Interim Report

Assessment of the Effectiveness of New MSAT2 Regulations on the Reduction of Indoor Benzene Concentrations in Homes with Attached Garages.

Anchorage Air Quality Program
Municipality of Anchorage
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Acknowledgements

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Introduction and Background

In February 2008 EPA promulgated the second phase of mobile source air toxics (MSAT2) regulations aimed at reducing gasoline-related benzene emissions. These regulations will limit the maximum allowable benzene content to 1.3% beginning July 2012.[*] The EPA has also mandated new standards for portable gasoline storage containers, effective January 1, 2009, that are intended to reduce hydrocarbon emissions from these containers by 75%. The purpose of the study is to quantify the effect of these new regulations on indoor air benzene concentrations in homes with attached garages in Anchorage, Alaska. This interim report discusses the first phase of a planned two-phase study.[†] The objective of the first phase was to characterize benzene concentrations prior to the implementation of the rule. The first phase of indoor air and gasoline sampling was conducted from September 2008 to October 2009. Phase 1 of a complementary study characterizing ambient (outdoor) concentrations was conducted at the same time. We are planning to conduct a second phase of indoor and outdoor sampling after the implementation of the MSAT2 rule to characterize concentrations after the rule has taken effect to assess its effectiveness in reducing indoor and outdoor benzene concentrations. A combined final report, discussing the impact of the rule on both indoor and outdoor benzene concentrations, is planned following completion of the Phase 2 studies.

Alaska gasoline contains approximately 5% benzene by weight. Previous studies in Anchorage have shown that stored gasoline and gasoline-fueled equipment are the primary source of benzene exposure in homes with attached garages (see References). These studies have shown that, on average, benzene concentrations in homes with attached garages are three to five times higher than outside. In 2007-2008, benzene, toluene, ethyl benzene and total xylene (BTEX) concentrations were measured over a one-week sample period in 509 randomly selected Anchorage homes with attached garages.[‡] The median benzene concentration was 2.9 ppb. Sixteen percent of the homes sampled exceeded the 9 ppb minimum risk level for acute exposure to benzene (≤14 days) recommended by the Agency for Toxic Substances and Disease Registry (ATSDR).

Study Design and Methods

This study is intended to be a longitudinal study that will track changes in indoor benzene concentration in a sample of Anchorage homes with attached garages before and after the implementation of the MSAT2 regulation. The study design set minimum sample size target of 60 homes for Phase 1 of the study with the hope that at least 30 of these households would agree to continue on through Phase 2. Prior analysis indicated that a sample size of 30 would be sufficient to adequately quantify the effects of the MSAT2 rule on indoor benzene concentrations. In Phase 1 each household was requested to deploy two passive organic vapor monitoring badges for one week each month; one in the living space of their home and the

[*] The rule will limit the average benzene content to 0.62% which refiners can achieve through trading. Individual refiners, however, must also meet an *actual* limit of 1.3%.

[†] It should be noted that Phase 2 of the indoor and outdoor studies are *planned*. Funding has not been secured for the second phase of either study.

[‡] This study investigated the association between asthma and the indoor concentration of volatile organic compounds. As single one-week BTEX measurement was taken from each household. The principal investigator was Mary Ellen Gordian, MD of the University of Alaska, Anchorage. This study will be referred to as the Asthma /VOC Study in this report.

other in their garage.[§] A small monetary incentive was provided to each household that continued to successfully deploy and return the passive badges for analysis in the laboratory each month.[**]

Recruitment

The 509 households that participated in the Asthma/VOC Study were used as a pool of potential recruits for this study. These households had demonstrated their capability to self-deploy, document and mail samples back to the laboratory for analysis. Prior sampling in these homes also gave some indications of the benzene levels expected in each home. Eighty two households were selected from the original pool of 509. Although the original pool was randomly selected, the 82 homes selected in this study were not. Homes with elevated benzene concentrations were purposely selected so that the impact of the MSAT2 rule changes could be more readily quantified. These 82 households had benzene concentrations that were generally in the upper quartile of the original pool.

A questionnaire was used to screen potential participants to determine whether they met qualifications for inclusion in the study. The questionnaire was used to exclude households that expected to move or remodel the house within the next five years. Because smoking is a potential source of benzene and could confound the evaluation of the MSAT2 rule effectiveness, households with smokers were excluded from participation.

The study began with 82 households because a fairly large drop-out rate from this monthly commitment was expected. Drop out rates were lower than expected; 67 of these households successfully deployed the passive monitors for at least ten of the 12 months of the study.

Sampling and Analysis of Indoor Air in Houses and Attached Garages

The 82 households selected for the study were mailed two organic vapor monitoring badges each month along with instructions on how to deploy the two badges in the living space and garage of their house. The instructions asked the householder to deploy the badge for one week in a commonly occupied part of their home (e.g., living room, bedroom) at breathing level in an area where it was unlikely to be disturbed by pets or children. They were also instructed how to document sample deployment and retrieval times and how to close the badge at the end of sampling. After the conclusion of the one-week sampling period each month, they were instructed to return the badges by mail in boxes with pre-paid postage.[††] If there were any discrepancies in the sample documentation the householder was contacted to clarify. If the return of a badge was delayed from a household, the participant was called with a reminder. After a few months a routine was established and most badges were returned promptly after exposure.

When the boxes were received they were opened and checked to make sure the organic vapor monitoring badges were correctly closed. The information was entered into a database and the badges were eluted and analyzed by gas chromatograph at the University of Alaska Applied

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[§] We utilized OVM3500 passive monitoring badges from 3M®.

[**] Participants were given a Tesoro gas card at the beginning of the study. The gas card was credited with an additional $35 each month after the badges were successfully deployed and returned.

