

**Investigation of Aplastic Anemia in Relation
to Concerns about Exposure to Benzene from
a Chemical Plant**

**Cowlitz County, Washington and Columbia
County, Oregon**

August 2006 – December 2007

Investigation of Aplastic Anemia in Relation to Concerns about Exposure to Benzene from a Chemical Plant

Cowlitz County, Washington and Columbia County, Oregon

August 2006 – December 2007

Final Report, March 2008

Cluster investigation team (alphabetical order):

Hilary Gillette-Walch, R.N., M.P.H., Cowlitz County Health Department
Michael Heumann, M.P.H., M.A., Oregon State Public Health Division
Kathryn J. Hughes, M.P.H., Washington State Department of Health
Richard F. Leman, M.D., Oregon State Public Health Division
Steven C. Macdonald, Ph.D., M.P.H., Washington State Department of Health
Dave Stone, Ph.D., Oregon State University
Juliet VanEenwyk, Ph.D., M.S., Washington State Department of Health

Consultants (alphabetical order):

Judy Bardin, Sc.D., Washington State Department of Health
Dave Bonauto, M.D., M.P.H., Washington State Department of Labor and Industries
George Davis, Environmental Engineer, Oregon Department of Environmental Quality
Mimi Fields, M.D., Cowlitz County Health Department
Hope Hough, Health Services Consultant, Washington State Department of Health
Matt Kadlec, Ph.D., Washington State Department of Ecology
David W. Kaufman, Sc.D., Slone Epidemiology Center at Boston University
Paul T. Mairose, P.E., Southwest Clean Air Agency
Dave McBride, M.S., Washington State Department of Health
Glen Patrick, Ph.D., Washington State Department of Health
Catherine A. Riddell, Oregon State Public Health Division
John St. Clair, M.S., Southwest Clean Air Agency
Ha Tran, Environmental Engineer, Washington State Department of Ecology
Theodora A. Tsongas, Ph.D., M.S., Oregon State Public Health Division
Carolyn Whitaker, M.S., C.I.H., Washington State Department of Labor and Industries
Julie Wroble, Toxicologist, U.S. Environmental Protection Agency

We thank the Cowlitz and Columbia County residents who provided health information to aid this effort.

For more information, in Oregon, contact Richard Leman, 971-673-0984 or by e-mail at richard.f.leman@state.or.us. In Washington, contact Steve Macdonald, 360-236-4253 or by e-mail at steven.macdonald@doh.wa.gov.

TABLE OF CONTENTS

EXECUTIVE SUMMARY	1
BACKGROUND	3
INTRODUCTION.....	4
METHODS AND RESULTS	6
I. Health data	
A. Rates of aplastic anemia and leukemia from routinely collected health data	6
B. Data collected from community reports and active case finding.....	8
C. Summary of health data	10
D. Limitations	10
II. Environmental data	
A. Benzene in air	11
1. Sources of benzene in outdoor air in Columbia and Cowlitz Counties	
2. Meteorology and air emissions transport at Emerald Kalama Chemical	
3. Longview air toxics monitoring	
4. Summary of air data	
B. Benzene in water.....	17
1. Groundwater and drinking water	
2. Summary of water data	
C. Acute benzene releases from Emerald Kalama	19
D. Limitations	21
CONCLUSIONS	22
REFERENCES.....	23
APPENDIX I Population Distribution of Columbia County, OR and Cowlitz County, WA .	24
APPENDIX II Technical Notes	25
APPENDIX III Interview Form	28
APPENDIX IV Links for Additional Information	30

EXECUTIVE SUMMARY

Background and Introduction

In August 2006, a citizen called the Washington State Department of Health, the Oregon State Public Health Division and the Cowlitz County Health Department to report six people diagnosed with aplastic anemia between 1999 and 2006. All six had lived in Cowlitz County, Washington or Columbia County, Oregon during relevant time periods prior to diagnosis. Most lived in the Longview/Kelso area of Washington State, which is the major population center in the two counties. The citizen was concerned that the diagnosis of six people with aplastic anemia in a relatively small population was unusual. The citizen also expressed concern that these illnesses might have been caused by exposure to benzene from the Emerald Kalama Chemical plant in Kalama, Washington. The plant, which releases benzene into the air each year, is located in Cowlitz County, Washington just across the Columbia River from Columbia County, Oregon.

Occupational studies have established that benzene can cause aplastic anemia. Benzene can also cause acute myeloid leukemia (AML) and might cause other types of leukemia as well. In addition to exposure to benzene, all of these conditions have other possible causes and for most people with these conditions, the cause is not known. Benzene is present in gasoline and some cleaning solvents and is released during most burning processes (for example, use of wood stoves and burning of cigarettes). Thus, exposure to benzene is common. However, documented development of aplastic anemia as a result of such exposure is rare. The reasons why some people are more susceptible to the harmful health effects of benzene remain unknown.

Methods

After receiving the citizen report, the Oregon State Public Health Division, the Washington State Department of Health and the Cowlitz County Health Department conferred with each other, and decided to initiate an investigation. The goals of our investigation were the following:

- Determine if there were more people with aplastic anemia and other health conditions associated with benzene exposure among residents of Cowlitz and Columbia Counties than would be expected, given the background rates of these diseases and population sizes of the two counties
- Determine the potential for exposures to benzene from Emerald Kalama to have caused these illnesses

We then conferred with personnel from state and local environmental agencies and the Washington State Department of Labor and Industries to determine availability of data pertaining to the concern and to assign responsibility for compiling and analyzing data. We subsequently obtained health and environmental data from many of these agencies, as well as from individuals identified in the initial report and from Emerald Kalama. We reviewed the relevant literature and also consulted with Dr. David Kaufman, a recognized expert on aplastic anemia from Boston University, for background information used to guide the investigation.

Results

- Over a ten-year period, seven people in the two counties were diagnosed with aplastic anemia. Given the size of the population, we would expect three cases of aplastic anemia, with a range, based on random variation, of zero to six. The seven people represent one more than would be expected based on random variation. No specific exposures or risk factors were identified.

- There were no statistically significant increases in aplastic anemia deaths or in new cases of acute myeloid leukemia (AML) in the two counties. This means that the numbers of observed cases of these conditions were not higher than we would expect based on random variation.
- Over the ten years, 193 people developed some form of leukemia. We would expect 163 cases with a range, based on random variation, of 139 to 189 for the two-county area as a whole. The 193 people represent four more than might be expected, based on random variation.
- If benzene from Emerald Kalama was causing leukemia in the surrounding communities, we would have expected to see an increase in AML diagnoses, since AML is the type of leukemia most strongly linked to benzene exposure, but this was not the case.
- Because Emerald Kalama employees would likely experience greater benzene exposure than community members, the absence of blood-related disorders among these workers in Washington Dept. of Labor and Industry databases supports the conclusion that exposure to benzene from the plant is unlikely to be causing such disorders in the community.
- Emerald Kalama and other point sources are not major contributors to airborne benzene in the two counties. The biggest contributors are vehicle exhaust and area sources such as wood stove burning. The amounts of benzene released during acute events at Emerald are usually small and would not substantially increase emissions on a typical day.
- Given predominant wind patterns and the population distribution of the two counties, the locations where the people with aplastic anemia lived at the relevant times prior to diagnosis do not support the hypothesis that benzene air emissions from the plant are causing illness among community members.
- The potential for harmful amounts of benzene to reach groundwater off-site at Emerald Kalama appears to be low. Consistent with this hypothesis, samples from public drinking water supplies in Cowlitz and Columbia Counties did not reveal detectable levels of benzene (with the exception of two wells in Cowlitz County located in a direction where groundwater from beneath the plant does not flow).

Conclusions

Because aplastic anemia might represent a rare reaction to a common exposure, it is impossible to say for sure whether any individual's aplastic anemia was or was not caused by exposure to benzene, either from Emerald Kalama or any other specific source. Based on the findings of this investigation, over a ten-year period, one additional person developed aplastic anemia beyond what would reasonably be attributed to chance, given the usual rate of disease and the number of people living in the area. There was also a small elevation in the number of people with leukemia, although not of the type most commonly associated with benzene exposure.

Additional health data, as well as air and water data reviewed for this report do not support the conclusion that benzene released from Emerald Kalama is the cause of the majority of aplastic anemia cases in Cowlitz and Columbia Counties. At this time, the agencies and organizations involved to date agree that further investigation is unlikely to find a focal cause of the cases of aplastic anemia occurring in Cowlitz and Columbia County residents. While there is no hard evidence that any specific benzene source was the cause of illness in the people we interviewed, there is strong evidence that exposure to this chemical can cause life-threatening illnesses such as aplastic anemia and cancer. Therefore, decreasing exposure to benzene in the general population by lowering the amount of this compound in petroleum products would help protect the public's health. The agencies will assess the need for further investigation as new information becomes available.

BACKGROUND

In August 2006, a citizen called the Washington State Department of Health, the Oregon State Public Health Division and the Cowlitz County Health Department to report six people with aplastic anemia. All six people were diagnosed between 1999 and 2006 and had lived in Cowlitz County, Washington or Columbia County, Oregon prior to diagnosis. The citizen was concerned that six people diagnosed with aplastic anemia in a relatively small population was unusual. The citizen also expressed concern that these illnesses might have been caused by exposure to benzene from the Emerald Kalama Chemical plant in Kalama, Washington. Kalama is in Cowlitz County near the Oregon border. Emerald Kalama has formerly been known by different names, such as Noveon and BF Goodrich. Through research, the citizen found that exposure to benzene can cause aplastic anemia and that Emerald Kalama releases benzene into the air.

Aplastic anemia is a blood disorder characterized by low counts of red blood cells, white blood cells and/or platelets due to a shortage of the bone marrow cells that produce these cells. People with this condition might experience symptoms such as fatigue, paleness, increased infections (and increased length of infections), bruising and bleeding. The cause of aplastic anemia is known for only about 20-30% of those who develop this condition. Some people develop aplastic anemia due to rare genetic disorders. Other known causes include exposure to certain organic chemicals, such as benzene and some agricultural pesticides, radiation and infections (hepatitis and possibly also the Epstein-Barr virus, which causes the condition called mononucleosis or “mono”). Also, some people develop aplastic anemia as a result of reactions to medications, including among others, certain antibiotics, anticonvulsants, non-steroidal anti-inflammatory drugs, cancer chemotherapy medicines, and steroids.

