Report on the Benzene Study of 2008-2009

by

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for

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Introduction and Background

The purpose of this study was to determine whether reducing the amount of benzene in gasoline, which is scheduled to take place in 2011, will effect a change in indoor air benzene levels in Anchorage, Alaska. This is an interim report that discusses the first phase of a two-phase study. The first phase measured benzene levels in homes and garages every month for over one year.

Due to the lack of chemical markets, the gasoline refined in Alaska contains 5% or more of benzene. Over the past two decades, volatile organic compounds (VOCs) measured in Anchorage, Alaska, have had higher concentrations in both indoor and ambient air than most other cities in the United States. Previous studies in Anchorage have shown that attached garages are a significant source of benzene and other VOCs in the living space of homes.

In 2007-2008 we conducted a randomized study of houses with attached garages in Anchorage, Alaska, to determine whether there were associated respiratory health risks. We asked the resident owners of these houses to measure the benzene, toluene, ethyl benzene, and xylenes (BTEX) in their homes for one week using a passive vapor monitor badge. The results of that study showed that 47% of the houses had indoor-air benzene levels that—if they were maintained throughout the year—would exceed the minimal risk levels for inhalation set by the Agency for Toxic Substances and Disease Registry (ATSDR). Sixteen percent of the houses exceeded the acute risk. The results also showed that the BTEX measured in the indoor air came from gasoline fumes.

We conducted this second study to determine whether levels found on a single, weekly measurement adequately represented the actual annual exposure in that house. We also wanted to see what the ratio was between levels in the garage and levels in the house since most of the exposure was thought to be coming into the house from the garage. We were also interested in any seasonal variation in the exposure to indoor benzene concentrations. This study would give us that sense of seasonal variability to be able to approximate long-term exposure and to guide future study. We were getting baseline data that could demonstrate the effect of the reduction in benzene in gasoline on the indoor air quality in Anchorage. It is expected that the level of benzene in gasoline will be reduced starting as soon as next year.

Methods

Recruitment

In October 2008 we recruited residents of 82 households from the original study who agreed to measure the benzene levels in their homes and in their garages every month for one year. Although we originally contracted to measure BTEX in 60 homes and garages every month for a year, we started with 82 households because we expected a fairly large drop-out rate from this monthly commitment.

Contrary to our expectations, we had very few drop-outs. After six months, 75 households were still participating regularly. Because we did not have funding to completely measure all 75 houses and garages for a full year, we asked households in which the results had been consistently low to stop measuring. Consequently, the total number completing ten or more measurements over the year was 67 households.

We recruited households by sending letters to the original participants in the randomized Indoor Air Study. We had information about the potential participants and sent the letters first to homes with the highest readings until we had a significant number willing to participate. Thirty-two of the participants had measured benzene in their homes in 2007 at more than 9 ppb—the acute risk level set by ATSDR for environmental exposure. All participants had received the results of their 2007 measurement and had also received information about the ATSDR minimal risk levels and the sources of benzene.

Because benzene exposure is the result of storing gasoline and gasoline engines in the garage and because control of this exposure is in the hands of the householder, we were concerned about the possibility that participation in the 2007 Indoor Air Study would bias the householders to change their gasoline-storage habits. However, it was important to have sufficient houses in the study with high levels of benzene in order to document changes over time, so we did not want to start with a randomized group when we knew from the Indoor Air Study that only 16% would have benzene levels above 9 ppb.

Upon receiving responses to our recruitment letter, we checked that the potential participant had the qualifying criteria; ie, there were no smokers in the house; they expected to remain in the house for the next five years; they were not planning any remodeling of the house within the next five years; and they were willing to have a home visit. Our recruitment letters were sent out in September 2008, and we were inundated with responses.

Sampling

We chose 82 qualified participants and by the third week of October sent the first boxes containing instructions and two canisters containing unopened badges. The instructions directed the householder to display the badges on top of the cans—one in the house in the same location they had used for the Indoor Air Study and one in the garage at breathing level where it would not be disturbed. Every twentieth box contained four cans for duplicate display. Participants were instructed how to close the badges and return them using the return-mail, postage-paid stickers included in the boxes. They were asked to record the badge numbers as well as the opening and closing times and dates both on the can and on the paper questionnaire that was returned with the badges. If any discrepancy occurred, the project manager would call to confirm dates and times. We had 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. We soon started to use stamps and have boxes returned by first class mail to prevent post office delay.

