Air-Free Measurement of Carbon Monoxide Emissions from Gas Ranges: Analysis and Suggested Field Procedure

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Introduction

Gas ranges are probably the most common unvented gas appliances in use in North America. Because they are unvented, they have the potential of significantly contributing to hazardous ambient indoor levels of carbon monoxide (CO). Fortunately, in most residential situations, they are not operated for long enough intervals to adversely affect occupants. However, there are cases where gas oven/ranges can emit enough CO to cause health hazards or trigger CO alarms. Examples include 1) user operation of a gas oven/range as a space-heating appliance[1]; 2) user alteration of the oven, such as lining the oven bottom with aluminum foil, inadvertently covering the secondary air ports; and 3) malfunctioning equipment, including excessive gas pressure, closed air shutters, damaged orifices, and warped flame spreaders.

As dwellings become tighter, the possible hazard of CO emissions from gas ranges increases. Lower air leakage rates can lead to higher ambient indoor CO levels resulting from a given source. This is of special concern for those tightening dwellings for the sake of saving energy: A given CO emission from a gas oven before house tightening might become dangerous after tightening. For example, if a particular mobile home is tightened from 1.0 air change per hour (ACH) to 0.5 ACH, the ambient indoor carbon monoxide levels resulting from the gas range emissions would increase from 32 parts per million (ppm) to 54 ppm.[2]

It is important to develop a reliable field procedure for measuring carbon monoxide emissions from gas ovens/ranges for many reasons, including 1) the use of gas ovens/ranges is widespread, 2) these appliances are often used as space-heating devices, 3) dwellings are becoming tighter, and 4) the public is becoming increasingly aware of the hazards of carbon monoxide. This field procedure should be in conformance with the American National Standard (ANSI Z21.1) to which manufacturers of gas ranges must comply. This article is an effort to move toward such a procedure.

Measuring CO

As the awareness of CO hazards increases, more technicians are using meters for measurement of CO emissions from combustion appliances. These electronic devices are connected to a plastic hose with a metal probe at the other end. When measuring CO emissions from a vented appliance, the metal probe is inserted into a drilled hole in the metal flue pipe. A vacuum pump in the measurement device pulls combustion gases through the metal probe, into the plastic hose and the CO measurement cell, and finally expels the gases through an exhaust port.

Measurement of CO emissions from a gas oven is performed with a similar technique. However, rather than inserting the probe into a drilled hole in a vent pipe, the metal probe is inserted into the oven-vent port that is usually located at the rear of the flat range top.

CO meters report emission concentrations in units of parts per million (ppm). One hundred ppm is the equivalent of 0.01 percent; one thousand ppm is the equivalent of 0.1 percent. One ppm is the similar to one inch in sixteen miles, one penny in $10,000, or one red Ping-Pong ball in a swimming pool full of white Ping-Pong balls.

There are two scales with which to measure CO: one is "as-measured" and the other is "air-free." *As-measured* is the method used by most technicians today. The CO is measured from a sample of combustion gases with no regard for the amount of excess air diluting the CO concentrations.

Excess air is the amount of air (specifically oxygen) in the combustion gases in excess of the exact amount needed for perfect combustion. When combustion is perfect, just the right amounts of fuel and oxygen are supplied to the combustion process so that all the oxygen is utilized—no oxygen remains in the combustion gases.

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1 Paul S. Heckerling, MD, *et al.* "Predictors of Occult Carbon Monoxide Poisoning in Patients with Headache and Dizziness," *Annals of Internal Medicine*, Vol. 107, No. 2, (August, 1997), 174-176. The authors states: "Among our patients, many of whom were indigent, 39% used gas stoves for supplemental heat, which was a significant predictor of the carboxyhemoglobin level." And: "These studies, as well as ours, suggest that in patient populations with inadequate home heating systems, use of stoves [gas ovens/ranges] for supplemental heat is common, and may be an important source of CO." Chances are that in many cases, as a result of room overheating, the range burners are turned off before CO concentrations reach dangerous levels.

2 The example mobile home is 5400 ft^3, the oven (18,000 Btu) and one range-top burner (9,000 Btu) are operating for two hours, the fuel is natural gas at 1,000 Btu per cubic foot of gas, the gas flue products are 8.528 cubic feet per cubic foot of fuel, the source strength of CO is 1000 ppm air-free. See equation 4 for calculation method.

