehyde are a combination glutaraldehyde/quaternary ammonium product; examples include Synergize® (Neogen) and Virocid® (CID LINES).
- Glutaraldehyde has been widely used for high level disinfection of medical (e.g., endoscopes) and thermosensitive equipment. A 2% concentration is used for high-level disinfection. It can also act as a sterilant with prolonged contact times. Efficacy is also increased by greater temperatures.
- Glutaraldehyde is considered more efficacious in the presence of organic matter, soaps and hard water than formaldehyde; however, its activity is affected by pH and temperature.
- The product remains chemically stable at acidic pH levels, but is more “active” at alkaline (pH 7 or greater) levels; however, pH over 9 can result in decomposition of the product.

- Although it can be less acutely toxic than formaldehyde, exposure can cause skin and mucous membrane irritation, epistaxis, and possibly asthma. Glutaraldehyde is considered noncorrosive and usually does not damage rubber or plastics; however, it may be mildly corrosive to metals.

Ortho-phthalaldehyde (OPA)
Ortho-phthalaldehyde (OPA) is a high-level disinfectant used for reprocessing reusable heat-sensitive semi-critical medical devices such as endoscopic, respiratory therapy, and anesthesia equipment. An example product is Cidex®

Alkalis

Alkali agents include products such as sodium hydroxide, sodium carbonate, and calcium oxide.

Their antimicrobial action involves the dissociation of hydroxyl ions (–OH), which alters the environmental pH. These products also have saponifying (soap) action on fats and the lipid envelope of the outermost membrane, which also contributes to the cleaning process.

Microbial spectrum:
Alkalis have good microbicidal properties, especially at high concentrations and at high temperatures. The range of microorganisms varies with agent and are described below.

Uses:
The use of alkalis is limited for routine use; however, they are commonly incorporated into cleaning products. Alkalis have been used to disinfect livestock- or poultry-production areas, including pens, yards, buildings, and effluent waste pits and sewage collection areas, since they can maintain effectiveness even with high concentrations of organic matter.

Characteristics of the class:
The activity of alkali compounds is slow but can be increased by raising the temperature. The activity of these products is optimum at pH greater than 9; however, a pH above 12.0 may be needed for resistant bacterial pathogens (e.g., *Mycobacterium*).

Alkalis are very corrosive to metals (especially aluminum) and painted or varnished surfaces; they will not harm bare wood. Health and safety concerns limit the use of these products to specific situations or warrant increased personal protection measures.

Health and safety:
Alkalis are very caustic. Personal protective equipment (e.g., rubber gloves, boots, raincoat or apron, goggles) is essential when preparing or applying any of these agents. Exposure can cause severe skin burns. Dust from these products may cause severe burning of the eyes and mucous membranes or respiratory tract if inhaled. They can also cause burns on the footpads of animals and hoof drying and cracking.

Specific alkali compounds:

- ***Sodium hydroxide [NaOH] (i.e., lye, caustic soda, soda ash)*** is a commonly used strong alkali which has been applied extensively for cleaning and disinfection in various industries (e.g., slaughter houses, dairy industry). It has been used to disinfect buildings. Only two products are registered by EPA and neither is for agricultural uses. Only USDA-APHIS has an exemption to use this chemical to inactivate foreign animal disease agents. It is considered an effective FMD disinfectant.

  Sodium hydroxide is highly caustic and can damage metals, especially aluminum and derived alloys. Protective clothing, rubber gloves, and safety glasses should be worn when mixing and applying the chemical.

Never pour water into lye! A violent chemical reaction can occur, and high heat will be generated (which can melt plastic containers). **Sodium hydroxide solutions should ALWAYS be prepared by carefully adding the lye into water.**

- ***Sodium carbonate*** [Na_2CO_3] (soda ash, washing soda) is a very good cleaning agent and has been used in a hot solution (180°F) for disinfecting buildings, which have housed animals with FMD. It is more effective as a cleanser than a disinfectant since it lacks efficacy against some bacteria and most viruses. A 4% solution has been listed as an approved chemical for the FMD virus. It has poor activity in the presence of organic material and can be deactivated by hard water. It can be irritating and requires protective clothing and is harmful to aquatic life. Only four products containing this active ingredient are EPA-registered, and the maximum concentration of active ingredient in one product is 3%. Only USDA-APHIS has an exemption for use of this chemical to inactivate FAD agents. A 4% solution has been used for washing vehicles and cleaning the hooves of horses being imported into the United States. This product can cause irritation during application and is harmful to aquatic life.
- ***Calcium oxide (quicklime)*** when mixed with water becomes lime wash, which is sometimes spread on the ground following depopulation of infected premise and has been used to retard putrefaction of buried carcasses after depopulation. It has biocidal effects on some bacteria and viruses. It is not very effective against the FMD virus. Only one product containing calcium oxide is EPA-registered, and that is labeled for treatment of medical wastes.
- **Calcium hydroxide** [CaOH] (i.e., air-slaked lime) is reasonably effective against many non-spore-forming organisms. No end-use products containing calcium hydroxide are currently EPA-registered, so the following uses are not registered at this time. When mixed with water, it forms hydroxyl ions (–OH) and liberates heat [$CaO + H_2O = Ca(OH)_2$ + HEAT]. Although it is not sporicidal, it has been used to disinfect premises. A 20% suspension is commonly used as whitewash.
- ***Ammonium hydroxide*** is an effective disinfectant against coccidia oocysts however strong solutions emit intense and pungent fumes.[5] This substance is not considered effective against most bacteria, therefore additional methods of disinfection should follow the use of this compound.

Note: Quicklime (calcium oxide) is produced by burning limestone. If water is added to quicklime, slaked lime is produced. If lime is exposed to the air, air-slaked lime (calcium hydroxide) is formed.

Biguanides

Biguanides are cationic compounds (e.g., surfactants) and are detrimental to microorganisms by reacting with the negatively charged groups on cell membranes which alters permeability. Chlorhexidine (e.g., Nolvasan®, Virosan®) is one of the most widely used biguanides.

Uses: Biguanides are most often used as a skin antiseptic and for preoperative skin preparation. It has also been used as an effective cattle teat dip. Two chlorhexidine products are EPA-registered for use on farm premises. They have been formulated in conjunction with quaternary ammonium compounds.

Microbial spectrum: Biguanides have a very effective bactericidal action, but are generally more effective against gram-positive species. Some bacteria (e.g., *Pseudomonas*) may be resistant. Effectiveness against viruses and fungi is variable. These products are not sporicidal or tuberculocidal (e.g., Mycobacteria).

Characteristics of the class:
Biguanides are easily inactivated by anionic soaps and detergents, hard water and organic matter and are pH sensitive, only functioning in the range of pH 5-7. These products are toxic to fish and should not be discharged into the environment.

Health and Safety:
As antiseptics, these products are generally safe for skin contact. Biguanides are toxic to fish and should not be discharged into the environment.

Halogens

Halogen-based compounds include chlorine (e.g., sodium hypochlorite/bleach, chlorine dioxide) or iodine-containing agents. They are strong oxidizing agents and commonly used disinfectants in animal settings. The antimicrobial impact of halogens is due to their electronegative nature (i.e., free chlorine or iodine) which denatures proteins.

Microbial spectrum:
When used on clean surfaces, halogen-based compounds are broad-spectrum, with efficacy against bacteria, most viruses, *Mycobacteria*, and fungi; they can be sporicidal at high concentrations. Efficacy can be rapid, but is related to the concentration level of free halogen ions. For example, the low concentrations (2 to 500 ppm) of chlorine compounds are active against vegetative bacteria, fungi and most viruses. Rapid sporicidal action can be obtained around 2500 ppm, however this concentration is very corrosive so should be limited in its use.

Characteristics of halogens:
Halogens are considered low in cost and easy to use. Halogens rapidly lose their efficacy in the presence of organic material. These products must only be applied to thoroughly cleaned surfaces. Fresh solutions should always be used. Sunlight (i.e., UV light), high temperature, pH and some metals can also inactivate halogen products. Solutions are not active at temperatures above 110^{o}F or at pH levels greater than 9. They are generally compatible with soaps and detergents and are not affected by water hardness. Chlorine-containing compounds are very corrosive to rubber, fabrics, and some metals; concentrated solutions can etch or erode concrete surfaces over time. Iodine containing products can stain surfaces.

