Emissions of Polynuclear Aromatic Hydrocarbons from the Open Burning of Household Waste in Barrels

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ABSTRACT

Backyard burning of household waste in barrels is a common waste disposal practice that produces emissions of numerous pollutants. Previous studies to characterize these emissions investigated a limited number of pollutants, and polynuclear aromatic hydrocarbon (PAH) emissions were not evaluated. PAHs are a ubiquitous class of compounds that result from the incomplete combustion of organic matter. Exposure to materials containing PAHs can cause several types of cancer in humans. The U.S. EPA and the International Agency for Research on Cancer recognize the carcinogenicity of several PAHs by inhalation and ingestion. Using a waste mixture designed to simulate waste generated by an "avid recycler" and a "non-recycler," the emissions of volatile and semivolatile organic compounds, metals, acid gases, and respirable particulates were measured from a 55-gal. (208 L) burn barrel at EPA's open burning test facility. Total measured PAH emissions ranged from 23 mg/kg of waste burned (avid recycler) to 83 mg/kg (non-recycler). This study provides important data on a potentially significant source of emissions of air toxics.

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INTRODUCTION

In many areas of the country, residential solid waste disposal practices consist of open-burning using barrels or other similar devices instead of, or in addition to, disposal in municipal landfills or municipal solid waste combustors. The motivations for households that open-burn their garbage may include convenience, habit, or waste disposal cost avoidance.[1] Some communities have regulations that ban the open burning of garbage, and others may provide educational materials to curb open-burning. Emissions from open-burning of residential solid waste are released at ground level resulting in decreased dilution by dispersion. Additionally, the low combustion temperature and oxygen-starved conditions associated with backyard burning may result in incomplete combustion and increased pollutant emissions. In contrast, modern refuse combustors have tall stacks, specially designed combustion chambers, and high efficiency flue gas cleaning systems, which serve to minimize the risk of waste combustion.

Only two of the available studies characterized emissions associated with open burning of residential refuse in a backyard burner (e.g., a 55-gal. drum). These studies were performed by the Western Lake Superior Sanitary District of Minnesota[2] and the Two Rivers Regional Council of Public Officials and Patrick Engineering, Incorporated, of Illinois[1]. The Illinois study included a survey of 187 residents in rural counties of Illinois to determine the quantity and type of wastes burned, the management of the ash, and motivation for burning. Both study designs included a hood and stack constructed above the 55-gal. drum to capture the plume and facilitate pollutant emissions tests. Both studies reported that a substantial amount of dilution air was entrained in the burn barrel stack. Rough estimates of dilution air ratios were calculated by comparison to incinerator volumetric flow rates. These studies estimated emissions per unit mass of waste initially present in the barrel for several different air toxics (e.g., polychlorinated dibenzo-*p*-dioxins and dibenzofurans [PCDDs/PCDFs], total volatile organic compounds [TVOCs] measured as methane, metals, particulate matter [PM], hydrogen chloride [HCl], carbon monoxide [CO], and oxides of sulfur and nitrogen) associated with open burning of residential solid waste. The results of these studies indicated that the estimated chemical-specific emissions per unit mass of waste initially present in the barrel were higher than for controlled incinerators. However, neither study evaluated the emissions of polynuclear aromatic hydrocarbons (PAHs).

The above studies characterized emissions associated with burning residential solid waste in 55-gal. drums. In another study, Gerstle and Kemnitz quantified emissions from the burning of municipal refuse on a burn table equipped with a cone to capture and funnel the pollutants to a sampling port.[3] Samples were analyzed for several combustion gases and hydrocarbons including PAHs. Estimated emissions of fluoranthene, pyrene, chrysene, benzo(a)anthracene, benzo(a)pyrene, benzo(e)pyrene, and benzo(g,h,i)perylene ranged from 0.14 to 1.41 mg PAH emitted per kg of material initially present.

