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HOW TO MANAGE TOXIC AND SUFFOCATING MANURE GASES

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TABLE OF CONTENTS

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INTRODUCTION

On August 10, 2021, three brothers at an Ohio dairy farm lost their lives simply trying to maintain a manure pit pump [1]. It is disheartening that dangerous gases produced in manure storages continue to take the lives of farmers. **The objective of this publication is to make sure such an accident never happens in Tennessee.**

Unfortunately, this recent accident is not unique. In 1989 five family members died after entering a Michigan manure storage pit [2] and in 2007 four family members and a young worker died in a Virginia manure tank [3]. To understand how these accidents occur, first consider that many thousands of labor hours are spent every year handling manure liquids and slurries on dairy and swine farms. Sampling, agitating and pumping manure from enclosed or confined manure storage structures is a routine but often urgent task. In reviewing reports for a number of these incidents, a commonality is that the manure storages had been entered many times prior without incidents [4, 5]. Thus, in these accidents, entry was made into a manure storage without taking proper precaution — multiple fatalities occurred as repeated rescue attempts were made into a toxic and/or suffocating environment caused by manure gases **(Figure 1). This publication is designed to promote a critical awareness and understanding of the dangers these gases present in enclosed spaces used to store manure.**

The fact is nearly every year farmers are killed entering manure storages that contain toxic and asphyxiating gases [5]. Such deadly places are regulated in industrial and commercial settings by the Occupational Health and Safety Administration (OSHA). OSHA defines **a confined space** as a place large enough to be entered for assigned work, that isn't designed to be occupied continuously, and that has limited means for entry or exit, which often causes poor natural ventilation. A **permittable confined space** is a confined space prone to having a hazardous atmosphere, in which case standardized safety measures are required for entry. While OSHA does not regulate these types of spaces on farms, it is important to realize that **many manure storages are confined spaces** and that **stored manure produces gases that make these places unsafe (Figure 1).**

This document is ultimately an educational tool designed to help livestock producers understand the **CAUSES** of hazardous atmospheres in manure storages. Practices are presented that will **PROTECT** livestock producers and their employees from the dangers manures gases pose. With proper knowledge and awareness, and using safety methods that are in common use in regulated confined space settings, manure storage fatalities can be prevented.