Health and safety:
Halogens products are generally considered to be low in toxicity; however, high concentrations of hypochlorites are irritating to the mucous membranes, eyes, and skin, and can cause damage to the footpads of animals. **Halogens, especially those containing chlorine, should never be mixed with strong acids or ammonia - toxic chlorine gas can form**. Halogens are highly toxic to aquatic animals; discharge into watersheds or waterways must be avoided. If this is not possible, efforts should be taken to neutralize the halogen solution with sodium thiosulfate.

Specific halogen compounds:

Chlorine containing compounds: Hypochlorites are one of the most widely used chlorine-containing disinfectants. They are sold in liquid form (e.g., sodium hypochlorite - household bleach) or as a solid (e.g., calcium hypochlorite - a swimming pool chemical). There are hundreds of EPA-registered antimicrobial pesticide products containing sodium or calcium hypochlorite as the active ingredient

- When using bleach, it is important to determine the stock concentration the product being used, as this will affect dilution ratios. Regular strength household bleach is a 5.25-6% aqueous solution of sodium hypochlorite (52,500-60,000 ppm available chlorine). Concentrated or "germicidal" bleach formulations are 8.25% sodium hypochlorite (82,500 ppm available chlorine).
- Sanitizing and disinfecting concentrations vary from 50 to 5,000 parts per million (ppm). A 1:32 (bleach:water) dilution is generally used for routine disinfection purposes. A 1:10 dilution may be used for outbreak situations, but this is a very strong solution and should be used on a limited basis. For example, this concentration has been used at anthrax clean-up sites under a crisis exemption.

Table 3. Bleach dilutions.

% standard bleach solution (5.25% sodium hypochlorite)	**0.025% bleach solution**	**0.05% bleach solution**	**0.1% bleach solution**	**0.16% bleach solution**	**0.5% bleach solution**
ppm available chlorine	~250 ppm	~500 ppm	~1,000 ppm	~1,562 ppm	~5,000 ppm
Use	Sanitizing	Disinfection	Disinfection	Disinfection	**Strong solution, use on limited basis**
Dilution (bleach:water)	1:200	1:100	1:50	1:32	1:10
Amount of standard bleach (5.25%) in 1 gallon of water	5 teaspoons 1.5 Tbsp	2-1/2 Tbsp. (1/6 cup)	2 Tbsp 1/3 cup	1/2 cup (4 fl. oz.)	1-1/2 cups (12 fl. oz.)

1 tablespoon = 3 teaspoons = 1/16 cup = 1/2 fluid ounce

Note: Always add bleach to water

A useful chlorine dilution calculator is available from Public Health Ontario.

Iodine-containing compounds: The most commonly used iodine-containing compounds for disinfection purposes are iodophors, complexes of iodine with a solubilizing agent which sustains slow release of free iodine. Povidone-iodine (i.e., polyvinylpyrrolidone) is one such example.

Iodophors are broad-spectrum disinfectants. They are bactericidal, mycobactericidal, and generally virucidal (may be less effective against non-enveloped viruses compared to chlorine-containing compounds). Several iodine-based disinfectants are EPA-registered. Concentrated Iodine-containing solutions can be irritating to the skin and may also stain clothes and damage rubber and some metals.

Peroxygen Compounds

Peroxygen disinfectants are another class of broad-spectrum, rapidly-acting oxidizing agents, that are commonly used in animal settings. Examples include hydrogen peroxide containing products (e.g., Accel® (also sold as Rescue or Intervention), peracetic acid, and peroxymonosulfates (e.g., Virkon ™ S). There are also several combination products (e.g., OxyCide™, a hydrogen peroxide + peracetic acid formulation). They function by denaturing the proteins and lipids of microorganisms leading to membrane disorganization.

Microbial spectrum:
Peroxygen compounds vary in their microbiocidal range (see specific peroxygen compounds for descriptions).

Characteristics of peroxygen compounds:
Peroxygens are considered effective on hard surfaces and equipment. These products may have some efficacy in the presence of organic material.

Health and safety:
In their diluted form, these agents are considered relatively low toxicity, but concentrates may be irritating to the mucous membranes, eyes and skin and damage clothing. These products are considered environmentally friendly, and has increased safety as it decomposes to oxygen and water.

Specific peroxygen compounds:
Hydrogen peroxide [H_2O_2] is rapid acting. Solutions of 5-20% are considered bactericidal, virucidal (for enveloped viruses), fungicidal, and sporicidal (at the higher concentrations). Non-enveloped viruses may be resistant, and its effectiveness against spores, and acid-fast bacteria (e.g., *Mycobacteria)* is limited. [Note: Household (over-the-counter) hydrogen peroxide consists of a 3-10% solution; industrial concentration hydrogen peroxide is a 30% or greater solution.] Over 100 antimicrobial pesticide products containing hydrogen peroxide are EPA-registered. Hydrogen peroxide solutions alone are generally unstable and can break down quickly, so fresh solutions should be used.

Accelerated hydrogen peroxide products (e.g., Accel Rescue/ Intervention) incorporate additional compounds, such as stabilizers to minimize the degradation after mixing and surfactants to enhance the cleaning ability.

Peracetic acid [$CH_3C(O)OOH$] (peroxyacetic acid) (e.g. OxySept™ 333, OxyCide, Oxonia Active™) is a strong oxidizing agent and is a formulation of hydrogen peroxide and acetic acid. It is considered bactericidal, fungicidal, sporicidal and virucidal. It is also effective against mycobacteria and algae and has some activity in the presence of organic material. Over 50 antimicrobial pesticide products containing peracetic acid are EPA-registered. Peracetic acid in its pure form is extremely shock sensitive and explosive; modern stabilized products are generally mixtures of low levels of peracetic acid (0.25%), hydrogen peroxide, and/or acetic acid to reduce this risk. Solutions may corrode soft metals such as copper or brass, as well as steel and galvanized iron. It can also react with natural and synthetic rubber, releasing potential carcinogens.

Peroxymonosulfate-based products (e.g., Virkon S, Viroxide) are broad-spectrum products with some efficacy in the presence of organic material. One example is Virkon™S, a buffered potassium peroxymonosulfate and sodium chloride formulation. This product is typically used at a 1% solution, which has a pH of 2.6, so it should not be used on skin. In general, the prepared solutions are considered to have low human toxicity; however, preparation of the powdered form can cause mucous membrane irritation. Face and eye protection should be worn. Virkon® S has been shown to be effective for direct misting of hard to reach surfaces and for footbath solutions. Prepared solutions are unstable once diluted (a 1% solution degrades to half-strength in six days. Product ingredient decomposition and degradation are considered comparatively harmless to the environment. It can be corrosive to steel, iron and concrete.

Phenols

Phenols [C_6H_5OH] are among the oldest established disinfectants and include compounds derived from coal-tar or synthetic formulations or various homologues (e.g., cresols, xylenols and ethylphenols). These compounds can have a strong pine-tar odor and usually turn milky when added to water. A commonly used phenol compound is orthophenylphenol. Over 90 antimicrobial pesticide products containing orthophenylphenol are EPA-registered. Examples include PhenoTek 128 (ABC Compounding Company, Inc.), Tek Trol II (2-benzyl-4-chlorophenol, o-phenylphenol).

Phenols function by denaturing cellular proteins and inactivating membrane-bound enzymes. This disrupts cell wall permeability and causes molecular instability of microorganisms.

Microbial spectrum:
Phenols are typically formulated with soap (anionic) solutions to enhance their penetrative power. The antimicrobial activity depends on the formulation. In general, phenolics are broad-spectrum, and considered effective against many bacteria, mycobacteria, fungi, and enveloped viruses. Their efficacy against non-enveloped viruses is variable. They have minimal sporicidal activity. One of the substituted phenols, 2-phenylphenol, is particularly effective against *Mycobacterium* species and was extensively used during the U.S. campaign against *Mycobacterium bovis*.

