Parsons, Susan

Subject: FW: LU 14-218444-HR-EN Testimony of Katherin Kirkpatrick 2015-05-28 -- Email 3 of 11

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Susan Parsons
Assistant Council Clerk

From: Kate & Chris [mailto:samsa@pacifier.com]
Sent: Thursday, May 28, 2015 2:11 AM
To: Council Clerk – Testimony
Cc: Hales, Mayor; Commissioner Fritz; Commissioner Fish; Commissioner Novick; Commissioner Saltzman
Subject: LU 14-218444-HR-EN Testimony of Katherin Kirkpatrick 2015-05-28 -- Email 3 of 11

Dear Karla:
Please accept this third portion of my attached testimony for submission into the record of LU 14-218444-HR-EN on the Mt. Tabor Reservoirs Decommissioning, scheduled for hearing this afternoon at 2:00 p.m.
This batch is devoted solely to Exhibit L in support of my legal brief. Please enter into the record:
This link is supplied as Exhibit L to the Testimony of Katherin Kirkpatrick in LU 14-218444-HR-EN dated 5/28/2015; it leads to a free PDF download of the 296-page National Academies Press definitive publication "Risk Assessment of Radon in Drinking Water," published in 1999, which is cited in my legal brief. The link is:

http://www.nap.edu/catalog/6287/risk-assessment-of-radon-in-drinking-water
Kindly send me an electronic receipt when this document/link is entered.

Thank you,
Katherin Kirkpatrick
1319 SE 53rd Avenue
Portland, OR 97215
samsa@pacifier.com

Parsons, Susan

From: Kate & Chris <samsa@pacifier.com>
Sent: Thursday, May 28, 2015 2:16 AM
To: Council Clerk – Testimony
Cc: Hales, Mayor; Commissioner Fritz; Commissioner Fish; Commissioner Novick; Commissioner Saltzman
Subject: LU 14-218444-HR-EN Testimony of Katherin Kirkpatrick 2015-05-28 -- Email 4 of 11
Attachments: LU 14-218444-HR-EN Testimony of Katherin Kirkpatrick 2015-05-28 -- Exhibit M.pdf; LU 14-218444-HR-EN Testimony of Katherin Kirkpatrick 2015-05-28 -- Exhibit N.pdf; LU 14-218444-HR-EN Testimony of Katherin Kirkpatrick 2015-05-28 -- Exhibit O.pdf

Dear Karla:
Please accept my attached testimony for submission into the record of LU 14-218444-HR-EN on the Mt. Tabor Reservoirs Decommissioning, scheduled for hearing this afternoon at 2:00 p.m.
This batch consists of the Exhibits M through O in support of my legal brief. Kindly send me an electronic receipt when the documents are entered.

Thank you,
Katherin Kirkpatrick
1319 SE 53rd Avenue
Portland, OR 97215
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SCIENTIFIC and PUBLIC HEALTH BASIS to

RETAIN OPEN RESERVOIR WATER SYSTEM

for the CITY OF PORTLAND, OREGON

****

Request for Waiver from the U.S. EPA Long Term 2

Enhanced Surface Water Treatment Rule (LT2)

Regarding Covered Reservoirs

"Science will determine the ultimate outcome."
–EPA Administrator Lisa Jackson, August 2011
letter to U.S. Sen. Charles E. Schumer (D-NY) acknowledging
his request for an "LT2 Rule" reservoir waiver

"We're just trying to get at the public health impacts and if there's a better way to do that we'll be wide open to it."
–EPA Administrator Gina McCarthy, April 2014
Congressional testimony response to U.S. Rep. Eliot Engel's (D-NY)
question about the status of New York City's reservoir waiver request

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By Scott Fernandez
M.Sc. Biology / microbiology & water chemistry

May 2014

www.bullrunwaiver.org | bullrunwaiver.org@gmail.com

Preface

Scientific accuracy is of utmost concern when determining the best system for treatment and storage of Portland's water supply. However in recent years public officials and some of the media have framed decisions affecting the city's water policy around opinion and expediency instead of sound science and engineering.

Far from being merely an "aesthetic" issue affecting Mt. Tabor and Washington parks, open reservoirs are of critical importance to drinking water quality and public health for every Portland resident. This paper addresses the urgent need to clear up confusion surrounding the vital public health component of open reservoirs for maintaining Portland's record of exceptional municipal water quality and will show that:

- City Council's push to cover Portland's open reservoirs – before the Environmental Protection Agency (EPA) completes its "LT2 Rule" review and waiver process in 2016 – will create more public health problems for residents than it solves.

- Unlike in other cities, Portland's water supply from the federally protected Bull Run watershed is not at-risk from sewage based microorganisms such as "Cryptosporidium" – which the EPA's blanket "LT2 Rule" is meant to address.

- Covering Portland's reservoirs will carry risk from enabling toxic and carcinogenic contaminants such as radon, chloroform and other disinfection chemical byproducts to accrue in the water supply in addition to nitrification, lack of oxygenation, and absence of sunlight.

- There are demonstrable public health benefits of open reservoirs due to efficient atmospheric volatilization, chemical biodegradation, and broad-spectrum sunlight saturation that reduce and eliminate contaminants. Portland's open reservoirs can already meet EPA microbial standard and are the most important water quality "barrier" in the Bull Run system. They block contaminants from reaching the downstream distribution system using the scientific principles of chemistry, physics, and microbiology.

- Public officials must preserve Portland's open reservoirs as an essential component of the water system to maintain municipal water quality and protect public health. The basis and merits for communicating effectively with EPA on this matter simply requires coordinated and committed support from Portland City Council, the Oregon Health Authority, Gov. Kitzhaber, and Oregon's Congressional delegation.

Contents

I. EXECUTIVE SUMMARY

The letter and spirit of the EPA drinking water regulation is to provide equal or greater public health benefits. ***A decade of experience under the 1986 EPA Safe Drinking Water Act (SDWA) revealed several areas where responsible, science-based flexibilities and a better prioritization of effort could improve protection of public health compared to the one-size-fits-all approach of the 1986 statute.*** **(EPA 1996)** It will be shown that the chemistry, physics, and microbiology principles of open reservoirs of Mt. Tabor Park and Washington Park will continue to provide safe healthy drinking water for generations to come. The reliable and scientifically-sound approach to unwanted environmental chemicals will be achieved through open reservoirs. Covered reservoirs degrade drinking water quality and increase public health risk through toxic and carcinogenic chemicals progression.

In the past 30 years the Safe Drinking Water Act has been highly effective in protecting public health and has also evolved to respond to new and emerging threats to safe drinking water. Disinfection of drinking water is one of the major public health advances of the 20th Century. One hundred years ago typhoid and cholera epidemics were common throughout American cities; disinfection from chlorine was a major factor in reducing these epidemics.

EPA's "Long Term 2 Enhanced Surface Water Treatment Rule" (LT2) addresses microorganisms which is the primary reason Portland deserves a waiver from the regulation. Because the Bull Run watershed does not have exposure to industrial, agricultural, or municipal sewage, Cryptosporidium, viruses, and other microorganisms become a non-issue in regard to public health risk for water users. In addition, sunlight is a powerful source of natural broad spectrum ultraviolet light (UV) that reduces infectivity of microorganisms. Portland's open reservoirs already meet EPA microbiological standards.

There have been no positives for Cryptosporidium, Giardia, and viral microorganisms in sampling of Portland open reservoir drinking water throughout the 1990's and beyond; in addition to a recent year-long study (AWWA RF 3021) in which the sampling methodologies used were more rigorous in assessment. Furthermore EPA assertions for the basis of LT2 nationwide proved to be incorrect. Cryptosporidium has not had the negative public health impact EPA projected. Scientists have not seen the deaths, widespread outbreaks, or endemic disease identified from Cryptosporidium drinking water public health data around the U.S.

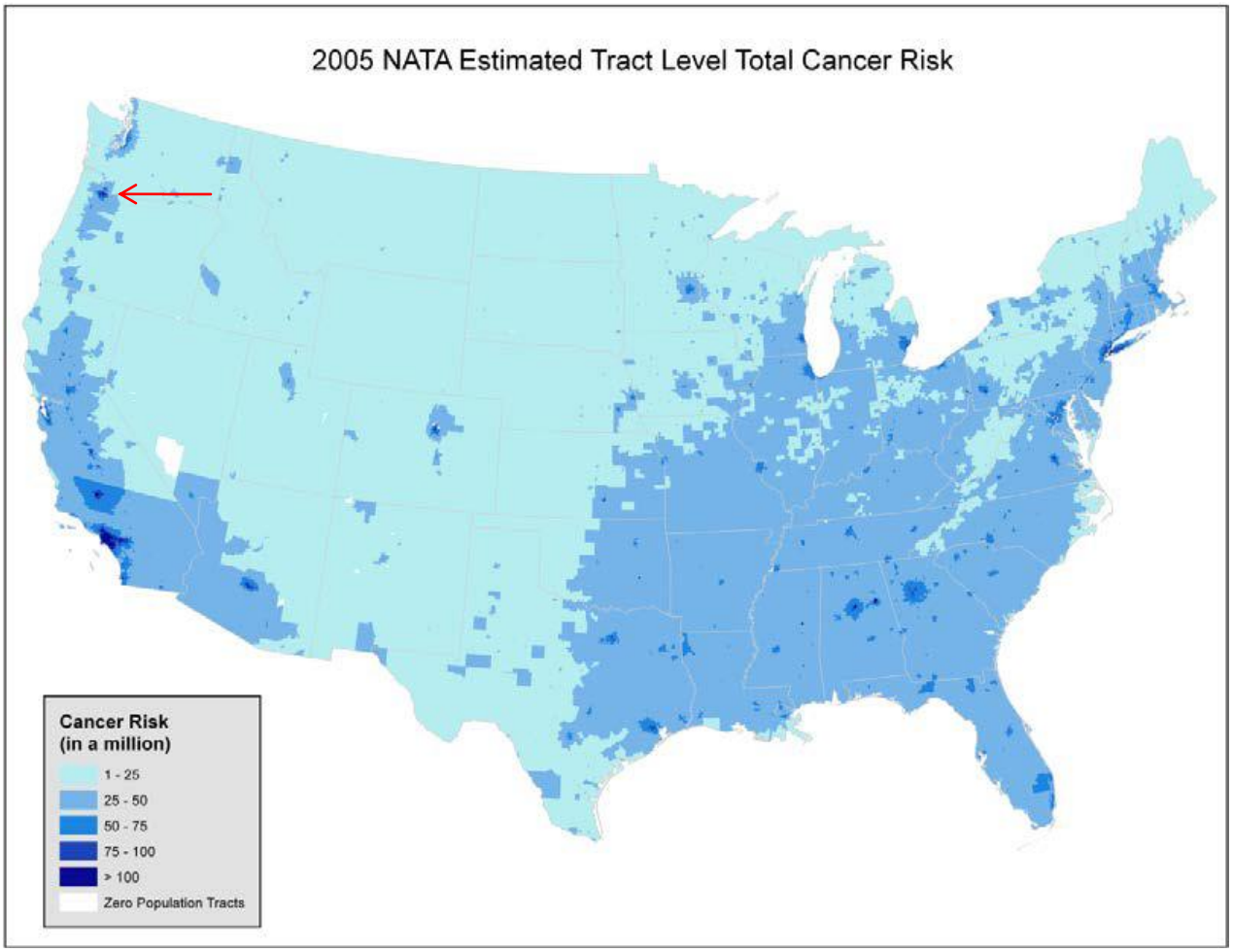
Second, open reservoirs allow for efficient ventilation of toxic gases such as radon.

Third, over the years scientists have learned that chlorine and chloramine can generate many unwanted disinfection byproducts. Open reservoirs address the issue of effectively managing chemical disinfection byproducts using a natural ecosystem, thus providing safer water quality in complete contrast to that of covered reservoirs. Open reservoirs provide safe drinking water by acting as a barrier to toxic and carcinogenic chemicals along with disinfection byproducts by vaporizing, microbial biodegradation, or sunlight break down of molecules.

While critical to maintaining Portland's healthy drinking water system, these scientifically supported public health benefits of open reservoirs have not been recognized by Portland City

Council and the Portland Water Bureau. These open reservoir public health benefits must be recognized as the basis for responsible management of Portland's existing high-quality water treatment and delivery system.

An additional note is that Portland has significant air quality problems. Thirty-five (35) Portland schools were ranked in the bottom 5% in the nation's high toxic hot spots from airborne metals and gases. Covering the reservoirs will not allow the chemical disinfection byproducts and other toxic and carcinogenic gases to vaporize efficiently before entering the water distribution system. These toxic and carcinogenic chemicals will end up being released from drinking water into homes, schools, and workplaces, thus adding to the already present and problematic environmental air public health burden.



Portland ranks in the highest percentile of U.S. cities for toxic air quality cancer risk. Residents, especially children with their lower body weight, are at highest risk from the additional toxic burden of degraded water quality. (See Refs. 1-5)

II. GLOSSARY

AWWA RF – American Water Works Association Research Foundation

CSSW – Columbia South Shore Wellfield located on the Columbia River between the Portland airport and Blue Lake areas. It is the source of our drinking water containing radioactive radon 222.

DBP – Disinfection By-product

pCi – pico Curie- measurement of radioactive material

EPA – United States Environmental Protection Agency

IARC – International Agency for Research on Cancer

LT2 – EPA Long Term 2 Enhanced Surface Water Treatment Rule

NAS – National Academy of Sciences

NDMA – Nitrosodimethylamine, a drinking water disinfectant byproduct that is broken down by sunlight in open reservoirs

NOM – Natural Organic Material, reaction with chlorine and chloramines

OHA – Oregon Health Authority

PAEC – Potential Alpha Energy Concentration

Precautionary Principle – Adopted by Portland City Council in 2006. "When an activity raises threats of harm to the environment or human health, precautionary measures should be taken even if some cause and effect relationships are not fully established scientifically." See "Toxics Reduction Strategy: A plan for minimizing use of toxic substances of concern in government operations by using the Precautionary Principle" (http://www.sehn.org/pdf/portland.pdf)

PWB – Portland Water Bureau

Radioactive Chemicals from Columbia South Shore Wellfield –
Bi- bismuth 214, 210 β, Γ
Pb- lead 214, 210, 206 β, Γ
Po- polonium 218, 214, 210 α
Rn- radon 222 α, Γ
(Symbol Key: α-alpha / β-beta / Γ-gamma – forms of radioactive particles)

S2DBP – Stage 2 Disinfection and Disinfectant Byproduct Rule

SDWA – EPA Safe Drinking Water Act

USGS – United States Geological Survey

WHO – World Health Organization

III. INTRODUCTION

Citizens of Portland have been asking City Council to formally request a waiver from the EPA "Long Term 2 Enhanced Surface Water Treatment Rule" regulation for over a decade. We are not alone in requesting this waiver. The City of New York, the New York State Department of Health, and the entire New York Congressional delegation are all requesting a similar waiver for their Hillview open reservoir.(Ref. 6) Portland City Council needs to join the citizens of Portland in pursuit of a scientifically supported EPA open reservoir waiver of the "LT2 Rule."