The boxes, upon their return, were opened and checked to assure that the badges were correctly closed. The badge numbers and the dates and times of opening and closing of canisters were entered into a database; the badges were then delivered to the ASET laboratory in batches. The ASET laboratory technicians requested that the garage badges be separated from the house badges because some of the garage badges were out of range and had to be diluted—a process that could be done more efficiently if they were prepared for that possibility.

We kept a log of the dates that badges were sent to participants and when they were returned. After a few months, a routine was established and most badges were returned promptly after exposure. Participants were asked to notify the project manager when they anticipated delays because of travel or other circumstances. When an unexplained delay occurred, the project manager called and left reminders.

We provided incentives to participants in the form of a $35 Tesoro gasoline card. Each month after the exposed badges were returned, we sent an e-mail to the Tesoro [business office] listing those cards which were to receive an additional $35 credit. This was done by credit card and was actively followed by the project manager, the business manager of ISER, and the principal investigator.

Results and Discussion

The quality-assurance measurements were adequate. Field and laboratory blanks were below the limits of detection. (We had asked the laboratory to run a laboratory blank prior to each run because the ASET laboratory was measuring the BTEX content of gasoline during this same time period.) Duplicates were run on 5% of the samples. Ninety-three percent of the duplicates met the quality standard of being within 25%, while 89% were within 15%. When I spoke to participants who had widely differing duplicates, one of them admitted that he had placed the badges in different parts of his garage rather than side by side as instructed. Another volunteered on a home visit that he appreciated when we had sent him extra badges as he placed one in the bedroom and one in the kitchen. We sent general instructions which included what to do with duplicates with every package. This quality assurance issue indicates to me that some participants didn’t read the instructions very carefully.

**Table 1. Descriptive Statistics for the Entire Year,
October 2008 to October 2009**

Value	House	Garage
N	821	821
Mean	7.1 ppb	30.9 ppb
Max	63.5 ppb	374.2 ppb
Min	0.0 ppb	0.0 ppb
Median	5.1 ppb	19.3 ppb

The variation in benzene concentrations throughout the year was very interesting. There appears to be very little variation in the average benzene concentration in the living space of homes over the year, but a very large increase in garage concentrations during the summer months. This could be due to the higher temperatures increasing the volatility of gasoline, thereby producing more evaporative emissions; or it could be because of increased use or storage of gasoline during the summer. Because the attached garages are all generally heated, I expect that increased use of gasoline is the more likely explanation.

We analyzed the results of the short questionnaire that was sent out monthly and related them to the measurement results for each household. We saw very few changes in the measurements that could be explained by the questionnaire. In two households, there was a precipitous drop in the benzene concentrations in the house and garage; but the questionnaires from these households did not indicate any behavioral changes that could account for the decline. Likewise, in many homes we observed elevations in garage benzene levels when the questionnaires for those households indicated neither increase in gasoline storage nor number of engines in the garage.

The wording of the questionnaire included in this study made it useless as a predictor of changes in measured levels. The only thing that it did confirm was the reason benzene levels in some houses decreased during the summer months was that windows were open. When garage benzene levels went up and the house levels remained stable or decreased, the householder had indicated on the questionnaire that their house windows were open.

The mean level for each house and attached garage was calculated. Three of the 82 garages (5%) had mean levels for the year that exceeded 100 ppb for benzene or the NIOSH recommended maximum exposure level for healthy workers. Fifteen garages (22%) had mean benzene levels of 50 ppb or more. Of the households that completed at least six months of measurements, 77% of the average garage values for benzene exceeded ATSDR's acute risk level of 9 ppb or more.

Nineteen of the 82 houses (25%) had mean benzene levels that exceeded ATSDR's minimal risk level (MRL) for acute exposure of 9 ppb.* The highest

* Acute exposure is defined by ATSDR as exposure for ≤ 14 days.

mean indoor air benzene level was 31 ppb. Eighty-one percent of the houses exceeded the MRL for chronic exposure to benzene.[†] Keep in mind that these houses were not randomly selected because most participants were solicited based upon previous findings of elevated benzene levels. Nine households invited to participate in this study had levels measured in 2007-2008 that were below 3 ppb; 41 had levels between 3 and 9 ppb; and 32 had benzene levels greater than 9 ppb. We initially included those houses with low benzene levels in order to determine if they remained at that low level.