[††] There was difficulty getting the boxes back from the post office when return mail stickers were used. The post office holds return mail until it has accumulated sufficient numbers to deliver. Eventually participants were given boxes affixed with stamps for first class mail to prevent them from languishing in the post office.

Science and Environmental Technology (ASET) laboratory. They analyzed target compounds (benzene, toluene, ethyl benzene and xylenes) using the National Institute for Occupational Safety and Health protocol (EPA Compendium Method TO-17) modified for the OVM3500 monitoring badges.

A short questionnaire was included in sampling kits mailed each month to the households participating in the study. The purpose of the monthly questionnaire was to document any changes in household behavior that could affect the benzene concentration in their house and/or garage. Householders were asked whether the storage of gasoline containers or gasoline-fueled equipment had changed, and if they had made changes that could effect the ventilation for either house or garage.

Gasoline Sampling and Analysis

During the same October 2008 – September 2009 period that indoor air sampling was being conducted, gasoline from ten Anchorage gas stations was sampled and analyzed on a bi-monthly basis for BTEX and other gasoline components. Samples were analyzed by the ASET laboratory to quantify gasoline components by ASTM Method D6729-04.

Results and Discussion

Quality Assurance

Quality assurance objectives established for the study in the Quality Assurance Project Plan were met. Less than one percent of the badges were found to be unusable because of lack of documentation or incorrect handling. All field and Laboratory blanks were below the limits of detection. Ninety-three percent of the replicate samples agreed within 25%, exceeding the data quality objective of 90%.

Some errors in the deployment of the replicate monitoring badges were encountered. Some homeowners were deploying replicate samples in different parts of the house or garage rather than side by side as instructed. Most of these issues were resolved as the study progressed.

Quality assurance objectives were also met for the gasoline sampling and analysis. Four replicate gasoline samples were collected during each bi-monthly gasoline sampling. All 24 replicates varied by 6.5% or less for benzene, well within the 15% criteria set for the quality of gasoline samples. Similar replicate results were found for the other BTEX components. Recovery of benzene in a certified gasoline standard (NIST #2297) ranged from 106.4% to 112.9%, satisfying our analytical criteria (>80%). Recovery of other BTEX compounds ranged from 98.9% to 109.0%. All BTEX compounds in laboratory blanks (5% pentadecane in dichloromethane), run every 20 samples, were below detection limit.

Statistical Summary

As noted earlier, 67 of the 82 households originally recruited for this study successfully collected samples from the living space of their homes and from their garage at least 10 of the 12 months of study. The 15 households that were missing three or more months of sampling data were excluded from this analysis. Descriptive statistics for the remaining 67 households are shown in Table 1.[‡‡] Again, it should be noted that the sample population for this study

[‡‡] Year-long statistical data were weighted by the number of days in each month.

was not selected randomly; these were households that exhibited elevated benzene concentrations in the previous Asthma/VOC Study.[§§] Thus results are not generally representative of Anchorage homes with attached garages.

Table 1.

Indoor Benzene Concentrations
Statistical Summary October 2008 – September 2009

	N	Mean (ppb)	Percentile Concentrations (ppb)				
			10th	25th	50th	75th	90th
House	67	7.3	1.7	2.8	5.3	8.8	15.6
Garage	67	32.7	4.4	11.3	21.7	41.6	75.2

As expected, benzene and other BTEX concentrations were substantially higher in garages than in houses.[***] Of the 758 paired house and garage measurements taken over the course of the 12 month study, there were only nine instances when the benzene concentration in the house was higher than the garage. Most of these occurred when both house and garage concentrations were low, 3 ppb or less.

Seasonal Variation in Benzene - Implications for Sampling Frequency in Phase 2

Figure 1 shows that average garage concentration increased rather dramatically in the summer months (May-September); presumably because of greater use of gasoline-fueled equipment (e.g.; lawn mowers) stored and/or fueled in the garage. The volatility of gasoline may also increase in warmer months. In contrast, however, average concentrations inside the house, declined slightly during this same summer period. Interestingly, garage concentrations peaked in July while the average house concentration reached an annual minimum. Presumably, during warm weather occupants open windows and doors more than in the winter and greater proportion of the air entering the house originates from outside air rather than the garage. Benzene concentrations in ambient air, especially in the summer, are much lower than the typical garage. During the summer, ambient benzene concentrations measured in Anchorage were nearly *100 times* lower than the average concentration in the 67 garages in this study.[†††]

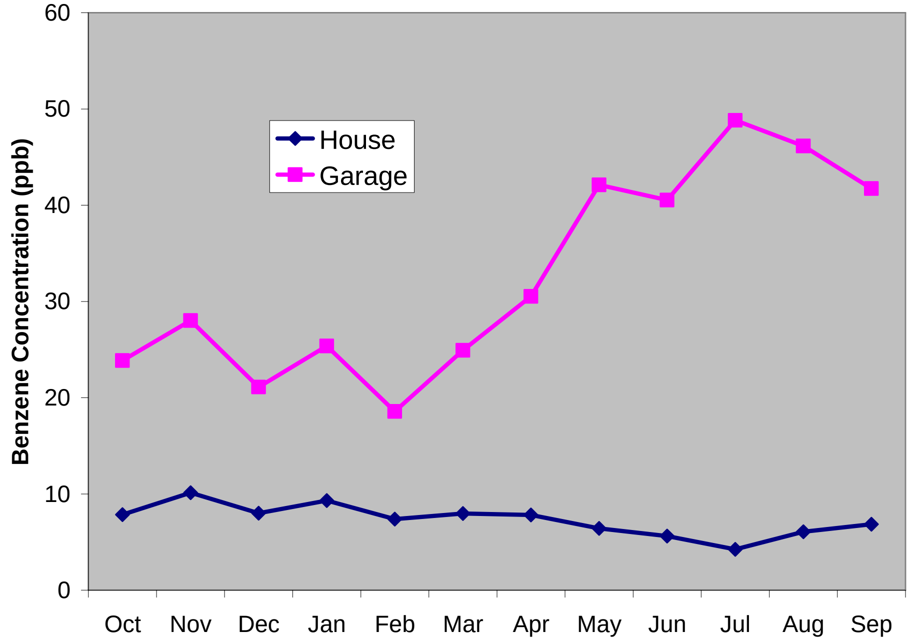
[§§] For comparison, the median indoor (house) benzene concentration in the Asthma/VOC study was 2.9 ppb, about 40% lower than this study.