This paper will review, identify, and demonstrate the superior public health benefits of the open reservoirs at Mt. Tabor Park and Washington Park that covered reservoirs cannot provide. These public health benefits were known over 100 years ago (see sidebar at right). Misinformation presented by the Portland Water Bureau will also be scientifically corrected.

Portland has had safe and healthy drinking water for over 100 years because federally protected Bull Run and the open reservoirs have been the foundation of the multiple-barrier approach to public health. This multiple-barrier approach allows Portland to already meet and exceed EPA regulated contaminant standards. Microbial contaminants have traditionally received more attention from a public health standpoint. Bull Run has no sewage exposures so microorganisms are principally a non-issue. However in recent years there has been a growing concern regarding chemical contaminants present in drinking water that affect public health.

The fundamental principles of sunlight disinfection are well-established. Esteemed epidemiologist Milton J. Rosenau wrote in 1902:

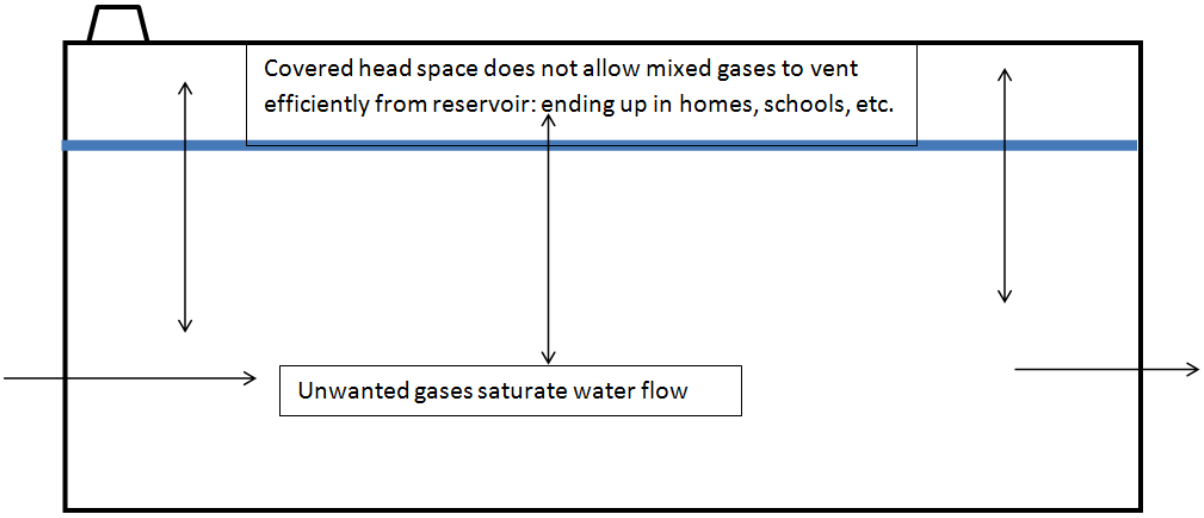
"Sunlight (direct) is an active germicide. It destroys spores as well as bacteria. The importance of the sun's rays in destroying or preventing the development or growth of microorganisms in nature cannot be overestimated. Even diffused light retards the growth and development of microorganisms, and if strong enough may finally kill them. In water or clear solutions it penetrates some distance. The importance of oxygen in the influence of light upon bacteria is emphasized. Bacteria in light, in the presence of oxygen and water, cause a production of hydrogen peroxide which is well known to have strong disinfection powers."

--Milton J. Rosenau, M.D., was commissioned as an assistant surgeon in the United States Marine Hospital Service (now the United States Public Health Service) in 1890. In 1899, he was appointed Director of the Hygienic Laboratory of that service. He was instrumental in 1922 in the establishment of the Harvard University School of Public Health and, in 1940, became first dean of the School of Public Health at the University of North Carolina.

As a community we have challenged the applicability of EPA's LT2 Rule and Cryptosporidium in Portland's drinking water system as a public health problem that does not exist because we don't have agricultural, industrial, or municipal sewage exposures in our Bull Run source water. Cryptosporidium has never been found in our open drinking water reservoirs. Equally important for continued public health, we need to include a discussion of the EPA Stage 2 Disinfection and Disinfectant Byproducts Rule (S2DBP) relating to disinfection byproducts and other unwanted chemicals that our open reservoirs remove from our drinking water. Utilizing the applied natural laws of microbiology, chemistry, and physics we show that our open reservoirs in Mt. Tabor Park and Washington Park provide safe and healthy drinking water superior to water in covered reservoirs. Direct sunlight, oxygenation, an aerobic microbial ecosystem, and the large surface areas of open-air reservoirs allow break down and venting of harmful gaseous chemicals reflecting the functioning of a healthy water system.

A. Adverse effects and public health problems of covered reservoirs

Covered reservoirs cannot effectively remove toxic and carcinogenic gases and other chemicals. Gases such as radon and chloroform remain saturated in the drinking water and they cannot efficiently escape. Because covering the reservoirs creates a drinking water system closed to sunlight and poorly exposed to the atmosphere, these toxic and carcinogenic gases then end up venting in our schools, homes, and businesses. Without sunlight carcinogenic chemicals such as NDMA (Nitrosodimethylamine) are not broken down and bacterial metabolic processes promoting toxic nitrification byproducts continue on unimpeded.



Two (2) small air vents opening combine to ~75 sq. ft. on a ~217,000 sq. ft. ~5-acre reservoir roof such as PWB 9-6-2013 Powell Butte 2. Small vent allows water to move through covered reservoir – otherwise a vacuum would be created and water flow would be restricted. Small air vents are inefficient in removing toxic and carcinogenic gases. The history of U.S. covered reservoirs also documents bird entry through small air vents to roost and contaminate water resulting in human death.

B. Public health benefits of open reservoirs

The Portland open reservoirs provide safe and healthy drinking water by naturally engaging in removal of toxic and carcinogenic disinfection byproducts and other chemicals. It is important to remove these environmental chemical exposures because they are the sources of great health risks, such as lung and other cancers from radon gas and radon progeny of which "there is no safe level of radon exposure." (US EPA) (Refs. 7-14)

Affected organ systems from chloroform include: Cardiovascular (heart and blood vessels); Hepatic (liver); Neurological (nervous system); Renal (urinary system or kidneys); Reproductive (producing children); Developmental (effects during periods when organs are developing). (Refs. 15-16)

Nitrosodimethylamine (NDMA), a drinking water disinfectant byproduct that is broken down by sunlight in open reservoirs, has been classified by the International Agency for Research on Cancer (IARC) as a probable carcinogen for humans (liver cancer). The mechanism by which NDMA produces cancer is well understood to involve biotransformation by liver microsomal enzymes generating the methyldiazonium ion. This reactive metabolite forms DNA adducts, with most evidence pointing to O6-methylguanine as the likely proximal carcinogenic agent. (Ref. 17)

Visionary leaders fought for our Bull Run water source over 100 years ago. **Bull Run source water is federally protected from human entry that is not exposed to industrial, agricultural, or municipal activities.** Portland is fortunate to have very few chemicals in our drinking water. Open reservoirs are efficient in removing the chemicals we don't want to drink or have in our environment. We want chemicals removed because EPA long-term drinking water standards are based only on adults, not considering the extended exposures that increase health risks for younger ages. EPA long-term chemical exposure risk levels are based on 70 kg / +154 lb. adults, not children. (Ref. 18)

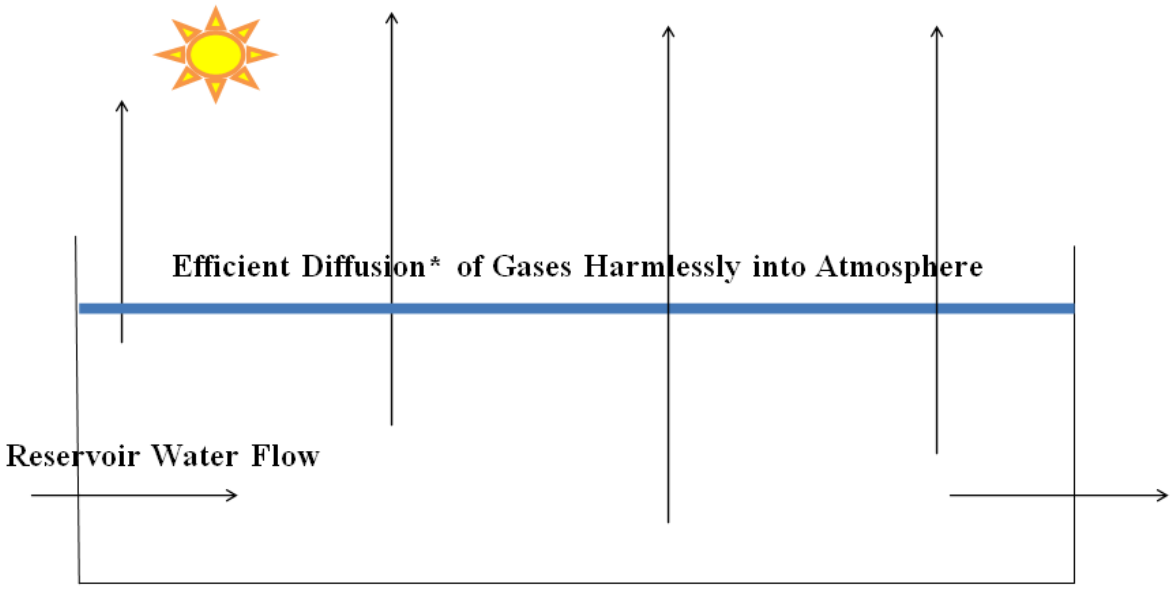
Portland's open reservoirs operate as unique barriers and provide superior efficiencies impeding the movement of toxic and carcinogenic gases and chemicals into the distribution system by utilizing the following scientific principles:

- Atmospheric volatilization of toxic, carcinogenic gases – Radon
- Atmospheric volatilization, Trihalomethanes, (THM) – Chloroform
- Aerobic microbial biodegradation – Haloacetic acids, (HAA5), Stage 2 DBP
- Natural oxygenation – Increases presence of helpful aerobic microorganisms
- Aerobic bacteria – 18x increased oxidative activity v. anaerobic bacteria
- Direct sunlight – Degrades carcinogenic N-nitrosodimethylamine (NDMA)
- Direct sunlight – Inhibits nitrification bacteria and the buildup of nitrites, nitrates and nitrosamines from ammonia disinfection
- Direct sunlight – Oxygen/photons, natural disinfection from oxides

Removing Portland's open reservoirs raises the threat to public health from increased exposure to toxic and carcinogenic chemicals. (Ref. 19)

Portland water users benefit from the environmentally sustainable and effective open air reservoir processes that remove or impede movement of toxic and carcinogenic gases and chemicals from our drinking water system. The "Precautionary Principle" (see Glossary) – the public health policy adopted by Portland City Council in 2006 – applies directly to decisions affecting Portland's water reservoirs. Open reservoirs provide an efficient method of eliminating unwanted drinking water gases such as radon-222 and chloroform through the process of *atmospheric volatilization*. Open reservoirs provide a natural, cost effective, and healthy solution to a recognized public health problem.

Reasons Open Reservoirs Function So Well: Open reservoirs act as a natural barrier to toxic and carcinogenic chemicals, harmlessly releasing them before they enter the drinking water distribution system.



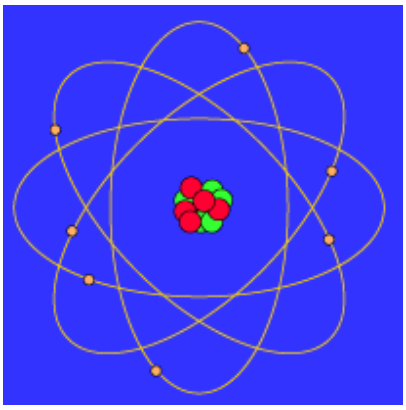
Highly efficient open reservoir chemical movement from water (high gas concentration) to air (low gas concentration) provides the desired natural and harmless removal of chloroform and radon gases from open reservoirs. Open reservoirs keep toxic gases out of water used in homes, schools, and workplaces.

Mt. Tabor Reservoir 6. Open reservoir water oxygenation from fountain and waterfall aeration also removes toxic and carcinogenic gases such as radon and chloroform. Gases escape efficiently through diffusion – the movement of particles from high concentration to lower concentration. Diffusion is enhanced by wind and natural convection in water wave action.

Mt. Tabor Reservoir 5. Open reservoir drinking water inlet: waterfall agitating action aerates water providing oxygen, promotes water movement, while removing unwanted gases. Open reservoir sunlight also provides a public health barrier, using a natural, sustainable, gravity fed carbon-free process delivering safe and healthy water.

IV. FINDINGS: PROBLEMS VS. BENEFITS

A. Radon – Concentration vs. Dissipation



Covered reservoirs are inefficient in allowing escape of radioactive radon and other toxic gases. Open reservoir atmospheric volatilization provides efficient escape of toxic and carcinogenic gases.

Portland's open reservoirs can efficiently vaporize /diffuse radioactive radon-222 gas to the atmosphere using natural aeration. Due to a high Henry's Law constant, radon can leave water on contact with air when agitated. Radioactive radon gas is a serious and widely underestimated health risk that is naturally occurring in soil and groundwater. Portland's drinking water radon gas originates from the Columbia South Shore Well field. Because it is not chemically reactive with most materials it will move freely as a gas and can move substantial distances from its point of origin. Ingestion of radon through drinking water can also contribute to internal organ illness such as stomach cancer once it is absorbed into the blood stream.

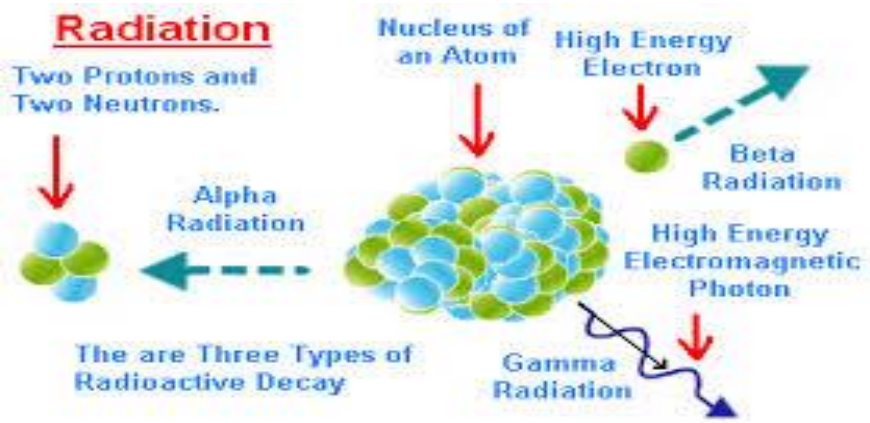
EPA acknowledges there is ***no safe level of radon exposure***, regardless of the source, air or water. The cancer risk of radon in water is higher than cancer risk from any other drinking water contaminant. Radon from drinking water can end up in the air of buildings in several different ways: **substantial radioactive water aerosols** can be created from showering, clothes washing, dishwashing, flushing toilets, and bathing.