Characteristics of phenols:
Phenols are stable at concentrated and use dilutions. They have a high tolerance of organic load and hard water. Some products may have residual activity after drying. Phenols are temperature sensitive and should be applied at a temperature of 60°F or greater. If the environmental temperature is below 60°F, heating the solution to 120°F (49° C) or higher can help ensure proper temperature during necessary contact time. Nonionic and cationic surfactants (e.g., quats) can reduce the activity of phenolic products. Phenols are readily absorbed by porous materials and can damage rubber and plastics.

Health and safety:
Phenols are readily absorbed through the skin and can cause severe burns at high concentrations. Skin and eye irritations have also occurred. These compounds can have a strong pine-tar odor that can be irritating to the respiratory tract. Phenols are fatal if swallowed.

Concentrations over 2% are highly toxic to all animals, especially cats (e.g., systemic toxicosis) and pigs (e.g., dermal contact lesions). Surfaces should be thoroughly rinsed prior to restocking of animals. There are environmental concerns when disposing of these compounds, so containment efforts may be warranted.

Quaternary Ammonium Compounds

Quaternary ammonium compounds (QAC, (sometimes referred to as “quats”) are a diverse group of cationic surfactants normally used for routine cleaning of noncritical surfaces. Hundreds of antimicrobial pesticide products containing QACs are EPA-registered.

There are several “generations” of products that vary in composition and performance. Later generations are typically more germicidal, less foaming, more tolerant of organic loads and anionic soaps and detergents. Active ingredients for each generation are listed below. Example QAC products include KennelSol®, Virex®, Lysol®; benzalkonium chloride is one of the most widely used.

QACs function by irreversibly binding to the negatively charged phospholipids in bacterial cell membranes and denaturing membrane proteins impairing permeability.

Table 4. Common active ingredients for various quaternary ammonium compound generations.

Generation	Active Ingredient Examples
First generation	Benzalkonium chloride ADBAC: alkyl dimethyl benzyl ammonium chloride
Second generation	ADEBAC: alkyl dimethyl ethylbenzyl ammonium chloride
Third generation	ADBAC + ADEBAC
Fourth generation	DDAC: alkyl dimethyl ammonium chloride (or dodecyl dimethyl ammonium chloride, dioctyl dimethyl ammonium chloride)
Fifth generation	DDAC +ADBAC

Microbial spectrum:
The antimicrobial spectrum of most QACs is generally limited. They are good against gram-positive bacteria. The can have limited efficacy against gram-negative bacteria, viruses and fungi. They are not generally mycobactericidal or virucidal for non-enveloped viruses. They are ineffective against spores.

Characteristics of quaternary ammonium compounds:
QACs are stable in storage, non-staining, and non-corrosive. Higher concentrations can be corrosive to metals. These products are affected by pH, and are more active at neutral to slightly basic pH but lose activity at pH less than 3.5. They can also have reduced activity in hard water conditions and are easily inactivated by organic material and anionic detergents (this may vary with the “generation”). Some products may have a bacteriostatic residual effect, keeping surfaces bacteriostatic for a brief time. Surfaces that will come into contact with food must be rinsed to ensure that there are no traces of chemical disinfectants that could contaminate the food.

Although uncommon, incorrect use or working at sub-lethal concentrations can lead to the emergence of tolerant microorganisms that make it necessary to increase the dose and/or combine different types of biocides. [Langsrud 2003]

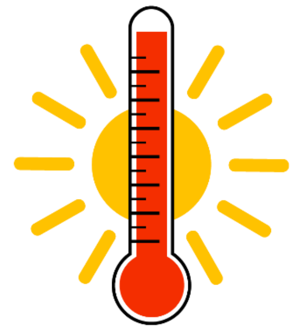
Health and safety:
When used at recommended dilutions, QAC are generally non-toxic. Higher concentrations can cause irritation of the skin, eyes, and respiratory tract, including oral and skin ulcerations, pneumonia and possibly rarely, death. Quats are highly toxic if ingested, so areas or items disinfected with these products should be rinsed thoroughly after an appropriate contact time and before animal use. These products are toxic to aquatic animals, particularly fish, so runoff into external water sources should be avoided.

PHYSICAL DISINFECTION
Disinfection can also include several physical methods, such as drying or desiccation, the application of heat, and the use of ultraviolet irradiation, and may be used in some circumstances in animal settings.

Drying (Desiccation)
Water is a critical component for the metabolism and survival of microorganisms. The loss of water (i.e., desiccation or dehydration) can inhibit the activity and growth, and possibly kill some microorganisms. However, a number of pathogens, such as parvovirus, calicivirus, many food-borne pathogens (such as *Salmonella*), bacterial endospores and protozoal oocysts can survive and be persistent in the environment. The effectiveness of drying varies and is influenced by environmental conditions such as moisture, pH, and

surface type, so the drying process is most often used in combination with other disinfection methods, and is an important last step in the C&D protocol.

Heat (Thermal Inactivation)



The use of heat is one of the oldest physical methods against microorganisms, and can be a fairly reliable method of sterilization. The process causes irreversible structural and functional damage (e.g., DNA disruption (breaks), protein denaturation, oxidative damage, and loss of membrane integrity) to microorganisms.

Heat can be applied under moist or dry conditions. Dry heat applications include burning or direct flaming, or hot air, such as baking. Moist heat can be effectively applied through steam, boiling, pasteurization, or autoclaving (i.e., steam under pressure). Moist heat applications are generally more effective and require less time than dry heat.

- Steam under pressure (e.g., autoclaving) is the most efficient since it can achieve temperatures above the boiling point of water, which may be necessary when dealing with thermally resistant bacterial spores.
- Dry heat applications involve incineration (i.e., direct flaming) or hot air (i.e., baking). In addition to temperature impacts, the loss of water loss of water content inhibits bacterial activity and growth and can result in the destruction of some bacteria in seconds. Heat baking transport trailers has been used as a measure to reduce the transmission of swine pathogens (van Kessel 2020, 2021; Dee 2005).
- Pasteurization - the application of heat to food or liquid items (e.g., milk, cheese) – uses heat at designated temperatures for an established amount of time (e.g., 145°F (63°C) for 30 minutes), to destroy pathogenic organisms. Pasteurization does not kill all microorganisms, but may be one process needed during an animal health emergency situation if the dumping of milk from affected animals is necessary.

Most microorganisms can be destroyed at temperatures greater than 158°F. Destruction is generally more rapid as temperature increases, and thermal inactivation can be a reliable method of sterilization. some pathogens (e.g., *Bacillus anthracis* endospores) are exceptionally thermostable and can require temperatures of 250°F or more for destruction.

However, the thermal inactivation process is gradual. It takes time for the process to have its effect. The time required for microbial death is inversely related to the temperature and directly related to the number of microorganisms. Microbes are generally killed more rapidly as temperature increases.

Considerations when using heat disinfection methods

- The object being heat disinfected must be able to withstand the temperature used. Heat disinfection works best for metal, glass, and fabrics; direct flaming has been used for concrete.
- The presence of organic material can impede heat disinfection processes. Surfaces need to be cleaned first.
- Temperature and exposure times need to be measured and monitored to ensure the targeted goal is achieved. Equipment, such as thermometers or monitoring equipment, should be periodically checked for accuracy.
- If the method is used for large areas (e.g., barns, vehicle bays), thermometers should be placed in various locations to ensure all areas reach the desired temperature.

Example 1: Dry Heat

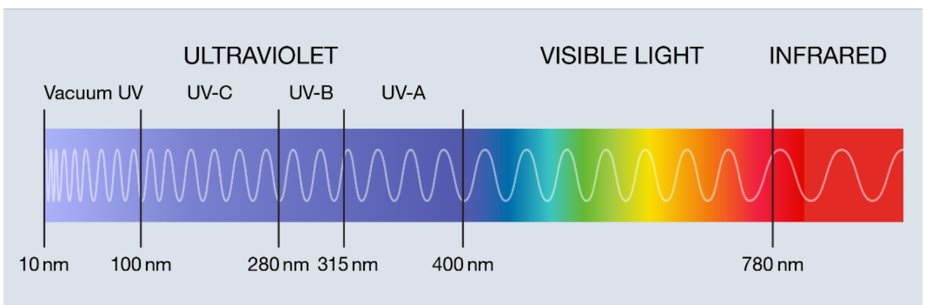
One example of the use of dry heat in animal settings is the heat baking of transport trailers. Thermo-Assisted Drying and Decontamination (TADD) systems use a natural gas or LP heater in combination with high-volume, high-velocity fans to heat and dry livestock trailers quickly. Chemical disinfection is not required. The temperature and time required to inactivate pathogens varies, but TADD systems are generally an effective and time-saving disinfection method compared to washing, chemical disinfection, and drying overnight.