The basic problem with the as-measured method is this: *As the amount of excess air increases, the as-measured CO value falls for a given source strength of CO.* In other words, the amount of excess air in the sample can significantly influence the as-measured value. This can cause a technician to mistakenly think that a hazardous burner is working properly.

Air-free measurement of CO takes account of the amount of excess air by incorporating an adjustment to the as-measured ppm value, thus simulating air-free (oxygen-free) conditions in the combustion gases. To do this, a reading of oxygen (O_2) or carbon dioxide (CO_2) percentage is taken from the combustion gases along with the as-measured CO reading. This can be done with a meter having the capability of measuring CO *and* O_2 or CO_2 percentage, or it can be done with two different meters, one measuring CO ppm and one measuring O_2 or CO_2 percentage.

If air-free CO is determined with a single meter, the meter will have an integral electronic chip that will calculate the air-free level from as-measured CO ppm and O_2 percentage.

If two meters are used, the equations below can be used to determine the air-free level of CO in a combustion gas sample.

For natural gas or propane, using as-measured CO ppm and O_2 percentage:

$$CO_{AFppm} = \left(\frac{20.9}{20.9 - O_2}\right) \times CO_{ppm} \qquad (1)$$

For propane, using measured CO ppm and CO_2 percentage:

$$CO_{AFppm} = \left(\frac{14}{CO_2}\right) \times CO_{ppm} \qquad (2)$$

For natural gas, using measured CO ppm and CO_2 percentage:

$$CO_{AFppm} = \left(\frac{12.2}{CO_2}\right) \times CO_{ppm} \qquad (3)$$

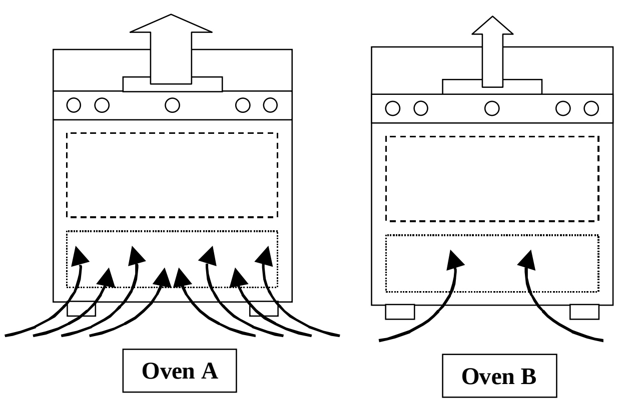
Where:

CO_{AFppm} = Carbon monoxide, air-free ppm
CO_{ppm} = As-measured combustion gas carbon monoxide ppm
O_2 = Percentage of oxygen in combustion gas, as a percentage
CO_2 = Percentage of carbon dioxide in combustion gas, as a percentage

The Problem with As-Measured Values

From any combustion, the highest percentage of oxygen (O_2) possible is 20.9 percent (that of the earth's atmosphere), and the lowest is zero, resulting from stoichiometric (perfect) or oxygen-starved combustion. Whereas the O_2 content of combustion gases from natural gas or propane furnaces or boilers is usually within a range of 4 to 10 percent, the percentage of O_2 for a natural gas or propane oven is much higher, normally within a range of 14 to 20 percent. This Oven A, the as-measured CO level is 18 ppm; safe by most higher range of O_2 (excess air) in the combustion gases leads to *lower* as-measured readings.

The two ovens pictured here demonstrate the inherent problem with as-measured values. Assume both ovens have the same Btu/hr burner input. For standards. For Oven B, the as-measured CO level is 209 ppm; unsafe by most standards. However, each oven is emitting the same level of air-free CO: 400 ppm. In other words, the *source strength of CO* from each oven is the same. Most technicians would pass



As-Measured CO = 18 ppm
Oxygen = 20%
Air-Free CO = 400 ppm

As-Measured CO = 209 ppm
Oxygen = 10%
Air-Free CO = 400 ppm

Oven A and fail Oven B, not understanding that each is contributing equally to hazardous levels of ambient indoor CO.