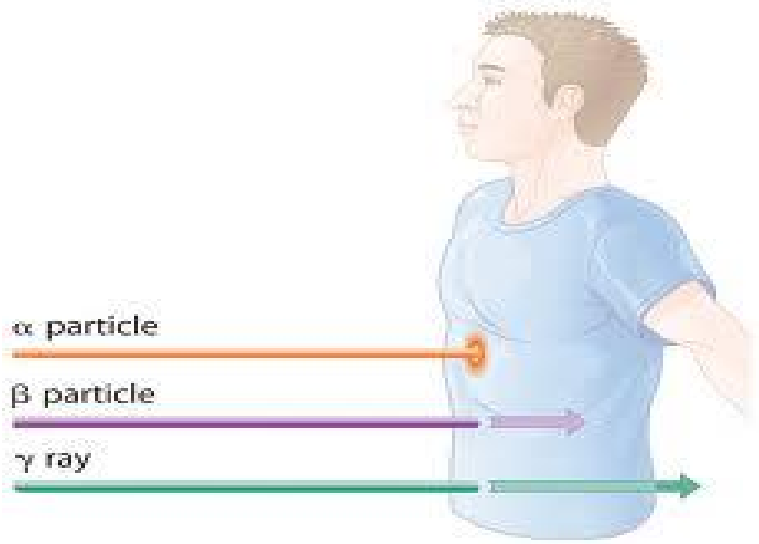
Radon is the second leading cause of lung cancer and contributes to +20,000 deaths each year. Radioactive alpha emitting radon gas also decays into radioactive atoms such as daughter progeny *polonium, lead*, and *bismuth.* These atoms can get trapped in the lungs when you breathe also emitting alpha, beta, and gamma particles continuing to release bursts of energy-damaging cells. This energy can genetically damage lung, blood, and other tissues' DNA. Over time these atomic exposures can lead to lung and other types of cancer. Because ***children have a much higher respiration rate than adults more radon can be inhaled***. EPA danger levels **underestimate** increased risk of radioactive particle inhalation and public health impact expectation in children.

Radon-222 Decay Process contains radioactive isotopes emitting all 3 types: Alpha, Beta, and Gamma particles

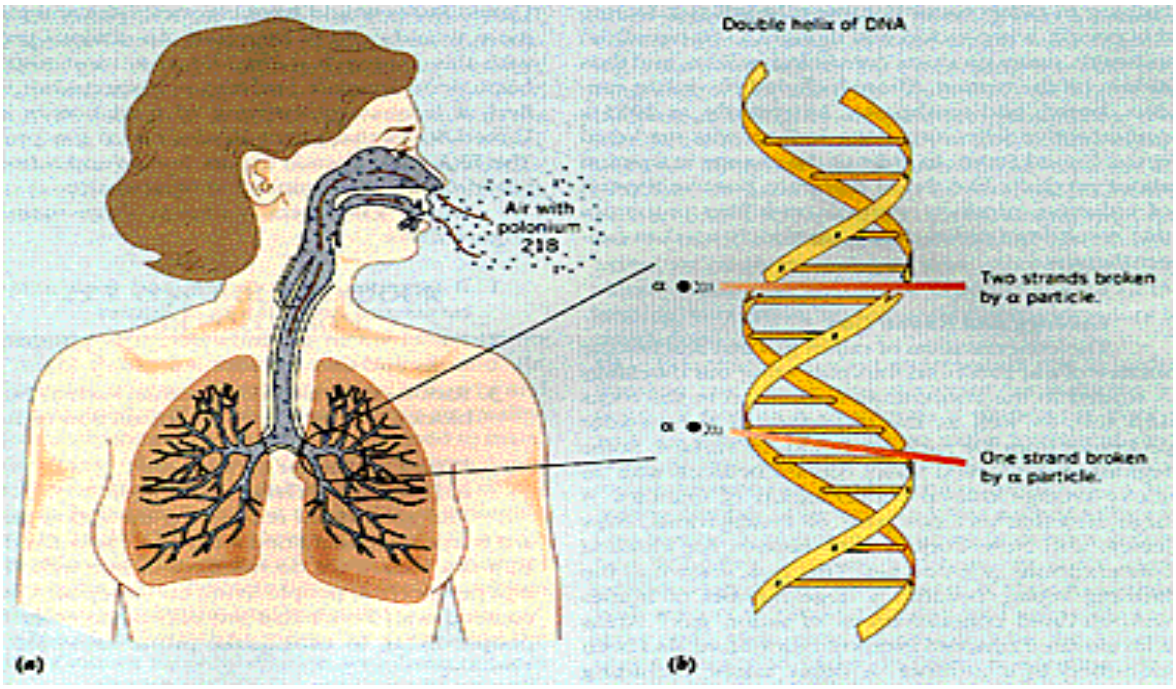
- Radon 222 – alpha particles and few gamma particles
- Polonium 218 – alpha decay
- Lead 214 – beta particles and gamma particles
- Bismuth 214 – beta particles and gamma particles
- Polonium 214 – alpha particles and few gamma particles
- Lead 210 – 22-year half-life so first 5 are basis for effect (Ref. 20)

Radon Isotopes And Decay Particles – Three (3) types of radioactive radon decay particle energy and negative impact on health:

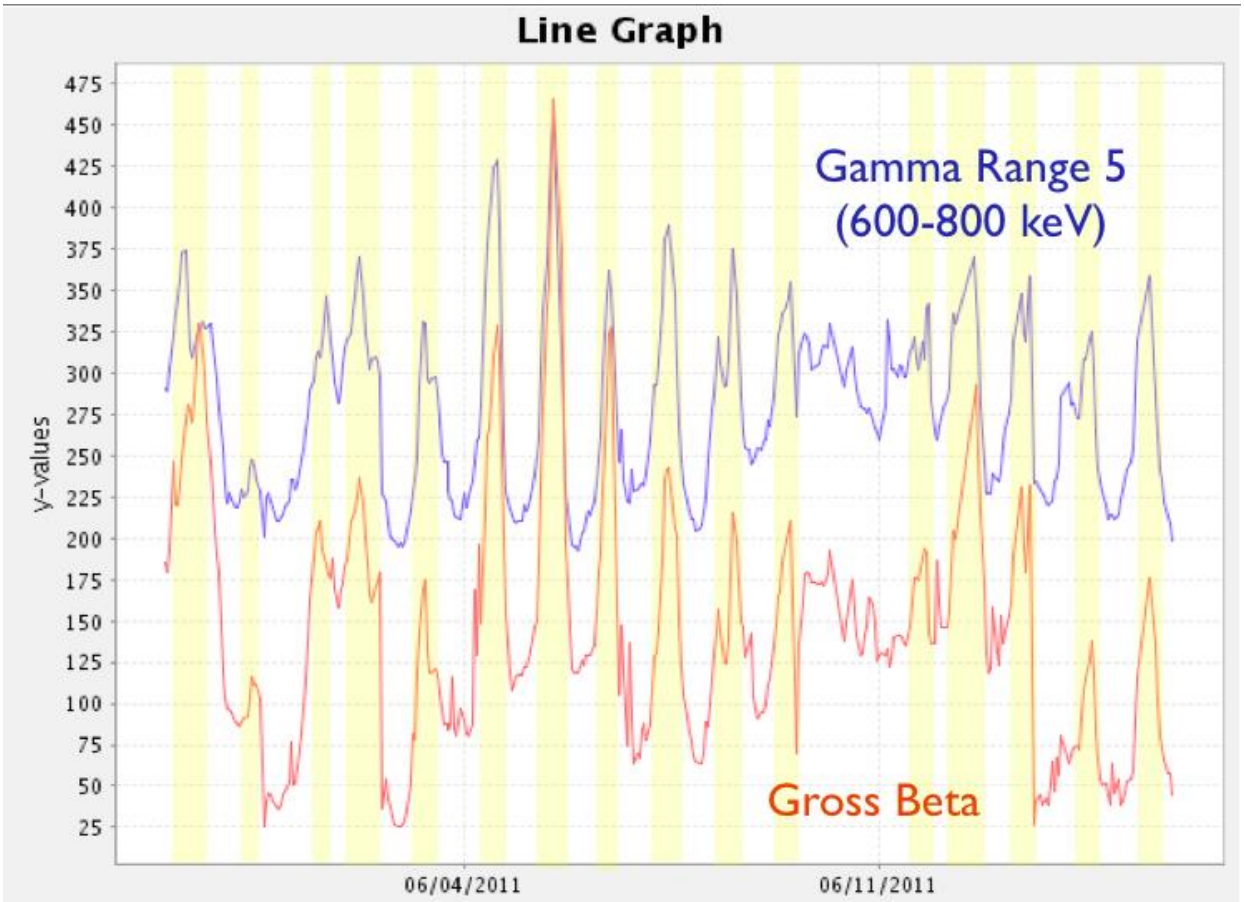




All radon decay particles – alpha, beta and gamma radioactive energy levels – can initiate negative health effects. Alpha particles, i.e., polonium, can penetrate cellular DNA promoting tissue damage and cancers. Beta and gamma particles have *much* higher energy levels that promote greater tissue damage resulting in *increased* health risks.



Radon- alpha particles penetrating cell DNA ending in tissue damage and cancers



Concurrent radioactive beta β and gamma Γ activity from radon 222 progeny

Data from the Oregon Department of Health and Human Services show more than 25% of the homes tested in Multnomah County exceed the soil origin ***indoor air*** action level of 4pCi / liter due to geological conditions. The Portland Water Bureau wrongly downplays the high public health risk of ***any*** level of radon in our drinking water by not acknowledging subsequent inhalation.

In a closed drinking water system without open reservoirs the risk of aerosolized radon inhalation from drinking water increases substantially. ***Any*** level of radon exposure from water would contribute to the total cumulative effect of inhalation risk associated with radioactive indoor air. A 1000 sq. foot house with a 4 pCi / of radon has nearly 2 million atoms in the air decaying every minute in *addition* to the decay atoms of the radioactive progeny such as polonium, etc. (USGS)

One single atom / alpha/ beta/ gamma particle can begin the cancer process when inhaled. Homes in the zip codes 97210- 97213 in north and northeast Portland are especially at risk, and there are many other areas in the city. ***Open air reservoirs provide the most efficient and sustainable radioactive radon risk mitigation process through volatilization***. The open reservoirs use the laws of chemistry and physics; utilizing diffusion up the water column, water agitation at the inlet, wind action promoting diffusion, leading to natural and harmless volatilization free of electricity. (EPA radon map)

The City of Portland Columbia South Shore Well fields (CSSW) produce radon 222 in excess of 300 pCi /L, exceeding the EPA action level. The Portland Water Bureau will tell the community the radon levels are diluted to 10% during summer usage. However if we incur turbidity events excluding Bull Run water we will be using CSSW water with radon 222 gas exceeding recommended levels. This does not include the cancer causing radioactive progeny atoms such as bismuth, polonium, lead, etc., from radon 222 decay. (Ref. 21)

EPA and Drinking Water Radon
EPA does not regulate radon in drinking water. The health concern with radon in drinking water is also associated with everyday household uses that can transfer radon to indoor air throughout the house along with the many radioactive decay isotopes. Radon in water can be released into the air when water is used for showering, laundry, washing dishes, toilet use, and other household activities. Some researchers have estimated that 1 pCi /L of airborne radon will result from the normal use of a water supply containing 10,000 pCi /L. This number is only an average and ***subject to variation***. The amount of radon transferred from water to air is a function of:

- The waterborne radon level;
- The amount of water used;
- The type of water use activity, e.g. shower (high transfer) vs. running water in a sink (low transfer); and
- The water and air temperatures (as the temperature of the water increases, radon transfer increases).

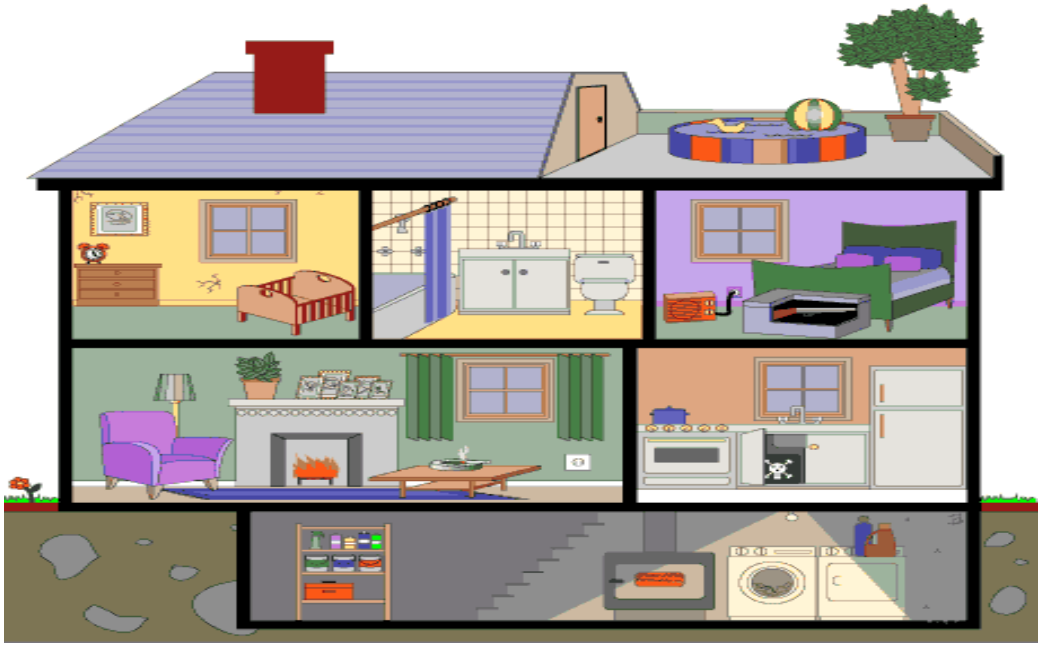
Because radon 222 is an unregulated EPA radioactive contaminant in drinking water, the Portland Water Bureau did not include it in our Water Quality Report in 2013. In past years we

have seen drinking water radon levels from the Columbia South Shore Well field above 350 pCi/L. The Portland Water Bureau continually yet incorrectly states that radon is a non-issue at these levels, yet EPA says "***there is no safe level of radon***". (EPA)

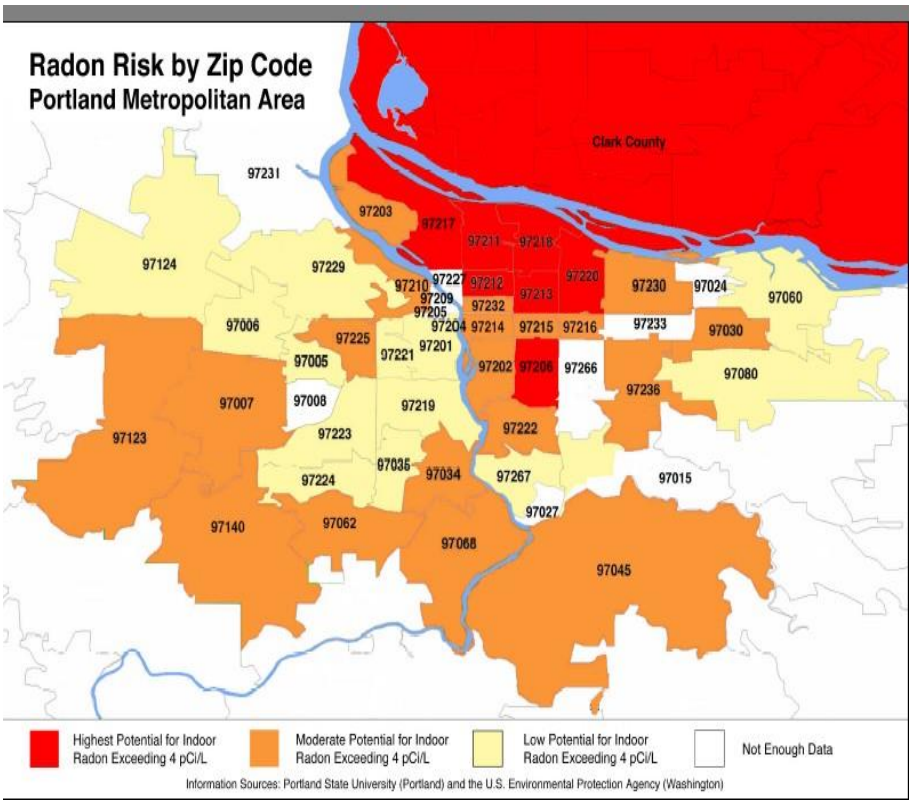
Even at small levels of radon, the cumulative effect of continuous household multiple water uses profoundly impacts the ultimate level of radon and daughter radioactive particles accumulating daily and weekly. Radon needs to be removed from our drinking water even if EPA has not completed a final radon drinking water rule.