Example 2: Dry Heat

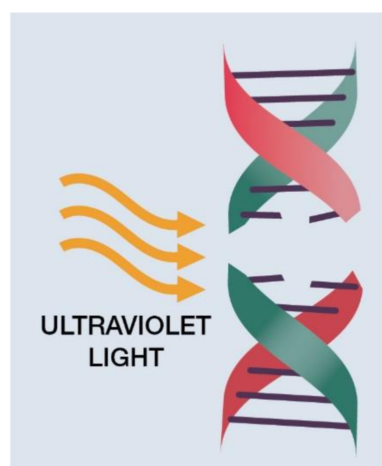
During the 2014-2015 HPAI outbreak response in the U.S. the heat treatment of poultry houses was a key method used for virus elimination. The process involved dry cleaning and the heating of poultry buildings to an established temperature over a set period of days. Barns/houses required heating between 100°F and 120°F for a total of 7 days; with at least 3 consecutive days (of the 7 days) of heating continuously to within this temperature range. This method was found to be a cost effective and accepted method of disinfection/virus elimination for the emergency response. Heat treatment may not be appropriate in all situations.

Ultraviolet Radiation

Another physical disinfection method used to destroy microorganisms involves non-ionizing radiation – in particular ultraviolet light (UV). This is most commonly applied by exposure to direct sunlight (solar radiation), but the use of mercury vapor lamps or ultraviolet light chambers or pass-through boxes are becoming more frequent.



UV light is a form of non-ionizing (low energy) radiation, with wavelengths between 100-400 nanometers (nm). The most effective biocidal wavelengths ("germicidal" range) fall within the UV-C range of 200-280 nanometers; this spectrum has biocidal effects on bacteria and can inactivate single-stranded RNA viruses on surfaces. [Ruston 2021, Cutler 2011]



The electromagnetic energy of UV light is invisible to humans. However, it damages or alters essential cell components, particularly nucleic acids (e.g., cellular DNA), through a photochemical reaction. This can have a detrimental effect on a number of microorganisms and may be a practical, supplemental method for inactivating viruses, mycoplasma, bacteria and fungi, particularly those that are airborne.

To be destroyed, microorganisms must be directly exposed to the UV-C beam. The required dose (e.g., length of exposure) varies by pathogen. Bacterial spores can be resistant, and require 10 times the exposure time as the vegetative forms of the organisms.

UVC radiation has been found useful for the control of airborne pathogens in enclosed areas, such as surgical sites, medical settings, or shelter environments. It has been used for air-handling units and ventilation systems, as well as for water disinfection.

UV light has a very limited capability to penetrate water, soil or organic material. A recent study [Ruston, 2021] found that while the top layer of an earthen manure storage (lagoon) exposed to direct sunlight was found to contain low levels of porcine epidemic diarrhea virus (PEDV), high amounts of infectious virus remained at increased depths. Therefore, the use of UV-C radiation is limited for surfaces, and like other disinfection methods, cleaning should occur prior to disinfection. Additionally, delivering the inactivating dose in a uniform and consistent manner can be a significant challenge.

UVC light can be used for on-farm disinfection of small items like lunch boxes, cell phones, tools, and medications. Most applications are designed as a pass-through chamber, where items move from the dirty side (entryway or hallway) to the clean side (office or break room). Items are cleaned and placed within the chamber on wire shelves with space in between them or treatment. To be effective, UVC chambers must be properly constructed and maintained. All individuals using the chamber must be trained.

Considerations when using ultraviolet light disinfection methods

- Ultraviolet light produces primarily a surface effect. It does not penetrate even a thin layer of dirt or debris. When used to inactivate airborne microorganisms, UV light efficacy can be affected by temperature and relative humidity. When used for water, the layers exposed to the light must be very thin.
- Irregular or porous surfaces, such as cardboard, cloth, cracks, or crevices, can shield microorganisms from the incident beam. Items should not be stacked on top of each other or block one another from exposure to the UV-C beams. Care should be taken to ensure there is space between items, so all surfaces can be exposed.

OTHER PHYSICAL METHODS OF MICROBIAL REDUCTION

Filtration: While not a true disinfection method, filtration can be used to physically remove microorganisms from gasses and fluids. For example, high-efficiency particulate air (HEPA) microfilters (≥0.3µm) use biologically inert material to prevent or retard the passage of microorganisms based on their size. This process enhances the safety of discharged air and has been used in some capacity in swine production. [Dee 2012]

Freezing: Freezing is a type of environmental stress for microbes, but it is not a reliable method of disinfection. While cold temperatures may inhibit or kill some pathogens, others can tolerate or may even adapted for it. For example, *Listeria monocytogenes*, can reproduce and survive in refrigerated foods.

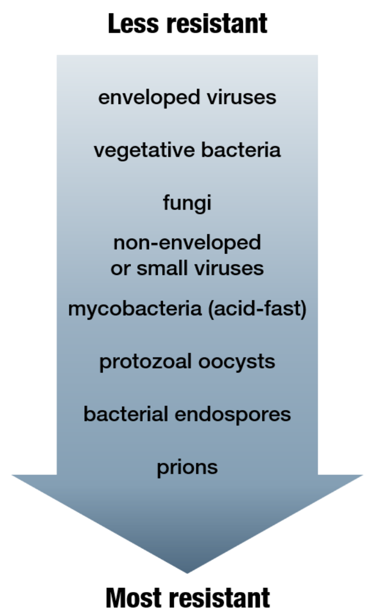
CONSIDERATIONS WHEN SELECTING A DISINFECTION PROCESS

Selecting an appropriate disinfectant (or disinfection method) is an essential component of any C&D program. No single disinfectant is adequate for all situations. There are a number of factors to be considered since they can impact efficacy, possibly cause failure of the disinfection procedures, or result in hazards or injury to personnel or animals. Selection will depend on the microorganism(s) suspected, availability, the characteristics of a specific disinfectant or process, environmental factors and safety issues.

MICROORGANISM CONSIDERATIONS

Selection of a disinfectant begins with the identification of the target microorganism. It is easier to select a product or protocol for a single microorganism, although this is not always possible in everyday practice. If the organism has not been identified, or a disinfectant is needed for a wide range of organisms, a broad-spectrum approach should be utilized.

General Microbial Resistance to Chemical Disinfectants



Resistance and Susceptibility

Microorganisms vary in their ability to survive or persist in the environment as well as their susceptibility to disinfection. It is important to not only be aware of the suspect or confirmed pathogen involved but also its ability to persist in the environment, its routes of transmission as well as its susceptibility to disinfection.

Bacteria: Most vegetative bacteria (e.g., gram-positive, gram-negative) are readily inactivated by disinfectants. Some, such as *Pseudomonas aeruginosa* and *Coxiella burnetii*, can have greater resistance to disinfection. *Mycobacteria* and other acid-fast bacteria and bacterial endospores are highly resistant to disinfection, often requiring specific products, increased concentrations, or prolonged contact times.

Fungi: The vegetative stage of fungal organisms are susceptible to most disinfectants; however, fungal spores are usually quite resistant.

Viruses: Virus susceptibility is generally related to the presence or absence of a lipid envelope and size.

- **Enveloped viruses** (e.g., coronaviruses, herpesviruses, orthomyxoviruses, paramyxoviruses, retroviruses) are generally the most susceptible due to their lipophilic nature.
- The lack of envelope for **non-enveloped or naked viruses** (e.g., adenoviruses, picornaviruses, reoviruses, rotaviruses) makes these pathogens more hydrophilic, resulting in increased resistance.
- **Small, non-enveloped viruses** (e.g., parvoviruses, picornaviruses, or caliciviruses) demonstrate even greater resistance due to their size and lack of an envelope.

Prions, the etiologic agents of bovine spongiform encephalopathy, scrapie, and chronic wasting disease, are exceptionally resistant to chemical inactivation.