These studies provide useful information; however, there are limitations associated with their results (e.g., the presence of dilution air in the stack, a limited number of target compounds, and unrefined characterization of the waste). This paper reports on a study to qualitatively identify

and quantitatively characterize the emissions due to open burning of residential solid waste in burn barrels using techniques that would minimize the limitations of previous studies. The comprehensive results of this project are contained in an EPA report[4]. This paper focuses on PAH emissions associated with the open-burning of residential solid waste in burn barrels. As is evident from the above discussion, little emissions data exist for PAH emissions associated with the open-burning of residential solid waste in barrels. PAHs are a class of compounds that result from the incomplete combustion of organic matter. Exposure to materials containing PAHs can cause several types of cancer in humans. The U.S. EPA and the International Agency for Research on Cancer recognize the carcinogenicity of several PAHs by inhalation and ingestion.[5,6]

EXPERIMENTAL APPROACH

This project aimed to qualitatively identify and quantitatively measure the emissions of hazardous air pollutants from the open burning of household residential refuse in barrels while controlling for the limiting factors of earlier studies. Analytical work was divided between ARCADIS Geraghty & Miller (ARCADIS) and the New York State (NYS) Department of Health, Wadsworth Center for Laboratories and Research (WCL&R). Though numerous pollutants were targeted in this study, this paper focuses on the methods used to estimate PAH emissions.

Due to the highly variable nature of household waste generation, a reasonable representation of a waste stream for disposal in a burn barrel was prepared according to the typical percentages of various materials characterized and quantified for NYS residents. The characterization was performed by NYS Department of Environmental Conservation's (NYSDEC's) Division of Solid Waste and is based upon waste stream characterizations for NYS. The simulated household wastes were prepared primarily from raw materials diverted from the household wastes of ARCADIS staff members.

Emissions from two categories of waste were analyzed in this study. These categories include waste from an avid recycling and a non-recycling family of four. Household hazardous wastes (e.g., household chemicals, paint, grease, oils, tires, and other vehicle parts) were not included in the waste to be burned. Table 1 presents the composition of the simulated waste streams for the two scenarios. For the recycling and non-recycling scenarios, 6.4 - 13.5 kg (14 - 30 lb) of waste was burned (in duplicate) in a specially designed burn barrel in the EPA's Open Burning Test Facility[4]. A 55-gal. steel drum was modified for ventilation as the burn device. The drum was sandblasted prior to use in order to remove paint, thus simulating the use of a weathered, used burn barrel that would represent the most common residential burn device. This combustion device was placed on an electronic scale platform to allow the mass consumed by combustion to be monitored.

Table 1. Composition of Waste

	Non-Recycler (%)	Avid Recycler (%)
PAPER		
Newspaper, books, and office paper	32.8	3.3
Magazines and junk mail	11.1	--
Corrugated cardboard and Kraft paper	7.6	--
Paperboard, milk cartons, and drink boxes	10.3	61.9
PLASTIC RESIN (all types may contain trace plasticizers; e.g., cadmium)[a]		
PET #1 (bottle bill)	0.6	--
HDPE: #2, LDPE #4, and PP #5	6.6	10.4
PVC: #3	0.2	4.5
PS: #6	0.1	0.3
Mixed #7	0.1	0.3
FOOD WASTE	5.7	--
TEXTILE/LEATHER	3.7	--
WOOD (treated/untreated)	1.1	3.7
GLASS/CERAMICS		
Bottles/jars (bottle bill)	9.7	--
Ceramics (broken plates and cups)	0.4	6.9
METAL - FERROUS		
Iron - cans	7.3	4.0
NON-FERROUS		
Aluminum - cans (bottle bill), foil, other	1.7	1.0
Other non-iron (wire, copper pipe, batteries)	1.1	3.7
PERCENT TOTAL	100	100
TOTAL WEIGHT GENERATED PER HOUSEHOLD FOR DISPOSAL IN BURN BARRELS	4.9 kg/day	1.5 kg/day

a - PET = polyethylene terephthalate; HDPE = high-density polyethylene; LDPE = low-density polyethylene; PP = polypropylene; PVC = polyvinyl chloride; and PS = polystyrene.

Before the initiation of each test, the material to be combusted was placed in the barrel, air flow through the facility was initiated, and 15 minutes of background data were obtained on continuous emission monitors (CEMs) and thermocouples. The material to be combusted was then lit for a short period (<3 min) using a propane torch. Sampling was initiated at least 2 minutes after the removal of the propane torch. Propane torches generally produce only water (H_2O), carbon

dioxide (CO_2), and small quantities of low molecular weight products of incomplete combustion. Since these products were expected to have largely dissipated before sampling is initiated, this procedure should not bias the results. This assumption was verified by a hut blank experiment during which the propane torches were lit, but household waste was not burned. Additionally, the hut blank experiment provided information for the assessment of background contaminant concentrations in the ambient air that is pumped through the facility.