[***] Toluene, ethyl benzene or total xylene concentrations were correlated with benzene. Much of the discussion regarding benzene would apply equally to these other compounds.

[†††] The mean benzene concentration measured at the Garden station in East Anchorage, May – September 2009 was 0.5 ppb. The average concentration in the 67 garages during this same period was 43.9 ppb.

Figure 1

Seasonal Variation in Benzene Concentration in Houses and Garages (N=67)
October 2008 – September 2009



Prior to this study, little was known about the seasonal variation in indoor benzene concentrations. For this reason, when Phase 1 of the study was designed, a decision was made to sample every month for a year to characterize this variation. Now that this variation is better understood, it may be possible to reduce the frequency of samples collected from each household in Phase 2 of the study. We examined how reducing the sampling frequency from monthly to quarterly (samples collected in February, May, August, and November) or semi-annually (February and August) might affect an estimate of the mean annual benzene concentration in the house and garage.

The scatter plots in Figures 2(a) and (b) compare the estimated mean annual benzene concentration inside the 67 homes sampled in the study computed from 12 monthly measurements to the mean computed from quarterly or semi-annual measurements. Figures 3(a) and (b) show the same comparison for the garage sampling.[‡‡‡]

The scatter plots show that annual house and garage mean concentrations computed from four one-week samples collected in February, May, August and November agree very well with those computed from more resource intensive monthly sampling (for house: R^2 = 0.93, garage:R^2 = 0.94). Semi-annual sampling also provides a reasonably good estimate of the mean but not as good as one derived from quarterly sampling (house: R^2 = 0.81, garage:R^2 =

[‡‡‡] An example of how this was done is shown below for one of the homes in the study:

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	**Mean**
monthly	4.04	5.82	4.32	6.22	3.67	7.56	5.31	1.26	1.10	1.24	1.82	3.92	**3.86**
quarterly		5.82			3.67			1.26			1.82		**3.14**
semi-annual					3.67						1.82		**2.74**

0.85). This suggests that the sampling frequency for Phase 2 of this study could be reduced to quarterly or perhaps even semi-annually and still provide a good estimate of the mean annual benzene concentration in each house and garage.

Figure 2(a)
Estimate of Mean Annual House Benzene
Quarterly vs. Monthly Sampling
(all values ppb)

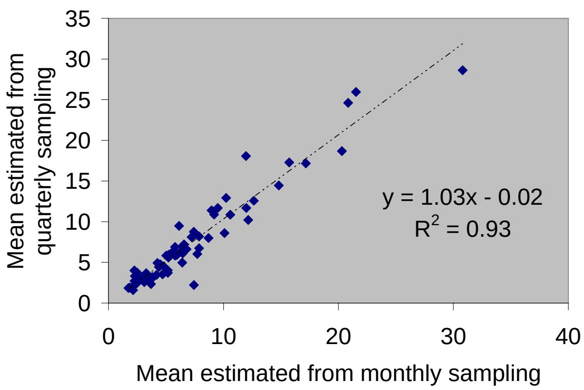


Figure 2(b)
Estimate of Mean Annual House Benzene
Semi-annual vs. Monthly Sampling
(all values ppb)

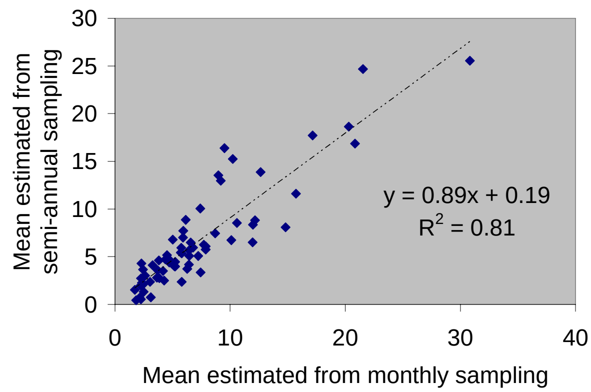


Figure 3(a)
Estimate of Mean Annual Garage Benzene
Quarterly vs. Monthly Sampling
(all values ppb)

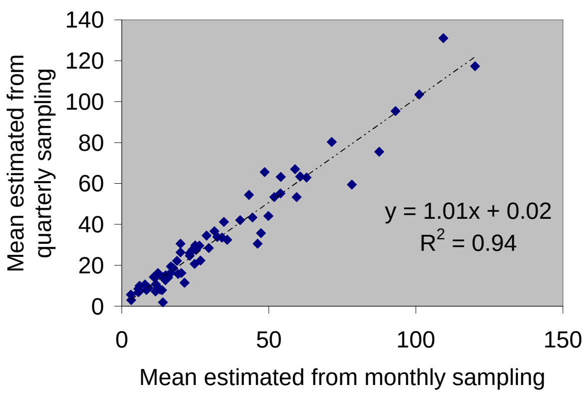
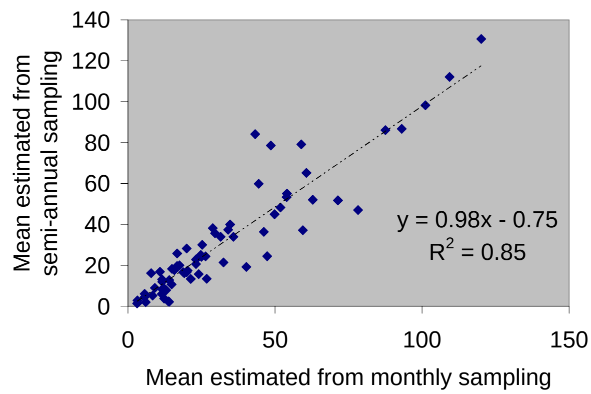