It is important to understand that the source strength has a direct effect on the ambient indoor levels of CO. If air-free CO is measured, technicians get a much better idea of the effect the CO emissions will have on indoor air concentrations.

As indicated above, the higher the percentage of O_2 (excess air) in the combustion gases, the *lower* the as-measured CO readings will be. If excess air is zero, as-measured and air-free measurements will be equal. As excess air increases, as-measured CO readings decrease, but air-free readings do not change. The high excess air percentages for gas ovens and range-top burners increases the importance of taking air-free measurements. This is because the high excess air can significantly lower *as-measured* readings, thus falsifying the true CO source strength.

It is common to find a 17 percent oxygen content in oven combustion gases. If this value is plugged into equation 1, the resulting air-free CO level is five times the as-measured value. This is a rough general rule one can use for relating as-measured to air-free CO values for ovens. Range-top burners can emit air-free CO that is as much as ten times greater than as-measured values because of higher excess air values.

Although using air-free measurement for vented appliances is recommended, it is not as important as it is for gas ovens and range-top burners. There are two reasons. First, the excess air percentage for vented appliances is lower, resulting in as-measured readings that are closer to air-free readings. Second, vented appliances do not contribute to ambient indoor air CO levels unless their venting systems are malfunctioning.

Air-Free Measurements and the US National Standard

Manufacturers of gas ranges must comply with American National Standards Institute document *Household Cooking Gas Appliances* (*ANSI Z21.1*, 1993). This standard states "An appliance shall not produce a concentration of carbon monoxide in excess of 0.08 percent [800 ppm] in an air-free sample of the flue gases when the appliance is tested in a room having approximately a normal oxygen supply."[3] The test procedure required by this standard is lengthy, but simply stated, this is it: Pans containing five pounds of water are placed on each of the four range-top burners. All the range-top burners and the oven are operated simultaneously. After five minutes of operation, the air-free CO is measured in a collection hood above the range. This air-free concentration must be 800 ppm or less.

In September 1996, the Gas Research Institute (GRI) published a topical report entitled *Critique of ANSI.Z21.1 Standard for CO Emissions from Gas-Fired Ovens and Ranges*. This Battelle Laboratory appraisal of the 800 ppm level, originally set in 1925, found "The underlying basis for and allowable limit set by the original CO standard were valid and conservative in 1925, and remain so today. . ."[4] The report continues with "Gas ovens/ranges do not pose a public safety or health threat with regard to CO emissions, a performance characteristic that can be reliably validated either in the lab, factory, or *field* (emphasis added) by using the current Z21.1 measurement protocol, and its specified limit of 800 ppm CO, O_2-free."[5]

Although this test works well in the laboratory of a manufacturing facility, it is difficult to simulate cost-effectively in the field, despite opinion of the report's author. More research is needed before a reliable *field* method of measuring CO from gas ranges is found.

Unlike the safety testing of vented appliances, which focuses on ensuring the uninterrupted flow of combustion products to the outdoors, the measurement of CO from an unvented appliance—such as a range—involves measuring combustion products retained in the living space. It is important that we develop a more thorough understanding of the relationship between the source strength of CO emissions and the resulting concentrations of ambient indoor CO. The following equation, used by gas range manufacturers, is helpful for demonstrating this important relationship.

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3 *ANSI.Z21.1 Standard*, Section 2.4.1, page 42.

4 J.J. Reuther, *Critique of ANSI.Z21.1 Standard for CO Emissions from Gas-Fired Ovens and Ranges*, GRI/Battelle, Sept., 1996. page 18.

5 *ibid.*

$$CO_{ppm} = \frac{CO_{AFppm} \times Vg \times Gr \left(1 - \frac{1}{2.713^{N \times t}}\right)}{N \times v} \quad (4)$$

Where:

CO_{ppm} = As-measured indoor ambient carbon monoxide, ppm
CO_{AFppm} = Air-free carbon monoxide, ppm
Vg = Ft^3 of *flue* gas per ft^3 of *fuel* gas (8.5 ft^3 for natural gas, 21.8 ft^3 for propane)
Gr = Gas flow rate, in ft^3/hr (gas flow rate = $\frac{\text{Input rate (Btu/hr)}}{\text{Heat value of fuel (Btu/ft}^3)}$)
(an average input rate for an oven is 18,000 Btu/hr, for a range-top burner 9,000 Btu/hr)
(an average heat value for natural gas is 1000 Btu/ft^3, for propane 2500 Btu/ft^3)
2.713 = Napierian logarithmic base
N = Number of natural air changes per hour (ACH) of room or house
t = Time interval, hours
v = Volume of room or house, ft^3

For example, if a natural gas range with a total input rate of 54,000 Btu/hr is emitting CO at an air-free rate of 800 ppm in a house of 8000 ft^3, having a natural air exchange rate per hour (ACH) of 1.5, what will the ambient indoor CO concentration be after 2 hours?[6]

$$CO_{ppm} = \frac{800 \times 8.5 \times 54 \left(1 - \frac{1}{2.713^{1.5x2}}\right)}{1.5 \times 8000} \quad (5.1)$$

$$CO_{ppm} = 29 \quad (5.2)$$

This assumes the ambient CO is evenly dispersed throughout the house. In reality, the concentrations could be much higher in the kitchen than in remote sections of the living space.

If the structure is tightened, reducing the ACH from 1.5 to 0.5, the ambient indoor CO level will increase. At the end of the two hour period it will be 58 ppm (see equations 6.1 and 6.2) rather than 29 ppm.

$$CO_{ppm} = \frac{800 \times 8.5 \times 54 \left(1 - \frac{1}{2.713^{0.5x2}}\right)}{0.5 \times 8000} \quad (6.1)$$

$$CO_{ppm} = 58 \quad (6.2)$$

It is clear that lowering the ACH can create a more hazardous indoor condition.

Chart 1 shows the above example at five leakage rates from 0.35 to 2.0 ACH. Notice that as the leakage rate decreases the indoor levels of CO increase and the number of hours to reach a stabilized level increases. For example, at 2.0 ACH the stabilized level of 23 ppm is reached after two hours. In contrast, at 0.5 ACH the stabilized level of 91 ppm is reached after 10 hours. This situation might occur if occupants were operating all the burners for space heating. With the oven door open, the duty cycle of the oven will be 100% because the oven thermostat will never be satisfied.

Chart 2 indicates the resulting ambient indoor CO levels from a hypothetical gas oven with an aluminum foil liner on the bottom. Field studies have revealed that this is a common practice that can lead to high CO emissions if the foil covers the secondary air openings. The chart results assume a 50% duty cycle for the oven, in other words, the burners are operating one-half of the time to maintain temperature. Notice that the as-measured CO value is 100 ppm; a level that some analysts might find acceptable. However, because of the high excess air (oxygen) of 20%, the air-free level of CO is an unsafe 2200 ppm. If this dwelling is tightened from 1.5 ACH to 0.5 ACH, baking a turkey over a four hour period in this oven would to lead to indoor air CO concentrations of 109 ppm. Once again, the air-free value clearly demonstrates there is a problem, while the as-measured value might cause the problem to be overlooked.

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[6] The emission of 800 ppm air-free carbon monoxide is used here because this is the number the gas range manufacturers use, as dictated by ANSI Standard Z21.1.

Suggested Action Levels for Field Testing

As a result of the recent critique of the ANSI Standard of 800 ppm air-free CO for manufacturers (see footnote 4), the validity of this decades-old guide has been substantiated. It is reasonable to use it as a basis for field testing of ranges, no matter what their age.

Using the Standard, we can set the action level for repair and replacement of oven and range-top burners simply by assigning a high limit of 800 ppm air-free emissions for each burner.

Because the measurement is parts per million (similar to a percentage, i.e., 800 ppm = 0.08 percent), the number of burners in operation makes no difference. If each burner is emitting 800 ppm air-free, when each additional burner is turned on, the actual amount of CO emitted increases, but the total amount of combustion gases also increases, therefore the 800 ppm reading—percentage—will not increase.

Using this as field testing action level for repair or replacement of burners approximates compliance with the ANSI Standard by which the range was tested by the original manufacturer.