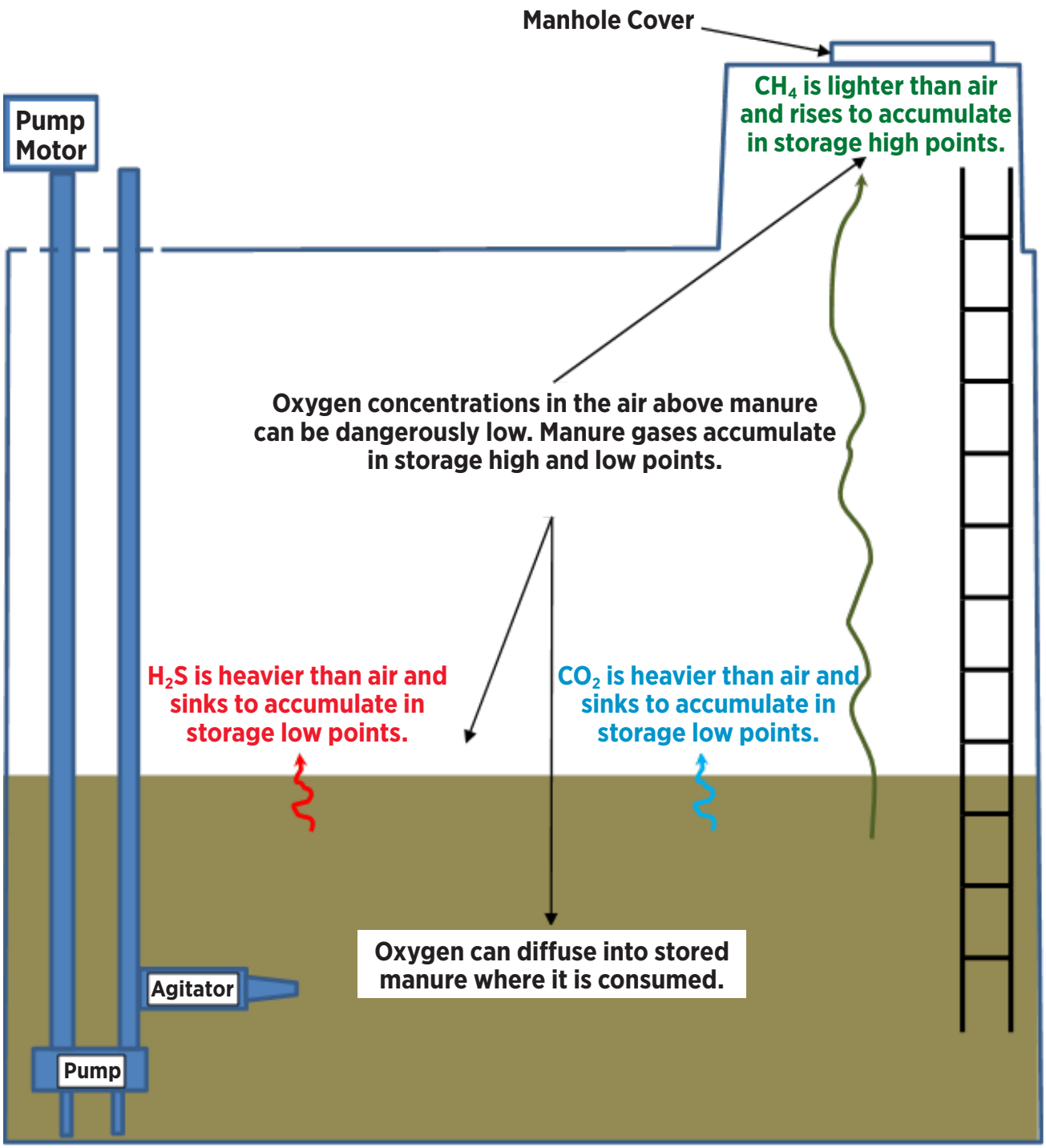

Figure 1. Diagram illustrating manure gas dynamics within a confined storage as organic matter decomposes. Hydrogen sulfide (H_2S) and carbon dioxide (CO_2) are more dense than air and settle into storage low points. Methane (CH_4) is less dense than air and rises into storage high points. Oxygen tends to be pushed out of manure storage high and low points as manure gases accumulate. Oxygen concentrations in the air above stored manure can also be low because it diffuses into the stored manure where it is consumed to degrade organic matter.

HYDROGEN SULFIDE

Hydrogen sulfide (H_2S) is a gas produced by bacteria that use sulfur to consume manure organic matter in anaerobic environments (where oxygen is absent). H_2S has caused numerous farm fatalities within manure storages [5, 6].

- **Hydrogen sulfide is toxic.** H_2S paralyses the respiratory system. At 700-1,000 parts per million (ppm), 1-2 breaths result in collapse **(Table 1)** [6]. Concentrations of 1,000-10,000 ppm are not uncommon in manure storages [7]. Clearly, holding your breath is **NOT** an option to enter such a dangerous atmosphere because you risk collapse in an inescapable, toxic environment [8]. Concentrations above 43,000 ppm H_2S are also explosive **(Table 1).**
- **Hydrogen sulfide is colorless and at high concentrations is odorless.** You can't reliably see or smell H_2S. At low concentrations it has an offensive, rotten egg odor, but our sense of smell is easily fatigued at concentrations the National Institute of Occupational Safety and Health (NIOSH) considers immediately dangerous to life and health (IDLH) (more than 100 ppm) [8] **(Table 1).**

Table 1. H_2S and health effects.