Total particulate-phase organics were sampled using a Graseby PS-1 sampler operated within the burn hut. This train, which is based on EPA's ambient sampling method TO-13,[7] consisted of an open-faced filter holder followed by a polyurethane foam (PUF)-sandwiched XAD-2 bed vapor trap. Due to the expected high concentrations of analytes in these tests, this sampler was operated at approximately 28.3 L/min (1 ft³/min). The temperature of air entering the train and within the PUF cartridge was assessed during preliminary tests in order to decide if further precautions were necessary to cool the system. Due to high temperatures in the burn hut, additional cooling was required and a copper cooling coil was fabricated to enclose the exterior of the PUF module. The semivolatile and particulate-phase organic sample was collected with a 110-mm diameter filter (Pallflex 2500 QAT-UP), and a glass and stainless steel cartridge containing PUF/XAD-2® resin sorbent. The filter and cartridge were then extracted together in a Soxhlet apparatus using methylene chloride. After extraction, a known fraction of the initial extract was sent to WCL&R for analysis. Both ARCADIS and WCL&R analyzed the combined organic particulate and XAD-2 sample extracts. These analyses followed EPA Method 8270[8] for the analysis of semivolatile/particulate bound organics using Gas Chromatography/Mass Spectrometry (GC/MS). WCL&R also performed a modification of EPA Method 8280[9] for the analysis of PAHs using GC/MS with selective ion monitoring (SIM) and isotope dilution quantitation to ensure adequate detection and quantitation of all target PAHs.

Estimated emissions of PAHs per unit mass burned were calculated using the measured concentrations of PAHs in the initial extract, the volume of air entering the burn hut facility, the volume of air drawn through the sampling device standardized to ambient temperature and barometric pressure, and the mass of waste consumed by combustion. These estimated emissions expressed a mass of analyte produced per mass of solid waste consumed in the combustion process.

RESULTS

PAH emissions data are reported in milligrams emitted per kilogram of residential solid waste consumed by combustion. Each sample train also included a hut blank, but the hut blank data are not included in this paper since there was no material burned in the hut blank and, as such, the estimated emissions per unit mass burned for those tests are undefined. Pollutant concentrations during the hut blank tests were insignificant in comparison to the household waste burn tests. In addition, data presented in this manner (as estimated emissions) do not take into account that the avid recycler produces only 30 percent of the mass of refuse produced by the non-recycler.

Tables 2 and 3 present the estimated PAH emissions in milligrams per kilogram of material consumed by combustion. These data are based on analyses performed by ARCADIS and WCL&R, respectively, using Method 8270. Both Tables 2 and 3 present several estimated emission results that are based on analytical data that were below the method detection limit (MDL) and present at values below the lowest calibration point (flagged with "J" in the tables) for Method 8270. Evaluations of these data indicate high variability between duplicate burns of similar waste. However, there appears to be reasonable agreement between the two laboratories on those compounds present in relatively high concentrations. Furthermore, the data from the individual tests do not show any strong trends related to the waste composition (i.e., avid recycler vs. non-recycler). However, average estimated PAH emissions for the non-recycler are higher than the estimated emissions for the avid recycler.

Table 4 presents the estimated PAH emission per kilogram of material consumed by combustion based on the SIM analyses. This method provides MDLs approximately five orders of magnitude lower than Method 8270. Thus reliable quantitation of all PAHs in the test burns was achieved even for those targets that were outside Method 8270's quantitation range. Examination of the data in Table 4 also indicates some variability between test burns using the same waste composition. As was found in the Method 8270 data, the emissions of PAHs from the non-recycler are higher than from the avid recycler. Total PAH emissions from the non-recycler are on the order of twice the level of the emissions from the average recycler per kilogram of material burned.