Figure 3(b)
Estimate of Mean Annual Garage Benzene
Semi-annual vs. Monthly Sampling
(all values ppb)



Relationship between Indoor BTEX Concentration and Gasoline Composition

During the same October 2008 – September 2009 period that Phase 1 sampling was being conducted, gasoline from ten Anchorage gas stations was sampled and analyzed on a bi-monthly basis for BTEX. Results for benzene in regular gasoline are tabulated in Table 2.

Table 2.
Summary of BTEX Content of Regular and Premium Anchorage Gasoline (% by weight)
October 2008 – September 2009

	Regular Gasoline				Premium Gasoline			
	mean	**min**	**max**	**stdev**	**mean**	**min**	**max**	**stdev**
benzene	4.99%	3.59%	5.50%	0.43%	5.32%	4.11%	5.82%	0.35%
toluene	17.38%	11.93%	21.47%	1.63%	19.29%	16.68%	21.44%	1.14%
ethyl benzene	2.36%	1.54%	3.05%	0.31%	2.86%	2.53%	3.23%	0.17%
xylenes	12.84%	8.37%	15.13%	1.02%	15.86%	13.66%	17.32%	0.89%

Mean BTEX concentrations measured in the house and garage of the 67 homes in the study are compared to gasoline composition in Anchorage in Figure 4 (a) and (b).[§§§] Figure 4(a) shows the relationship between the BTEX composition of gasoline and the average concentration of those same gasoline BTEX components in the house.[****] Figure 4(b) shows the same relationship for the air in the garage. Results indicate that the relative concentrations of the BTEX compounds found in the air inside homes and garages closely mirror the composition of gasoline. For example, toluene is found in the highest proportion in gasoline and it is also found in the highest concentration in the air of homes and garages.

Figure 4(a)
House
BTEX Concentrations vs. Gasoline Composition

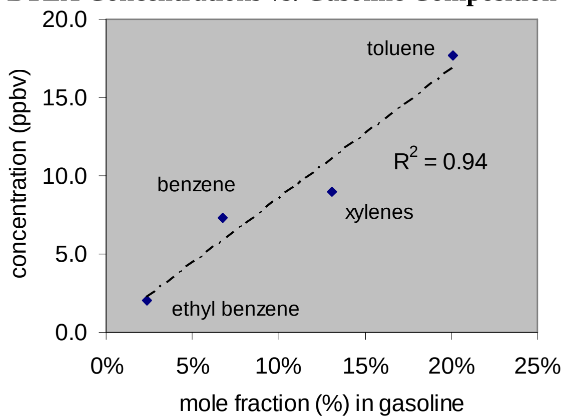
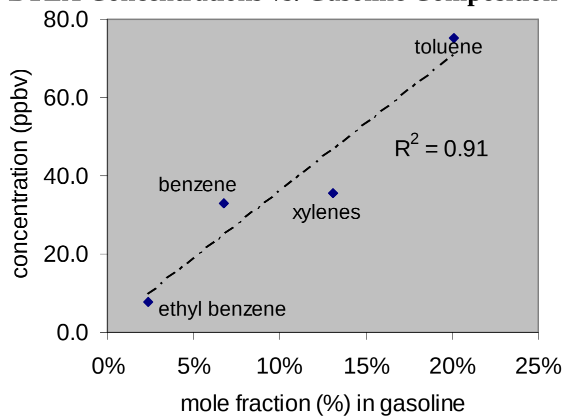


Figure 4(b)
Garage
BTEX Concentrations vs. Gasoline Composition



§§§ We estimated that 88% of all gasoline sold in Anchorage was regular grade; 12% was premium. For Figures 4(a) and 4(b) we computed a single estimate of % BTEX content from the weighted average of regular and premium grades.

**** The mole fraction (%) of each gasoline component is used because when these components become volatilized their concentrations are measured in terms of volume (ppbv). The ideal gas law can be used to estimate the relative amount of volume occupied by each gasoline component after volatilization. The volume occupied by each component is proportional to its mole fraction compared to other components. The mole fraction (%) can be computed from the molecular weight of each gasoline component and its mass % content in gasoline. For example, the average molecular weight (mw) of gasoline is reported as 105 grams per mole, the mw of benzene is 78.1. The mole fraction of benzene in gasoline is therefore:

mole fraction (%) benzene = 5.01% x 105/78.1 = 6.76%

Concern Regarding Potential of Bias Introduced into Phase 2

At the conclusion of Phase 1, the householders participating in this study were sent a letter with the results from benzene sampling in their house and garage. The letter also noted whether the estimated mean annual benzene concentration in their home exceeded the ATSDR minimum risk level for chronic exposure to benzene.[††††] They were advised that removing stored gasoline and gasoline-fueled equipment from their garage and weather-stripping the door between the house and garage were good ways to reduce their exposure to benzene. It seems reasonable to assume that at least some householders will make changes between Phase 1 and Phase 2 that could lower benzene concentrations in their homes. This would increase the apparent effectiveness of the new MSAT2 rule as indicated by the decline in benzene between in Phase1 and 2 measurements.