H_2S, ppm	Health Effect
Less than 5	Rotten egg odor
More than 100	IDLH, eye/lung irritant
More than 700	Collapse in 1-2 breaths
More than 1,000	Near instant death
More than 43,000	Explosive atmosphere

- **Hydrogen sulfide is heavier than air.** There is often little natural air movement into and out of manure storages. As H_2S is generated, it settles and displaces good air, often accumulating to dangerous concentrations in the lower reaches of confined spaces **(Figure 1).** Be aware that H_2S can settle within manure storages as they are pumped, so lethal concentrations can be present in empty manure storages [9-11]. Always test the air in the lower reaches of manures storages for accumulated H_2S.
- **Hydrogen sulfide is rapidly released when manure is agitated.** When manure is agitated, trapped H_2S can be quickly released in huge quantities [12, 13]. This is particularly true if floating solids/crusted manure or foam are present [13, 14]. In one accident, a young farmer died as a result of exposure to H_2S released as manure with floating solids was agitated [15]. In this case, the manure storage was an open, unconfined (in-ground) pond and the H_2S apparently flowed along the ground to where he was operating the agitator. When agitating manure, operators are likely safer in enclosed tractor cabs [16].
- **Hydrogen sulfide is especially problematic if certain feeds/bedding are used.** Feeding distillers grain, which is high in sulfur [17], can also result in manure that generates high H_2S concentrations when it is agitated [15]. Dairies that use gypsum (calcium sulfate) bedding are also more likely to experience elevated H_2S concentrations (more than 1,000 ppm) during manure agitation [18].

METHANE

Methane, like H_2S, is produced by bacteria that degrade manure organic matter without oxygen. This gas is produced in anaerobic manure digestors as well as in manure pits.

- **Methane is explosive.** Methane (CH_4) will combust when present in air at a 5-15 percent concentration (50,000 to 150,000 ppm) if sufficient oxygen and an ignition source (e.g., heaters or electric motors) are present. Manure foam often contains CH_4 at combustible concentrations. Explosions have occurred when foamy manure was agitated and the encapsulated gases mixed with surrounding air near an ignition source. This has occurred a number of times at deep pit swine houses [19], but be aware that explosive CH_4 concentrations have been documented above dairy manure [7]. The Great Plains Center for Agricultural Health publishes special precautions to take when agitating foaming swine manure [20].
- **Methane is an asphyxiate.** Asphyxiation occurs when the brain is deprived of oxygen (O_2). It can be caused by manure gases that accumulate and displace O_2 from the air. Methane asphyxiation has been linked with a number of fatalities in manure pits [6], though suffocation in such cases may have been caused by a buildup of multiple manure gases [21]. Loss of consciousness can occur in minutes or even seconds when air is less than 6 percent O_2 **(Table 2)** [22]. Commercial confined space gas monitors include an O_2 sensor to alert users to suffocating air. It is important to keep in mind that any O_2 concentration below 20.8 percent is a concern. Also, air with an oxygen concentration of 21 percent may **NOT** be safe to breathe because toxic gases (H_2S) can be present [8].
- **Methane is colorless and odorless.** Like H_2S, methane cannot be seen or smelled. The smell associated with commercial natural gas, which is 95 percent methane, is caused by a chemical with a distinctive odor that is added so leaks can be quickly detected.
- **Methane is less dense than air.** Unlike hydrogen sulfide, methane is less dense than air so it tends to rise and disperse from manure storages but can accumulate at enclosure high points **(Figure 1).** When using an air monitor, be sure to sample the air near the top of a manure storage to detect an explosion or asphyxiating hazard. Most multi-gas monitors are calibrated with methane to test the air for ignition potential relative to a Lower Explosive Limit (displaying the percentage of the LEL). For maximum safety, LEL values should not exceed 2 percent **AND** oxygen values should be greater than 19.5 percent **(Table 2).**

Table 2. Oxygen levels and health effects.