National Academy of Sciences (NAS) conclusions are assumptions based on estimates that underestimate the overall public health effect. If the NAS study was acceptable as scientific fact, why was it not adopted by EPA as the standard for the final EPA Radon regulation? EPA says radon is the most cancer causing contaminant, yet there is **no** EPA Radon drinking water regulation.

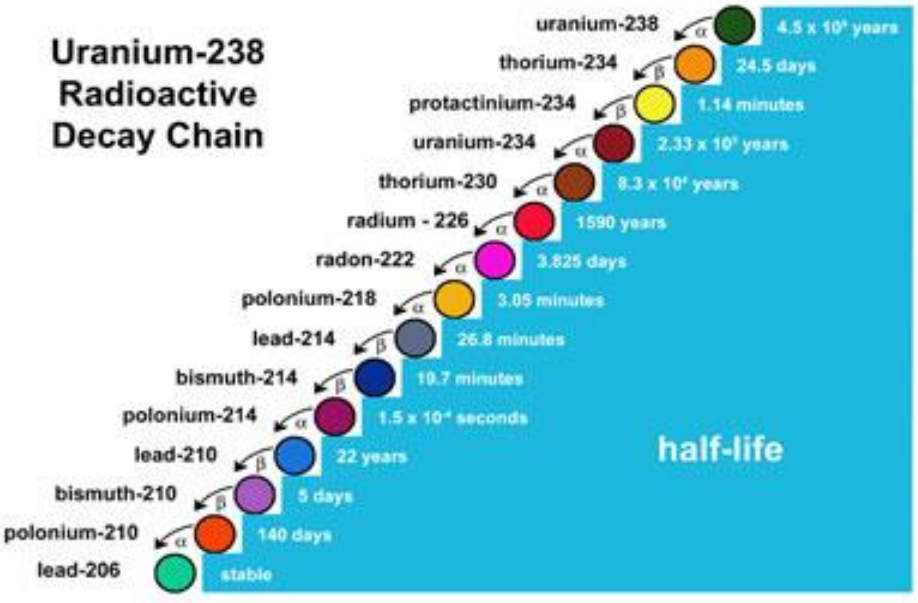
Open reservoirs will harmlessly and efficiently vent the radon and other gases into the atmosphere. Covered reservoirs are not designed for such activity of radon removal. So we begin to see what the effect of even conservatively estimated exposures will present from our closed water system and covered reservoirs.



Radon and other drinking water gases can enter your entire home, school, and workplace through the shower, toilet, washing machine, and faucets. Open reservoirs act as a barrier allowing gases to harmlessly vent into atmosphere before entering distribution system downstream.



Portland metropolitan radioactive radon-222 areas of risk. (US EPA)



Radon -222 is a gas with a half-life of about 4 days. However, the radon 222 decay products are isotopes of *solid elements* and will quickly attach themselves to molecules of water and other atmospheric gases. These, in turn, attach to dust particles. If inhaled, the decay products, whether attached to aerosol particles or 'unattached', will largely be deposited on the surface of the respiratory tract and, because of their short half-lives (↓half an hour), will begin to decay there.

Projection Estimate: Drinking Water Radon-222 Exposure in Closed System During Bull Run Turbidity Event

Radioactive decay process for radon-222 from Portland CSSW drinking water

–Radon-222 decays / 1000 sq. foot house with 4pCi radon = 2,000,000/min (USGS)

–In one hour there would be 120,000,000/hour radon 222 radioactive decays not including progeny.

–PWB CSSW >300 pCi / L radon x .0001 water transfer/air variable = .03 pCi /L (EPA)

1 pCi/L air = 500,000 radon decays/ minute

500,000 x .03 = 15,000 radon decays / minute

Decay time for daughter progeny

–Estimated radioactive decays in ~ one hour with continuous .03 pCi /L exposure

–Radon-222- 60 min. x 15,000 decay/min = 900,000 decay

–Polonium 218- 3minutes

–Lead 214- 29 minutes

–Bismuth 214- ~11 minute

–Polonium 214- <1 second

–Lead 210- 22 years

Estimated Household Impact from Continuous Decay of Radon 222 and Radioactive Decay Chain Progeny Over One-Hour Period

Minutes	RADON 222 α	POLONIUM 218 α	LEAD 214 β Γ	BISMUTH 214 β Γ	POLONIUM 214 α	LEAD 210
1	15kdirect >	15k				
2	15k	15k				
3	15k	15k 3 min >	15k			
4	15k	15k	15k			
5	15k	15k	15k			
6	15k	15k	15k			
7	15k	15k	15k			
8	15k	15k	15k			
9	15k	15k	15k			
10	15k	15k	15k			
11	15k	15k	15k			
12	15k	15k	15k			
13	15k	15k	15k			
14	15k	15k	15k			
15	15k	15k	15k			
16	15k	15k	15k			
17	15k	15k	15k			
18	15k	15k	15k			
19	15k	15k	15k			
20	15k	15k	15k			
21	15k	15k	15k			
22	15k	15k	15k			
23	15k	15k	15k			
24	15k	15k	15k			

25	15k	15k	15k			
26	15k	15k	15k			
27	15k	15k	15k			
28	15k	15k	15k			
29	15k	15k	15k			
30	15k	15k	15k			
31	15k	15k	15k			
32	15k	15k	15K29min>	15k		
33	15k	15k	15k	15k		
34	15k	15k	15k	15k		
35	15k	15k	15k	15k		
36	15k	15k	15k	15k		
37	15k	15k	15k	15k		
38	15k	15k	15k	15k		
39	15k	15k	15k	15k		
40	15k	15k	15k	15k		
41	15k	15k	15k	15k		
42	15k	15k	15k	15k		
43	15k	15k	15k	15k11min>	15k x 60/min	Stable
44	15k	15k	15k	15k	15k	
45	15k	15k	15k	15k	15k	
46	15k	15k	15k	15k	15k	
47	15k	15k	15k	15k	15k	
48	15k	15k	15k	15k	15k	
49	15k	15k	15k	15k	15k	
50	15k	15k	15k	15k	15k	
51	15k	15k	15k	15k	15k	
52	15k	15k	15k	15k	15k	
53	15k	15k	15k	15k	15k	
54	15k	15k	15k	15k	15k	
55	15k	15k	15k	15k	15k	
56	15k	15k	15k	15k	15k	
57	15k	15k	15k	15k	15k	
58	15k	15k	15k	15k	15k	
59	15k	15k	15k	15k	15k	
60 min	15k	15k	15k	15k	15k	
	~ 900,000	~ 900,000	~ 855,000	~ 420,000	~ 15,200,000	Decays

Hour = ~18,275,000

Public Health Risks from Showering With Radon-Rich Water

- ~70% of radioactive radon 222 gas is released in shower aerosol into household
- Percentage measurements of radioactive radon 222 gas becoming aerosol from shower heads at different water temperature
- Aerosol dynamics of radon in water before and after shower eventually decaying into radioactive daughter progeny

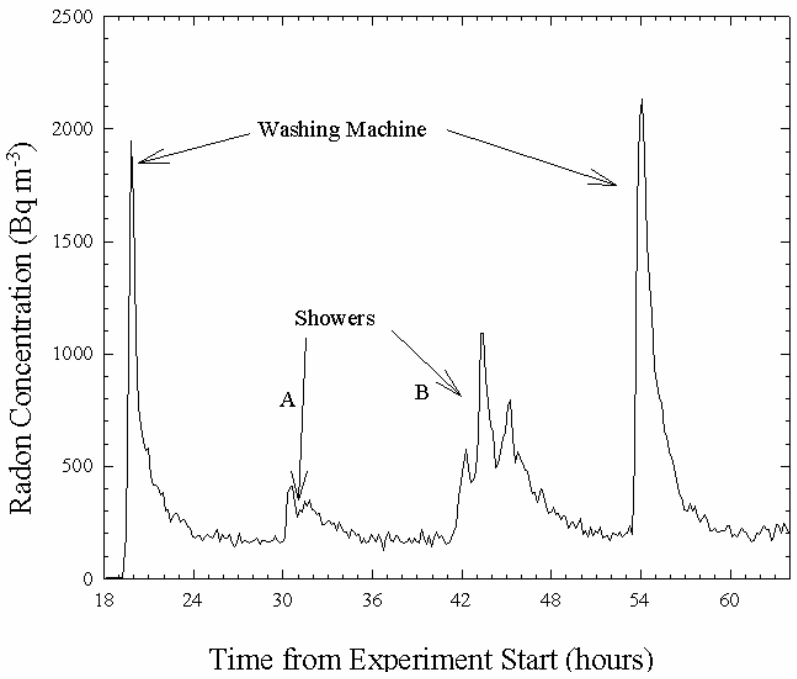
- One of the potentially important sources of short-term exposure is the emanation (discharge) of radon from water during showering and the subsequent in-growth of the radon decay products that continue to produce radioactive materials shower after shower.

TABLE 1. Laboratory Measured Emanation Fraction

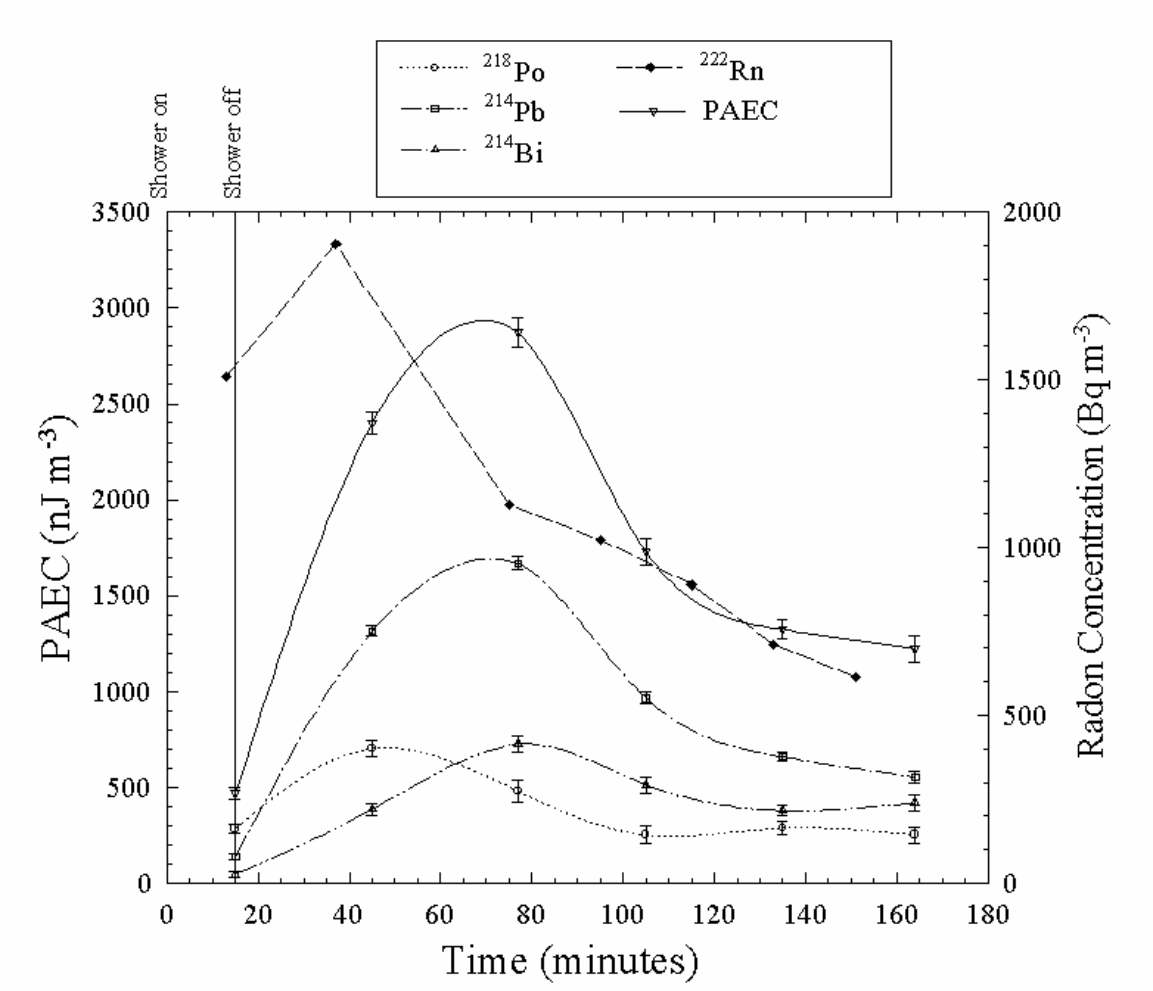
shower head	water temp (°C)	^{222}Rn in water concn before shower (kBq m^{-3})	^{222}Rn in water concn after shower (kBq m^{-3})	emanation (%)
head 1	32	374	108	71
	32	773	233	70
	21	375	124	67
	21	207	58	72
head 2	32	254	69	73

[a] Errors in these values are approximately ±2%.