Tables to review animal virus families by type (enveloped or non-enveloped) and by size can be found on the CFSPH Disinfection webpage. An *Antimicrobial Spectrum of Disinfectants* table, that shows general susceptibilities to disinfectant chemical classes can also be found on the webpage.

Other Resistance Mechanisms

Biofilms

Although cleaning may appear to remove all debris, biofilms - an invisible, complex aggregation of bacteria - may remain on surfaces. Some bacteria (e.g., *Staphylococcus aureus, Staphylococcus epidermidis* and *Pseudomonas aeruginosa*) can create biofilms, which enhances their ability to persist in the environment and avoid the action of disinfectants. This action is often triggered in response to variety of environmental stresses, such as UV radiation, desiccation, extreme pH or temperatures - many of the same methods used for disinfection purposes. Biofilms are highly resistant to disinfection. The use of detergents, mechanical scrubbing, brushing, and scraping can help remove biofilms.

Repair mechanisms
Some bacteria have the ability to counter the effects of the disinfection process (e.g. nucleic acid repair).

Number and location of microorganisms
The location of microorganisms can also pose challenges disinfection. While smooth, non-porous surfaces are generally easy to clean and disinfect, items with complex structures, multiple pieces, crevices, or joints can present challenges during the disinfection process. Additionally, the larger the number of organisms present, the greater the quantity of germicide and time will be needed.

DISINFECTANT CONSIDERATIONS

The effectiveness of a particular disinfection product or method depends on its composition and the conditions under which it is used.

An ideal disinfectant is one that is broad spectrum, works in any environment and is non-toxic, non-irritating, non-corrosive and relatively inexpensive. Unfortunately, no disinfectant is ideal. Therefore, careful consideration of the characteristics of a disinfectant (or disinfection method) is essential to select the most useful, effective and cost-efficient product.

Chemical Class

As previously discussed, chemical disinfectant classes vary in their effectiveness against pathogens. Each class varies in its mechanism of action, microbial spectrum, as well as advantages and disadvantages for use, including safety issues. Combination products may have synergistic properties that expand its microbial spectrum. Read the product label (e.g., kill claims) before use so an effective product is selected.

Disinfectant Concentration.

Use of the proper concentration of a disinfectant is important to achieve the best results for each situation. Some products will have different dilutions depending on the desired use of the product (i.e., -*static* versus –*cidal* action; sanitizing vs. disinfection action). While using higher concentrations can be more efficacious, routine use may be limited by the degree of risk to personnel, surfaces or equipment, and cost of the chemical. However, over-dilution of a product will cause the disinfectant to be ineffective against the targeted microorganism(s). The product label will list the best concentration to use for each situation. Consider any standing water or other water sources (i.e., rainfall) as a potential dilution source for a disinfectant.

Application Method.

Disinfectants can be applied in a variety of ways including wiping, brushing, spraying, misting, soaking, fumigating, etc. Application methods should follow instructions described on the label should be used. If application results in insufficient coverage of surfaces, it can lead to ineffective efforts.

Contact Time.

Contact time is critical! Disinfectant products and methods need time to have their effect. This will vary depending on the product or method selected. For example, 70% isopropyl alcohol can destroy *Mycobacterium tuberculosis* in 5 minutes, whereas 3% phenol requires 2-3 hours. Poor application or evaporation during high temperatures will impact sufficient contact times. The minimum contact time needed will be provided on the product label. Surfaces must remain wet (for chemical disinfectants) or exposed (for physical methods) for the full contact time. Some chemicals may have residual activity (i.e., QAC) while others may evaporate quickly (i.e., alcohols), especially with high temperatures.

Stability and Storage.

The efficacy of a disinfectant product can also be affected by its stability after preparation as well as its shelf life. Use of an expired product or one with reduced active ingredients may be ineffective. Some disinfectants will degrade over time, especially when stored for long periods. Others can be inactivated by heat or light, or lose stability quickly after preparation. Many disinfectant products have test kits available to allow for assessment of the concentration of active ingredients. Disinfectant product labels may list the shelf life of the concentrated product. To maximize stability and shelf life, products should be stored in a dark, cool location and preferably in stock concentrations.

Safety Precautions.

Most disinfectants can cause irritation to eyes, skin and/or the respiratory tract, therefore, the safety of all personnel should be considered. Training on proper storage, mixing and application procedures is essential. Personal protective equipment (PPE), such as gloves, masks and eye protection, should be worn during the mixing or application of disinfectants. All chemical disinfectant have a Material Safety Data Sheets (MSDS) listing the stability, hazards and personal protection needed, as well as first aid information. This information should be available to all personnel. A 3-ring binder containing this information in one easily accessible location may be useful.

Expense.

Economic considerations are always important when selecting a disinfectant. Disinfection is generally a cost-effective means of reducing pathogenic organisms. Disinfectants vary in cost, contact time and dilution. **<u>Costs should always be calculated on a per gallon of use/dilution rather than the cost of concentrate</u>**. For example, consider a QAC concentrate that costs $68.00 per gallon (128 oz.). The dilution required is 0.5 ounces concentrate per gallon of water, which will cover approximately 100-150 square feet (10-15 m^2). The cost to disinfect a 500 (5*100) square foot room would be calculated as:

- Concentrate needed to cover the area: 0.5 oz per gallon x 5 gallons to cover the 500 sq. foot area = 2.5 oz concentrate needed to cover the 500 sq. foot area
- Concentrate cost per oz = $68.00/128 oz (i.e., gallon) concentrate = $0.53 per oz.
- $0.53 per oz x 2.5 oz (needed for 500 sq. foot area) = $1.33

Human Factor – Ease of use

Another important consideration is ease of use. How easy or hard is the product to apply? Does the product have an offensive odor? Is a long surface contact time, and possible reapplication required? These factors can impact the level of compliance personnel may have during a C&D procedure, and should be considered.

ENVIRONMENTAL CONSIDERATIONS

Environmental conditions can have a profound effect on disinfection success. This includes factors such as the organic load, the type of surface, temperature, water hardness, pH or the presence of other chemicals.

Organic Load (Heavy Soiling)

The presence of organic matter (e.g., soil, manure, body fluids, bedding) is one of the most important environmental factors to influence disinfection activity!

Organic matter provides a physical barrier that protects microorganisms from contact with the disinfectant. Additionally, debris and organic material can neutralize many disinfectants (e.g., chlorine, QACs), reducing the level of active ingredient available to attack microorganisms. Ultraviolet light applications, including direct sunlight, have limited penetration below the surface of organic matter. Some disinfectants, such as phenols or glutaraldehyde, are less affected by organic matter, and may need to be considered when the complete removal of organic debris is difficult. However, these products are not effective for heavy loads of organic material, so surfaces should still be cleaned first.

Surface Type

Surfaces in animal settings can be quite diverse. They may include various metals, glass, rubber, plastic, concrete, wood, or fabric or woven material (e.g., clothes, nets, and ropes). The type of material or complexity of an item can factor into disinfection efficacy.

Disinfectants are labeled for use on hard, non-porous surfaces (e.g., glass or stainless steel). Surfaces that are porous, cracked, or pitted (e.g., wood, concrete) or that have complex structure, such as hinges, bends, or crevices can be challenging to disinfect effectively. Some chemical disinfectants can be incompatible with or corrosive to certain materials or surface types.

Some products have been developed for use on porous surfaces, but generally require much longer contact times or higher concentrations. Alternative or supplemental disinfection methods, such as gaseous or vaporous sterilant products or physical disinfection methods (e.g., drying, ultraviolet light) should be used for treating porous surfaces. Flame guns (i.e., application of heat) may be a useful alternative if the item can withstand the high temperature.

Temperature

Temperature is another important environmental factor that can affect disinfectant efficacy. Considerations should include both the ambient temperature as well as that of the disinfectant solution. The exposure temperature is particularly important if you will be disinfecting outdoors (e.g., vehicles).