Percent O_2	Effect
20.8-21.0	None (ambient air)
19.5	Minimum safe level
12-15	Fatigue/poor coordination
10-12	Poor judgement/heart damage
Less than 10	Fainting almost immediate

CARBON DIOXIDE

Carbon dioxide (CO_2) is a gas produced as organic matter is decomposed by bacteria using oxygen. Oxygen can be transiently introduced into liquid manure during operations such as flushing or agitation. It is also produced by confined animals as they breathe, combusting heating fuels, and when using CO_2 gas cylinders (e.g. for welding).

- **Carbon dioxide is heavier than air and can contribute to an asphyxiation hazard.** CO_2 can be produced in large quantities as manure degrades, especially in transitory storages where oxygen is sometimes present, such as flush lane manholes/transfer pits. Because CO_2 is 1.5 times heavier than air it sinks and can accumulate and persist in these types of confined spaces. Oxygen levels near the bottom of these types of manure storages tends to be very low, partly because O_2 in the air space can diffuse into manure and be quickly consumed **(Figure 1).** Accumulating CO_2 and air space oxygen O_2 consumption can together lower oxygen concentrations to dangerous levels **(Table 2).** This scenario was documented in a 2015 sewer manhole fatality [23].
- **Carbon dioxide is toxic.** CO_2 is often thought of as just a suffocating gas. However, a CO_2 concentration of 70,000 ppm is needed to lower the oxygen concentration below 19.5 percent [24]. A concentration above 40,000 ppm exceeds the National Institute for Occupational Safety and Health (NIOSH) Immediately Danger to Life and Health (IDLH) standard **(Table 3)** [24]. Be aware that most commercial confined space air monitors include sensors for O_2, H_2S, and the Lower Explosive Limit (LEL), but not CO_2. While you can consider the CO_2 concentration to be safe when the O_2 concentration is at ambient levels (20.9-21.0 percent), it is advisable to purchase a separate CO_2 detector **(Figure 2)** and sample the air near the bottom of manure storage structures prior to entry.
- **Carbon dioxide is colorless and odorless.** Unfortunately, just like H_2S and CH_4, dangerous concentrations of CO_2 cannot be seen or smelled. The only way to know that a manure storage is safe to enter is to use a multi-gas air monitor to test for O_2, H_2S, and LEL **AND** to test for CO_2 using a dedicated meter **(Figure 2).**

Table 3. CO_2 exposure limits/symptoms.

CO_2, ppm	Limit and/or Symptom
410	Concentration in air (2021)
1,000	Slight increase respiration
5,000	- NIOSH 10-hour workday limit - Stuffy air
30,000	- NIOSH 15 minute exposure limit - Increased breathing, heart rate
40,000	- NIOSH IDLH limit - Possible brain damage at 30 minutes
More than 100,000	Loss of consciousness at 15 minutes

Figure 2. CO_2 gas monitor.

ACCIDENT PREVENTION

Train employees. It is important to train employees to be aware of the risks posed by manure gases. Specifically, workers should understand that dangerous gases are produced anywhere manure is conveyed or stored and that these gases can be toxic, explosive and cause suffocation. The risk increases tremendously where manure is stored in mostly enclosed tanks or pits where entry and exit and natural airflow are restricted. The dangers are also high in animal housing located above slatted in-ground manure storage pits, such as in deep pit swine houses.

Post signs. At places where manure is stored in confined spaces, post signs to remind employees that the space is unsafe to enter **(Figure 3).** A survey of producers recently indicated that only 25 percent of farms use these signs [5]. They are important training reminders that provoke appropriate caution and transition the mindset to one that is safety oriented. Such a reminder is especially important during time sensitive tasks such as manure pump maintenance [2].

Figure 3. Manure gas danger sign.