The effect of receiving knowledge about a single measurement did not contribute a significant bias since the correlation between benzene measured in the house during a single week in the winter of 2007-08 (Indoor Air Study) and the average benzene measured in these same houses during the winter months in 2008-09 was 0.50. There was some reduction toward the mean, which is expected with repeated measurements.

The table below compares the same houses in what was measured in 2007-2008 and the average of what was measured in 2008-9.

Table 2. Comparing Results from Indoor Air Study with Average Values in 67 Homes

Values from	Mean	Median	Maximum	Minimum
Indoor Air Study 2007-08	10.5 ppb	7.9 ppb	58.3 ppb	0.8 ppb
Repeat BTEX study, winter months 2008-09	7.9 ppb	5.8 ppb	36.4 ppb	0.8 ppb

The following two graphics show the mean indoor benzene from 67 houses and garages and the median indoor air benzene in these same houses and garages. There is little difference between them except that the mean level of benzene remains constant through the summer months while the median level drops. This is probably driven by a few cases where the benzene levels in the house increased with the increasing garage levels in the summer. These houses also did not indicate that they had opened their windows. The majority of houses did have reduced benzene in summer compared to winter as is shown in the graphic of the median values.

These graphics also illustrate the strong effects of seasonality in the levels of benzene in indoor air.

[†] Chronic exposure is defined by ATSDR as exposure ≥ one year.

Figure 1. Average Values from 67 Homes Completing 10 Months or More

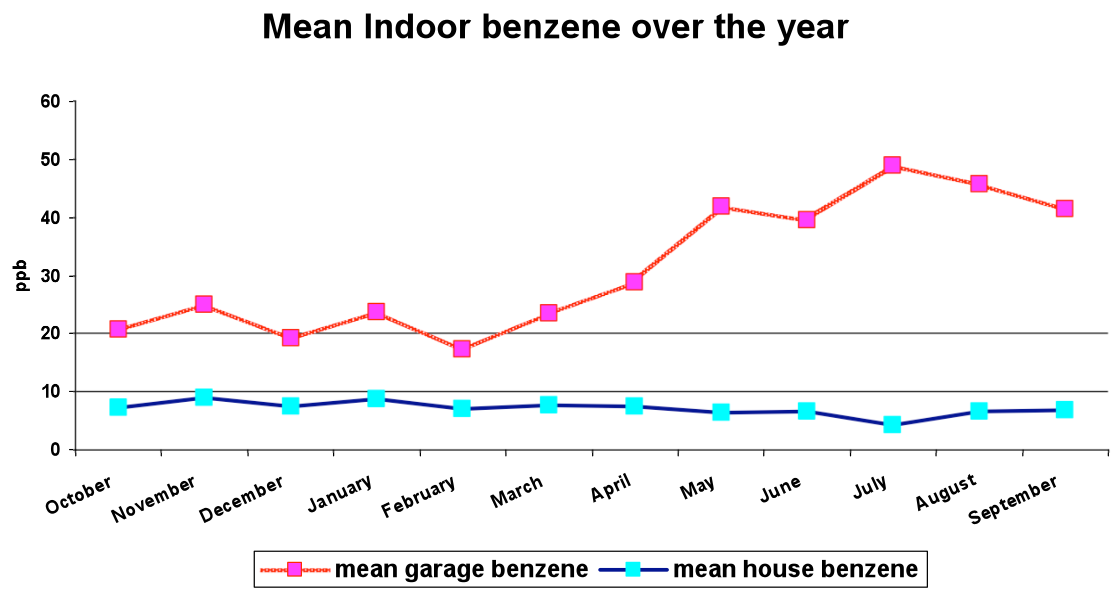
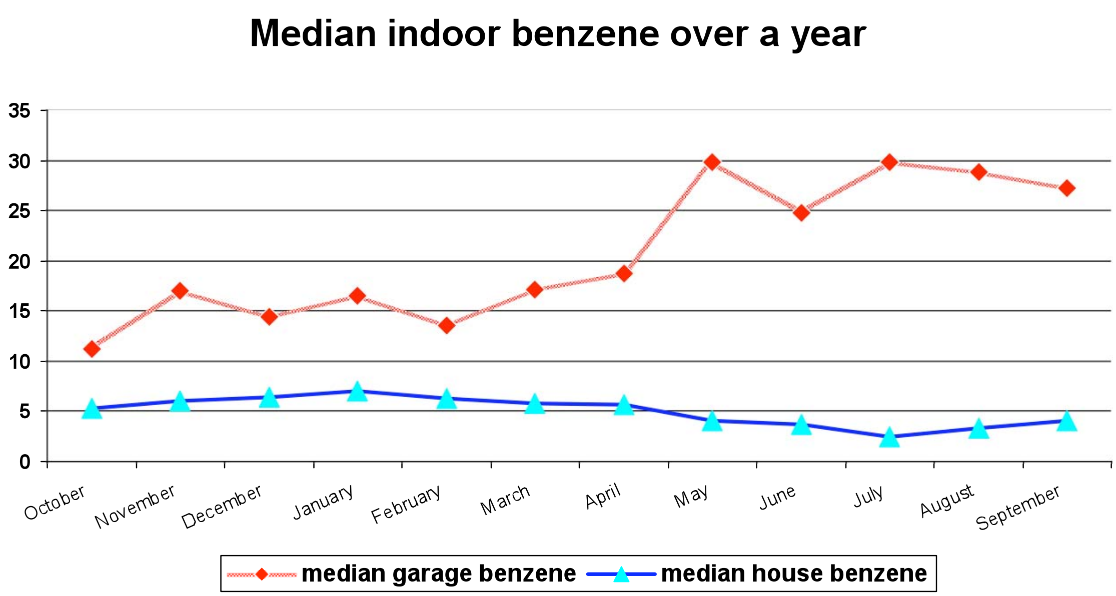