Benzene is a volatile, colorless and highly flammable liquid that can cause aplastic anemia and leukemia, particularly acute myeloid leukemia (AML). Although the highest exposures to benzene typically occur in occupational settings where the chemical is used in commercial processes, non-occupational exposures to relatively low levels of benzene are common. Because benzene is present in gasoline, people are often exposed to the compound by driving, riding in or refueling vehicles, or living next to busy streets and highways. Burning most other types of fuel, including wood in wood stoves and fireplaces, and cigarettes also releases benzene into the air. Some household and industrial cleaning solvents contain benzene, which can evaporate into the air. Additionally, while exposure to benzene is common, documented development of aplastic anemia as a result of such exposure is relatively rare. The reasons why some people are more susceptible to the harmful health effects of benzene remain unknown.

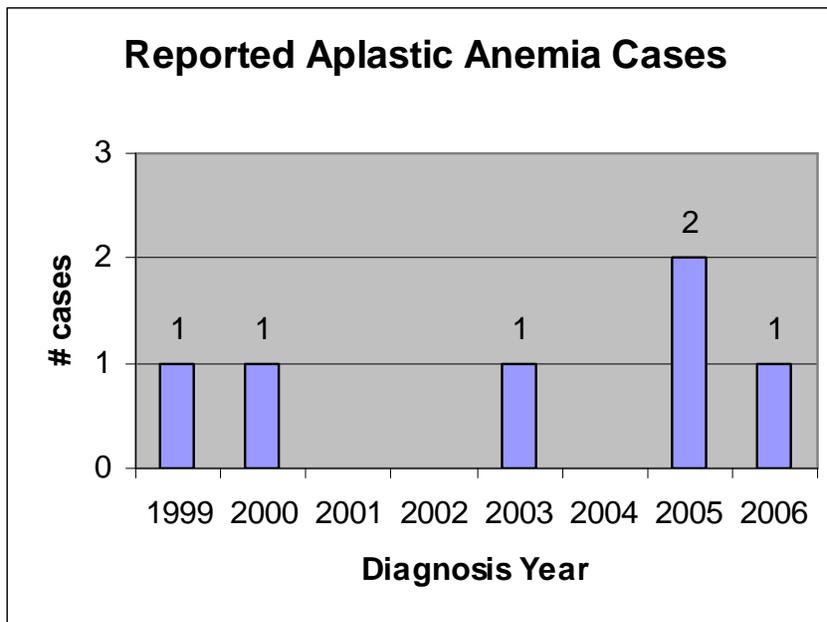
INTRODUCTION

Multi-Agency Response

The Washington State Department of Health, the Oregon State Public Health Division and the Cowlitz County Health Department consulted with a variety of other agencies, including the Washington State Department of Labor and Industries (L&I), the Washington State Department of Ecology (Ecology), the Oregon Department of Environmental Quality (ODEQ), the U.S. Environmental Protection Agency (EPA) and the Southwest Clean Air Agency (SWCAA) about the citizen's concerns. SWCAA is responsible for issuing air quality permits, inspecting and monitoring emissions of and practices relating to toxic air pollutants from Emerald Kalama in accordance with SWCAA's local air quality regulations (SWCAA 400), the Washington State Clean Air Act (Revised Code of Washington 70.94), the Washington State toxic air pollutant rule (Washington Administrative Code 173-460) and Title 5 of the federal Clean Air Act. After these consultations, the investigative team agreed to confirm the aplastic anemia case reports, to search for additional people diagnosed with aplastic anemia in the same geographic area and to examine previously collected health and environmental data to determine 1) if, for the size of the population, there were more people with aplastic anemia and other health conditions associated with benzene exposure among residents of Cowlitz and Columbia Counties than would be expected, given the background rates of these diseases, and 2) the potential for exposures to benzene from Emerald Kalama to have caused these illnesses.

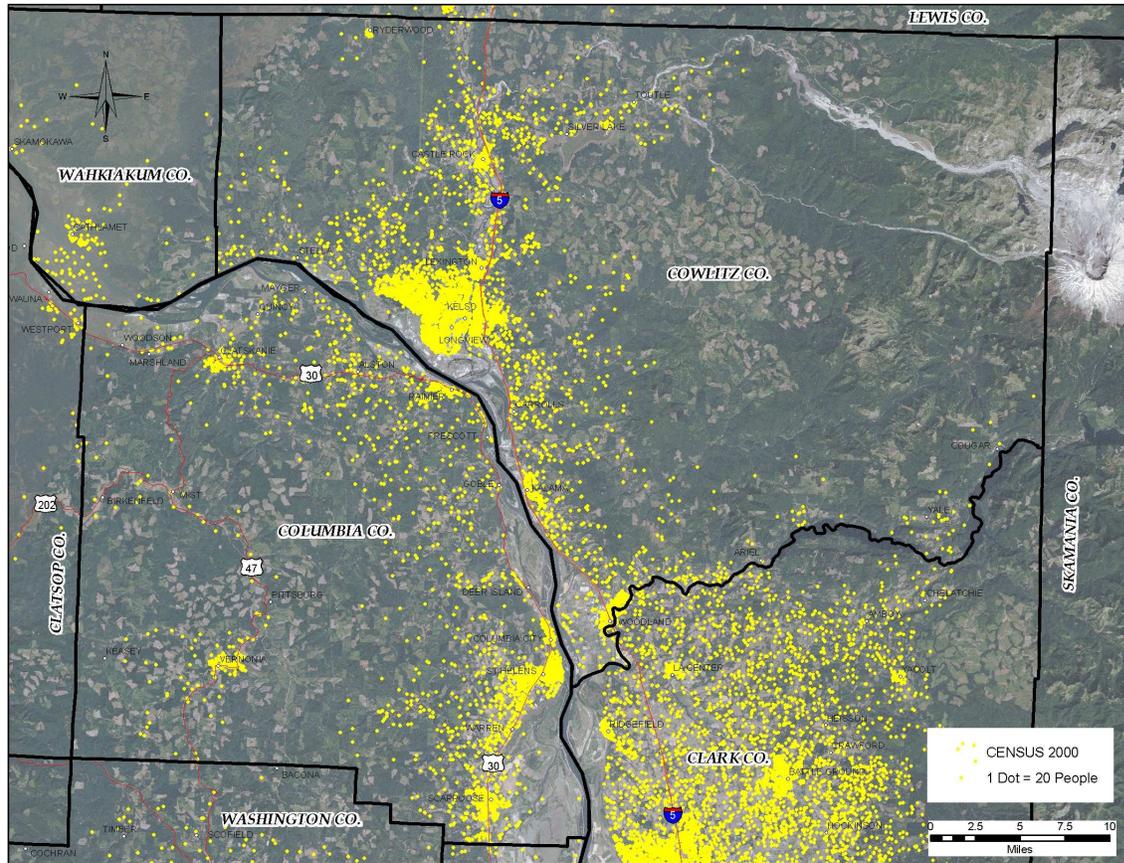
Temporal and Geographic Characteristics of the Reported Cases

The following chart shows the year of diagnosis for the six people identified in the initial citizen report. One additional case, found during the course of the investigation, was diagnosed in 1998.



The following map (also presented in a larger size in Appendix I) depicts Cowlitz County, Washington and Columbia County, Oregon and their bordering counties. Each yellow dot on the map represents 20 residents. Brighter yellow areas correspond to regions with greater population density. Based on this information, the major population center in these two counties is the Longview/Kelso area in Cowlitz County. Sizable numbers of people also live in St. Helens and

Scappoose in Columbia County and in the vicinity of Woodland in Cowlitz County. The rest of the population in these counties tends to cluster along roadways, such as I-5, U.S. Highway 30 and Oregon State Route 47, leaving much of each county sparsely populated. Three of the people reported with aplastic anemia lived in the Longview/Kelso vicinity in an area between north and northwest of Emerald Kalama during the relevant time period prior to diagnosis. Two of the three people in the Longview/Kelso area lived about eight or nine miles from Emerald Kalama and the third person lived about 18 miles away. Another person also lived in the area between north and northwest of the plant, about three miles away. The remaining two people lived about two to four miles from Emerald Kalama, one west by southwest and the other east by southeast.



Population distribution of Columbia County, OR and Cowlitz County, WA

METHODS AND RESULTS

I. Rates of aplastic anemia and leukemia from routinely collected health data

IA. Existing health data (Contacts: Kathryn Hughes, Richard Leman, Catherine Riddell, Dave Bonauto)

The investigation team used a number of existing data sources to determine whether there was an excess of aplastic anemia or other diseases associated with benzene in Cowlitz and/or Columbia Counties. Using Oregon and Washington State death certificate data, we examined deaths from aplastic anemia from 1999 through the most recent year available, 2004 at the time we began our investigation. We chose this study period for several reasons. First, we wanted to explore current, rather than historic patterns of disease. Second, the coding system for deaths changed in 1999, making it difficult to compare data for aplastic anemia before and after the change (NCHS, 2007).

Given that benzene has been linked to several common types of leukemia and particularly to acute myeloid leukemia (AML) (Schottenfeld and Fraumeni, 2006; The Leukemia & Lymphoma Society, 2006), we used state cancer registry data from both states to examine newly diagnosed leukemia and AML. The earliest year of cancer data for Oregon is 1996 and so we restricted the cancer analyses to the period 1996 through 2003, which was the most recent year of data available when we began our investigation. Additionally, looking back to 1996 would still allow us to explore current patterns of disease.