Figure 1 illustrates the difference between emissions of PAHs from the two different waste-stream scenarios and compares the different analytical methods. The data in Figure 1 were derived from all data generated using Method 8270 from both laboratories and Method 8280 to obtain average PAH estimated emissions for the non-recycler and the avid recycler waste scenarios. Values that were qualified with a "J" were used as is, and values that were reported below the detection limit were used as the value of the detection limit. In order to better illustrate all the emissions data, the y-axis is a log scale. Data gaps exist where a PAH was a target compound for either the 8270 Method or the SIM method but not for both. As seen by this Figure, the modified Method 8280 data are consistent with the less sensitive data obtained using Method 8270, and this method provides reliable quantitation of target PAHs. Figure 1 also indicates that, although there are differences between emissions of specific PAHs for the two waste streams, the overall PAH profile is consistent for the two waste-stream scenarios.

Table 2. Estimated Emissions of PAHs as Analyzed by ARCADIS by Method 8270, mg/kg

Test No. PAH	1 Avid Recycler	2 Avid Recycler	4 Non-Recycler	5 Non-Recycler
Acenaphthene	< 0.4	1.3 J[a]	1.5 J	1.0 J
Acenaphthylene	6.2	18.0	28.0	18.0
2-Acetylaminofluorene	< 0.4	< 1.8	< 2.5	< 1.8
Anthracene	1.5 J	3.9 J	5.4 J	3.1 J
Benzo(a)anthracene	2.6 J	0.6 J	2.5 J	1.4 J
Benzo(a)pyrene	1.6 J	< 1.8	2.7 J	1.2 J
Benzo(b)fluoranthene	< 0.4	< 1.8	< 2.5	< 1.8
Benzo(g,h,i)perylene	1.1 J	< 1.8	2.0 J	< 1.8
Benzo(k)fluoranthene	0.5 J	< 1.8	< 2.5	< 1.8
2-Chloronaphthalene	< 0.4	< 1.8	< 2.5	< 1.8
Chrysene	3.2 J	< 0.6 J	3.1 J	1.6 J
Dibenz(a,h)anthracene	0.4 J	< 1.8	< 2.5	< 1.8
Fluoranthene	3.1 J	3.4 J	8.3 J	4.4 J
Fluorene	1.6 J	7.0 J	7.2 J	4.6 J
3-Methylcholanthrene	< 0.4	< 1.8	< 2.5	< 1.8
2-Methylnaphthalene	2.6 J	18.0	6.8 J	9.4 J
Naphthalene	15.0	81.0	37.0	70.0
Phenanthrene	7.5	18.0	26.0	15.0 J
Pyrene	4.1	3.0 J	8.6 J	4.9

a - J = (PQL), Quantified outside of instrument calibration range

Table 3. Estimated Emissions of PAHs as Analyzed by WCL&R by Method 8270, mg/kg

Test No. PAH	1 Avid Recycler	2 Avid Recycler	4 Non-Recycler	5 Non-Recycler
Acenaphthene	0.25 J [a]	0.85 J	1.3 J	0.68 J
Acenaphthylene	4.5	12.0	26.0	11.0
2-Acetylaminofluorene	< 2.8	< 2.5	< 8.8	< 6.4
Anthracene	0.97 J	1.9	3.1 J	1.3 J
Benzo(a)anthracene	1.5 J	0.27 J	2.0 J	0.66 J
Benzo(a)pyrene	0.99 J	0.15 J	2.0 J	0.60 J
Benzo(b)fluoranthene	0.68 J	0.19 J	1.6 J	0.67 J
Benzo(g,h,i)perylene	0.81 J	0.26 J	2.1 J	0.74 J
Benzo(k)fluoranthene	0.70 J	0.18 J	1.3 J	0.60 J
2-Chloronaphthalene	< 1.3	< 1.2	< 4.2	< 3.1
Chrysene	3.0	0.49 J	3.4 J	1.2 J
Dibenz(a,h)anthracene	0.065 J	0.032 J	0.31 J	0.074 J
7,12-Dimethylbenz(a)anthracene	< 0.6	< 0.5	< 1.8	< 1.3
Fluoranthene	2.6	1.9	6.5	2.6 J
Fluorene	1.2 J	4.4	7.2	3.1 J
3-Methylcholanthrene	< 1.2	< 1.1	< 3.9	< 2.9
2-Methylnaphthalene	2.0	16.0	6.8	6.2
Naphthalene	13.0	54.0	37.0	47.0
Phenanthrene	6.5	14.0	27.0	11.0
Pyrene	3.9	2.6	11.0	3.9