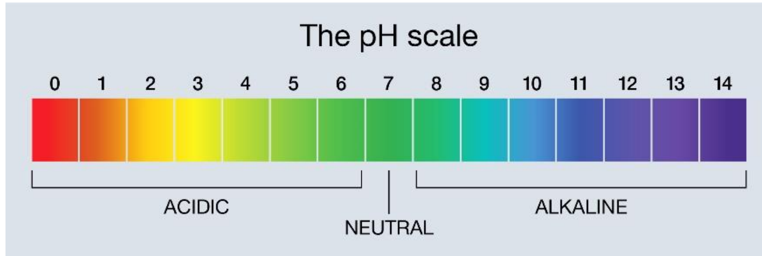
Most chemical disinfectants work best at temperatures above 68°F (20°C). Lower temperatures can reduce disinfectant efficacy or solutions may freeze in these conditions. Some disinfectant products are compatible with the addition of ethylene glycol to prevent freezing. Read the product label for appropriate instructions. Caution should be used, since antifreeze solutions can be highly toxic. The runoff of any solutions containing the chemical should be contained or avoided when possible.

Conversely, while elevated temperatures can aid in microorganism destruction, it can also accelerate the decomposition or evaporation of a disinfectant, thereby reducing the ability to achieve the necessary contact time, thereby affecting efficacy. Heat may also damage items being disinfected.

pH

pH extremes can be detrimental to microorganisms, however environments that are very acidic or very alkaline can alter the effectiveness of some disinfectants. pH changes in the environment may be caused by organic material, water composition (e.g., water hardness ions), or from other chemical products used. These conditions may change the degree of ionization or dissociation of the active ingredient of a chemical disinfectant or the stability of a solution. Examples include phenolics, hypochlorite, and iodine compounds.

This can affect efficacy. Some disinfectants have optimum pH ranges at which they work best. For example: The efficacy of glutaraldehyde is best at a pH greater than 7. Quaternary ammonium compounds have the greatest efficacy at a pH of 9-10.

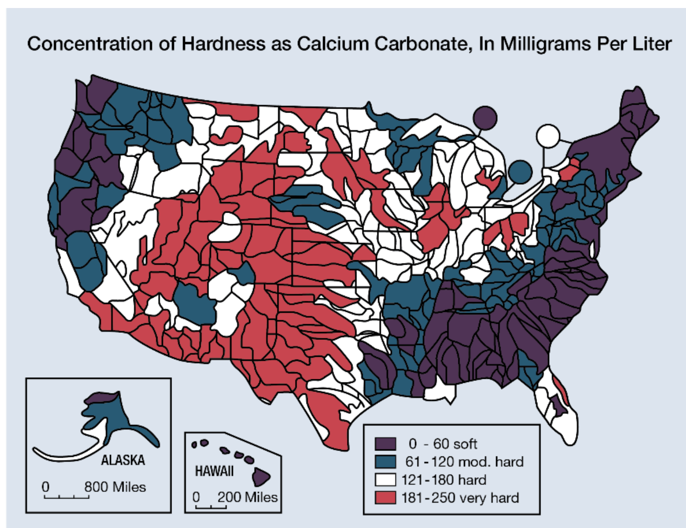


Presence of Other Chemicals

Another confounding factor that can impact disinfectant efficacy is the presence of other chemicals. While some disinfectant products contain cleaning or surfactant components to potentiate their effect, others can be inactivated by the residue when present. For example, iodine-based agents are inactivated by quaternary ammonium compounds, while phenols are commonly formulated with soaps to increase their penetrative ability.

Water Hardness

A factor not always considered influencing disinfectant activity is the hardness of water. Water hardness is determined by the amount of dissolved minerals, primarily calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions, in a water source. The presence of these ions can form complexes with cleaning and disinfection products, leading to inactivation, reduced efficacy, or residue buildup. This impact is particularly important for quaternary ammonium compounds, iodophors, and phenols. Many products have chelating agents, such as EDTA, to help bind these ions. Acids, such as acetic acid, can aid in dissolving mineral particles.



Water hardness varies throughout the United States (see map above). Commercial test kits to measure water hardness are available. Water harness classifications (in mg/L calcium carbonate) are listed below:

- 0 to 60 mg/L – soft;
- 61 to 120 mg/L - moderately hard;
- 121 to 180 mg/L – hard;
- greater than 180 mg/L - very hard

Relative Humidity

When using gaseous disinfectants, activity is influenced by the relative humidity of the environment. Relative humidity also influences the efficacy of ultraviolet light methods. Moisture content can affect the ability of the gaseous product to reach intended surfaces. For example, formaldehyde fumigation requires a relative humidity in excess of 70% for effectiveness.

DISINFECTANT PRODUCT LABELS–FINDING INFORMATION YOU NEED

Disinfectant product labels contain important information on the proper use and hazards of a chemical. This information is often overlooked, but understanding this information is essential for developing an effective disinfection protocol.

The product label tells important information, such as:

- What microorganisms the product is effective against
- The product's effectiveness under certain conditions (e.g., water hardness, presence of organic material)
- How to mix and apply the solution
- The necessary contact time the solution will need
- Any health and safety concerns
- Other considerations, such as storage and disposal or environmental impacts, flammability or corrosiveness

This information will vary among products, so it is always important to read the product label before use.

It is a violation of federal law to use a product in a manner inconsistent with its labeling.

EPA REGISTRATION NUMBER

Chemical disinfectants in the United States are registered and regulated by the U.S. Environmental Protection Agency (EPA). Products intended for the control, prevention, and destruction of pathogenic microorganisms on inanimate objects and surfaces are classified as "antimicrobial pesticides" under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA). This includes sanitizers, disinfectants, and some sterilants.

Any pesticide sold or distributed in the United States must be registered. Prior to registration and marketing of the chemical, the product's chemistry, efficacy, toxicity to humans, animals and plants, and other parameters must be tested and submitted for EPA review and approval.

- Most products are registered under FIFRA Section 3, Regular label.
- Some products can be registered under FIFRA Section 18, Emergency Use Exemptions. These are discussed in greater detail in Lesson 10: C&D During Disease Outbreaks.

All EPA-registered pesticides must have an EPA registration number listed on the label., which consists of a company identification number and a product number (e.g., 123-45). The EPA Registration Number indicates the product has been reviewed by the EPA and can be used with minimal risk when the label directions are properly followed. The number is not an endorsement or guarantee of product effectiveness.

Finding EPA-registered Products: The product label for any EPA-registered disinfectant may be retrieved by entering the registration number in the EPA's Pesticide Product Label System (PPLS) search engine. **Try it out! Enter the EPA-registration number of a product you currently use to obtain its product label and registration information.**

PRODUCT INFORMATION

Product Type

Chemical disinfectant products can be labeled as a cleaner, deodorizer, sanitizer, disinfectant, fungicide, virucide, tuberculocide, for hospital, institutional and industrial use, agricultural premises and equipment, veterinary use, etc.

Effectiveness Under Certain Conditions

The testing conditions used (e.g., efficacy in simulated organic load or hard water conditions) are provided. All disinfectants are tested in a manner that simulates the product's effectiveness under field conditions. These parameters are hard water conditions (e.g, up to 400 ppm hardness ($CaCO_3$) in the presence of 5% serum contamination). If a product has been tested under additional conditions, this will be indicated on the label.

CHEMICAL INGREDIENTS

Active Ingredients

The individual active ingredients contained in the product are listed as percentages and include the chemicals responsible for the control of the microorganisms. This information can be used to determine chemical class categories.

Table 5. Examples of active ingredients for various chemical classes of disinfectants

Chemical Class	Example Active Ingredients
Acids	Acetic acid, citric acid
Alcohols	Ethanol, isopropanol
Aldehydes	Glutaraldehyde, formaldehyde
Alkalis	Sodium hydroxide, calcium hydroxide, ammonium hydroxide, sodium carbonate, and calcium oxide
Chlorine-containing compounds	Sodium hypochlorite, calcium hypochlorite, chlorine dioxide
Peroxygen compounds	Hydrogen peroxide, peracetic acid, potassium peroxymonosulfate
Phenols	Orthophenylphenol, 2-phenylphenol
Quaternary Ammonium Compounds	Benzalkonium chloride, alkyl dimethyl ammonium chloride, alkyl didecyl dimethyl ammonium chloride, and dialkyl dimethyl ammonium chloride

Note: Some disinfectants can have a combination of chemical classes.

Inert Ingredients

Inactive ingredients are often lumped into one statement and include items such as soaps or detergents, dyes or coloring agents, perfumes, and water.