We compared the numbers of deaths from aplastic anemia and the numbers of diagnoses of leukemia and AML in Cowlitz and Columbia Counties to the numbers we would expect based on the amounts of aplastic anemia deaths and leukemia diagnoses (background rates) in Washington and Oregon, respectively, accounting for the relative ages and sizes of the populations. To do this, we made a ratio of the number of observed deaths or diagnoses to the number expected (abbreviated as O/E). A ratio of 1.0 means that there is no difference between the observed and expected numbers. A ratio greater than 1.0 means there are more deaths or diagnoses than expected and a ratio less than 1.0 means there are fewer than expected. For example, an O/E of 1.5 indicates there are 50% more people with a diagnosis or death than expected given background rates. An O/E of 0.5 indicates 50% fewer diagnoses or deaths than expected. Additionally, if our finding is different from 1.0, then we need to determine whether the difference is greater than we might expect by chance. We can do this by calculating a number called a “p-value” using a statistical test. If the p-value for a test is greater than or equal to 0.05, we generally conclude that the difference could reasonably be attributed to chance. If the p-value is less than 0.05, we say the result is statistically significant, meaning that 95 times out of 100, the difference would not be due to chance or coincidence. Thus, in statistical tests for observed-to-expected ratios, we only conclude there is an excess of disease (or deficit if the O/E is less than 1.0) when the associated p-value is less than 0.05. Otherwise we say the O/E is not significantly different from 1.0. We combined data for the two counties when we observed a similar result in each county separately.

In our analyses examining health data for each county, there were no statistically significant elevations in aplastic anemia deaths or diagnoses of all leukemias or AML.

	Columbia County, Oregon	Cowlitz County, Washington	Columbia and Cowlitz Counties combined
Aplastic anemia deaths	Data years: 1999-2004 Observed: 4 Expected: 3.2 O/E: 1.3 p-value: 0.79	Data years: 1999-2004 Observed: 11 Expected: 9.9 O/E: 1.1 p-value: 0.81	Data years: 1999-2004 Observed: 15 Expected: 13.0 O/E: 1.2 p-value: 0.65
All leukemia incidence	Data years: 1996-2003 Observed: 50 Expected: 38.7 O/E: 1.3 p-value: 0.09	Data years: 1996-2003 Observed: 117 Expected: 109.0 O/E: 1.1 p-value: 0.46	Data years: 1996-2003 Observed: 167 Expected: 145.6 O/E: 1.1 p-value: 0.09
Acute myeloid leukemia (AML) incidence	Data years: 1996-2003 Observed: 17 Expected: 12.5 O/E: 1.4 p-value: 0.26	Data years: 1996-2003 Observed: 22 Expected: 30.6 O/E: 0.7 p-value: 0.13	

We performed these initial calculations in the fall of 2006. At the time, the only population data we had for Columbia County and Oregon State were for 2000 and so we used the 2000 populations for these regions in all years of the calculations. In March 2007, the Oregon State Public Health Division obtained refined population estimates from the Population Research Center at Portland State University for 1996 – 1999 and 2001 – 2005. (See Appendix II for information on the Oregon population data.) By April 2007, another year of cancer registry data and another year of death data were also available for both states. We updated our calculations using the new population, death and cancer data.

Results of our final analyses, using death data from 1999 to 2005 and cancer registry data from 1996 to 2004 for both states, are depicted in the following table. The ratios of the observed-to-expected numbers are similar to those for the 1996 – 2003 cancer data and 1996 – 2004 death data. However, the finding for the two-county area for all leukemias became statistically significant. As before, there were not statistically significant increases in aplastic anemia deaths or diagnoses of AML in the two counties.

	Columbia County, Oregon	Cowlitz County, Washington	Columbia and Cowlitz Counties combined
Aplastic anemia deaths	Data years: 1999-2005 Observed: 4 Expected: 3.7 O/E: 1.1 p-value: 1.00	Data years: 1999-2005 Observed: 13 Expected: 11.5 O/E: 1.1 p-value: 0.73	Data years: 1999-2005 Observed: 17 Expected: 15.0 O/E: 1.1 p-value: 0.67
All leukemia incidence	Data years: 1996-2004 Observed: 56 Expected: 43.3 O/E: 1.3 p-value: 0.07	Data years: 1996-2004 Observed: 137 Expected: 123.5 O/E: 1.1 p-value: 0.24	Data years: 1996-2004 Observed: 193 Expected: 163.3 O/E: 1.2 p-value: 0.03 **
Acute myeloid leukemia (AML) incidence	Data years: 1996-2004 Observed: 18 Expected: 14.2 O/E: 1.3 p-value: 0.37	Data years: 1996-2004 Observed: 25 Expected: 33.9 O/E: 0.7 p-value: 0.14	

** Denotes observed-to-expected value statistically significantly differs from 1.0 (Poisson p-value<0.05)

We consulted with staff at the Washington State Department of Labor and Industries (L&I) to determine whether any blood-related disorders occurred among employees of the Emerald Kalama Chemical plant. If the airborne benzene emissions are the most concentrated closest to their origin and given that workers are rarely required to wear respirators (Mairose, personal communication), we would expect employees to experience greater benzene exposure, both in terms of dose and frequency, than community members. With greater benzene exposure, we would also expect greater risk of developing diseases, such as aplastic anemia, that are associated with this exposure. Based on a search of records for Emerald Kalama employees in the workers' compensation database from 1990 to 2006, L&I reported no records of blood-related disorders, including leukemias and aplastic anemia. Additionally, L&I queried their databases to search for any claim with an assigned or bill payment code suggestive of a blood disorder and examined employer information for workers with such a claim. No blood disorders among workers at Emerald Kalama were detected in this manner in data from 1990 to 2006.

IB. Data collected from community reports and active case finding (Contacts: Richard Leman, Hilary Gillette-Walch, Dave Stone, Kathryn Hughes)

We obtained contact information for the people with aplastic anemia in the two counties from the citizen who initially reported the concern. Staff from the Oregon Public Health Division, the Washington State Department of Health and the Cowlitz County Health Department then called each of these people and interviewed them or their families using a standardized interview form. These interviews covered a variety of topics. (See Appendix III.) We wanted to confirm that they were diagnosed with aplastic anemia by a health care provider and that they had lived in Cowlitz or Columbia County for at least 30 days before diagnosis. Additionally, anyone who met the 30-day residence requirement, but was diagnosed after moving out of the two-county area must have been diagnosed within 12 months of the move to be included in the analysis. We also asked about possible exposures that might have put them at risk. Everyone confirmed that they or their child had been diagnosed with aplastic anemia by a health care provider and that they met the

residence length and timing requirements. Based on the interviews, we did not find any commonalities in potential risk factors.

We set residence for 30 days as a requirement for inclusion in the investigation because we did not want to include people who had undiagnosed aplastic anemia when they moved into the two-county area. Additionally, Dr. Kaufman reported that 30 days is typically the minimum amount of time for aplastic anemia to develop after exposure to benzene. We included anyone who was diagnosed up to 12 months after moving out of the two-county area given that the interval for being diagnosed with aplastic anemia following benzene exposure may be up to one year (Kaufman, personal communication, 2006).

We did not include non-residents with aplastic anemia who spent time in the two-county area because we had no way to determine the total number of people who spent time in the area. This number would be needed to determine whether the observed number of people with aplastic anemia exceeded the number expected.

We took additional steps to identify anyone else living in Columbia or Cowlitz County who had been diagnosed with aplastic anemia. Since aplastic anemia is not a reportable disease in Oregon or Washington, there is no formal system to track new diagnoses of this condition. We consulted with hematologists (the medical specialists who typically treat aplastic anemia) serving the two counties to identify any additional people diagnosed with aplastic anemia. The hematologists also provided information about which hospitals or other medical facilities in Oregon and Washington serve as referral centers for Columbia and Cowlitz County residents with aplastic anemia. We identified four facilities and worked with these centers to determine if they had records of any additional people who had been diagnosed with this condition between January 1, 1997 and December 31, 2006.

In most cases, we were able to search through electronic health records or billing databases with information about diagnoses for all of the years of interest. At one of the health facilities, the electronic database did not contain information for visits prior to 2002. However, we supplemented this information with reports from hematology staff working at this facility to search for people with aplastic anemia who were seen in earlier years.

We chose 1997 – 2006 as the investigation period for several reasons. First, we believed that the medical records and billing databases used in finding cases were most accurate and complete during this period. Additionally, investigation across this 10-year interval provided a sufficiently broad time to detect additional cases of aplastic anemia if they had occurred, but allowed us to focus on currently relevant findings. We chose 2006 as the last year to examine because it was the most recent complete year of data available.

We compiled the information from these different sources and developed a list of people with aplastic anemia who had lived in Columbia or Cowlitz County during the relevant time period before diagnosis. We then compared the number of people with aplastic anemia with the number that would be expected in the two counties based on the background rate of the disease and the population sizes of the counties. We were not able to account for age because we do not know the background rates of developing aplastic anemia for different age groups. However, given the large age range among people with aplastic anemia, this is expected to have a minimal effect on the findings (Kaufman, personal communication, 2007).

Case ascertainment efforts through healthcare facilities identified one additional person diagnosed with aplastic anemia. The person was diagnosed in 1998. Further investigation revealed that the person was living in the Longview/Kelso area before and at the time of diagnosis. The estimated background rate for new cases of aplastic anemia is two per one million people per year (Kaufman, et al., 1991). With the combined annual populations of Cowlitz and Columbia Counties (about 136,508 for 2000 based on U.S. Census data), we would expect 2.8 people in the two-county area to have developed this condition during the 10-year period, 1997-2006, with a range, based on random variation of zero to six. We observed a 2.5-fold increase (7 observed/2.8 expected) in the number of people diagnosed with aplastic anemia over this period. This finding was statistically significant (Poisson p-value: 0.048). The threshold for statistical significance is reached when the p-value is less than .05.

IC. Summary of Health Data.

The investigation revealed that, over a ten-year period, seven people in the two-county area were diagnosed with aplastic anemia. This is one more than what might reasonably be expected, based on random variation and given the number of people living in the two counties. We also observed a small, statistically significant elevation in the number of people who developed leukemia in the two-county area compared to the expected number (193 observed, compared with a range of 139 to 189 cases expected, based on random variation). However, if exposures to benzene from Emerald Kalama were causing leukemia in the surrounding communities, we would have expected to see an increase in AML diagnoses since AML is the type of leukemia most strongly linked to benzene exposure, but this was not the case.