a - J = (PQL), Quantified outside of instrument calibration range

Table 4. Estimated Emissions of PAHs as Analyzed by WCL&R Using Modified Method 8280 (SIM), mg/kg

| Test No. PAH	1 Avid Recycler	2 Avid Recycler	4 Non-Recycler	5 Non-Recycler
Acenaphthene	0.24	0.78	0.96	0.58
Acenaphthylene	2.7	4.0	14.0	9.0
Anthracene	0.61	0.93	2.4	1.3
Benzo(a)anthracene	1.1	0.43	3.1	1.3
Benzo(a)pyrene	1.1	0.24	3.1	1.1
Benzo(b)fluoranthene	1.6	0.54	3.8	1.5
Benzo(g,h,i)perylene	0.99	0.28	2.8	1.1
Benzo(k)fluoranthene	0.52	0.12	1.6	0.41
Chrysene	1.6	0.46	3.6	1.5
Dibenz(a,h)anthracene	0.38	0.067	0.49	0.16
Fluoranthene	1.5	1.5	5.2	2.9
Fluorene	1.5	3.2	4.8	2.5
Indeno(1,2,3-c,d)pyrene	1.0	0.30	2.8	0.95
Naphthalene	4.0	6.4	19.0	16.1
Phenanthrene	2.8	3.9	9.0	5.6
Pyrene	1.7	1.4	6.1	3.5
Total	23.3	24.5	82.8	49.5
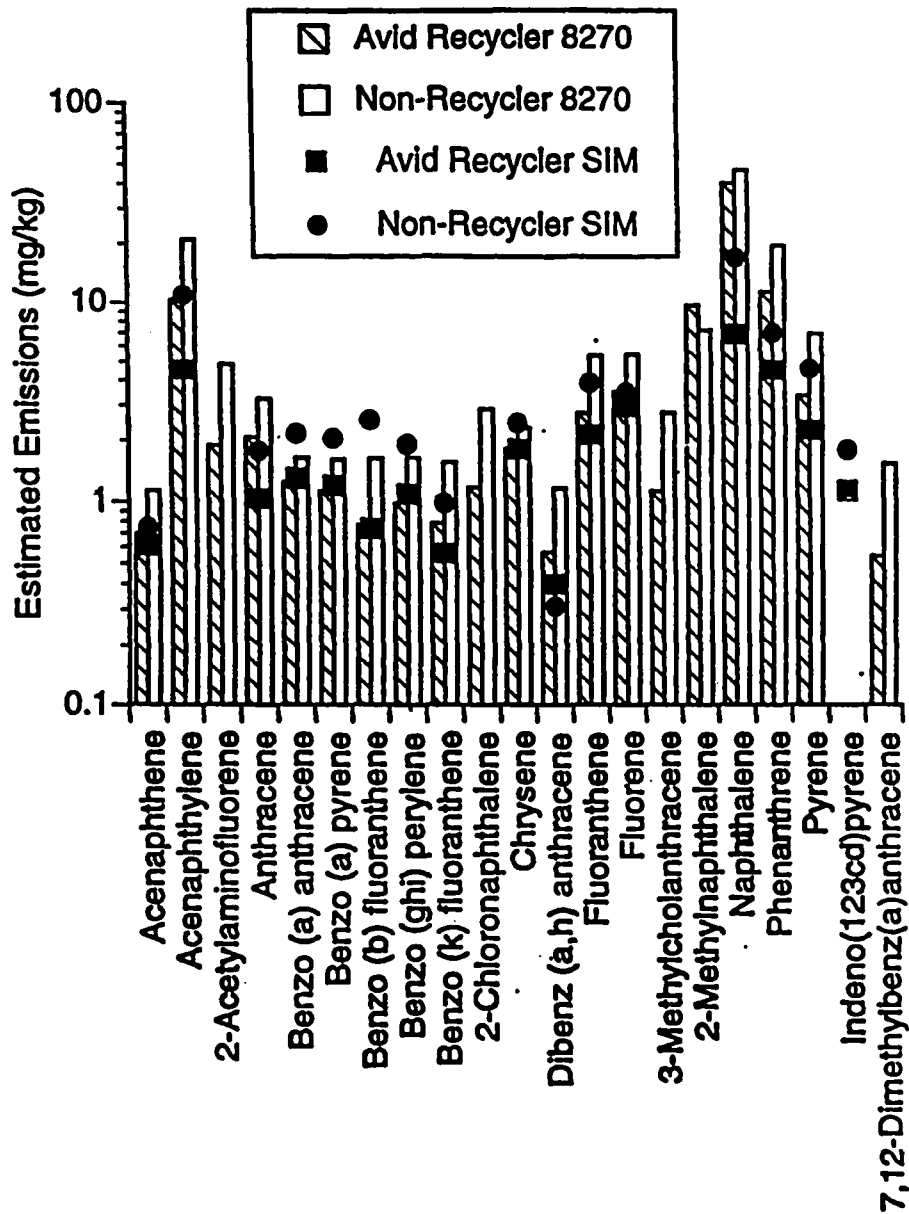
Figure 1. Average Emissions of PAHs by Waste Composition and Analytical Method. Data represent the average of duplicate tests using the values in Tables 1, 2, and 3 and ignoring data qualifiers (less than detection limits and Js).