Household – Aerosol of Radon 222 Gas Exposures from Everyday Activities

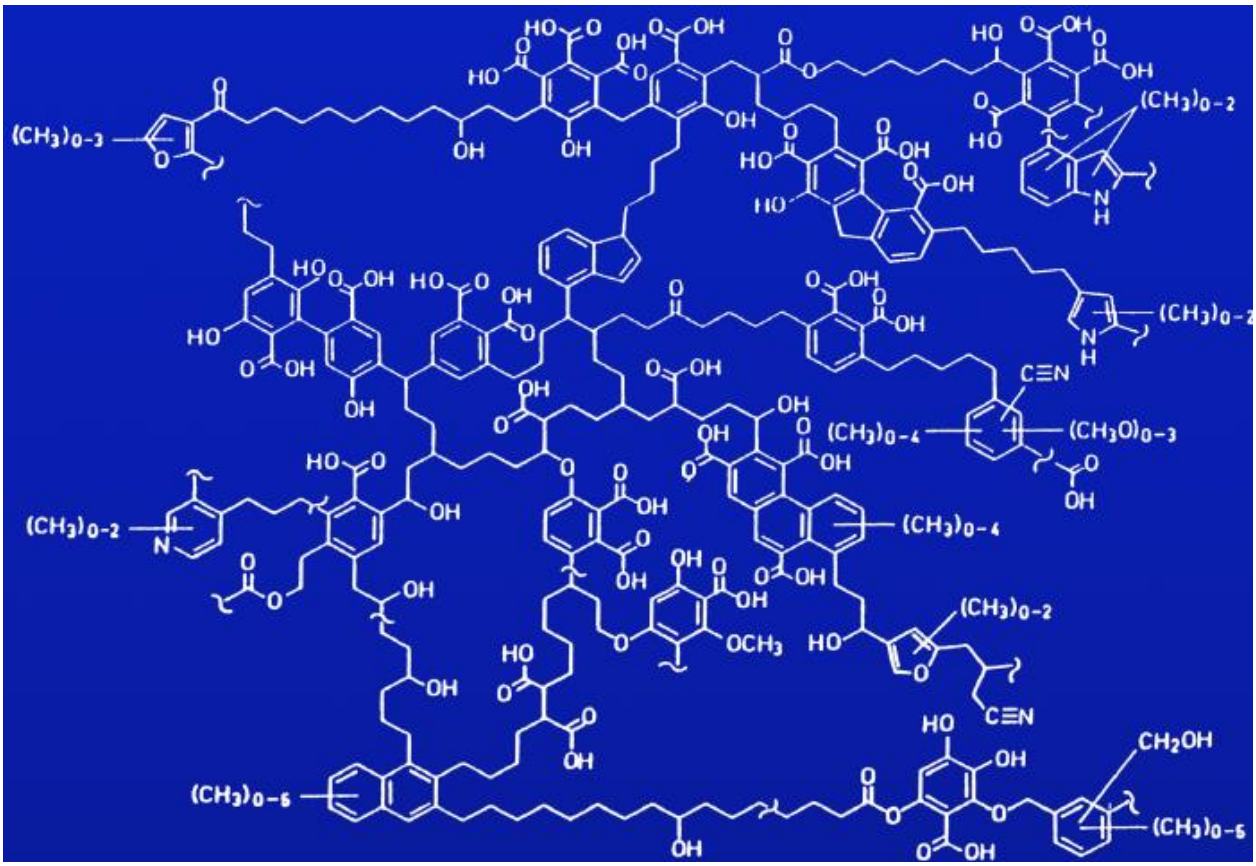


Spikes of radon 222 gas filled drinking water entering home from closed system that did not allow radioactive gas escape, ie., covered reservoirs.



Drinking water- aerosol of radioactive radon decay. Radioactive radon decay appeared later as expected establishing an aerosol presence over a long time period. (PAEC – potential alpha energy concentration) (Ref. 22)

B. Chloroform Formation – Concentration vs. Dissipation



Structure of acidic natural organic material (NOM) reacts with chlorine generating disinfection by-products such as chloroform. Chlorine alone added at Bull Run Headworks in the Bull Run Management Unit watershed for hours of disinfection exposure.

Elimination of Disinfection Byproducts Produced By Chlorine

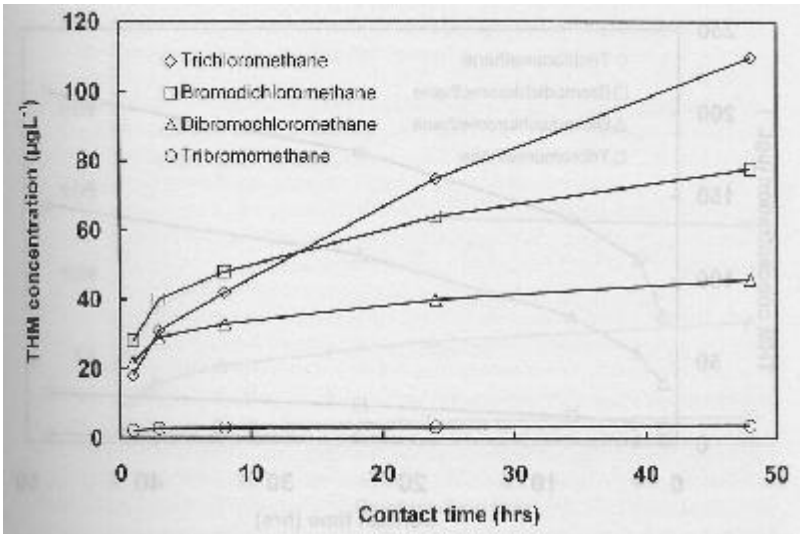
TTHM –Trihalomethanes

Trihalomethanes were among the first disinfection byproducts to be discovered in chlorinated water. These EPA regulated chemical substances are one of many types formed during the disinfection process. The EPA regulated Stage 2 DBP chemicals such as trihalomethanes and haloacetic acids are tested by Portland every three months. TTHM's can be divided into four different classes:

- Trichloromethane (chloroform, $CHCl_3$)
- Bromine dichloromethane (BDCM, $CHBrCl_2$) (no bromines in system)
- Chlorine dibromomethane (CDBM $CHBr_2Cl$)
- Tribromomethane (TBM $CHBr_3$)

These chemicals contain chlorine and bromine but are not in a reaction with methane. These reactions originate with NOM such as humic acid. Chloroform is a commonly occurring trihalomethane and the principle DBP, making it the most important chemical of this group to

remove from our drinking water. One of the important chemical properties of chloroform's environmental fate is its ability to volatilize, easily passing into air as a gas. Open air reservoirs naturally provide volatilization, enhanced through the fountain spray effect as seen in reservoir 6 and water fall/ agitation used in other reservoirs. Open air reservoir actions efficiently vaporize this unwanted toxic gas where it is then harmlessly broken down by sunlight. (Refs. 23-25)



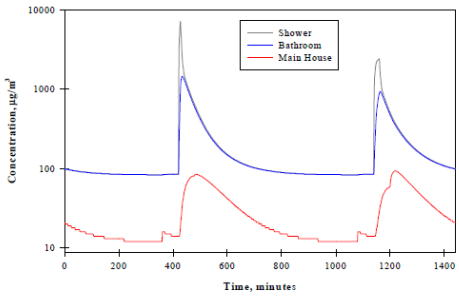
Chloroform (trichloromethane) production v. contact time. Chloroform gas content increases with increase in organic material contact time. PWB distribution system has been poorly maintained leading to increase in biofilm/sediment reactions resulting in greater chloroform gas generation. Open air reservoirs allow increases in chloroform to vaporize before entering distribution.

Covered reservoirs distribute toxic and carcinogenic contaminants into homes daily

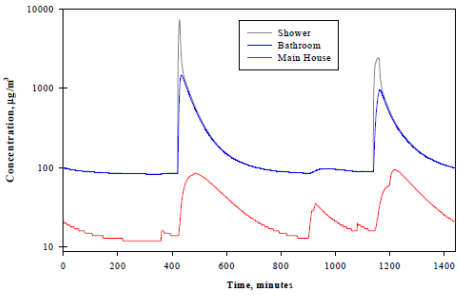
Reasons for open reservoirs and unwanted chemicals

"***Some people who drink water containing haloacetic acids in excess of the MCL over many years may have an increased risk of getting cancer. Some people who drink water containing trihalomethanes in excess of the MCL over many years may experience problems with their liver, kidneys, or central nervous system, and may have an increased risk of getting cancer."*** (EPA)

The following diagrams demonstrate how chloroform can increase – in a home supplied with water from a covered reservoir system – through drinking water aerosols formed through evaporation or routine activities such as showering, bathing, washing clothes, and cleaning. Because of the high Henry's Law constant, inhalation can provide the greatest public health risk by absorption in the human respiratory system including the surface of the lung. The primary factor that determines the relative magnitude of deposition in different regions of the respiratory tract (nose, airways, and alveolar) is the particle size distribution of the aerosol. Another potential source of exposure from aerosols is via dermal sorption when the aerosols are deposited on the exposed skin surface during different water use activities. Open reservoirs can reduce or eliminate THM chloroform gases using efficient open air reservoir volatilization before entering homes, schools, and work places.



a: Concentration Profile of Chloroform – Washing Machine Off



b: Concentration Profile of Chloroform – Washing Machine On

(a.) Concentration of household drinking water chloroform: shower, bath room, main house. Washing Machine OFF
(b.) Concentration of drinking water chloroform increasing: shower (top), bathroom (middle), main house with washing machine ON (bottom) (Ref. 26)

Waterfall effects of an open reservoir promote volatilization of gases before they enter your home.

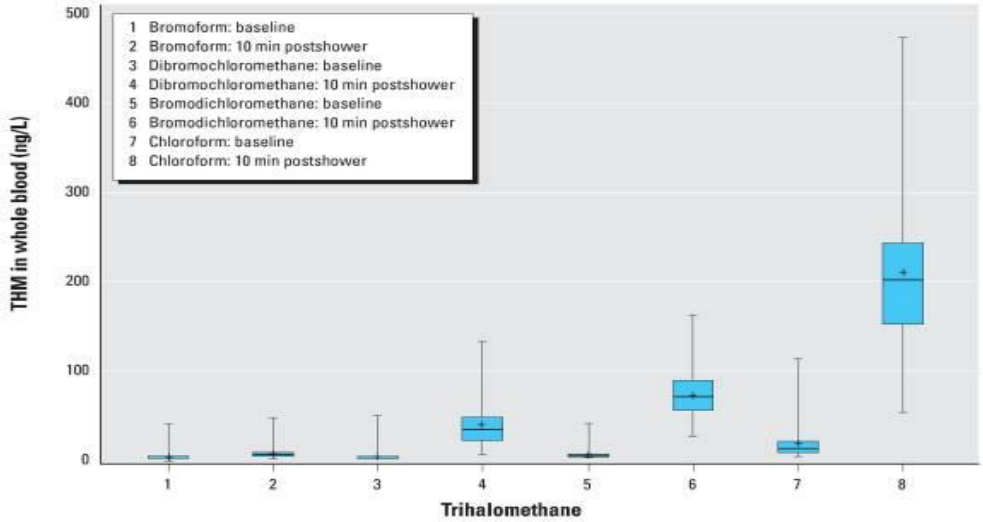
Water use in homes contributes considerably to levels of chloroform in indoor air and total exposure. Toxic and carcinogenic chloroform can enter your body in four ways: as you breathe, eat food, drink water, and it easily passes through your skin as you take a bath or shower. Chloroform can cross the placenta and is also found in breast milk. When chloroform crosses the placenta in humans, it can result in concentrations in fetal blood that are greater than maternal blood concentrations.

An epidemiological study indicated an association between chloroform concentrations in drinking water and intrauterine growth retardation. Concentrations of chloroform in indoor air were higher than those in ambient outdoor air owing primarily to volatilization during water use. When the shower water is hot enough for it to vaporize, inhalation of even more chloroform will occur. Ongoing and continuous exposures to chloroform – such as showering from the inefficiently vented closed reservoir water system – can allow for increased toxicity. Studies in people and in animals show that after you breathe air or consume food that contains chloroform it can quickly enter your bloodstream from your lungs or intestines.

Chloroform is carried by the blood to all parts of your body, such as the nervous system, fat, liver, and kidneys. Indoor air exposure to the volatile THMs such as chloroform is particularly important with houses having low rates of ventilation and high rates of showering and bathing. Chloroform is a California Proposition 65 carcinogen. (Refs. 27-30)

Open Reservoir Atmospheric Volatilization – Total Trihalomethanes (TTHM)
THM concentrations were important predictors of blood THM concentrations immediately after showering. Chloroform concentrations in the shower stall air are the most important predictor in determining blood concentrations after the shower.

Chloroform can be degraded photo-chemically by sunlight and evaporates easily utilizing the open reservoir air surface/ water partial pressure differences in promoting atmospheric volatilization. The open reservoirs provide significant opportunities to efficiently volatilize toxic and carcinogenic THMs. In a closed system such as a covered reservoir, such sunlight degradation and atmospheric volatilization does not occur.



High chloroform blood level saturation from shower shown at 7 & 8. (Ref. 31)

More EPA Regulated Disinfection By-Products Generated from Chlorine and Chloramine

Haloacetic Acids – HAA_5
The five most common are

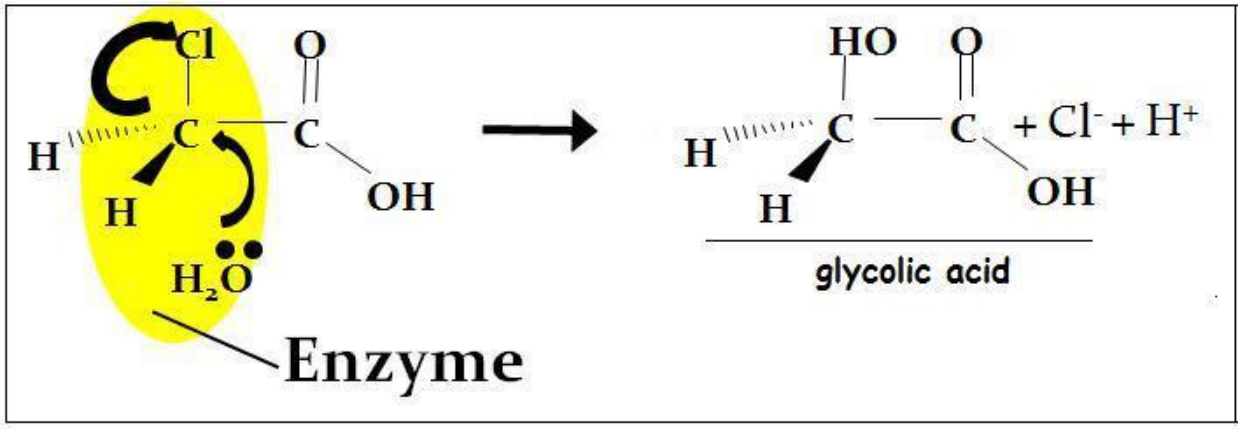
- Monochloroacetic acid (MCAA) ClCH2COOH
- Dichloroacetic acid (DCAA) Cl2CHCOOH
- Trichloroacetic acid (TCAA) Cl3CCOOH
- Monobromoacetic acid (MBAA) BrCH2COOH
- Dibromoacetic acid (DBAA) Br2CHCOOH

In addition to trihalomethanes (THM), haloacetic acids HAA_5 are a class of disinfection byproducts produced by chlorine and chloramine chemical reactions with natural organic material in the water. These disinfection byproducts are also regulated by EPA because of public health concerns. Loss of HAA_5's in water distribution systems has been frequently attributed to biodegradation. Experimental *aerobic* biodegradation rates have shown to be rapid. Oxygen loving aerobic bacteria are associated with the biodegradation and removal of the HAA_5's toxic and carcinogenic disinfection byproducts. Aerobic bacteria have a beneficial role in suppressing the concentrations in tap water. They are integral part of the efficient HAA_5 removal in drinking water such as open reservoir system. (Refs. 32-35)

Oxygen loving aerobic bacteria in our open reservoirs can biodegrade and remove HAA_5 from water

HAA_5 are the second most prominent class of EPA regulated drinking water halogenated disinfection byproducts and are water soluble. HAA_5 chemicals such as DCAA and TCAA present a toxic and potentially hepatocarcinogenic public health hazard that can be expected to be detected in chlorinated drinking water distribution systems. Genotoxicity, reproductive toxicity, embryo toxicity, neurotoxicity and immunotoxicity of DCAA have also been reported. The presence of DCAA and TCAA increases the toxicity of chloroform in female animal studies. (Refs. 36-38)

Microbial removal of these HAA_5's increases water quality and health.