Plan confined space entry carefully. The most common activity involved in documented manure storage fatalities is maintenance (34 percent) [5]. Maintenance should be planned well in advance rather than performed spontaneously, especially when it will be necessary to enter a confined manure storage. Several deaths have resulted from unessential or non-urgent tasks, such as retrieving equipment dropped into manure storages [9, 25-27]. Manure storages should not be entered unless it is imperative, and then only after proper safety precautions are taken.

Follow proper safety procedures when entering manure storages. There may be times, such as when a pump shear pin breaks or manure line clogs, that it becomes necessary to enter confined manure storages. Train employees to be aware that entering these structures alone is absolutely forbidden — a designated safety person **MUST** be present. Entry can be attempted **ONLY** if proper safety measures are taken to assure that toxic or suffocating manure gases are purged from the manure storage. Three safety steps are described in the remainder of this document that can be used to make entering confined manure storages much safer.

STEP 1 – VENTILATE!

Purge manure gases. Most manure storages, including many under animal confinement houses, do not have dedicated ventilation systems [28]. Lack of ventilation is the root cause of the dangers that manure gases present. To make entry safer, manure storages must always be well ventilated prior to entry. Several vendors offer portable, explosion-proof ventilation fans with attached flexible ducting specifically designed to ventilate confined spaces **(Figure 4)** [20]. In making your purchasing decision, buy a fan large enough to replace the volume of your largest enclosed manure storage once every minute. Smaller fans can be used, but they will increase the amount of time it takes to safely force bad air out of the manure storage. These fans should always be set up to force fresh air into the manure storage, preferably through an attached flexible duct dropped into the bottom far reaches of the enclosure (do not suck air out of a manure storage). The air forced into the storage should be free of manure gases. For a demonstration of how ventilation lowers risk, see the excellent demonstration YouTube video produced by Penn State University.

How long to ventilate? A technical standard has been published by the American Association of Agricultural and Biosystems Engineers to calculate the time required to replenish oxygen and push manure gases out of a storage [29]. Contact (shawkins@utk.edu) for assistance using this standard. If you do not use the standard, blow fresh air into the structure for 20 minutes **before entry** at a rate that would replace the empty storage volume at least once every minute.

Ventilating slatted manure pits under confinement barns. If the manure pit is under confined animals and H_2S exceeds 80 ppm, delay work until the animals are removed [20]. If animals are present, the barn ventilation system must be engaged at full capacity for five minutes **PRIOR** to ventilating the manure pit. Additional precautions to take include:

- Ventilate the building from the outside, down through the slotted floor, and out pit openings. This directs manure gases away from confined animals.
- Fully open building curtains and windows before manure agitation. Do **NOT** ignore this recommendation simply to avoid increased utility cost.
- Continue to ventilate manure pits during and for five minutes after agitation ends.

Figure 4. Confined space ventilation fan.

STEP 2 – MEASURE

Use a gas monitor. Only 10 percent of farms use gas monitors when entering manure storages **(Figure 5)** [28]. Before and during ventilation, and certainly during entry and occupation of a manure storage, a portable multi-gas monitor **MUST** be used to measure H_2S, O_2, and the explosive gas potential. For maximum safety purchase a second meter to measure CO_2 **(Figure 2).** Never enter a confined space used to store manure unless you know for certain that the air is safe to breathe, meeting all the requirements in **Table 4.**

Look for a monitor with an integrated air pump that offers replaceable sensors, an H_2S detection range above 100 ppm, and bump testing and calibration. High-quality units can be purchased from safety equipment vendors for $1,000 to $2,000. For a producer that only occasionally needs a monitor on a predictable schedule, consider renting this equipment. For regular manure storage entry, which might be practiced by custom manure applicators, a professional confined space monitor is essential. Don't cheap out - avoid disposal gas monitors.