PRODUCT LABEL KILL CLAIMS (MICROBIAL SPECTRUM)

Review product label claims before choosing a disinfectant. Label claims list the microorganism (e.g., bacteria, viruses, protozoa) the product has been shown to be effective against when used according to label directions. Label claims must be supported by efficacy testing. Tests used are standardized and conducted under laboratory conditions that mimic field conditions.

Basic Efficacy Testing

EPA registers three types of disinfectant products based on efficacy data submitted using three specific test microorganisms:

- A **limited** efficacy disinfectant only has efficacy against one specific microorganism group, this is either the Gram-positive bacteria, *Staphylococcus aureus* or the Gram-negative bacteria, *Salmonella enterica*. The label must specify the group against which the product is effective.
- A **general or broad-spectrum** disinfectant is effective against both gram-positive and gram-negative bacteria. This claim must be supported by efficacy testing against *S. aureus* and *S. enterica*.
- A **hospital** designation is a general or broad-spectrum disinfectant that is also effective against the nosocomial bacterial pathogen, *Pseudomonas aeruginosa*

** Pseudomonas aeruginosa may be substituted for Salmonella enterica*

Additional Organisms

Efficacy claims against additional organisms (e.g., viruses, fungi) must be supported by established standardized testing for each particular organism. All data must be reviewed by EPA before it can be added to a product label.

In some instances, surrogate organisms may be allowed for certain claims. For example, *Mycobacterium bovis* is used as a surrogate for human *Mycobacterium tuberculosis* to determine tuberculocidal claims. Feline calicivirus is used as a surrogate for norovirus (i.e., small non-enveloped viruses). Testing for sporicidal claims use spores of *Bacillus subtilis* and *Clostridium sporogenes* or *B. anthracis.* Claims against biofilms must attain a minimum mean six log reduction of *Pseudomonas aeruginosa* or *Staphylococcus aureus* biofilms.

To learn more, see the EPA's Efficacy Requirements for Antimicrobial Pesticides and the EPA Product Performance Test Guidelines (OCSPP 810.2000).

Emerging or Novel Pathogens

What about emerging pathogens, particularly viruses? Many instances have occurred in recent years - Ebola virus, Mpox virus, rabbit hemorrhagic disease virus. These novel or emerging pathogens were unpredictable and are often not found on disinfectant product labels. Prior to 2019, labels did not include SARS-CoV-2. The EPA has a process where a company can apply for an emerging viral pathogen claim. In general, claims for harder-to-kill viruses may be allowed for acceptable emerging claims after review by the EPA.

The EPA and CDC divides viruses into three viral subgroups based on their relative resistance to inactivation by typical disinfectant products: small non-enveloped, large non-enveloped, and enveloped viruses.

- **Small, Non-Enveloped Viruses (<50 nm):** Considered highly resistant to inactivation by disinfection due to their very resistant protein capsid. Includes the families of Picornaviridae, Parvoviridae, Caliciviridae, Astroviridae, Polyomaviridae

- **Large, Non-Enveloped Viruses: (50-100 nm):** Considered less resistant to inactivation by disinfection compared to small, non-enveloped viruses, based on their larger size. Includes the families of Adenoviridae, Reoviridae, Papillomaviridae
- **Enveloped Viruses:** Considered the least resistant to inactivation by disinfection due to the presence of a lipid envelope, which is easily compromised by most disinfectants. Includes the families of Arenaviridae, Bornaviridae, Bunyaviridae, Coronaviridae, Filoviridae, Flaviviridae, Hepadnaviridae, Herpesviridae, Orthomyxoviridae, Paramyxoviridae, Poxviridae, Retroviridae, Rhabdoviridae, Togaviridae

Using this approach, antimicrobial products that can kill a small, non-enveloped virus should be able to kill any large, non-enveloped virus or any enveloped virus. Similarly, a product that can kill a large, non-enveloped virus should be able to kill any enveloped virus.

For more information see: selected EPA-registered disinfectants and antimicrobial products registered with EPA for claims against common pathogens and the EPA Emerging Viral Pathogen Program Guidance.

Emergency Exemptions

What about highly contagious foreign animal diseases? While some companies have conducted testing for some FAD organisms (FMD, ASF), other diseases may not be tested.

In the event of a FAD outbreak, when a particular pathogen is not be listed on the product label of an EPA-registered disinfectant, an exemption (Section 18 of FIFRA) may be authorized by EPA to allow Federal Agencies or States to use unregistered pesticides or the "off-label" uses of a registered pesticide for a limited time.

USDA-APHIS and EPA have been preparing for such an event, and have developed listings of approved disinfectants with both FIFRA Section 3 (i.e., a regular label) or exempted under FIFRA Section 18 (i.e., emergency use label) for use against select foreign animal diseases.

For more information on emergency exemptions:

--USDA-APHIS: Potential EPA-registered disinfectants to use against the causative agents of selected foreign animal diseases in farm settings

--EPA: Pesticide Emergency Exemptions

--Code of Federal Regulations Title 40, part 166. Exemption of Federal and State agencies for use of pesticides under emergency conditions

DIRECTIONS FOR USE

The use directions for the product are stated on the label. This may include housing areas, vehicles, equipment, footwear, etc. All disinfectants are labeled for hard, non-porous surfaces; some may be labeled for food or non-food contact surfaces, wood or concrete. Different concentrations, contact times, or application methods may be needed depending on the surface or area being disinfected.

- **Where to Use:** Registered use locations are listed and may include hard, non-porous surfaces, food or non-food contact surfaces, boot or shoe wash, vehicles, wood or concrete.

- **How to Use:** Formulations may be ready to use (RTU) or concentrated and require dilution or mixing. Mixing or dilution directions will be on the label. The application method (e.g., spray, wipe, soak) to for the product will also be noted on the label.
- **Storage and disposal:** Instructions for storing the product and for disposing of any unused pesticide and the pesticide container will be listed.
- **Compatibilities:** The label will also include considerations such as optimum temperatures, organic matter, and other factors that may affect the product's efficacy.
- **Specific Uses:** Instructions for specific uses such as boot baths, vehicles, or food-contact surfaces will be provided.

HEALTH AND SAFETY INFORMATION ON THE PRODUCT LABEL

A critical area of the product label is the Health and Safety section. All chemical disinfectants have safety concerns. Precautionary statements, hazards to humans, animals, or the environment, protective equipment that should be worn, first aid and medical treatment information will be provided. This information should be read and understood by anyone using the product.

Hazards/Precautionary Statement

Most disinfectants will have a Hazards/Precautionary Statement. Specific "signal words" are used to indicate the degree of hazard. Descriptors used (from least harmful to most harmful) are:

- "Caution",
- "Warning",
- "Danger" and
- "Danger-Poison".

Most contain "Keep out of Reach of Children" Statement, which may extend to dangers for animals.

Additional Health and Safety Information

- **PPE:** The product label – either in the health and safety information section or the Directions for Use section will outline **personal protective gear** that should be worn when mixing and applying the product.
- The **first aid** section will contain instructions for handing various routes of exposure (e.g., accidental swallowing, inhalation or skin contact with the product).
- A **"Notes to Physicians"** section may be listed with specific medical information needed by medical professionals in the case of poisoning.
- **Physical or chemical hazards**, such as flammability, corrosiveness, or explosive characteristics will be stated, with guidance on precautions to take.
- **Environmental hazards** are listed and address risks to birds, mammals, fish, aquatic invertebrates and estuarine organisms, and pollinating insects.

HEALTH AND SAFETY DURING C&D

Ensuring the health and safety of people, animals, and the environment during C&D procedures is essential. All disinfection methods have some level of hazard associated with their use. Careful attention should always be paid to warning and safety statements printed on the product label. Personnel training, personal protective measures and safety precautions should always be taken.

CHEMICAL HAZARDS

All chemical disinfectants can have some level of hazard if not used appropriately. Exposures may occur during preparation of a product or when applying solutions. During preparation, exposure to concentrated solutions can occur if the product is spilled or if splashes occur while pouring. During application, sprays or misting of solutions can expose the eyes, skin, or the respiratory tract.