Figure 2. Median Value from Same Homes



Because of the strong influence of seasonality, I elected to look at the results divided into two seasons—winter (October through April) and summer (May through September).

Table 3 gives an overview (an average) of the results from 75 homes divided by season.

Table 3. Comparing Indoor Air Benzene Parameters in Winter and in Summer

Season	Winter	Summer
Mean House in ppb	7.9	6.1
Mean Garage in ppb	23.1	43.5
House-Garage Correlation (r^2)	.67	43.5
Average% of Garage Air Infiltrated into House	42%	20%
Maximum Air Infiltration	87.3%	86.7%
Minimum Air Infiltration	6.1%	3.8%
Median Air Infiltration	40.8%	12.5%

These results clearly show that most houses have higher benzene concentrations in the winter even though garage concentrations almost double in the summer. House concentrations follow the garage concentrations more closely in the winter. The other source of benzene is smoking, and there were no smokers in the houses we chose. Because benzene has been listed as a known carcinogen for more than 20 years, it has been removed from all household products. Assuming that the participants in our study are not using antiquated household products, there should be no other source of benzene in the house.

The amount of benzene in the house divided by the amount in the garage, both corrected for ambient benzene levels, would give the percentage of air infiltration from garage to house. While this varied widely between houses because of construction techniques, it was also strongly affected by season.

Individual homes had different infiltration rates that presumably are based on how the garage was constructed and the source of indoor air. I did home visits to nineteen homes, including some with very high and very low infiltration rates. Most people did not know whether there was a vapor barrier between the house and the garage. Five participants said there was a vapor barrier between house and garage; four of these had winter infiltration rates less than 20%. However, one had an infiltration rate of 67%, making it unlikely that there was an intact vapor barrier in place. Unfortunately, only one of the owner-built homes had a vapor barrier. Venting in the garage varied from none to multiple windows. Combustion vents varied from none to 3 or 6 inches. Some people did not know if the garage was vented and because there was so much “stuff” inside, it was impossible to see the walls. While conducting home visits, I found only four garages which were not used for parking; they were used for storage, crafts, and a workshop. The other 15 were used primarily for parking and storage. There did not seem to be any association with where the residents said they stored gasoline or the number of engines in the garage and the level of benzene in the small sample (19) that I visited. A few participants said they had moved gasoline storage to a shed or were in the process of doing so after receiving the results of the Indoor Air Study. I found a gasoline-powered engine in at least one of the garages where the owner said he had removed the gasoline. The owner said he had forgotten about it.

At every house I visited, the primary entry into the house was through the garage. That is, the residents did not enter through the main door, but daily entered and left through the garage. Most of the doors connecting garage and house were fire doors although there was at least one exception. None of the doors had automatic closure systems which closed the door if it was not held open. In fact, one of the “improvements” that homeowners said they had made after receiving results from the 2007-08 Indoor Air Study was to close the door between the house and the garage when not in use. From this, I can assume that this door is often left open. The majority of the houses that I visited were two-story homes with tucked-in garage; two were multilevel with the garage above the living space; two were ranch style with garage on the side. There were too few houses to detect a trend in style for infiltration, but the multi-level homes were both on the low end.