Measuring H_2S will NOT eliminate short-term exposure risk during agitation. While it improves safety tremendously to use gas monitoring equipment, this **WILL NOT** reduce the H_2S exposure hazard during manure agitation [12, 13]. This is particularly true within animal confinement buildings constructed on top of a slatted manure pit. H_2S concentrations can increase to lethal concentrations in a matter of seconds inside these buildings when manure is agitated, much faster than the response time of gas monitors [13]. There have been numerous incidents where cattle and pigs have been killed when subfloor manure pits were agitated, even though the building air was safe immediately before agitation began [30].

Animal confinement buildings should **NEVER** be entered during manure agitation, even when using an air monitor. In 2003, a 42-year-old farmer died of H_2S poisoning when he entered a hog barn while the manure was being agitated [26].

Table 4. Manure gas concentrations that can be considered safe when stable.

Gas/Risk	Safe Level
Hydrogen Sulfide	Less than 10 ppm
Methane	Less than 2 percent LEL
Oxygen	More than 19.5 percent
Carbon Dioxide	Less than 5,000 ppm

Figure 5. Multi-gas monitor.

STEP 3 – BUDDY-UP AND USE SAFETY EQUIPMENT

Never enter alone. Many of the fatal accidents that have occurred in manure storages resulted when a person initially entered a confined space alone. If an incapacitating atmosphere is encountered, there is no hope of escape or of someone rescuing you without putting their life at risk. Always buddy-up — never enter a confined space used to store manure alone, even if the space has been ventilated and air contaminant concentrations appear safe. A designated buddy has one responsibility, that is to keep a watchful eye on the person whose job it is to enter the confined space and to first call 911 and then perform a rescue from outside the storage should an accident occur.

Use a lifeline. At a minimum, the person entering a confined space used to store manure should wear a safety harness. The safety harness should be tethered to a point outside the confined space. It is the job of the buddy to perform a rescue using the tether, rather than entering the confined space. Many of the deaths (22 percent) attributed to poisonous and suffocating manure gases are actually would-be rescuers [31].

If a worker collapses in a manure storage, it can be very difficult for one person to pull them to safety without mechanical aid or several helpers. Thus, the lifeline is best attached to a winch which can be used to pull an incapacitated person to safety quickly. If a storage structure or tank is entered vertically, for example through a manhole, a tripod with an attached winch that is centered over the opening is the preferred safety lifeline **(Figure 6).**

Use a respirator when hydrogen sulfide is detected. If a manure storage has a history of containing H_2S, or the H_2S concentration is above 10 ppm at any time during ventilation, wear a full-face respirator fitted with acid gas filter cartridges for entry **(Figure 7).**

Be aware that respirators will NOT make spaces with a low O_2 concentration safe to enter. Only professional grade supplied air systems, wherein an air tank and airline is tethered to a mask, can be used to enter confined spaces with low O_2 concentration.

Figure 6. Professional harness, winch and tripod assembly for confined space entry.

Figure 7. Full face respirator.

CONCLUSIONS

Live another day. Livestock farming is high-paced and stressful during manure land application. It is easy to let safety lapse in the rush to land apply manure during tight windows of good weather. But safety is not something that can be neglected when it comes to entering manure storages for repairs or maintenance. You put your life at risk when you enter manure storages without safety precautions, and you also put at risk the lives of your family members and coworkers who will feel compelled to rescue you if you collapse.

Confined spaces are especially dangerous. Safety is critically important for manure storages that are difficult to enter and exit. All confined manure storages are prone to accumulate toxic and asphyxiating gases, even when the manure has been removed.

Safety is everybody's responsibly. Safety begins with you. Show this by investing in equipment to help make manure storage entry safe: ventilators **(Figure 4),** air monitors **(Figures 2 and 5),** safety harnesses **(Figure 6),** and respirators **(Figure 7).** Put in place warning signs **(Figure 3)** and implement manure storage entry procedures. This will keep your family, coworkers and employees safe from dangerous manure gases.

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