Comparison of BTEX measurements made during the Asthma/VOC Study to the same households in this study a year later suggests that participating in studies like this may motivate some householders to make changes to lower their benzene exposure. As was the case with Phase 1 of this study, participants in the Asthma/VOC Study were also provided with the results of the benzene testing done in their homes and were advised on ways they could reduce exposure. Benzene concentrations in those same houses dropped by an average of 29% when they were re-tested as part of this study.[‡‡‡‡] Indoor concentrations of toluene, ethyl benzene, and total xylene declined by similar amounts. Nearly one- third of the households exhibited a benzene decline of 50% or more. A paired t-test indicated that there was a statistically significant ($p=0.02$) decline of 1 ppb or more in house benzene concentrations between the first and second study.

Even if participants were not informed about the results of testing or the risks of exposure to benzene, just knowing that their house was being sampled for benzene could stimulate some to investigate why benzene might be of interest, research the risks of exposure, and induce them to make changes to reduce this risk. The only way to effectively eliminate the possibility of some householders making changes in behavior as a result of participation in this study would be to design a one-sided blind study that keeps householders completely in the dark about what was being sampled and why. This did not seem practical.[§§§§]

Fortunately there appears to be a way to distinguish the changes in benzene concentration that occur due to modifications in household behavior from those resulting from the MSAT2 rule implementation. The MSAT2 rule is expected to reduce the average benzene content in gasoline from approximately 5% to 1.3% or lower. Although there are likely to be consequent changes in content of toluene, ethyl benzene and total xylenes, the magnitude of these changes are expected to be much smaller on a relative basis. In any case, we plan to sample gasoline again during Phase 2 to document changes in the composition of gasoline that have occurred. Indoor measurements of toluene, ethyl benzene and total xylene in the

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[††††] 78% of the homes in the study exceeded the recommended chronic exposure limit of 3 ppb. ATSDR defines chronic exposure as exposure of duration one year or more.

[‡‡‡‡] The Asthma/VOC Study collected a single one-week sample in each house sometime between December 2007 and May 2008. We compared the result from that sample to a sample taken during the corresponding month in this study so that seasonal variation would not be a factor.

[§§§§] We believe that it would have been much more difficult to solicit and keep volunteers in a one-sided blind study. We think many volunteers agreed to on-going participation because they were interested in seeing the results for their house.

house and garage will enable us to determine whether individual households have made behavioral or architectural changes between Phase 1 and 2 that resulted in reductions in gasoline exposure. For example, if we see dramatic reductions in the indoor concentration of toluene, ethyl benzene and total xylene that are not explained by a reduction of these same components in gasoline, it is reasonable to assume that some factor other than changes in gasoline composition are responsible. Conversely, if dramatic reductions are observed in indoor benzene that are not accompanied by declines in the other BTEX compounds, we can assume that the MSAT2 rule is primarily responsible. Statistical methods can be used to quantify and distinguish effect of the MSAT2 rule from other factors. One possible method for doing this is outlined in the Appendix to this interim report.

Recommendations for the Design of Phase 2

1. Recruit as many of the 67 households that participated in Phase 1 for Phase 2 of the study. A minimum sample size of 30 or greater is advisable.
2. Postpone indoor sampling for at least one year after the benzene content in gasoline has been reduced to 1.3% or lower. This will allow households an opportunity to use up older, higher benzene content they may be storing. It will also allow time to use up the gasoline in seasonally used equipment (e.g., summer-use lawn mowers, winter-use snow blowers). Sample gasoline stored in the garages in a portion of households prior to commencing the study to verify whether households have in fact replaced "old" gasoline with new. Postpone study longer if necessary.
3. Carefully construct a new questionnaire prior to repeating sampling in households involved in the first phase of the study to determine whether they have made changes in behavior or architectural changes that could affect exposures to benzene and other BTEX compounds in the indoor air. Phase 1 results suggested that householders often overlook factors that could have an important influence on benzene concentrations. Consider conducting personal interviews and a garage/house inspection with participants to gain a more accurate picture of changes that might have occurred. Determine whether households have purchased new MSAT2-compliant fuel storage containers and have replaced their old containers or have simply added the new containers to the old ones in their attached garages. The questionnaire should be designed so that results can be utilized to help quantify and distinguish the effect of the reduction of the benzene content in gasoline from other factors that could also affect indoor benzene concentrations.
4. Consider reducing indoor air sampling frequency from monthly to quarterly. Repeat sampling in both house and garage.
5. Repeat gasoline sampling. Analyze results from Phase 1, collect new information from refiners and distributors of gasoline and determine whether the frequency and number of samples that should be collected to accurately characterize BTEX content after gasoline composition can be reduced. It may be possible to reduce the level-of-effort required in Phase 2.

References

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Appendix

Proposed Method of Quantifying the Impact of the MSAT2 Rule on Mean Indoor Benzene Concentration before and after Change in Gasoline Composition

Proposed Method of Quantifying the Impact of the MSAT2 Rule on Mean Indoor Benzene Concentration before and after Change in Gasoline Composition

We are proposing to use a linear regression method to distinguish the effect of the MSAT2-required change in the benzene content in gasoline from other effects unrelated to the MSAT2 rule. For example, some households that participated in Phase 1 of the study may make a conscious effort to reduce their exposure to benzene and other gasoline components by removing gasoline equipment and fuel storage cans from the garage. The proposed method for separating these types of effects from the effect of the MSAT2-required change in gasoline benzene content is described later in this Appendix.