Summary and Discussion

This is a difficult study to summarize because there were so many variables and so much data. From an environmental health standpoint, it is an important concern because people are exposing themselves to high doses of gasoline with benzene in their homes. The exposure to benzene will most likely improve when the composition of gasoline changes to less than 1% benzene as is expected next year.

Home visits were instructive. The typical home had two cars parked in the garage. One house had five cars parked in the garage, and the householder showed me a lift which would allow him to park another car on top of an already parked car (giving a whole new meaning to double parked). Another garage had four ATVs parked in it, which the householder assured me was temporary as they were about to go on an expedition. Two garages had boats with motors onboard. One householder told me that he cleaned parts with gasoline in the garage but left the garage door open when he did that. It is no wonder that these houses had high benzene levels in the garage and in the house.

Two factors determine exposure: one is the presence of gasoline—either in stored containers or in engines; the other is the ease of passage of vapors from the garage into the house. Removing the source of gasoline from the garage would solve the problem; however, the garage has always been the place for adult toys and small machinery as well as a place to park the car. That is not likely to change. New vehicles allow vapors to be captured, and new gasoline storage cans do the same.

The problem then becomes the small engines that do not have the technology to control vapors. These engines should be stored in sheds or outbuildings that are not connected directly to the house. However, as one homeowner said to me: he had completely overlooked a chain saw because he forgot that it used gasoline. Small engines are so common that changing people's behavior regarding where they are kept will be hard to do.

There will always be the potential for gasoline vapors in the garage—starting vehicles, opening gas cans, etc. To protect the house, an attached garage should have a vapor barrier completed over all surfaces that are contiguous with the house. Additionally, the house should have a separate source of fresh air that is not coming from the garage. Because the door between the garage and the house appears to be the major entry and exit, it should be replaced by a well-ventilated passageway. This will require changes in building codes and massive retrofitting.

Taking benzene out of the gasoline will certainly reduce exposure to benzene, but until other measures are taken, people living in houses with attached garages will still be exposed to gasoline fumes with or without benzene.

Recommendations for the Next Study

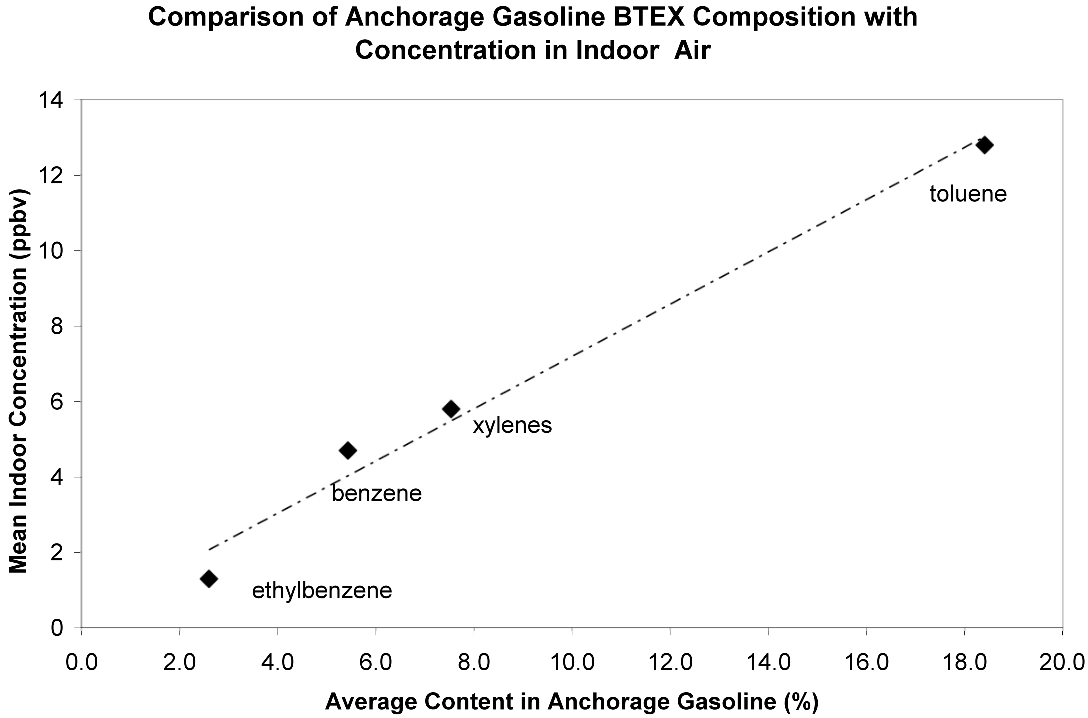
After the composition of gasoline changes, the second part of this study will be conducted to determine if the change in gasoline composition affects indoor air exposure to benzene. Since many people may only buy gasoline once a season for small engines, such as lawn mowers or weed whackers, the new composition of gasoline should be in effect for more than one year before the second part of the study is begun.