The word "approximates" is emphasized for several reasons, including 1) action levels in tight buildings should be lower than in loose buildings, as demonstrated by equations 4 through 6.2 and Charts 1 and 2; 2) the ANSI Standard uses aggregated CO emissions rather than those from individual burners; 3) gas ovens are difficult to test because of on-off or modulating burner operation; 4) range-top burners are difficult to test without an emissions-containing device allowing standardized and repeatable testing[7]; 5) CO emissions can be measured only with + 30% reliability[8]; and 6) this method has not been tested for validity.

Additional research and field measurement will lead to the refinement of these action levels.

Summary

It is important to measure CO emissions from gas oven and range-top burners using air-free values rather than as-measured values for the following reasons:

- Gas ovens and range-top burners have higher levels of excess air than most vented appliances. This causes a weaker relationship between as-measured CO and CO source strength, than for vented combustion appliances.
- Ambient indoor CO levels are a direct function of air-free CO emissions from gas ranges.
- Gas ranges are the most common unvented combustion appliance, thus it is more important to measure CO levels with a method that directly reflects CO source strength.
- Air-free CO values allow field-testing action levels to be more readily coordinated with ANSI Standard Z21.1.
- Air-free CO measurement affords a better opportunity of discovering serious CO hazards resulting from gas ranges.
- Air-free measurement takes us closer to a workable protocol for field testing gas ranges.

There are some obstacles to air-free CO testing:

- The required equipment costs more and requires more maintenance than equipment used for as-measured readings.
- Depending on the equipment used, air-free readings might require additional measurement time compared to as-measured readings.

It is suggested that an air-free field testing procedure be adopted using action level of 800 ppm for range burners and for oven burners. These action levels are based on the ANSI Standard Household Cooking Gas Appliances (ANSI Z21.1, 1993).

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7 Instructions for such a device, the CO Hot Pot, are available at this web site. See "Making a CO Hot Pot."

8 J.J. Reuther, Critique of ANSI.Z21.1 Standard for CO Emissions from Gas-Fired Ovens and Ranges, GRI/Battelle, Sept., 1996. page 15. He states: "In summary, CO emissions can be measured to within only about + 30%. Therefore, the Z21.1 CO limit would be expressed more appropriately as 800 + 240 ppm, or 560-1040 ppm. . ."