Before we could evaluate the proposed linear regression method, we first used a Monte Carlo procedure to construct a data set of what might be expected for Phase 2 results. The procedure used the mean annual BTEX measurements from individual houses in Phase 1 as a starting point and modified these values with a series of random effects and non-random effects that could occur between Phase 1 and Phase 2 to produce "new" benzene, toluene, ethyl; benzene and total xylene concentrations for Phase 2. An Excel random number generator was used to produce random numbers, fitting a normal distribution, around a pre-specified mean that reflected the expected average effect of a certain variable. The standard deviation of the distribution was also specified in the Excel procedure. For example, the benzene content in gasoline is expected to drop from 5% to 1.3% between Phase 1 and 2, a reduction of 74%. The effect of this reduction on indoor benzene concentrations was assumed to be proportional to this reduction and was modeled using a normal distribution with a mean change of -0.74 with a standard deviation of 0.05. Table A-1 describes how each random and non-random effect was modeled in the spreadsheet.

Table A-1 Monte Carlo Modeling of Random and Non-Random Effects Influencing Indoor BTEX Concentration between Phase 1 and Phase 2

Variable	Distribution Used to Model Variable	Explanation
MSAT2-required reduction in gasoline benzene content	Normal distribution, $\mu = -0.74$, $\delta = 0.05$	Assume that indoor [benzene] will drop in proportion to reduction in gasoline benzene content (74%) with some variation among individual households
Incomplete turnover of stored gasoline in attached garage	Normal distribution, $\mu = 0.85$, $\delta = 0.20$	Assume average household will have replaced 85%of all stored gasoline with new gasoline with lower benzene content and there will be random variation ($\delta = 0.20$) among individual households.
Increase in toluene content in gasoline (assume toluene increases to compensate for loss of benzene)	Normal distribution, $\mu = 0.12$, $\delta = 0.03$	Assume toluene content in gasoline increases by 12% to compensate for reduced benzene. Some individual random variation ($\delta = 0.03$) among households. (No change was assumed in ethyl benzene or xylene content)
Conscious decisions by some householder to reduce exposure to benzene by changing storage habits.	Normal distribution, $\mu = -0.50$, $\delta = 0.70$	Assume that 50% of homeowners make choice to make changes such as removing gasoline equipment from garage. Among those that make this choice, average reduction in benzene and other BTEX is 50% with widely varying results ($\delta = 0.70$) among households.
Unexplained random variation between Phase 1 and 2	Normal distribution, $\mu = 0.00$, $\delta = 0.25$	Average effect of random variation is zero (applied to all BTEX).

The Monte Carlo simulation was performed five times to produce five different Phase 2 data sets. In addition, because we expect that some households will not participate in Phase 2, we randomly dropped approximately 50% of the Phase 1 households from the study. The number of households varied from simulation-to-simulation.

End results of the first simulation are shown in Table A-2. The table shows actual Phase 1 data (mean annual concentration in ppb) to the "constructed" Phase 2 data. In this simulation, 37 of the 67 original Phase 1 households continued participation in Phase 2.

Table A-2 Phase 1 Indoor BTEX House Concentration compared with Phase 2 Data Constructed from Monte Carlo simulation of Random and Non-random Effects (Simulation #1)

	Phase 1 Data House Concentration (ppb)				Phase 2 Data House Concentration (ppb)			
ID	[benzene]	[toluene]	[ethyl benzene]	[xylenes]	[benzene]	[toluene]	[ethyl benzene]	[xylenes]
4	3.64	11.20	1.02	4.41	2.42	12.50	1.03	4.40
7	2.49	8.15	0.86	3.67	0.62	3.95	0.40	1.70
14	5.79	12.52	1.46	6.57	1.98	7.77	0.93	3.21
25	2.33	5.11	0.75	3.25	1.82	9.06	1.17	5.19
43	6.42	14.65	1.83	7.96	4.22	17.93	1.76	8.30
48	12.16	30.94	3.48	15.67	2.51	16.98	1.77	8.56
60	8.97	25.57	2.67	12.84	5.89	41.45	4.29	20.89
67	5.91	15.04	1.91	8.11	1.19	10.37	0.98	4.35
86	4.39	15.22	1.82	7.26	1.01	8.36	0.85	3.75
153	21.54	48.35	5.03	24.95	14.15	67.35	6.41	28.55
167	3.04	7.69	1.01	3.93	0.55	6.12	0.83	3.35
180	2.48	5.31	0.68	2.85	0.65	3.59	0.43	2.07
182	4.80	10.38	1.21	5.18	1.59	12.30	1.19	5.58
183	9.19	21.00	2.53	11.63	1.88	10.79	1.19	5.81
204	3.86	10.66	1.02	4.31	0.62	2.93	0.27	1.05
240	14.82	41.83	3.54	17.17	6.34	45.83	3.41	17.77
247	8.70	18.28	1.68	7.23	0.43	4.13	0.28	1.31
270	5.24	22.02	1.85	8.13	1.75	20.73	1.28	6.28
274	11.99	29.16	4.06	18.76	3.87	30.08	3.91	18.71
305	1.85	11.70	0.59	2.07	0.78	12.30	0.63	2.08
315	6.79	14.53	1.47	6.13	2.89	16.23	1.75	7.03
333	4.17	8.46	0.95	4.28	0.94	9.65	0.78	4.06
341	20.30	46.33	4.74	23.08	3.47	22.16	2.44	9.41
342	5.72	13.58	1.72	6.99	0.48	3.84	0.51	2.05
387	3.82	8.44	0.90	3.86	0.87	7.94	0.76	2.55
400	2.62	11.57	0.83	3.45	1.92	12.20	0.95	3.75
430	3.71	8.65	0.90	3.82	1.23	9.17	0.84	3.84
442	10.60	22.84	2.88	12.56	1.87	10.13	1.14	4.86
448	30.82	62.02	5.81	25.55	9.39	53.92	4.21	20.81
480	3.27	6.40	0.73	3.02	0.48	3.46	0.32	1.26
497	5.16	16.10	2.30	10.06	1.83	16.81	2.26	8.24
501	5.75	14.61	1.67	7.09	1.80	16.51	1.82	7.13
544	6.43	15.06	1.69	7.53	1.43	11.03	1.19	4.86
577	7.88	20.42	2.65	11.95	3.05	25.63	3.11	13.99
578	2.22	5.05	0.57	1.92	0.75	3.59	0.37	1.26
587	10.24	22.40	2.25	10.15	3.00	9.23	1.09	4.32
607	6.28	26.83	1.96	9.13	1.59	28.51	1.88	7.48