SUMMARY AND CONCLUSIONS

Despite the carefully controlled nature of these experiments, the PAH emissions data presented in this paper demonstrate variability between duplicate tests of the same waste stream. Greater variability would be expected between emissions from the general use of burn barrels since the waste composition and combustion conditions are likely to vary.

.Using waste generation rates per household reported by NYSDEC and assuming that all waste is disposed of by open-burning in a burn barrel, PAH emission rates can be estimated on a per household basis. For the non-recycler, estimated total PAH emissions range from 245 to 402 mg/day. For the avid recycler, estimated total PAH emissions are 36 mg/day. Thus, on a per household basis, estimated PAH emissions for the non-recycler would be dramatically (approximately 7 to 11 times) higher than for the avid recycler. The Illinois study indicated that, on the average, approximately 36 percent of households in small municipalities burned their solid waste in burn barrels.[1] Therefore, open burning of household waste may be a significant contributor to ambient levels of PAHs.

The PAH-specific emissions data from Gerstle and Kemnitz were 2 to 13 times lower than the estimated average PAH-specific emissions data for the non-recycler and the avid recycler.

PAH emissions from these tests were also compared to emissions from two full-scale municipal waste combustors (MWCs): a modern MWC that possesses good combustion conditions and flue gas cleaning technology and an older mass-burn incinerator that possesses no air pollution control devices.

The comparison to the modern MWC was based on data from a field test at a refuse-derived fuel facility using the average of the "Normal Good" PT-08, PT-09, and PT-11 test conditions at the pollution control device outlet[10]. Total PAH emissions from this MWC are 0.017 mg/kg. The estimated average total PAH emissions from the open-burning tests are 66 and 24 mg/kg for the non-recycler and avid recycler, respectively.

The emissions test report for the older mass-burn incinerator presented an emission rate only for benzo(a)pyrene. Based on the incinerator's capacity and the benzo(a)pyrene emission rate, the estimated emissions for benzo(a)pyrene are 0.003 mg/kg.[11] The open-burning tests yielded estimated average benzo(a)pyrene emissions of 2.1 and 0.67 mg/kg for the non-recycler and avid recycler, respectively. Based on these comparisons, it is readily apparent that even the significant differences between the avid recycler and non-recycler emissions are minor in comparison to the difference between open burning of household waste and the controlled/uncontrolled combustion of municipal waste at dedicated MWC facilities.

This study adds to the limited current database for emissions associated with open-burning of household waste in a burn barrel. However, there are limitations with the use of these data. As previously noted, burn barrel emissions are variable; no two burn barrels can be expected to emit similar quantities of PAHs. Additionally, there is a lack of information about the exact composition of what people typically burn in their barrels and the frequency and prevalence of this

waste disposal activity. The Illinois study is the only study that evaluated these important aspects of open-burning of residential solid waste.

ACKNOWLEDGEMENTS

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17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
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