There were no statistically significant elevations in the number of people who died from aplastic anemia or the number of people who developed acute myeloid leukemia (AML) in either of the two counties separately or combined. This means that the numbers of people with these conditions were within the range one might expect due to random variation. Assuming that Emerald Kalama employees would experience greater benzene exposure (both in terms of dose and frequency) than community members, the absence of blood-related disorders (including leukemias and aplastic anemia) among these workers supports the conclusion that exposure to benzene from Emerald Kalama is unlikely to be causing blood-related disorders in the community.

ID. Limitations

Although the Oregon and Washington State databases of deaths and cancer diagnoses are almost 100% complete, it is possible that we did not identify everyone who died from aplastic anemia or who was diagnosed with leukemia. For example, we could have missed a person who lived in the two-county area for many years and was later diagnosed with AML after moving away from the area. Neither death nor cancer registry databases track information about previous residence. It is also possible that we did not identify everyone who was diagnosed with aplastic anemia in the two-county area. Fortunately, most people do not die from aplastic anemia. This makes mortality a less useful indicator of the number of people with aplastic anemia. We searched medical and billing records to get a more complete profile of people diagnosed with the disease.

II. Environmental data

IIA. Benzene in air (Contacts: Paul Mairose, John St. Clair, George Davis, Julie Wroble)

To determine the potential for exposure to benzene emitted into the air from Emerald Kalama Chemical, we obtained emissions data from the Washington State Department of Ecology (Ecology) and the Oregon Department of Environmental Quality (ODEQ) and data on wind direction from the Southwest Clean Air Agency (SWCAA) and Emerald Kalama.

IIA.1. Sources of benzene in outdoor air in Columbia and Cowlitz Counties

Ecology data for 2002, shown in the tables below, indicate that the predominant source of benzene in the air in Cowlitz County was from traffic on roads (on-road emissions). Major contributors also included sources such as wood stoves, fireplaces, residential trash burning and small commercial facilities, were also major contributors. Benzene emissions were identified from three point sources (Emerald Kalama, Weyerhaeuser and Longview Fibre). Together these point sources accounted for about 6% of the total benzene released into the air in Cowlitz County in 2002. Emerald Kalama's specific contribution was about 3% of the total benzene emissions in the county (7.9 of 229 tons). Similar data from ODEQ for Columbia County, Oregon in 2002, also shown below, indicate that point sources (including Boise Cascade Corporation, Armstrong World Industries Inc. and Portland General Electric) contributed only a small proportion (about 1.5%) of benzene in the air in the county. The largest contributors to benzene in the air in Columbia County in 2002 were on-road and area sources. More information about how these emission inventories were created, including how the different source groups were defined, is located in Appendix II.

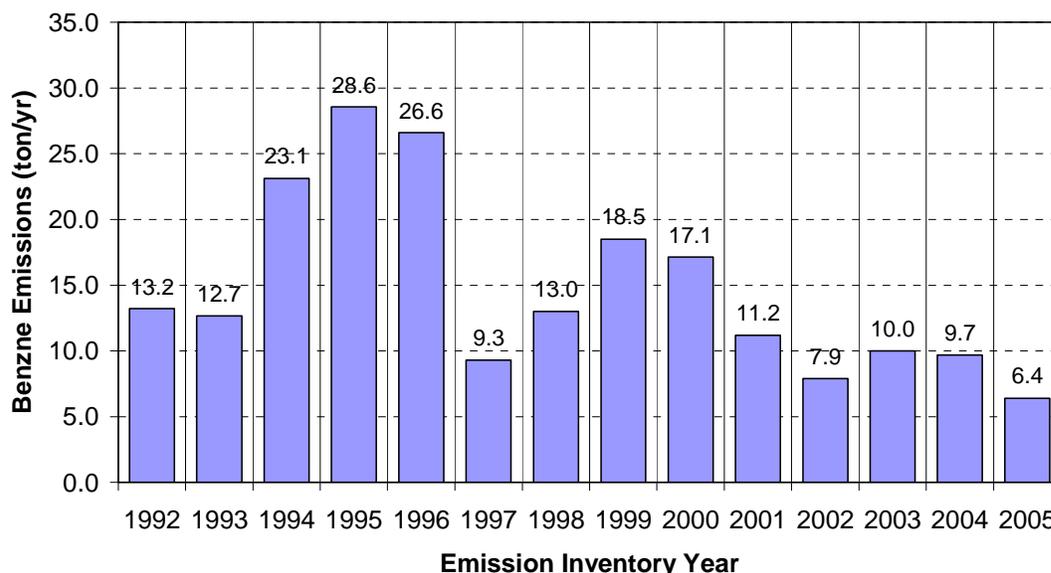
Benzene Emission Inventories by Sector for 2002 (All figures are in tons per year.)			
	Cowlitz County, Washington	Columbia County, Oregon	Total
Point Sources	14.3	1.5	15.8
Area Sources	34.8	41.2	76.0
Non-road Sources	27.4	13.7	41.1
On-road Sources	152.5	44.4	196.9
Total	229.0	100.8	329.8

Benzene Emission Inventories for Point Sources only for 2002 (All figures are in tons per year.)			
Cowlitz County, WA (point source, location)	Benzene Emissions	Columbia County, OR (point source, location)	Benzene Emissions
Emerald Kalama, Kalama	7.9	Boise Cascade, St. Helens	1.5
Weyerhaeuser, Longview	4.4	Armstrong World Industries, St. Helens	0.0021
Longview Fibre, Longview	2.0	Portland General Electric Beaver Plant, Clatskanie	0.022
Total	14.3		1.52

Although the amount of benzene air emissions from Emerald Kalama compared to the amounts from other sources was relatively low in 2002, we examined additional information about these emissions to assess patterns and trends. We also examined meteorological data to determine predominant wind patterns in the area in order to understand where most of the air emissions would be transported. We compared those directions to the areas where the people with aplastic anemia lived relative to the plant.

According to SWCAA, normal plant processes cause a comparatively low but continuous release of benzene to outdoor air. Annual benzene air emissions, shown in the following bar chart, tended to decrease in recent years, with 2005 having the lowest reported emissions. Since 1997, the year when emissions showed the greatest decline and after which emissions have remained consistently lower than in previous years, annual emissions ranged from about six to 19 tons, with an average of about 11.5 tons per year. If released fairly consistently, 11.5 tons per year equates to about 63 pounds of benzene daily. SWCAA was formed in late 1968 and first inspected the Emerald Kalama plant (then Dow Chemical) in August 1969. Since that time, the plant has undertaken numerous modifications in infrastructure and processes that have been subject to permitting and compliance determinations by SWCAA. SWCAA files contain details of plant modifications, inspections and compliance reports. Since Emerald Kalama was first inspected by SWCAA, the plant has been in compliance with maximum allowable benzene emissions per year.

Emerald Kalama Chemical Benzene Emissions 1992 to 2005



According to SWCAA, about one-third of Emerald Kalama benzene emissions into the air are “stack” emissions, meaning that they pass through a defined opening or pathway, such as the exhaust stack of a boiler. The remaining air emissions are called “fugitive” and can occur in a variety of ways (for instance, evaporation of a chemical from an open tank or leakages through cracks or incomplete seals in hoses or pipes). Both of these types of emissions occur through normal plant processes on an almost continuous basis. A more detailed explanation of the various sources of benzene air emissions from Emerald Kalama and how estimates of release amounts from these sources were generated is located in Appendix II.

IIA.2. Meteorology and air emissions transport at Emerald Kalama Chemical

The U.S. Environmental Protection Agency (EPA) required Emerald Kalama to collect on-site meteorological data for use in a mathematical model showing the dispersion of emissions from an on-site Boiler Industrial Furnace (BIF) unit in a manner consistent with the Prevention of Significant Deterioration (PSD) data quality specifications. EPA mandated that Emerald Kalama collect data on-site because the closest existing meteorological station is in Longview, Washington, and the data collected at Longview are not representative of Kalama. This is in part because the Columbia River, which influences wind direction, changes directions between Kalama and Longview (Mairose, personal communication).

In the PSD specifications, EPA provides guidance on data collection such as:

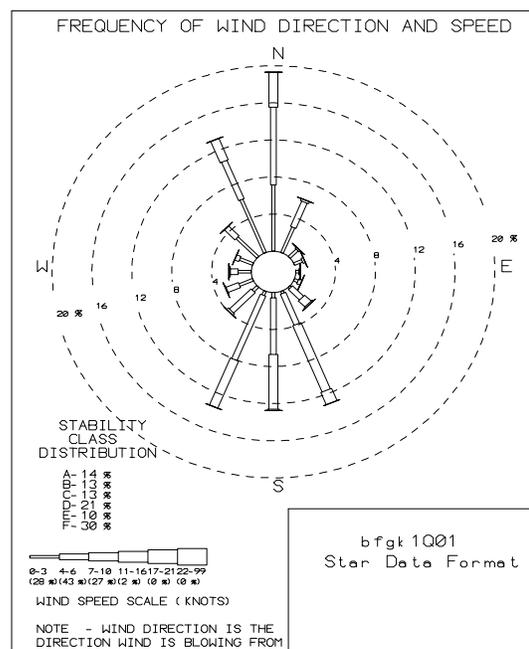
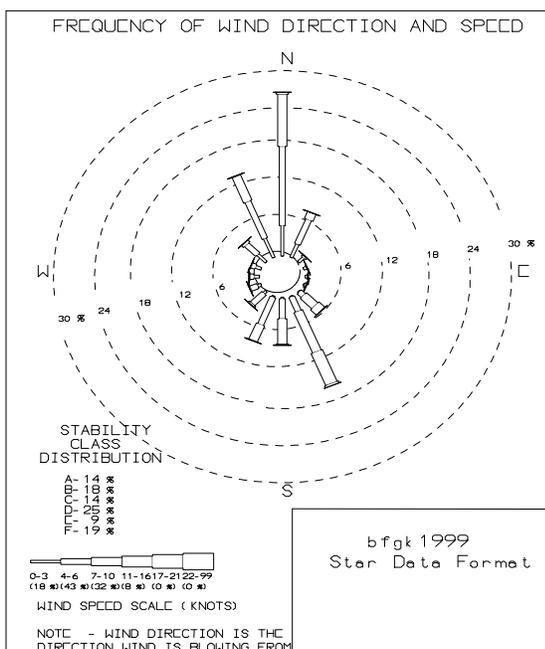
- Where the meteorological tower should be located to avoid structural wake effects;
- What type of data must be collected (wind direction, wind speed, solar radiation, etc.) and the allowable equipment types;
- The minimum amount of data capture;
- The total amount of data needed (usually between two and five years);
- The instruments’ calibration and audit frequencies (quarterly);
- The data sampling and averaging periods; and
- The statistical methodology used to process the data.