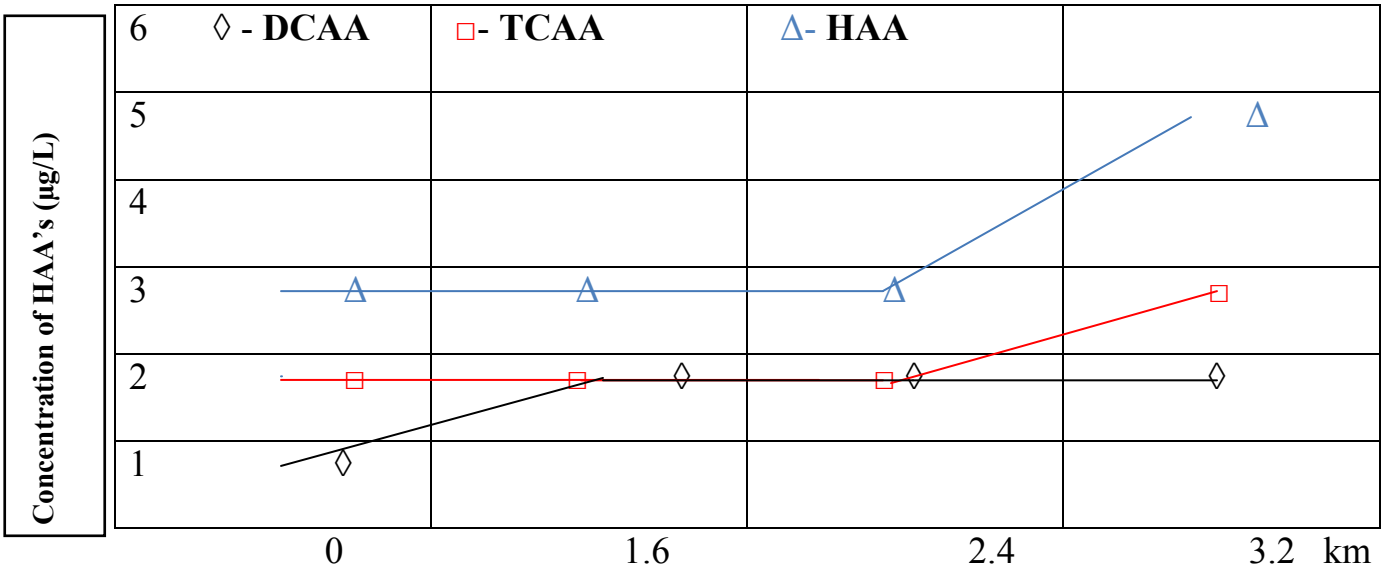
Potential bacterial biodegradation pathway of MCAA. Glycolic acid is then in the general metabolism, and may be photodegraded by sunlight, stopping the HAA from being able to biopersist or bioaccumulate in the environment. (Refs. 39-40)

Summary of how open reservoirs provide support removing HAA_5

- The open reservoirs can provide a natural and sustainable aerobic biodegradation process of the unwanted HAA_5
- Different bacteria are known to aerobically degrade HAA_5 either co-metabolically or as a sole carbon and energy source
- Because HAA_5 are biodegradable compounds they can utilize the enhanced efficiency of *aerobic* microorganisms as a benefit for the open reservoir drinking water quality

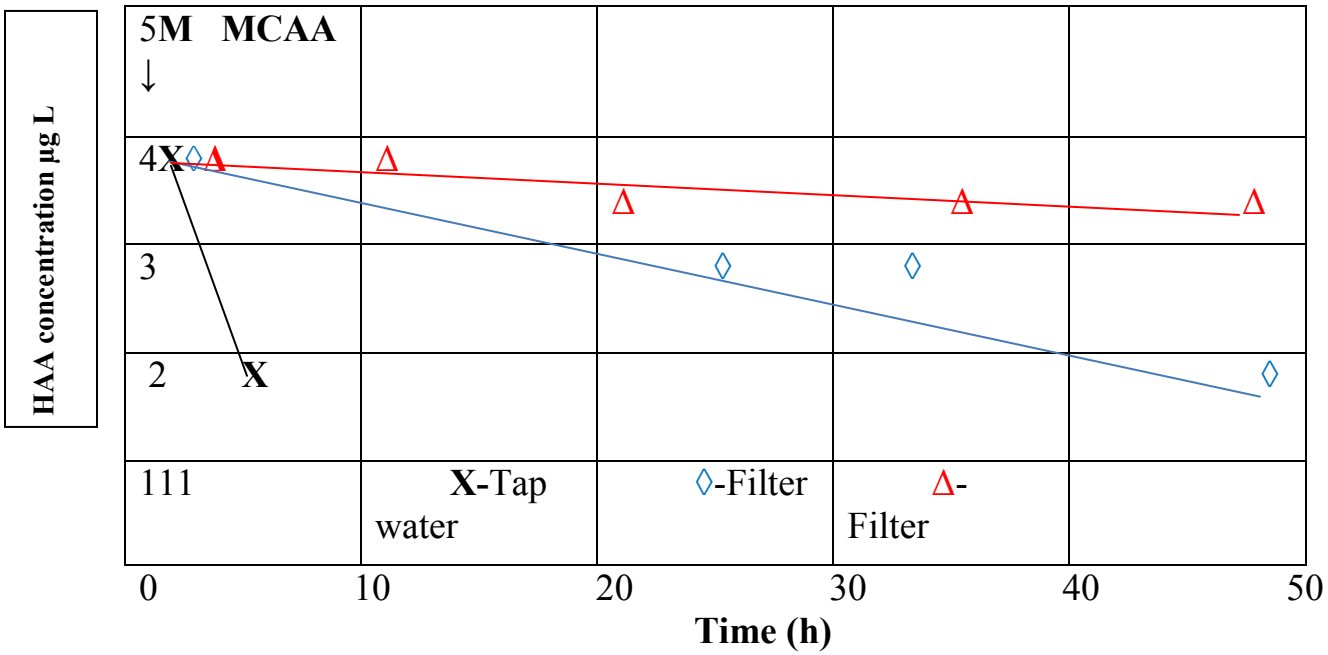
- Aerobic microorganisms are 18 times more efficient in metabolizing chemical compounds than the *anaerobic* microorganisms, found in closed and covered reservoirs
- Oxygen loving aerobic microorganisms degrading HAA_5 act as another desirable public health barrier found in the open reservoirs
- Photolysis/ sunlight can provide additional degradation pathways for HAA_5 in natural waters
- Open reservoirs support peroxide formation in aerobic biodegradation as a mechanism for reduction HAA5 in surface waters before entering distribution systems
- **Aerobic biodegradation in open reservoirs provides superior public health benefits to the anaerobic conditions of covered and closed reservoirs**

Haloacetic Acids Increase in Poorly Maintained Distribution System

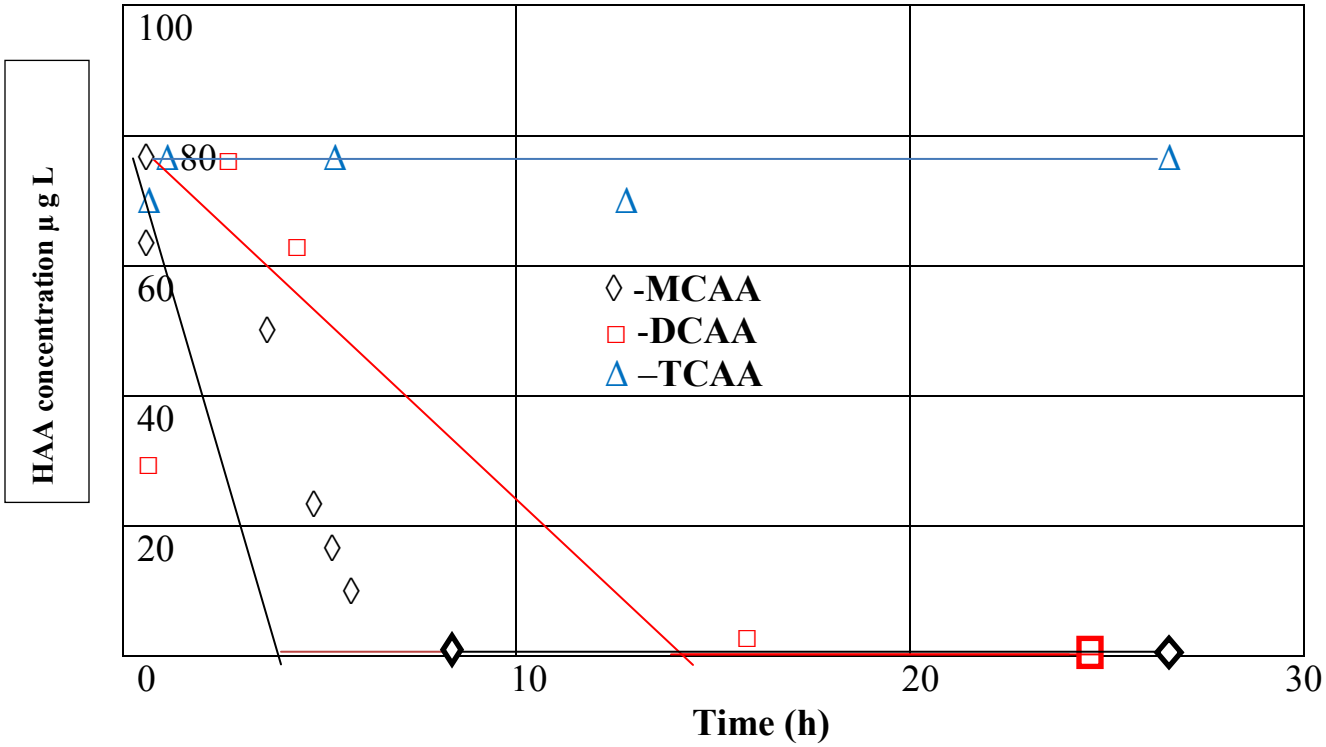


Biofilm from poorly maintained distribution system, i.e., Portland Water Bureau, can increase HAA from continuous chlorine reaction in water pipes

Aerobic Microbial Degradation of Haloacetic Acids - HAA's



HAA Biodegradation by Selected Isolates-R2A DR8 Pseudomonas Tap Water



HAA Biodegradation - R2A-DR11 Aquabacrterium sp. Tap Water

Isolation of HAA degrading bacteria from drinking water using complex media (Ref. 41)

C. Other Disinfection Chemicals – Higher vs. Lower Use

EPA Stage 2 Disinfectants and Disinfection Byproducts Rule (Stage2DBP)
The Bull Run drinking water system was designed by highly accomplished engineers who incorporated the brilliant scientific and public health principles established within fundamental laws of chemistry and physics. As a continued reminder our Bull Run drinking water system was designed with **three critical public health barriers**:

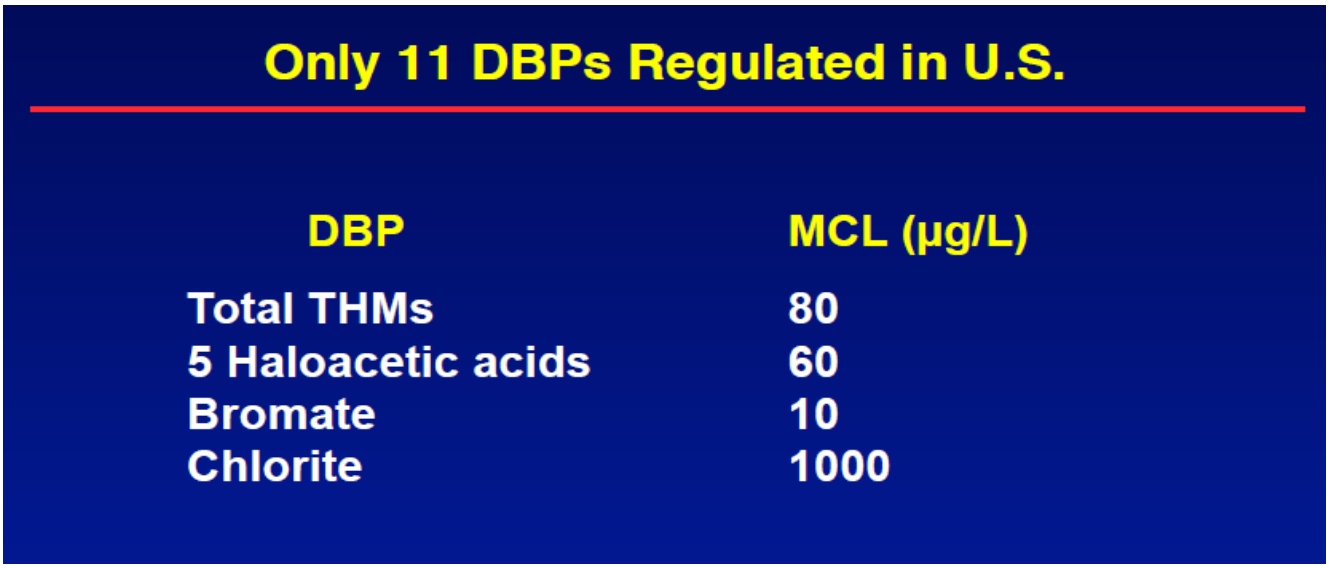
- Portland is truly fortunate to have the federally protected closed to human entry Bull Run Management Unit as our first public health ***barrier***, providing safe drinking water free of municipal, industrial, and agricultural sewage exposure that are the primary sources of US surface drinking water contamination.

- The second ***barrier*** is simple chlorine/ammonia as a disinfection process that provides protection against waterborne disease causing microorganisms.

- Portland's open reservoirs provide a crucial third ***barrier*** by removing unwanted gases, chemicals, and disinfection byproducts (DBP) using natural sustainable aerobic processes before entering our major distribution system. Open reservoir removal of toxic and carcinogenic chemical DBP take place through the following processes:
  -Volatilization efficiency -Biodegradation-microbial
  -Aerobic activity/oxygenation -Photolysis/sunlight -Water agitation

We Need Open Reservoirs to Address the Environmental Chemical Challenges of the Future

The **EPA Stage 2 Disinfectant Byproduct Rule** is intended to reduce potential cancer, reproductive, and developmental health risks from disinfection byproducts which form when disinfectants are used to control microbial pathogens. Our open reservoirs not only currently meet EPA LT2 needs but are also needed to enhance the removal of the EPA regulated trihalomethanes (TTHM), haloacetic acids (HAA_5), as well as other toxic chemicals before these can enter our homes, schools, and workplaces. Natural aerobic atmospheric volatilization of gases and biodegradation of DBP chemicals from open reservoirs diminish the related potential health risks and can provide more efficient public health protection than covered reservoirs can offer. Long-term EPA drinking water standards do not include children but are based on 70 kg /+154 lb. ***adults***. Further DBP chemical removal enhanced by our open reservoirs is needed to decrease public health risk for children, pets, as well as adults.