Health effects may occur acutely or develop after prolonged or extended exposures. Effects can range from mild irritation to severe damage of the skin, eyes, or respiratory tract. Impacts to people and possibly animals may include:

- Irritation to the eyes, skin, mucous membranes, or respiratory tract
- Allergic reactions, such as allergic dermatitis or asthma attacks
- Irreversible eye damage
- Chemical burns from corrosive chemicals, especially concentrates
- Respiratory distress, if inhaled
- Some chemical classes of disinfectants (e.g., formaldehyde) are considered potential carcinogens.
- All are toxic if ingested

Product labels should always be read for any health and safety risks and the recommended protection measures. All chemical disinfectants also have a Material Safety Data Sheet (MSDS) listing the stability, hazards, and personal protection needed, as well as first aid information. This information must be kept on site and be available to all personnel handling disinfectants. A 3-ring binder containing this information in one easily accessible location is recommended.

PHYSICAL HAZARDS

In addition to potential chemical exposures and injuries, various physical hazards are also a concern during C&D duties. The following highlights some of these risks:

- Cutaneous burns when using hot water, steam, flame, or other heat disinfection methods.
- Direct exposure to high levels of UV light can damage the skin or eyes.
- Skin punctures or injury from water jets are possible when using high pressure sprayers.
- Respiratory irritation may occur from the generation of dust during the cleaning phase.
- Musculoskeletal injuries may occur following a slip, trip or fall working in wet, slippery conditions.
- Tripping hazards from hoses or other C&D equipment will be in the work area.
- PPE worn can limit a person's range of motion and vision, predisposing them to falls and it can also quickly lead to overheating.
- Electrical shock can be a risk when electrical equipment is not turned off.

Table 6. Summary of some of the health risks for the chemical classes of disinfectants.

Chemical Class	Hazards to People, Animals, or the Environment
Acids	Corrosive - can damage skin and lungs; high concentrations can cause chemical burns; may be toxic in the air at high concentrations
Alcohols	Flammable and should be stored away from heat sources
Aldehydes	Aldehydes are highly irritating and toxic to animals and humans through contact or inhalation. Formaldehyde has been identified as a potential carcinogen. Occupational Safety and Health Administration (OSHA) standards limit the exposure time for personnel. Glutaraldehyde is less acutely toxic than formaldehyde, but exposure can cause acute and chronic skin and mucous membrane irritation, epistaxis, and possibly asthma.
Alkalis	Very caustic - exposure can cause severe skin burns, burns on the footpads of animals and hoof drying and cracking. Dust from these products may cause severe burning of the eyes and mucous membranes or respiratory tract if inhaled. Lye is highly reactive with water.
Biguanides	Can cause minimal skin irritation or allergic reactions. Toxic to fish; avoid discharge into the environment
Chlorine compounds	High concentrations are irritating to the mucous membranes, eyes, and skin, and can cause damage to the footpads of animals. Toxic gas can be formed when mixed with strong acids or ammonia Highly toxic to aquatic animals; avoid discharge into the environment
Peroxygens	Concentrated products can be irritating to the mucous membranes, eyes, and skin. Powdered concentrates can cause mucous membrane irritation. Face and eye protection should be worn.
Phenols	Readily absorbed through the skin; high concentrations can cause severe burns; skin and eye irritation Odor can be irritating to the respiratory tract Fatal if swallowed Concentrations over 2% are highly toxic to all animals, especially cats and pigs Highly toxic to aquatic animals; avoid discharge into the environment
Quaternary ammonium compounds	High concentrations can cause irritation of the skin, eyes, and respiratory tract, including oral and skin ulcerations, pneumonia, and possibly (rarely) death Highly toxic if ingested Toxic to aquatic animals, particularly fish; avoid discharge into the environment

BIOLOGICAL RISKS

Consideration should also be given to any potential biological risks. Some disease situations may involve C&D to contain zoonotic pathogens. Since this activity will occur in some of the most contaminated areas (e.g., animal housing areas), personnel need to be cautious to avoid exposures through inhalation, ingestion, or direct contact on skin, eyes or mucous membranes. Cleaning activities such as sweeping and scraping, or washing, particularly with high powered sprayers, or drying activities using blowers may disturb and further disseminate pathogens. When dealing with a potentially zoonotic disease, use careful dry and wet cleaning methods and wear personal protective equipment (PPE).

PROTECTING PEOPLE

Health hazards and exposure risks can be minimized through training, safety precautions, and personal protective measures.

Read the Label

Warnings and safety information is printed on the product label. This will include, any hazards to humans, animals, or the environment; protective equipment that should be worn; the necessary first aid and medical treatment information; and any hazards, such as flammability, corrosiveness, or explosive characteristics

The recommended precaution measures listed on the label should always be followed.

Safety Data Sheets

All chemical disinfectants have a Safety Data Sheet (SDS) listing the stability, hazards, and personal protection needed, as well as first aid information. This information must be kept on site and be available to all personnel handling disinfectants. A 3-ring binder containing this information in one easily accessible location is recommended.

Personnel Training

Ensure all personnel have training on the proper handling, preparation and application of chemical disinfectants. They should be aware of any hazards from the products being used, and the protective measures necessary. They should follow all product label safety precautions and wear appropriate PPE (e.g., gloves, goggles), as required. Be sure personnel know what PPE is needed and how to don and doff (put on and take off) the equipment properly.

Personal Protective Equipment (PPE)

Personal protective equipment should always be worn when handling, mixing and applying disinfectants.

At a minimum this should include waterproof gloves, protection for exposed skin (e.g., coveralls, long sleeves), and eye/face protection (e.g., goggles, face shield). Masks or respirators may be needed for some products. They should also be worn for situations involving significant amounts of dust generation or zoonotic disease potential.

Additional personal protective equipment, such as waterproof or chemical-resistant suits (including both pants and jackets with hoods), waterproof aprons, or respirators may be necessary for some situations (e.g., formaldehyde or acidic disinfectants).

Handwashing

Personnel should always wash their hands after handling, mixing or applying disinfectant solutions and before eating, drinking, or other possible exposure risk activities.

PROTECTING ANIMALS

Animals can be at risk to the same chemical and physical hazards previously described. Animals are also more prone to incidental ingestion or chemical exposures on feet or skin. Efforts to eliminate health issues for animals need to be addressed.

- Disinfectants should not be applied directly to animals unless labeled for such use.
- Most disinfectants cannot be used when animals are present.
- All disinfectants are toxic if ingested and must be rinsed away before animals are introduced to the area. This is especially critical for feeding and watering equipment.
- Some products can damage the foot pads or hooves of animals.
- Some disinfectant products recommend cleaning and rinsing ***after the disinfection phase*** for animal contact areas, feeders and waterers.

PROTECTING THE ENVIRONMENT

Protecting the environment during C&D procedures is also critical. Many chemical disinfectants are toxic or ecological hazards for aquatic organisms and plants. Runoff should be avoided or controlled to prevent entry into waterways, such as lakes, streams, ponds or wetlands. The use of berms and pumps to collect wastewater may be necessary. Products that are biodegradable or safer for the environment should be considered.

SUMMARY

The prevention of disease in animal settings involves effective cleaning and disinfection of contaminated surfaces. Properly performed C&D decreases pathogen levels on surfaces and reduces exposure risks. Successful C&D involves remembering and understanding the key principles and steps for the process, choosing the best method, and recognizing any limitations.

KEY PRINCIPLES OF C&D

Regardless of the setting, item or area, ensure the five key C&D principles.

1. Clean surfaces before disinfection.
2. Use the right disinfection product for the situation.
3. Read the product label.
4. Give it time to work.
5. Keep everyone safe.

Keep in mind these common failures of C&D success.

- The target pathogen is resistant to the disinfection process or product used.
- The surface type (e.g., porous, cracked) allowed the pathogen to persist in the environment.
- Surfaces were inadequately cleaned prior to disinfection.
- An ineffective disinfectant concentration was used.
- The product or process was not used (applied) correctly.
- The necessary contact time was not observed.
- Environmental factors such as organic load, temperature, pH or water hardness are impacting the selected disinfectant or method.

FOR MORE INFORMATION

To learn more about disinfection in animal settings, check out the following resources from the Center for Food Security and Public Health (CFSPH):

- Disinfection 101
- Characteristics of Selected Disinfectants
- Antimicrobial Spectrum of Disinfectants
- Reading Disinfectant Product Labels
- Other Disinfection Resources, including staff or client educational handouts

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