Additional information on these guidelines can be found in the following publications:

- EPA's Ambient Monitoring Guidelines for the Prevention of Significant Deterioration (PSD), EPA-450/4-87-007, May 1987;
- EPA's Guidelines for Siting and Exposure of Meteorological Instruments for Environmental Purposes, January 1976;
- EPA's Quality Assurance Handbook for Air Pollution Measurement Systems, Volume IV, Meteorological Measurements, EPA/600/4-90/003, August 1989;
- EPA's On-Site Meteorological Program Guidance for Regulatory Modeling Applications, EPA-450/4-87-013, June 1987.

The meteorological tower was set up and maintained by TRC Environmental Corporation (TRC) from October 1995 through March 2001. The tower was instrumented to measure wind speed, wind direction, outdoor temperature two meters above ground, outdoor temperature ten meters above ground, atmospheric stability (as indicated by sigma theta), solar radiation and precipitation. These factors were measured because each influences how emissions from a source disperse. TRC calibrated and audited the instruments quarterly. According to the EPA, the location of the tower met the applicable EPA siting criteria (criteria related to location) and the instruments were high quality, PSD-grade. EPA approved the data as PSD quality for use in a risk assessment study required for the operation of the BIF unit (Mairose, personal communication).

Wind roses show the percentage of time that the wind blows from a given direction and the average wind speed. Two of the wind roses created from the data collected at the Emerald Kalama site (during 1999 and the first quarter of 2001) are presented in figures below. For example, in the first diagram, based on wind data collected throughout 1999, the wedge showing wind blowing from the north is the longest, signifying that the wind at Emerald Kalama most often blows from the north, towards the south. In this case, the wind blew from the north to the south about 25% of the time as indicated by the wedge extending just past the circle marked 24. The thickness of the wedge represents the wind speed. Both Emerald Kalama wind roses pictured below indicate that the predominant wind direction is northerly or southerly, with very little movement in either the easterly or westerly directions.



The wind is heavily influenced by the topography surrounding the plant (Mairose, personal communication). A predominant feature of this topography is the Columbia River, which flows in a northerly direction near the Emerald Kalama plant before turning to the northwest about 10 miles north near Longview, WA. Other data collected at the Emerald Kalama site between October 1995 and March 2001 also show a predominant northerly-southerly wind direction.

The following table shows the same data as in the wind roses, but does not include information on wind speed. Additionally, the table shows the total amount of time the wind blew from different directions over the time period as a whole.

Number of hours wind blew from a given direction at Emerald Kalama

Year	N	NNE	NE	ENE	E	ESE	SE	SSE
1994-5	1952	486	132	61	56	52	501	1112
1996	1837	427	125	60	56	55	647	1070
1997	1711	381	101	49	39	45	635	1080
1998	1425	340	108	57	54	118	663	1562
1999	2319	689	116	49	41	40	404	1374
2000	2272	805	178	78	44	45	258	1017
2001	417	133	28	24	10	17	61	282
Total	11933	3261	788	378	300	372	3169	7497
Percent	22.1	6.0	1.5	0.7	0.6	0.7	5.9	13.9

**Number of hours wind blew from a given direction at Emerald Kalama
(continued)**

Year	S	SSW	SW	WSW	W	WNW	NW	NNW	Total
1994-5	1073	669	215	159	141	147	514	1487	8757
1996	973	812	265	159	165	176	490	1416	8733
1997	905	807	309	194	182	211	519	1409	8577
1998	1567	513	189	126	107	149	391	1023	8392
1999	681	691	274	158	132	140	391	1256	8755
2000	724	829	339	176	166	184	386	1237	8738
2001	275	292	86	63	49	41	97	285	2160
Total	6198	4613	1677	1035	942	1048	2788	8113	54112
Percent	11.5	8.5	3.1	1.9	1.7	1.9	5.2	15.0	

The following table shows where the people with aplastic anemia lived during the relevant time periods before diagnosis and the percent of time the wind blew from Emerald Kalama toward these residences.

Direction of residence relative to Emerald Kalama	Percent of time the wind blew towards that direction, October 1994 – March 2001	Number of people
NW – NNW	20% (13.9% + 5.9%)	2
N	12%	2
NW	6%	1
WSW	<1%	1
ESE – SE	7% (1.9% + 5.2%)	1

Although the wind blew relatively frequently in northerly directions towards areas where some of the people with aplastic anemia lived, it blew almost 50% of the time toward the south between SW and SE (including the percentage of time the wind blew due SW and due SE). Despite the large proportion of time the wind blew between SW and SE of the plant and the sizable population in that area, we did not identify anyone in that area with aplastic anemia. The fact that the wind moved less than 1% of the time towards the WSW lowers the potential for people living in that direction to develop aplastic anemia due to exposure to benzene air emissions from Emerald Kalama. Additionally, while we were not able to model dispersion of emissions from Emerald Kalama, concentrations of chemicals in air emissions generally decline with distance from the source. It is unlikely that the person living 18 miles from the plant would be affected by benzene emissions from Emerald Kalama. The people living eight or nine miles from the plant are also likely to be most affected by local sources of benzene.

IIA.3. Longview air toxics monitoring

From May 2004 – May 2005, SWCAA conducted a study to better understand air toxics in Longview. This area was of interest because it has a large industrial presence, a high volume of diesel traffic and prevalent wood stove use. No monitoring was previously conducted in the area. Concentrations of benzene exceeded Washington's acceptable source impact levels, Oregon's ambient benchmark concentrations and EPA's chronic screening value (the level at which a person can be exposed continuously over a 70-year lifetime without increased risk of cancer and other health conditions). SWCAA concluded that although levels of benzene in the air in Longview pose a potential health risk, the amount of benzene was similar to that found in studies in Seattle and in other urban areas in the country. For more information, please consult the Longview air toxics report at the following site: <http://www.swcleanair.org/reports.html>.

IIA.4. Summary of air data

Because aplastic anemia associated with benzene appears to represent a rare reaction to a common exposure, it is impossible to say for sure whether any individual's aplastic anemia was or was not caused by exposure to benzene, either from Emerald Kalama or some other source. However, the pattern of residence at diagnosis, the population distribution of the two counties and the prevailing wind patterns do not support the hypothesis that exposure to airborne benzene from Emerald Kalama is causing a cluster of illness among community members. Although the wind blew relatively frequently toward northerly directions, four of the five individuals who lived in these locations in relation to the plant resided in Longview-Kelso, the major population center of the two counties. It is not unusual that most of the people with a specific disease live in the largest population centers. Additionally, if benzene is playing a role in the development of aplastic anemia in the Longview-Kelso area, given the locations of major roads and the distance from Emerald Kalama, it is likely that this area would be more affected by benzene arising from sources closer by, such as transportation-related sources, rather than Emerald Kalama. Given that the wind moved most frequently toward southerly directions and that sizable numbers of people live near the chemical plant in that direction, we would have expected to identify some people with aplastic anemia in these areas if benzene released from Emerald Kalama were causing illness. However, none of the people we identified lived in areas southwest to southeast of the facility. Additionally, the fact that the wind rarely blows toward the WSW lowers the potential that people who live WSW of Emerald Kalama would develop aplastic anemia due to exposure to benzene released from the plant.

IIB. Benzene in water (Contacts: Matt Kadlec, Ha Tran, Dave McBride, George Davis, Dave Stone, John St. Clair)

IIB.1 Groundwater and drinking water

We investigated the possibility that benzene released from Emerald Kalama through liquid spills could reach groundwater or drinking water off-site. According to the Washington State Department of Ecology (Ecology), there are three aquifers beneath the Emerald Kalama facility. The upper aquifer flows outward from the south central area of the plant in north to northeast and westerly directions during both the wet and dry seasons. The intermediate sand aquifer flows west, whereas the deep sand aquifer flows west towards the river in certain seasons and southwest in others. Ecology reported that the spills at the plant known or suspected to have contaminated the three aquifers occurred between 1961 and 1990. Ecology further reported that groundwater sampling on the Emerald Kalama property in 1999 indicated that benzene was not moving with the deep aquifer water. As a result, benzene in the groundwater at Emerald Kalama moves only with the upper and intermediate aquifers toward the western and northern boundaries of the plant property.

Emerald Kalama reported that interception wells were constructed along the northern edge of their property in 1995 and along the western edge of their property in 1995 or 1996 as part of a groundwater clean-up effort. These wells were constructed under the direction and oversight of the U.S. Environmental Protection Agency (EPA). Since 1998, Ecology has been responsible for oversight. Ecology requires quarterly and annual monitoring of both groundwater level and water quality to verify that the interception system operates properly and is effective in capturing contaminated groundwater. Data from 22 monitoring points northeast of the plant and 35 monitoring points along the Columbia River help Ecology make this assessment (Tran, personal communication).

Emerald Kalama reported that the interception wells began to capture and pump contaminated groundwater moving with the aquifers in the northern and western areas to a treatment facility in 1996 and 1997, respectively. The facility further reported that any liquid from spills occurring currently would be captured in concrete containment areas (Wrobel, personal communication). According to Ecology, these areas help minimize spills to the soil and groundwater. Ecology further reported that Emerald Kalama is required to submit a Spills Plan, which describes structures and other spill prevention measures currently in place at the plant. We were unable to locate written documentation that Ecology approved these plans. However, Ecology is in the process of reviewing the most recently submitted Spills Plan (Tran, personal communication).