Chart 1

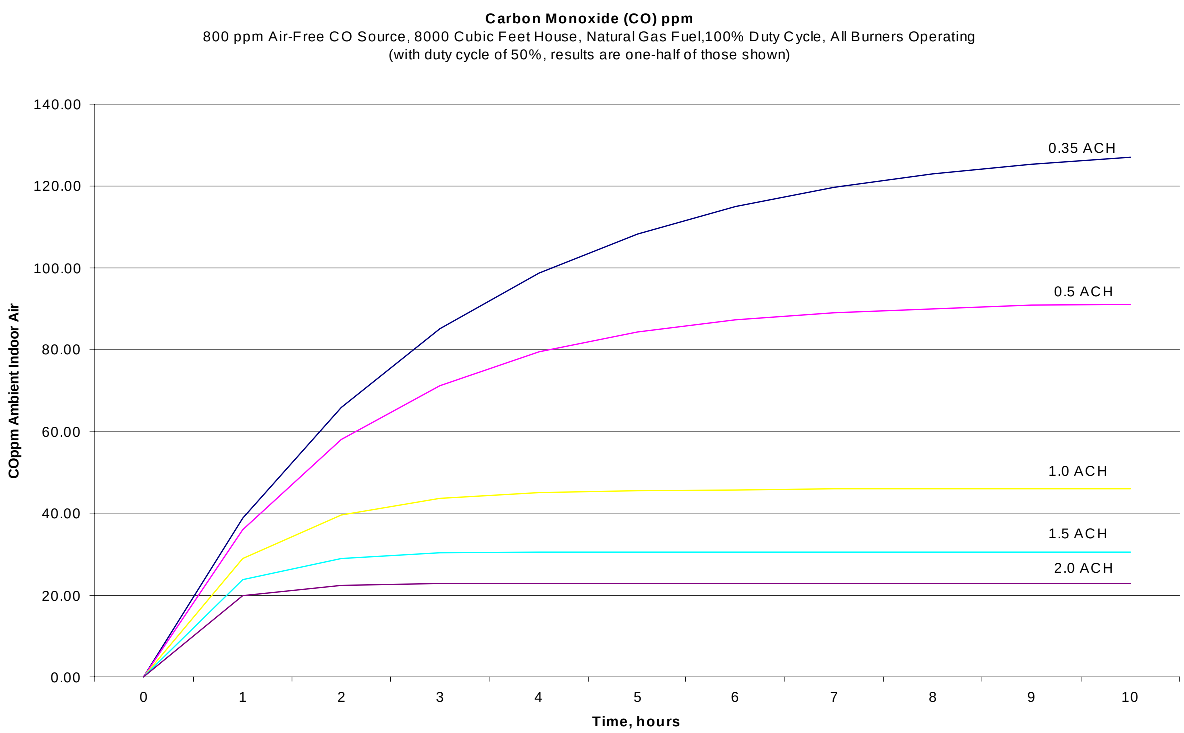
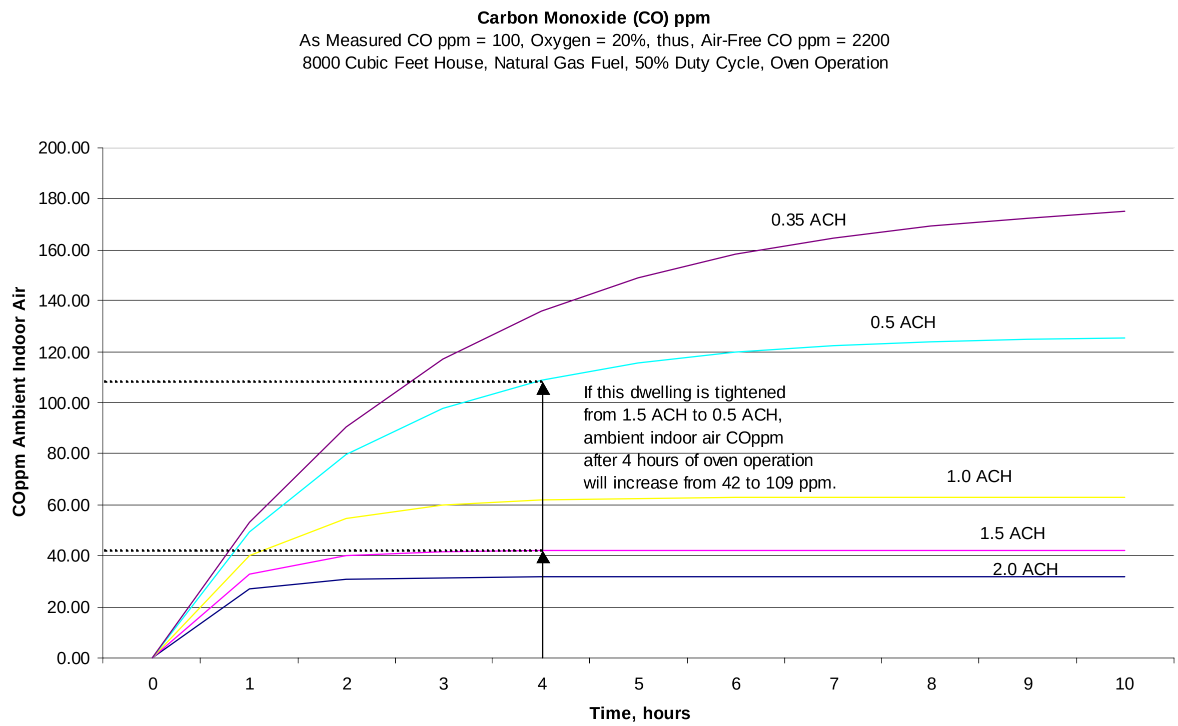

Carbon Monoxide (CO) ppm
800 ppm Air-Free CO Source, 8000 Cubic Feet House, Natural Gas Fuel,100% Duty Cycle, All Burners Operating
(with duty cycle of 50%, results are one-half of those shown)
COppm Ambient Indoor Air
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
0.35 ACH
0.5 ACH
1.0 ACH
1.5 ACH
2.0 ACH
0
1
2
3
4
5
6
7
8
9
10
Time, hours

Chart 2



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