Toxic and carcinogenic disinfection byproducts regulated by EPA Stage 2DBP

List of EPA's 11 regulated DBP's – sampled only 4 times / year

Total Tri Halo Methanes (TTHM's)

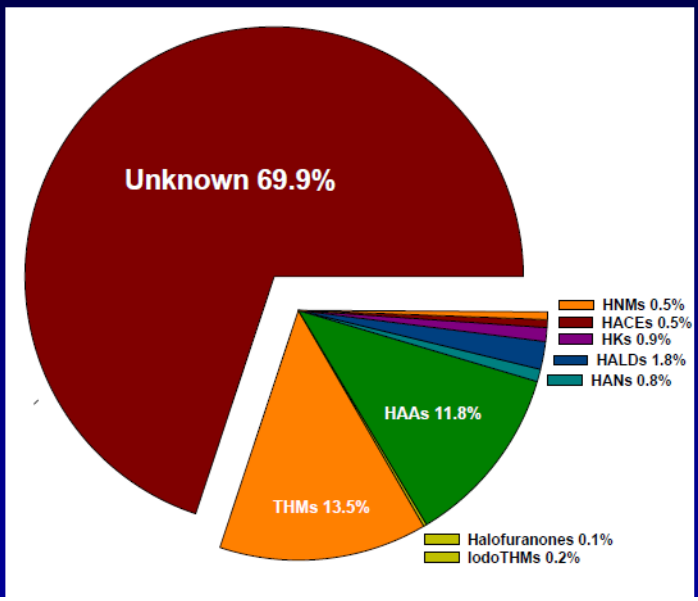
- Chloroform – most prevalent
- Bromoform
- Bromodichloromethane
- Dibromochloromethane

Halacetic acids (HAA's)

- Monochloro
- Dichloro
- Trichloro
- Monobromo
- Dibromo
- Bromine-
- Chlorite-

In addition, many disinfectant byproducts are not known or well-studied. Open reservoirs can reduce/remove many toxic and carcinogenic chemicals before being inhaled, ingested, and absorbed through skin exposures.

But, more than 50% still not known….



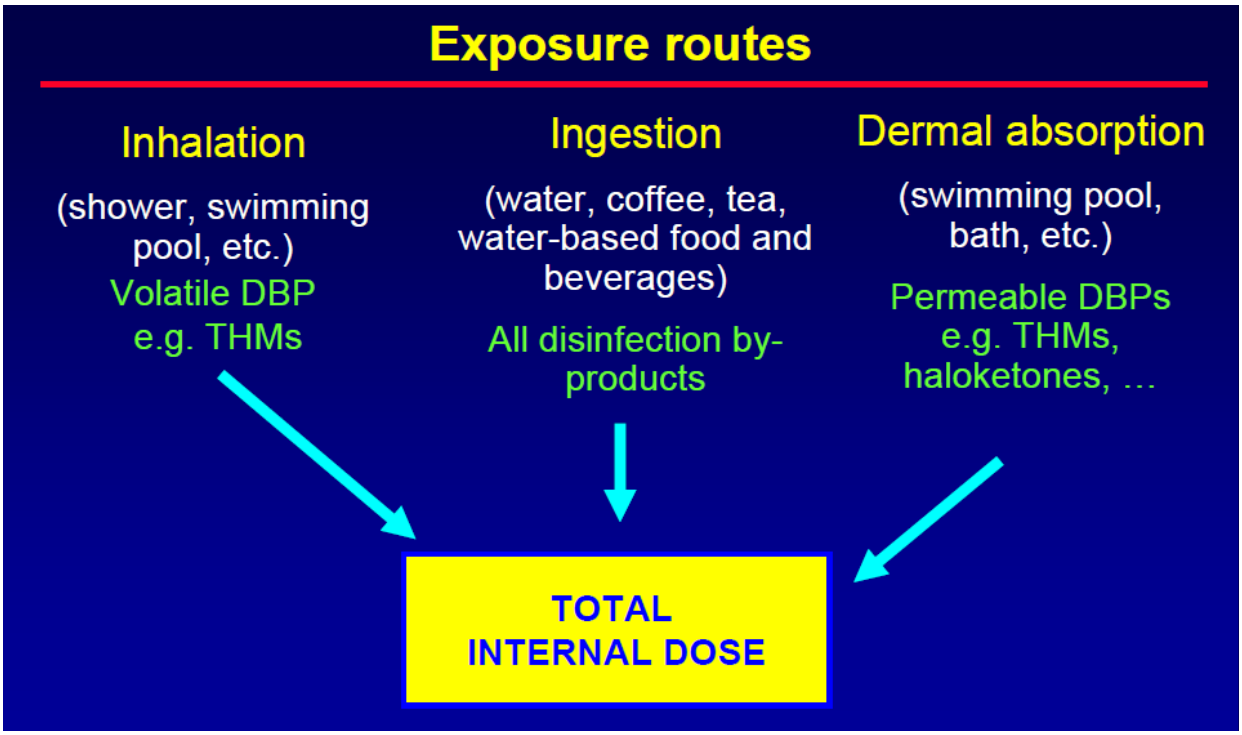
(US EPA)

>600 DBPs Identified

Halogenated DBPs
- Halomethanes
- Haloacids
- Haloaldehydes
- Haloketones
- Halonitriles
- Haloamides
- Halonitromethanes
- Halofuranones (e.g., MX)
- Oxyhalides (e.g., bromate)
- Many others

Non-halogenated DBPs
- Nitrosamines
- Aldehydes
- Ketones
- Carboxylic acids
- Others

(US EPA)

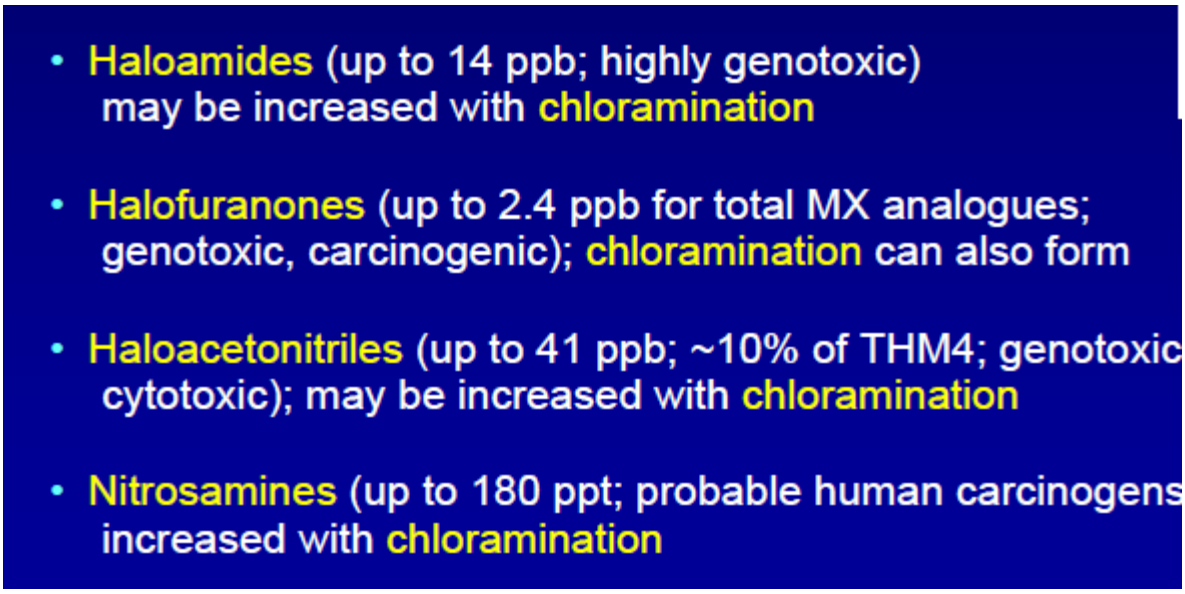


(US EPA)

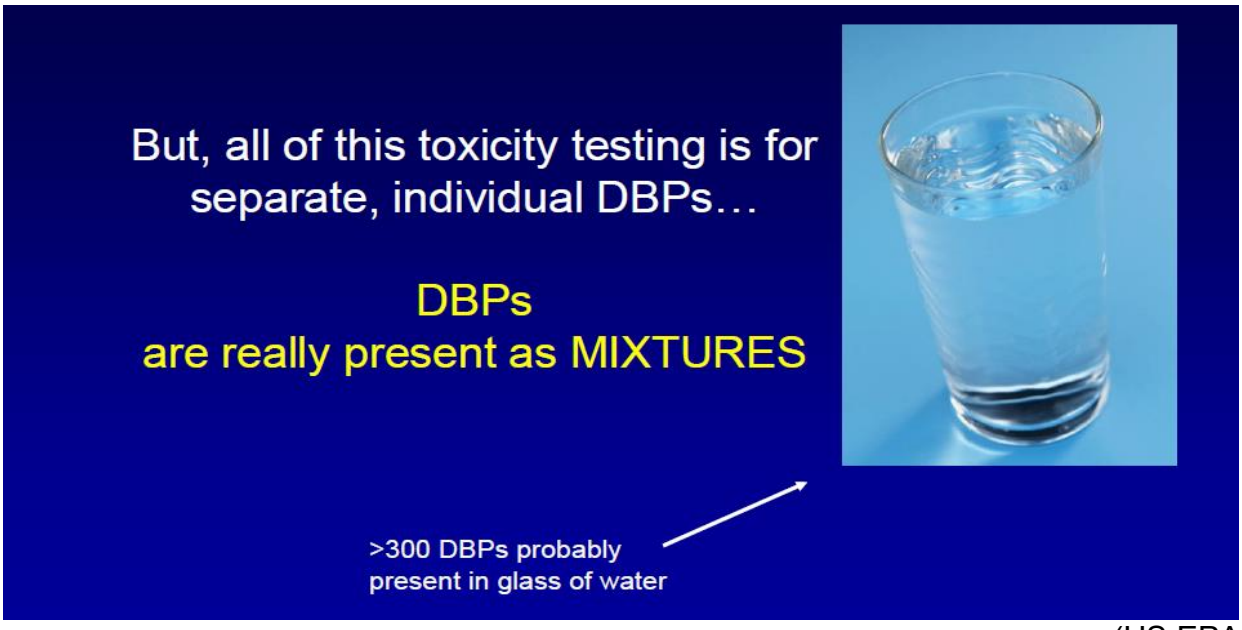
Route of exposure is important….

- Can get 2X exposure from 10 min shower compared to drinking 2L of tap water (inhalation)
- Some DBPs dermally absorbed
- Evidence of increased bladder cancer with swimming in indoor pools (inhalation, dermal): Villanueva et al., *Am. J. Epidemiol*. 2007, *165*, 148-156.

(US EPA)



Emerging Chloramination Disinfection By-Products (US EPA)



(US EPA)

D. Nitrification – Presence vs. Absence

Nitrification is a microbial process by which reduced nitrogen compounds (primarily ammonia) are sequentially oxidized (broken down) to nitrite and nitrate. Ammonia can be present in drinking water through either naturally-occurring processes or through the addition of ammonia to the already present chlorine, during the secondary disinfection process to form chloramines. Drinking water chloramines provide the greatest source of nitrogen which under certain conditions can be used to produce the nitrites/nitrates eventually leading to nitrosamines.

Ultraviolet light depletes free chlorine, whereas chloramines seem to be quite stable in sunlight. Although monochloramine can degrade *slowly* when exposed to the atmosphere at varying rates depending on the amount of sunlight, wind, and temperature, the nitrifiers (bacteria) are very sensitive to near UV, visual, and fluorescent light. Consequently, nitrification episodes in distribution systems occur in the dark (in covered reservoirs, pipelines, taps, etc.) Because of exposure to sunlight, nitrification has not been generated in open reservoirs. (Refs. 42-44)

The nitrification process is primarily accomplished by two groups of autotrophic (self feeding) nitrifying bacteria.

Step 1- Nitrosomonas sp. oxidizing ammonia → nitrite

$$NH_3 + O_2 \rightarrow NO_2^- + 3H^+ + 2e^-$$

Step 2- Nitrobacter sp. oxidizing nitrite → nitrate

$$NO_2 + H_2O \rightarrow NO_3^- + 2H^+ + 2e^-$$

The two groups of bacteria commonly found in aquatic environments can break down ammonia into nitrite and nitrate. The presence of nitrite in a water supply is undesirable because of health concerns such as methemoglobinemia where nitrogen replaces oxygen in red blood cells. Nitrite can also accelerate the decomposition of monchloramine and interfere with chlorine and chlorine residual measurements.

Increased chlorine demand and decay change the disinfectant residual (concentration levels) as it travels through the distribution system as monochloramine. Ammonia concentrations naturally increase as the chlorine concentration decreases through this process***. Sunlight in open reservoirs inhibits nitrification bacteria from oxidizing ammonia to nitrite and nitrate***. Application of chlorine at the reservoir outlet binds to the ammonia efficiently and cost-effectively increasing chloramine residual downstream in the distribution system. ***The absence of sunlight and the dark environment in closed and covered reservoirs allows microbial nitrification activity to continue oxidizing ammonia into unwanted nitrite and nitrate, etc***. Nitrification issues have been documented in Los Angeles covered reservoirs such as Garvey and Orange County.

N-nitrosodimethylamine (NDMA) important nitrogenous chemical reaction-

Nitrate → nitrite → nitrosamines

Chlorine and chloramine can react with organic nitrogen material that can contain precursors to NDMA. NDMA is routinely detected in drinking water utilities. NDMA detection may vary during seasonal changes due to differences in organic material levels. Water quality data from surface water sampling demonstrated that NDMA is significantly broken down in surface water due to ultraviolet degradation from exposure to sunlight. Based on the data, a half-life of 2.2 hours in surface water was estimated for NDMA.