Ecology data from the monitoring and remediation wells near the northeast corner of the Emerald Kalama property confirm that the northern interception system is effectively capturing benzene in the groundwater that is moving in northerly directions (ThermoRetec, 2000). The Ecology data further show that some benzene in the Emerald Kalama groundwater bypasses the interception trench and recovery wells in the western area of the plant and enters the Columbia River (see Appendix IV). Ecology estimates that the level of benzene in the groundwater captured by the recovery wells was historically in parts per million, but since 1998 has decreased to the part per billion range. Ecology reports that the levels are above human health standards, but that the likelihood of harmful benzene levels reaching groundwater in Columbia County is low. First, Ecology reports that, of the small amount of benzene that could potentially reach the

Columbia River, much of it would evaporate and the remaining amount would become very diluted once it reaches the river. Second, Ecology reports that given the northerly flow of the river near Kalama, Washington, it is unlikely that any benzene entering the river from Emerald Kalama groundwater would be able to move west across the river to reach Columbia County. Such movement could only happen if the river were flowing minimally for a prolonged period.

According to Ecology, the potential for much benzene from Emerald Kalama to reach groundwater off-site in Cowlitz County is also low. This is because of the presence of effective interception wells at the northern edge of the plant property where the contaminated groundwater could otherwise move off-site into Cowlitz County.

We also examined all available drinking water data in both Columbia and Cowlitz Counties to assess the presence of benzene contamination. In Washington, the Office of Drinking Water at the Washington State Department of Health maintains drinking water data for group A and B water systems. Group A systems are those with at least 15 connections and group B systems generally have between 2 and 14 connections. We examined Washington data collected between February 1990 and September 2006 for 36 group A and B public water systems located within 20 miles of Emerald Kalama. We also examined data on the limited number of private wells for which data were available. None of the samples from the private wells and only two of 253 public water samples were above the state's reporting limit of 0.5 micrograms per liter ($\mu\text{g/L}$). None of the samples was above the national maximum contaminant level (MCL) of 5 $\mu\text{g/L}$ established by the EPA in 2002. Under the authority of the Safe Drinking Water Act (SDWA), EPA has set standards for approximately 90 contaminants, including benzene, in drinking water. For each of these contaminants, EPA sets a legal limit, the MCL, or requires a certain treatment such as disinfection or filtration. Water suppliers are required to provide water that meets these standards. Water that meets these standards is considered safe to drink (EPA, 2007). The two samples in which benzene was detected were drawn from group A wells in the Woodland area of the county about five miles south of Emerald Kalama Chemical. Based on movement of benzene in groundwater at Emerald Kalama to the northern and western boundaries of the plant property, it is unlikely that the two wells could have been affected by contaminated Emerald Kalama groundwater.

Oregon Department of Environmental Quality (ODEQ) staff checked data on benzene measurements taken from 10 drinking water systems in Columbia County near the residences of several people with aplastic anemia. All of these drinking water systems use groundwater as their source of drinking water. These data are available online from the Oregon Department of Human Services, Public Health Division at the Department of Human Services website under Public Health Division>Environmental Health Program>Drinking Water Program>Data Online (in Menu)>Inventory. None of these water systems showed detectable levels of benzene (above 0.005 mg/L). The data in the inventory generally covered 1991 through 2003, but the years of data and the number of samples varied substantially by water system. One of the drinking water systems, the Goble Water Association, showed detectable levels of several halogenated hydrocarbons, as well as toluene ($\text{C}_6\text{H}_5\text{CH}_3$), xylenes ($\text{C}_6\text{H}_5(\text{CH}_3)_2$) and ethylbenzene ($\text{C}_6\text{H}_5\text{C}_2\text{H}_5$), but not benzene (C_6H_6). Levels of toluene, xylenes and ethylbenzene were below the MCLs, but four out of 27 samples of tetrachloroethylene and one sample of 1,2-dibromo-3-chloropropane were above the MCLs. Benzene, ethylbenzene, toluene, and xylenes (referred to as BETX) are related compounds that all include the C_6 "benzene ring" structure and are all found in gasoline. The presence of three out of four of the BETX group suggests possible

gasoline contamination of the sample; however, gasoline is ubiquitous, and it is possible that the water samples were contaminated by gasoline vapors in the air after the samples were taken. Halogenated hydrocarbons can originate from many sources, including dry cleaners and cleaning/disinfectant agents. With the exception of toluene, Emerald Kalama does not use either of these classes of chemicals (gasoline-associated chemicals or halogenated hydrocarbons) as raw materials or produce them as products (Wrobel, personal communication; Mairose, personal communication).

IIB.2. Summary of Water Data

The water data we examined indicate that no movement of benzene in groundwater at the plant is occurring off-site in northerly directions. The data further indicate that some benzene is able to escape into the Columbia River from the west-flowing aquifers. However, the potential for harmful amounts of benzene to reach Columbia County groundwater is very low. This is because of substantial evaporation of any benzene that could potentially reach the river, dilution of the remaining benzene (in the river), and the northerly flow of the river, which would prevent movement of contaminants west towards Columbia County. Consistent with this information, no benzene was detected in drinking water stemming from groundwater near the Columbia River in Columbia County. The potential for much benzene from Emerald Kalama to reach groundwater off-site in Cowlitz County is also low. This is due to the presence of effective interception wells at the northern edge of the plant property where the contaminated groundwater would otherwise move off-site in Cowlitz County. In fact, only two of 253 drinking water samples for 36 group A and B public water systems in Cowlitz County showed detectable levels of benzene. Both of these were in group A wells in Cowlitz County, located more than five miles south of Emerald Kalama, and the levels in both wells were below the national MCL. The EPA considers water below this level safe to drink. Given that benzene in Emerald Kalama groundwater does not flow south from Emerald Kalama, it is unlikely that these Cowlitz County wells were affected by benzene in groundwater on the plant property. Thus, we have no evidence to show that residents of Cowlitz and Columbia Counties are exposed to benzene from Emerald Kalama through contaminated water.

IIC. Acute benzene releases from Emerald Kalama

Occasionally, unplanned, short-term benzene releases, termed acute releases, occur. These types of releases include spills, evaporation/aerosolized (vapor), fires and explosions. Section 103 of the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), Section 304 of the Emergency Planning and Community Right-to-Know Act (EPCRA) and Washington Administrative Code (WAC) 173-303-145 require that any person responsible for spill or discharge of a dangerous waste or hazardous substance into the environment report it immediately to the National Response Center (NRC), state emergency response commissions (SERCs) and/or local authorities in accordance with the local emergency plan, except when the release is otherwise permitted under state or federal law. The EPA requires that companies report acute releases of benzene exceeding 10 pounds within 15 minutes of discovery. The Washington Hazardous Substances Emergency Event Surveillance System (HSEES) collects specific data from the reports in order to identify strategies for preventing future events, injuries and death.

The following table shows that Emerald Kalama reported 20 acute releases of benzene from 1998 to 2006. Of these releases, half occurred in 2006. Most of the other releases occurred in 1998. Average daily releases based on usual benzene air emissions from the plant during 1997-

2005 (shown in the bar chart on page 16) were about 63 pounds per day. In February 1998, Emerald Kalama reported its largest acute release of 100 pounds, which would more than double the amount of benzene emitted on an average day. In January and April of 1998 and February of 2006, Emerald Kalama experienced acute releases of 40 pounds. Releases on these days would exceed the amount of benzene emitted on a typical day by about 60%. The next highest release, 29 pounds, occurred in October 1998. This amount would have resulted in about a 50% increase in the amount of benzene emitted that day. Other than these incidents, the amounts of benzene emitted from the acute releases were small relative to the amounts typically emitted from the plant.

Event Date	Quantity Released (in pounds)
01/27/1998	40
02/10/1998	100
03/26/1998	15
04/28/1998	40
10/13/1998	29
12/23/1998	12
03/10/1999	<2
05/22/1999	10
04/05/2001	2
08/11/2003	1.5
01/28/2006	<10
02/04/2006	1.23
02/07/2006	<<0.0001
02/08/2006	40.9
03/03/2006	<0.1
03/10/2006	0.0 ***
07/19/2006	~4.0
08/09/2006	6.9
08/20/2006	1.0
09/05/2006	0.1

*** It is not always possible to calculate the amount of benzene released in 15 minutes. As a result, Emerald Kalama reports all releases when the amounts cannot be calculated with certainty in that time frame. For this particular release, after making the initial report Emerald Kalama staff reported that no benzene was released in the event.

IID. Limitations

There were several limitations of the available environmental data. First, except for Longview where SWCAA performed an air toxics study, we were unable to examine concentrations of benzene in the air in Columbia or Cowlitz Counties. Initiating collection of data on benzene air concentrations in other parts of the counties at this time would not be useful in characterizing levels of benzene at the time periods relevant to developing aplastic anemia because emissions from Emerald Kalama have declined over time.

Sometimes it is possible, using mathematical modeling, to estimate the dispersion of emissions from a point source. However, such modeling would have been very complex in this case because there are multiple sources of benzene emissions at Emerald Kalama. Additionally, modeling for Emerald Kalama would be especially complex because most emissions at the plant are fugitive rather than stack in nature. With predominantly stack emissions, it is easier to predict where the emissions go because they are released in a certain direction and with a certain velocity, both of which can be measured. However, fugitive emissions do not have these characteristics. The absence of large elevations in the rates of aplastic anemia and acute myeloid leukemia in the two counties, as well as the absence of blood-related disorders (including aplastic anemia and leukemias) among Emerald Kalama employees did not support moving forward with the modeling.

Another limitation is that we could not examine possible contamination of private and domestic wells, unless these wells served a monitoring purpose. However, we found small potential for benzene from Emerald Kalama to contaminate groundwater off-site and no evidence of unsafe drinking water due to benzene in the public water sources.