In a future, follow-up study, it might be helpful to tape the duplicate canisters together and attach special instructions for duplicate packages.

The wording of an accompanying questionnaire needs much more thought and testing. One concern that I would like to raise for any future study regards the question that asks if there had been any changes in the number of engines or gasoline or vehicles in the garage in the last month. I suggest that it should read "How many vehicles, how many engines, how many gasoline cans are present in the garage during the measurement week?" and "Was any work done in the garage during the week of measurement involving the use of gasoline as a solvent or cleaning agent?"

The composition of existing gasoline is known because of the measurement of BTEX in gasoline that was done in 2009. The ratio between BTEX components of gasoline mirrors the ratio of BTEX components in indoor air, as measured in the randomized Indoor Air Study conducted in 2007-08 (see Figure 3). The composition of BTEX in gasoline needs to be measured again after the benzene rule has been in effect long enough to have new gasoline in all the stations.

Figure 3. Relationship Between BTEX Composition of Gasoline and BTEX Concentration in Homes with Attached Garages



Graphing the results of BTEX measured in indoor air and BTEX measured in gasoline provides good evidence that the benzene found in indoor air is coming from gasoline emissions. The measurement of BTEX fingerprint from gasoline should be recalculated after the new benzene rule restricts the amount of benzene that is allowable in gasoline. If the fingerprint of new gasoline is known, a repeat randomized study of houses with attached garages where gasoline or gasoline-powered engines are stored should present a similar graph showing the fingerprint of gasoline in indoor air but with reduced benzene levels. This would provide clear, irrefutable evidence that the high indoor benzene levels we are now experiencing come from exposure to gasoline and that reducing benzene in gasoline reduces benzene in indoor air.

We originally designed this study with the idea that we could go back to the same houses and re-measure indoor and garage air to see the effect of the benzene rule on indoor air composition, but we did not take into account that these are human subjects who will learn from this experience. It is very unlikely that after committing to a full year of participation, they would be unaffected by the results. The people who participated in this year-long study will most likely make changes based on the new knowledge they are getting about their indoor air. It would be impossible to remove the bias from the knowledge that they have acquired. Asking them whether they made changes would be insufficient; as we see from the questionnaire that they were asked to complete each month, they often said there were no changes made, but the evidence said there had been a change. In one house visit, I had received results that showed very high levels of BTEX in the garage the previous month, but no changes had been noted on the questionnaire. When I told the participant about the high levels and asked why he thought that might be, the participant remembered that he had cleaned some tools with gasoline in the garage. He did not consider it significant enough to note on the questionnaire.

If it becomes necessary to do multiple testing over time to confirm these findings, I would suggest starting with a new group. Not everyone who had high indoor air benzene levels on the Indoor Air Study participated in the year-long study. Those non-participants should not be affected by the results of the year-long study except in a general way as the level of understanding in the community changes regarding indoor air pollution. A new group could also be created by recruiting participants with attached garages who store gasoline and/or gasoline-powered small engines in the garage.

We learned a great deal about indoor air from these studies. We know where to look and in what season to look; we know that householders can do their own measurements with good results. It will not be difficult to show that reducing the benzene in gasoline reduces the benzene in indoor air. In fact, we already know this by comparing the indoor air benzene in homes in other parts of the country where benzene in gasoline is already required to be less than 1%.

In the Indoor Air Study we showed that in homes with benzene above the acute MRL (9 ppb), there was ***a significant increase in asthma severity***. Homes that had high benzene levels also had high gasoline exposure. Is the benzene causing increased asthma severity or is it gasoline exposure? To me, a far more useful study would be to repeat a randomized indoor air respiratory health study after the benzene in gasoline is reduced. People will be exposed to less benzene, but most likely they will not be exposed to less gasoline. Is there a respiratory health effect of breathing high levels of gasoline fumes (with or without benzene) in your home day after day? While benzene exposure may decrease, gasoline exposure is not going away any time soon. The health of the population may depend on the answer to this question.


ALASKA