Using Linear Regression to Distinguish the Effect of MSAT2-required Reduction in Gasoline Benzene Content from Other Effects

After constructing a plausible Phase 2 data set, a linear regression procedure was used to separate the impact of MSAT2-required changes in gasoline benzene content from other factors that could also affect the benzene concentration measured in our Phase 2 households. A step-by-step description of this procedure follows.

1. *Develop linear regression model to predict indoor benzene concentration from indoor toluene concentration from Phase 1 data.*

   Indoor benzene is highly correlated with the other BTEX compounds. The coefficient of determination (R^2) between each of the estimated mean BTEX concentrations in each of the 67 households that Participated in Phase 1. is shown in Table A-3 below. There is an especially strong association between benzene and toluene (R^2 = 0.91). For this reason, we will develop a linear regression relationship using indoor toluene as a predictor of indoor benzene. The regression relationship is shown in Figure A-1.

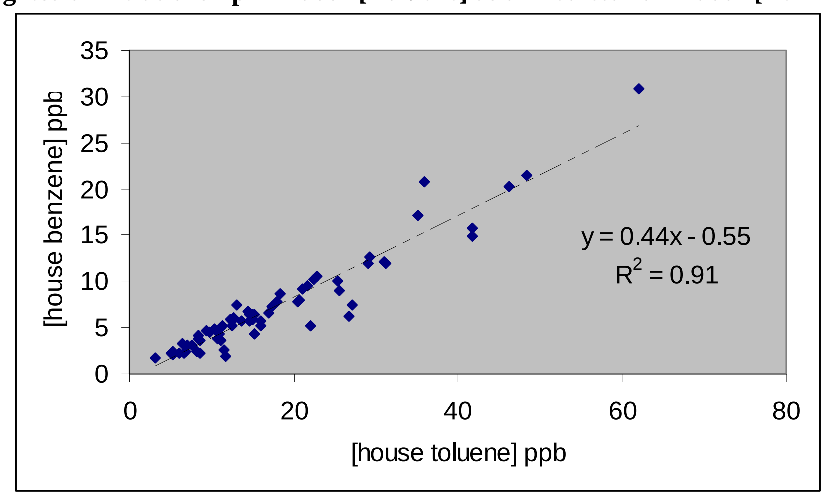
Table A-3

R^2 between Indoor BTEX Concentrations in Phase 1 Houses

	benzene	toluene	ethyl benzene	xylenes
benzene	1.00	0.91	0.75	0.77
toluene	0.91	1.00	0.81	0.83
ethyl benzene	0.75	0.81	1.00	0.99
xylenes	0.77	0.83	0.99	1.00

Figure A-1

Regression Relationship – Indoor [Toluene] as a Predictor of Indoor [Benzene]



2. *Modify regression equation to account for changes in the toluene content of gasoline between Phase 1 and Phase 2.*

   The benzene content of gasoline is expected to be reduced four-fold between Phase 1 and Phase 2. Other BTEX components could also change but probably not nearly so dramatically. The regression equation was modified slightly by adding the coefficient *k* to account for the possibility that the toluene content in gasoline could change between Phase 1 and Phase 2. If the toluene content increases in Phase 2, we would expect that the relationship between indoor *[toluene]* and indoor *[benzene]* would change proportionally. If the benzene content in gasoline didn't change in Phase 2, we would have to adjust the coefficient (0.44) downward in proportion to the higher relative content of toluene in gasoline.

   [benzene] = 0.44(k)[toluene] – 0.55

   where *k* = (toluene % in gasoline Phase 1)/(toluene % in gasoline Phase X)

   we assume that the toluene content in gasoline will increase from 17.6% to 19.7% between Phase 1 and Phase 2 so the value of *k* is 0.893 in Phase 2; *k* is 1.0 in Phase 1.

3. *Apply the regression equation developed in Step 2 above and examine results.*

   The predictions from the linear regression model are compared to observed values in Figures A-2(a) and A-2(b) below. Although the R^2 between observations and predictions is reasonably high in both Phase 1 and 2, the slope of the regression line is much different. The slope of the line in Phase 1 is near 1.0 but in Phase 2 it is 0.43. This suggests that a significant factor, unaccounted for in the regression model has had the effect of reducing the indoor benzene concentration relative to the indoor toluene concentration. Presumably this is the effect of MSAT2-required changes in gasoline.