CONCLUSIONS

While one cannot determine what causes an individual to develop aplastic anemia in the majority of cases, in this investigation, we evaluated the evidence concerning whether aplastic anemia in Columbia and Cowlitz Counties might be due to exposure to benzene released from the Emerald Kalama plant. Over a ten-year period, one more person developed aplastic anemia in the two-county area than we would expect based on random variation, given the number of people living in the two counties. Over this time period, there were four additional cases of leukemia beyond what would be expected based on random chance. However, rates of acute myeloid leukemia, the type most strongly associated with benzene exposure, were not elevated.

Evidence from health, air and water data does not support the hypothesis that benzene emissions from Emerald Kalama are causing aplastic anemia in Cowlitz or Columbia County residents. At this time, the agencies and organizations involved in this assessment agree that further investigation is unlikely to find a focal cause for aplastic anemia in Cowlitz and Columbia counties. The agencies will assess the need for further investigation as new information becomes available.

The largest proportion of benzene in the air in Columbia and Cowlitz Counties is due to road sources. This is important when thinking about limiting exposures to potential hazards. Efforts to lower emissions from mobile sources may have the greatest potential to reduce exposures of the general public to benzene. Such efforts could have a greater impact in the Pacific Northwest than elsewhere since gasoline used in this area contains more benzene than gasoline in other parts of the country (Oregon DEQ, 2007). The U.S. Environmental Protection Agency (EPA) released a new rule on February 9, 2007 that has set a cap for the maximum amount of benzene allowed in gasoline by percent volume (EPA, 2007). This rule will lower the amount of benzene in gasoline and will also make benzene concentrations in gasoline the same across the United States. This rule will go into effect in 2011. For background information on EPA's broader plan to reduce emissions of hazardous air pollutants such as benzene from mobile sources, please see the following website: <http://www.epa.gov/otaq/regs/toxics/420f06021.htm#background>.

We wish to express our appreciation to the citizens who brought this concern to our attention, the families who shared information with the investigators, and the health facilities that aided in the investigation. We hope the information generated is helpful to those who raised the concerns.

References

Kaufman DW, JP Kelly, M Levy, and S Shapiro. The Drug Etiology of Agranulocytosis and Aplastic Anemia. New York: Oxford University Press, 1991.

Kaufman, David W., Sc.D. Associate Director, Slone Epidemiology Center at Boston University; Professor of Epidemiology, Boston University School of Public Health. Personal communication, October 26, 2006.

Kaufman, David W., Sc.D. Associate Director, Slone Epidemiology Center at Boston University; Professor of Epidemiology, Boston University School of Public Health. Personal communication, May 9, 2007.

Mairose, Paul T., P.E. Chief Engineer, Southwest Clean Air Agency, Vancouver, WA. Personal communication, July 2007.

National Center for Health Statistics (NCHS). 2007. Data Warehouse - Comparability of cause-of-death between ICD Revisions.

<http://www.cdc.gov/nchs/datawh/statab/unpubd/comp.htm#A%20guide%20to%20state%20implementation%20of%20ICD-10>.

Oregon Department of Environmental Quality. Fact Sheet: Benzene in Oregon's Air.

http://www.deq.state.or.us/aq/factsheets/06-aq-018_benzene.pdf

Schottenfeld, D. and J.F. Fraumeni, Jr. (editors). Cancer epidemiology and prevention. Third edition. Oxford: Oxford University Press, 2006.

The Leukemia & Lymphoma Society. 2006. Leukemia Facts and Statistics.

<http://www.leukemia-lymphoma.org/all_page?item_id=9346> (Accessed April 5, 2007).

ThermoRetec Consulting Corporation. Remedial Investigation, Revision 1 – BFGoodrich Kalama Facility, October 16, 2000.

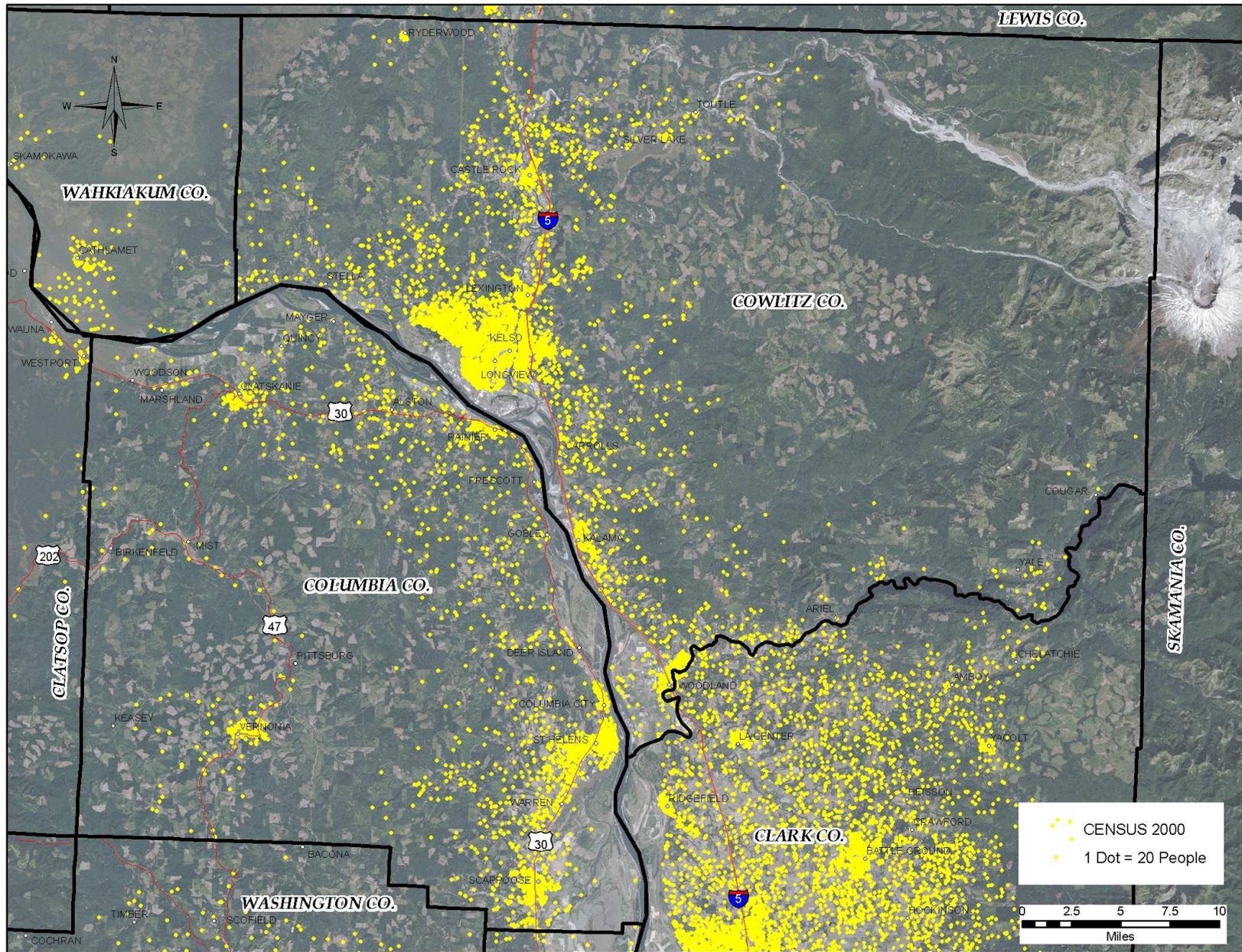
Tran, Ha. Environmental Engineer, Washington State Department of Ecology. Personal communication, June – July 2007.

U.S. Environmental Protection Agency. Control of Hazardous Air Pollutants from Mobile Sources: Final Rule to Reduce Mobile Source Air Toxics. Released February 2007.

<http://www.epa.gov/otaq/regs/toxics/420f07017.htm>

U.S. Environmental Protection Agency. 2007. Groundwater and Drinking Water – Frequently Asked Questions. <http://www.epa.gov/safewater/faq/faq.html>.

Wrobel, Christopher L., PhD. Environmental, Health, Safety & Security Manager, Emerald Kalama Chemical, LLC. Personal communication, April – July 2007.



Appendix I. Population distribution of Cowlitz County, Washington and Columbia County, Oregon

Appendix II. Technical Notes

A. Additional Oregon population data used in health-related calculations (Contacts: Kathryn Hughes, Catherine Riddell)

In the first set of calculations to determine whether there were elevations of aplastic anemia deaths, total leukemias or acute myeloid leukemia in the two counties of concern, we applied the 2000 U.S. Census populations for Oregon State and Columbia County for all years examined because inter-censal population estimates were not readily available for Oregon. Inter-censal population estimates refer to estimates of population sizes for the years between administrations of the U.S. Census. The Census collects demographic information once every ten years at the start of each decade (1990, 2000, etc). To ensure we were using the best available population estimates for both states, we acquired population estimates for inter-censal years in Oregon from the Population Research Center at Portland State University (<http://www.pdx.edu/prc/annualorpopulation.html>). As for Washington, the Oregon estimates for inter-censal years in the 1990s were adjusted to take into account information gathered through the 2000 Census. However, unlike the Washington estimates for these years, only total population estimates by year (and not estimates by age group for each year) were adjusted. To obtain age-specific adjusted population estimates for inter-censal years in the 1990s for Oregon State as a whole and Columbia County, we applied the originally projected age-distributions in each of these years to the adjusted total population.

The range of expected values based on random variation was determined by means of a two-tailed Poisson p-value calculation using SAS software. For the upper end of the range, we calculated the threshold number of observed cases above which the comparison of observed vs. expected cases produced a p value of less than .05 (a conservative and commonly accepted indicator of statistical significance). For the lower end of the range we calculated the threshold number of observed cases below which comparison of observed vs. expected cases produced a p value of less than .05 (or if this value was less than zero, we chose zero for the lower bound).

B. Generation of benzene air emissions inventory in Columbia County, Oregon and Cowlitz County, Washington

The benzene emission inventory for Columbia County (and all other Oregon counties) is a calculated estimate of benzene emissions from a variety of sources and source categories. The emission factors (EF) are usually standard factors developed by the U.S. Environmental Protection Agency (EPA). Inventories for Washington counties are based, whenever possible, on direct measurements from the different sources of emissions (also called “source tests”). When direct measurement is not feasible, EPA EFs are used as in Oregon. The Oregon Department of Environmental Quality (ODEQ) generates these inventories for Oregon, whereas the Southwest Clean Air Agency (SWCAA) conducts inventories for point sources and the Washington State Department of Ecology (Ecology) handles these for the remaining types of sources in Washington.

“Point sources” are larger industrial facilities that have a permit (for example, the pulp mill in St. Helens has a permit from ODEQ). Emissions from such facilities are estimated based on a standard EF for each process at the facility and an annual operating rate for each process. For example, a boiler is estimated to use a certain amount of fuel each year. The fuel usage is multiplied by a benzene EF for that type of fuel, resulting in an estimate of benzene emissions from that boiler. This type of calculation is repeated for each process at each point source.

“Area sources” are smaller industrial and commercial facilities that generally are not required to obtain permits, such as small printers and dry cleaners. This category also covers the pollution driven by the

activities of Oregonians and Washingtonians such as residential wood combustion, architectural surface coating, residential backyard burning, structure fires and vehicle refueling. Emissions from such categories are estimated using population-based activity, such as per capita solid waste generation or tons of cordwood burned, and EFs that were developed from small-scale studies of these types of activities and extrapolated to the county's population. The population can be multiplied by the EF to estimate emissions from all area sources or area source subcategories.

“On-road sources” refer to vehicular emissions from highway use (e.g. cars, trucks, and buses). “Non-road sources” refer to vehicles and machinery that are not used on roads (e.g. construction machinery, off-road recreational vehicles, etc.). The estimating methodology is similar to that for area sources, using population-based EFs that assume a certain total of emissions from these sources for a given population size. Mobile non-road source emissions are estimated using computer models developed by the EPA. The non-road model calculates emissions based on a nationwide survey of small engines used for any activity, such as lawnmowers, leaf blowers, tractors, bulldozers, or water pumps, and internally correlates that info with the number of people undertaking that activity. It is used by all states to calculate the non-road emissions.

For the on-road mobile sources, ODEQ and Ecology use MOBILE6.2, another EPA model, which utilizes numerous inputs including registered vehicle (cars, trucks, motorcycles) age groups, local weather conditions, and the properties of fuels sold in Oregon and Washington to produce an EF in lbs/vehicle mile traveled (separated for cars, light trucks or heavy duty trucks, etc.). Then the agencies multiply the EF by an estimate of the miles driven by vehicles in each county. In Oregon, the Oregon Department of Transportation generates this estimate.

C. Generation of benzene air emission estimates for Emerald Kalama (Contacts: John St. Clair, Paul Mairose)

Emerald Kalama Chemical is required by law to report its emissions each year. Intentionally hiding, misleading or in any way obfuscating the data is a criminal offense (Mairose, personal communication). Emissions sources are tested by an outside contractor in accordance with local, state and federal regulations and the plant's Air Operating Permit (Mairose, personal communication). The contractor uses the most recent source tests to calculate quantities of all plant emissions and reports these directly to the Southwest Clean Air Agency (SWCAA). SWCAA verifies all source tests and emissions calculations. In addition, SWCAA visits the plant many times during the course of a year to observe source testing activities and to perform inspections. The Air Operating Permit and all of the regulations are in the public domain (Mairose, personal communication). Anyone interested in details of the permit can contact Paul Mairose at SWCAA (paul@swcleanair.org or 360-574-3058, ext 30). Links to additional information about regulations on Emerald Kalama (including those that relate to reporting emissions) are available in Appendix IV.

According to SWCAA, most benzene emissions into the air from Emerald Kalama in a given year occur during the wastewater treatment process. Organic compounds in the plant's wastewater, including benzene, are treated biologically, similar to a municipal wastewater treatment plant. Microbes in the treatment system break down the organic compounds as food and effectively remove the compounds from the water. The majority of the wastewater is routed to treatment tanks, which are open to the atmosphere. Benzene can volatilize from these tanks into the air, but the oxygen is required by the microbes to consume the organic compounds. The rest of the wastewater, which contains the highest benzene concentration, is directed to the anaerobic treatment plant. The anaerobic plant is also a biological treatment system that uses microorganisms that do not need oxygen to break down organic compounds. Based on frequent measurements of the benzene concentration at various sampling points throughout the wastewater treatment system and mass balance calculations, about 4 tons of benzene per year (almost two-thirds of the benzene emitted to the atmosphere in 2005) is released from wastewater treatment activities.

Benzene vapors from the plant processes are controlled using carbon beds and regenerative thermal oxidizers (RTOs). These two systems operate together to recover and then destroy any remaining organic compounds that would otherwise be emitted to the atmosphere (Wrobel, personal communication; Mairose, personal communication). First the carbon beds remove much of the organic compounds by adsorption. The organic chemicals are recovered from the carbon beds using heat and steam. The carbon beds exhaust to the RTOs, where any organic chemicals, including benzene, that made it past the carbon beds are destroyed (Mairose, personal communication). The RTOs destroy all of the organic chemicals through a process known as thermal oxidation. Emissions from this process accounted for 1.23 tons of benzene in 2005. Both RTO units were source tested in 2007 and the carbon beds are tested monthly in order to monitor their benzene and toluene removal efficiencies (Wrobel, personal communication; Mairose, personal communication).

Other, very small (0.35 tons/year) sources of the benzene releases include the production of chemicals such as benzyl alcohol, benzyl amine and hexyl cinnamic aldehyde. When producing these chemicals, benzene is sometimes formed as an unwanted by-product. Liquid benzene, which is formed as a by-product in some of Emerald Kalama's processes, is shipped off-site in railcars. Less than one pound of benzene was emitted to the air in 2005 from loading benzene into railcars for transport. Emissions from the railcar loading operation are controlled by a carbon adsorption system. The railcar carbon adsorption system is continuously monitored for benzene breakthrough.

Appendix III. Interview form

Initial Cluster Inquiry Report Form

1. Name of Patient: _____
2. Name of person providing information: _____
3. Relationship to the patient: _____
4. Date of birth of the patient: ____/____/____ 5. Age at last birthday: _____
6. Address of patient: _____

- Phone (day) _____ (evening) _____
7. Length of residence in community: _____
8. Patient's gender: _____ Male _____ Female
9. Patient's race: _____ Ethnicity: Hispanic? _____ Yes _____ No
10. Physician diagnosis (please be as specific as possible):

11. Date of diagnosis (month and year): _____
Address at time of diagnosis: _____

12. Name & telephone of primary physician: _____

13. Please list any other major health problems the patient has had (include major illnesses, long term conditions, sensitivities, etc.): _____

14. Patient's work history (please include the occupation, industry and length of employment for each major job--begin with the current or most recent job): [If child (age 1-17), then list work history of parents – father and mother – separately.]

15. If other family members have had this diagnosed illness, please list their relation to the patient and the age at diagnosis (include parents, grandparents, siblings, aunts and uncles):

16. Does the patient presently smoke tobacco, or has the patient smoked tobacco in the past?

_____ No _____ Yes: Number of years of smoking: _____

17. Is there anyone in the household who presently smokes tobacco, or has smoked during the patient's lifetime? _____ No _____ Yes: Number of people who smoke or smoked: _____

18. What is the source of drinking water for the patient's residence? _____

19. Please list major hobbies that are practiced in the patient's house by any family member:

20. If you have any thoughts about what may have caused or contributed to this diagnosed illness, please list them _____

21. If patient deceased, please list date of death and place (city, state): _____

22. Date form completed: _____

23. Interviewer (if different from item 2): _____

Thank you for taking the time to complete this form. If there is any other information you think is relevant, please include it on an additional sheet of paper. Please mail the completed form to:

If you have questions, please call me at: () .

NOTE: This form has been supplied by the State agency for use by citizens. While information on this form may be reviewed by the agency, the use of the form does NOT constitute an official inquiry. Completion of this form is optional.

Appendix IV. Links for Additional Information

For more information about benzene and its health effects:

- CDC. Frequently Asked Questions about Benzene. <http://www.cdc.gov/nceh/clusters/fallon/benzenefaq.htm>.
- ATSDR. Public Health Statement for Benzene, Sept. 2005 <http://www.atsdr.cdc.gov/toxprofiles/phs3.html>.

For information about Washington regulations on air and water quality:

- Washington State Department of Ecology. Index of Laws. <http://www.ecy.wa.gov/laws-rules/ecyrcw.html>.
- Washington State Department of Ecology. Index of Rules. <http://www.ecy.wa.gov/laws-rules/ecywac.html>.

For information about Oregon regulations on air and water quality (Note- these regulations do not apply to Emerald Kalama Chemical, located in Washington State):

- The Oregon Revised Statutes (ORS) under which the Oregon Department of Environmental Quality (ODEQ) operates <http://www.deq.state.or.us/regulations/statutes.htm>
- Oregon Administrative Rules (OAR) pertaining to all ODEQ programs (see Divisions 41-82 for water-related rules; 200-268 for air-related rules) <http://www.deq.state.or.us/regulations/rules.htm>

For information about regulations that apply to Emerald Kalama Chemical (Note- this list is not exhaustive):

- The Federal Clean Air Act, <http://epa.gov/air/caa/peg/>.
- The Washington State Clean Air Act (RCW 70.94), <http://apps.leg.wa.gov/RCW/default.aspx?cite=70.94>.
- Washington State Department of Ecology. Air Quality. <http://www.ecy.wa.gov/programs/air/airhome.html>
- Emerald's air emissions permit and permit background document (Statement of Basis) can be downloaded at <http://www.swcleanair.org/PermitsTitleV.html>.
- Regulations from the Southwest Clean Air Agency are available at <http://www.swcleanair.org/regs/reg400.pdf>.