Figure A-2(a)

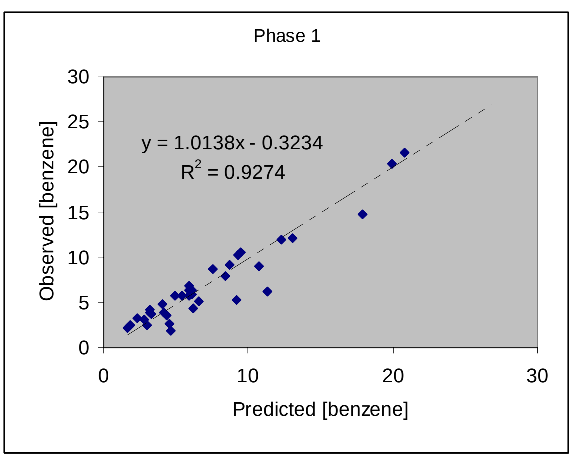
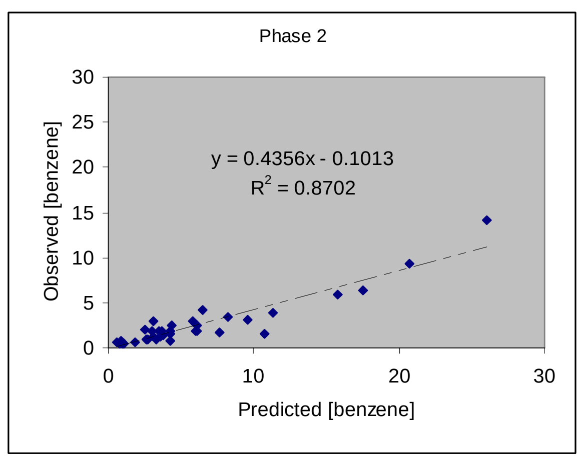


Figure A-2(b)



We can gain further insight by comparing key measurements and regression model predictions from Phase 1 to and Phase 2. Table A-4 shows comparisons for the first simulation of Phase 2 results.

Table A-4
Observed Indoor BTEX Measurements (Phase 1 vs. Phase 2)
N = 37

	Mean [benzene]	Mean [toluene]	Mean [ethyl benzene]	Mean [total xylene]
Phase 1	7.44	18.60	1.97	8.82
Phase 2	2.47	16.34	1.58	7.02
% change	-66.9%	-12.1%	-20.0%	-20.4%

When we constructed Phase 2, we made the assumption that the benzene content in gasoline would drop by 74% and that the toluene content would increase by 12%. We assumed that there would be no change in the gasoline content of ethyl benzene or total xylene. Nevertheless, ethyl benzene and total xylene drop by about 20% between Phase 1 and our simulated Phase 2. We can assume that this decline is due to something other than the changes in gasoline composition (in benzene and toluene) that result from MSAT2 requirements. Presumably, changes in household behavior account for this 20% decline.

The regression model predictions in Phase 1 and Phase 2 can be used to "tease out" the effect of the MSAT2-required gasoline changes on the indoor benzene concentration from other effects like changes in household behavior.

observed mean [benzene] Phase 1 =	7.44 ppb
Predicted mean [benzene] Phase 2 =	5.89 ppb
observed mean [benzene] Phase 2 =	2.47 ppb

The regression equation model developed from Phase 1 predicts that the indoor benzene concentration "should" fall from 7.44 ppb in Phase 1 to 5.89 ppb based on the observed change in the indoor toluene concentration in Phase 2 (after adjustment for the increased toluene content in gasoline). However, the observed mean concentration (2.47 ppb) is considerably lower. Again, this discrepancy is the result of a significant factor, unaccounted for in the regression model, namely the MSAT2-required reduction in gasoline benzene content. This "unaccounted for discrepancy" can be easily distinguished from other factors (like household behavior changes) as follows.

Indoor [benzene] reduction due to all factors = $\frac{7.44 - 2.47}{7.44} =$ 66.8%

Indoor [benzene] reduction due to behavioral changes = $\frac{7.44 - 5.89}{7.44} =$ 20.8%

Indoor [benzene] reduction by unaccounted factors in model (MSAT2) = 66.8% - 20.8% = 46.0%

The regression technique was applied to the other four Phase 2 data sets constructed by Monte Carlo simulations yielded results fairly similar to the first one. Results of all five simulations are shown in Table A-5.

Table A-5

Results of Estimation of Indoor Benzene Reduction from MSAT2 vs. Other Factors (5 simulations of Phase 2 data)

Simulation	N	Phase 1 Observed mean [benzene] ppb	Phase 2 Predicted mean [benzene]	Phase 2 Observed mean [benzene] **	Estimated % [benzene] reduction from all factors	Estimated % [benzene] reduction from behavioral changes	Estimated % [benzene] reduction from MSAT2
#1	37	7.44	5.89	2.47	66.8%	20.8%	46.0%
#2	33	6.98	5.96	2.21	68.3%	14.6%	53.7%
#3	28	6.95	4.33	2.06	70.3%	37.7%	32.6%
#4	45	8.31	6.62	2.72	67.3%	20.3%	47.0%
#5	33	6.56	4.70	1.90	71.0%	28.3%	42.7%

** The "observed" [benzene] was constructed by a Monte Carlo procedure

The rule effectiveness of the MSAT2-required gasoline change can be estimated by comparing the benzene concentration expected in Phase 2 (i.e.; the benzene concentration predicted from the "normalized" indoor toluene concentration) and the observed Phase 2 concentration. The estimated MSAT2 rule effectiveness for the five simulations of the Phase 2 is shown in Table A-6.

Table A-6

Estimated Rule Effectiveness MSAT2-required Reduction of Benzene in Gasoline

Simulation	Phase 2 Predicted mean [benzene]	Phase 2 Observed mean [benzene] **	Estimated MSAT2 Rule Effectiveness
#1	5.89	2.47	58.1%
#2	5.96	2.21	62.9%
#3	4.33	2.06	52.4%
#4	6.62	2.72	58.9%
#5	4.70	1.90	59.6%

Note that the estimated rule effectiveness in all five simulations is below the assumed hypothetical 74% reduction in indoor benzene assumed in the construction of the simulated Phase 2 data sets. The simulations fall short of the 74% hypothetical value because we assumed that there would incomplete turnover of the old, high benzene content gasoline (see Table A-1).