Photo degradation (sunlight) is the main process for removing NDMA from the aquatic environment, yet NDMA can persist in the absence of sunlight such as in a closed and covered reservoir. From a covered reservoir the toxic NDMA continues on into the drinking water distribution system to be consumed in our homes, schools and businesses. (Refs. 45-46)

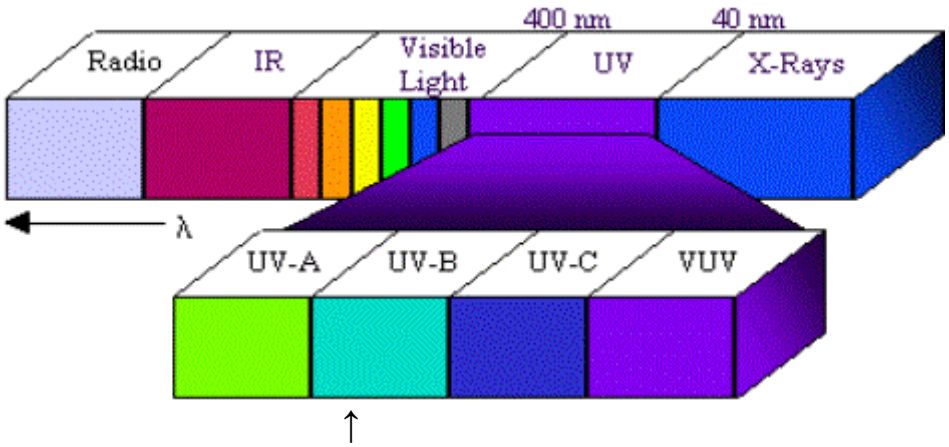
N-Nitrosodimethylamine (NDMA) is a member of a family of extremely potent carcinogens, the *N* – nitrosamines. Their cancer potencies are much higher than those of THM's. Concerns about NDMA mainly focused on the presence of NDMA in foods and drinking water. NDMA has produced liver tumors and parenchymal cell tumors when administered orally**. NDMA acts as a transplacental carcinogen and has been found in breast milk**. NDMA can be inhaled, and absorbed through the skin. Increases in lung, liver, and kidney tumors have been observed after inhalation exposure. NDMA is structurally related to known carcinogens and can be mutagenic in microorganisms. (Refs. 47-50)

"Blue Baby"syndrome from nitrification of drinking water. Nitrate poisoning where red blood cells have decreased oxygen, resulting in *methemoglobinemia*

E. Oxygenation – Absence vs. Presence

Oxygen introduced at the open reservoirs' fountains and waterfall inlets saturates the water and provides many public health benefits. Oxygenation provides a secure environment for helpful aerobic bacteria, reduces unwanted anaerobic bacteria, and provides a natural source for disinfection precursors such as oxides and peroxides. Oxygen enriched water naturally enhances aerobic bacteria metabolism, yielding a superior efficiency in chemical biodegradation than anaerobic bacteria metabolism found in covered reservoirs. Closed and covered reservoirs do not provide these advantages.

F. Light Disinfection – Broad Spectrum Sunlight



Natural broad spectrum sunlight benefits in open reservoirs. The many wavelengths of natural sun light provide well established disinfection properties that artificial UV used in drinking water treatment cannot. Arrow at UV-B shows the artificial UV radiation 254 nm wavelength used for drinking water facilities. The single wavelength 254 nm provides significantly less energy to break down microorganisms than does natural sunlight.

Natural disinfection from sunlight is well known. Sunlight is among the most potent abiotic factors in the inactivation or killing of bacteria and other microorganisms in water. Sunlight imparts a broad and effective spectrum of photon wavelength exposures that include: gamma, x-ray, ultraviolet, visual, infrared. Sunlight photolytically (breaks apart) reacts with and disrupts microorganism chemical structures. Additionally our open reservoirs incorporate efficient oxygenation of water at the fountains and the inlet waterfalls, synergistically enhancing microbial disinfection. This is achieved when sunlight photons react with oxygen-based molecules forming free radicals and oxides such as peroxide. These chemicals also react with microbial structures providing a sustainable and natural disinfection effect. Covered and closed reservoirs cannot provide the natural disinfection benefits of sunlight.

The condition of oocysts is very important in determining the risk of infection. Oocysts are exposed to many conditions in the environment that can reduce their infectivity before entering the distribution system. The length of time post shedding, water temperature, and the amount of

ultraviolet UV exposure from sunlight can effectively reduce oocyst infectivity. Although oocysts are considered environmentally resistant they exhibit considerable loss of infectivity as environmental temperature increases. Above 50^0F loss of infectivity increases. In addition, surface waters are exposed to natural UV irradiation in sunlight which may damage oocyst DNA therefore inhibiting DNA replication and reducing infectivity. Due to specific gravity influences, many organisms such as Cryptosporoidium, Giardia, etc., exist at the top of the water column surface where UV sunlight can easily render them harmless. (Refs. 51-53)

G. Public Health Record of Closed Reservoirs

From 1949-1969 the American Water Works Association, American Public Health Association, and U.S. Public Health Service proposed covering reservoirs ***even though there were no historical or current public health problems with open reservoirs.*** While these organizations were covering reservoirs for alleged public health reasons, closed reservoirs were being built and maintained with materials such as ***lead-based paints and petroleum-based coatings*** on the interior of these reservoirs. As early as 1904 lead-based paints were recognized as toxic. Since the 1920's *benzene*, a component of petroleum-based coatings, has been known to cause cancer. Thus, these materials have been widely known and recognized for decades as toxic and carcinogenic while in direct contact with drinking water. These toxic and carcinogenic chemicals can still be found and used with closed reservoir structures placing drinking water and public health at risk. (Ref. 54)

Although the covered reservoir storage facility is normally an enclosed structure, numerous access points can become entry points for debris and contaminants. Consumer deaths from closed reservoirs are historically well-documented from these points of entry.

These contaminant pathways include roof top access hatches, sidewall joints, vent and overflow piping, roof cracks, and workmanship inconsistencies.

The most common problems reported from inspectors in covered reservoirs:

- No bug screens on vents and overflows
- Cathodic systems not adjusted or operating properly
- Unlocked access hatches
- Presence of lead paint (interior and exterior) and the presence of unapproved paints

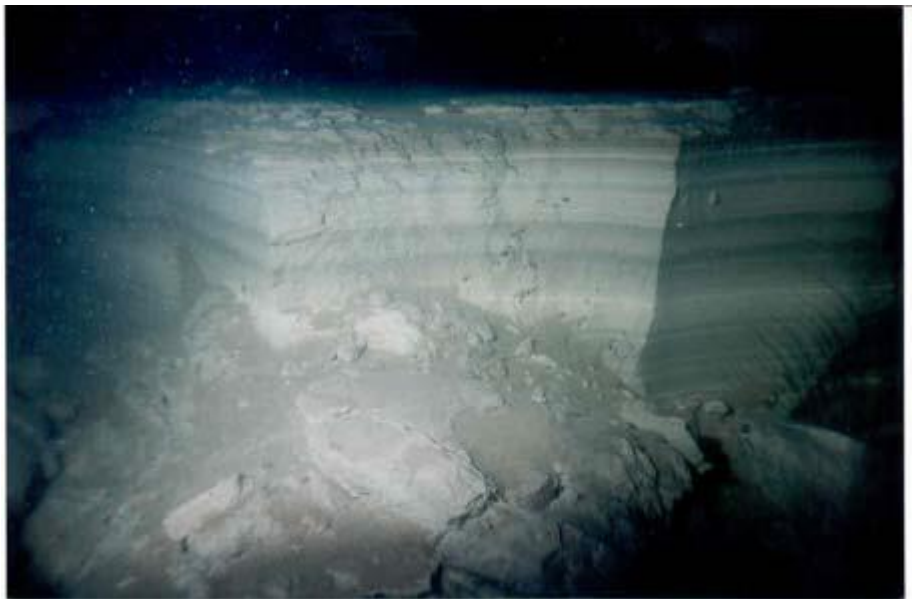
Common coating problems reported by tank inspectors relating to water quality:

- Chemical leaching from incompletely cured coating
- Corrosion product buildup from excessive interior corrosion
- Turbidity events from bottom sediments
- Unknown chemical leaching from non-approved coatings and lead leaching from lead-based interior coatings

Points of public health concern:

- Disinfectant decay – nitrification facilitation from dark environment
- Chemical contaminants – toxic and carcinogenic coatings

- DBP retention – lack of atmospheric volatility
- DBP retention – lack of sunlight
- Tastes and odors – anaerobic flora metabolites
- Sedimentation / biofilm – less-frequent cleaning schedule +5 years
- Microbial contaminants – known source of many consumer deaths
- Roof leakage and contamination cement seams (Seattle)
- Roof leakage and benzene from rubberized asphalt degrading (Seattle)
- Accumulation of toxic filtration media remaining in seldom-cleaned tanks



Unhealthy accumulation of post-filter media in drinking water: aluminum sulfate (alum) in seldom-cleaned covered reservoir. (Ref. 58)

Microbial case studies

Covered reservoir storage facilities have been identified in microbial drinking waterborne disease deaths and outbreaks:

- In 1993 Salmonella typhimurium was identified in a Gideon, Missouri, outbreak from bird contamination in a covered municipal water storage tank. Pigeon droppings from the roof area carried into the openings of a closed tank were identified as the etiological agent. Seven persons died, and hundreds became ill.

- Also in 1993, a Campylobacter jejuni outbreak in Minnesota from a drinking water storage tower. Fecal coliform were also found.

- In 2008, Salmonella typhimurium caused another death and hundreds of illnesses from a covered drinking water reservoir in Alamosa, Colorado. Contaminants identified from bird access unobserved in covered reservoir.

Covered Alamosa, Colorado reservoir where Salmonella bacteria from prolonged bird roosting exposures were not visible or detected, causing illness and death

Concerns from Questionable Water Engineering Judgment Decisions: Past and Current Covered Reservoir Surfaces Coated with Toxic Materials

Coating materials are used to prevent hydrostatic (water) moisture migration in concrete tanks, pH changes, and corrosion of steel storage tanks. Coatings used in finished water storage facilities were selected because of their structure protection and ease of application. The common use of coal tars, greases, waxes, and lead paints as interior tank coatings was accepted by engineers. These products contributed significant toxic chemical exposure to the drinking water. Grease coatings can differ in their composition from vegetable to petroleum and can provide food for bacteria resulting in disinfection problems along with taste and odor issues in finished water.

Toxic chemical case studies:

- Petroleum grease applied in 1925 in a Florida storage tank interior caused odor, taste, disinfectant, and slime problems. In 1988 the grease was reapplied. The grease was removed in 1996 and a polyamide epoxy was applied.

- East Bay Municipal Utility District used hot-mopped coal tar as their interior coating material for tanks through the 1960's. Hot-mopped coal tar is still seen today in operating water tanks at other utilities.

- Structural and building designs continue to be problematic in closed and covered reservoirs. Cracks in the ceiling of the new 2009 Seattle reservoirs can allow for intrusions of contaminated water and be problematic, regardless of the rubberized asphalt

barrier replacement. The new toxic and carcinogenic material placed over cracks in the reservoir ceiling is a petroleum based asphalt/benzene material. Microorganisms can break down the petroleum-based carbon substrate releasing benzene and other toxins into reservoir ceiling cracks and water.

There are newer coating applications such as aluminum, polyurethane, and chlorinated rubber. Leaching of organic contaminants from flat steel panels can occur with various coatings including vinyl, chlorinated rubber, epoxy, asphalt, and coal tar, etc. Coal tar coating and lining can still be found, and is used in California as a coating material. Elevated levels of alkyl benzenes and polycyclic aromatic hydrocarbons (PAH's) have been reported in coal tar bituminous coatings. In tanks that remain in use, organics can be leached into drinking water, especially if there is not enough curing time after coating application.

Additional closed reservoir chemical problems occur from reduced disinfectant residual and sedimentation. Debris can enter any closed reservoir system. Cleaning schedules in closed reservoirs are recommended to be ~5 years. A case study of three elevated tanks in Brookfield, Wisconsin, documented cleaning intervals of 15 years for one closed reservoir, and 7-year cleaning intervals for the other two closed reservoir tanks. Sediment of 28 inches was found in the 15-year tank and 4-12 inches of sediment in the other two tanks. Extremely high bacteria counts were found in all tanks. (Refs. 55-58)

Deceased rat on layers of sediment in a covered reservoir. Common entry points for rodents, cats, and birds in covered reservoirs are hatch or access openings, vent pipes, structural cracks, and overflow pipes. (Ref. 58)

H. Public Health Record of Portland's Open Reservoirs and Bull Run Watershed

Provided below are recent and supportive open reservoir engineering assessments and scientifically supported answers for the community's understanding of the public health benefits of open reservoirs.

Condition of open reservoirs at Mt. Tabor Park – 2009 Report
The Mt. Tabor Park Reservoirs' structures and buildings are considered nationally significant as part of an early design for a city's open water storage system. The system is historically significant for its initial construction and subsequent additions involving monumental civic undertakings, for the exemplification of early concrete engineering construction technology, and for its architectural design. As recognition of their historic significance, the buildings, structures, and site were nominated to the National Register of Historic Places and received designation as the Mt. Tabor Park Reservoirs Historic District on January 15, 2004. Generally, those features within the district boundary that date from the initial construction in 1894 through construction and additions dating to 1951 are considered historic contributing.

As viewed from a historic resource perspective, the Mt. Tabor Park Reservoirs Historic District are, for the most part, in good condition. The structures and buildings were carefully designed and were built for durability and low maintenance. Those considerations have allowed the structures to age gracefully. The facilities are currently used on a daily basis.

Very few original construction components have been lost or removed. There have been minor modifications to the facilities to allow continued operation. In many cases, these alterations, such as new electronic measuring or pipe controls, supplement the historic resources instead of replacing them. The most significant deterioration is found at the oldest facility, Reservoir No. 1, where the decorative concrete finishes on the site wall and gate house are deteriorated. Some components have been recently renovated, such as painting of the wrought iron fencing assembly located around Reservoirs No. 1 and No. 5. Other components, such as roofing, are currently in serviceable condition but will need to be replaced shortly. Still other features may be advised to be replaced for restoration purposes. (Ref. 59)

The general summary of the facilities being in good condition reflects the strong construction and engineering principles of 100 years ago. Attending to deferred maintenance and some cosmetic intervention of our open reservoirs will provide many more years of reliable safe and healthy drinking water for all.

History
The City of Portland has five open reservoirs for drinking water. Three of the reservoirs are located at Mt. Tabor Park and two are located in Washington Park. Reservoir 1 at Mt. Tabor Park and Reservoirs 3 and 4 at Washington Park were all completed in 1894. Reservoirs 5 and 6 at Mt. Tabor Park were completed in 1911. All of the reservoirs are of concrete construction and reflected the best thinking of the 1890's and early 1900's from an advanced engineering perspective and from the perspective of managing a public water supply. The engineering and construction principles of our open reservoirs were ahead of their time using advanced technologies that provide safe and healthy drinking water for us today. Ernest Ransome provided specialized cold twisted metal rebar rods and innovative reinforced concrete to build the open reservoirs that have lasted over a century and will last decades longer when properly maintained.

Ernest Ransome's engineering skills that were applied to our open reservoirs are further recognized from innovative construction in the San Francisco Bay area. Ransome's two experimental buildings at Stanford University survived the 1906 San Francisco earthquake essentially without damage while the university's newer, conventional brick structures literally crumbled around them. The published analysis of Ransome's two buildings by fellow engineer John B. Leonard did much to advance the safety of buildings in post-1906 San Francisco and nationwide.

The movement to covered reservoirs came after 1946 when new jobs were needed for returning veterans. The U.S. Public Health Service and American Public Health Association made the recommendation for covered reservoirs based on health benefits that contradict earlier acknowledgements of open reservoir health benefits. (Dr. M. J. Rosenau, 1902 Harvard School of Public Health).

Covered reservoirs have security and contamination issues. Open reservoirs are cleaned 2x/year. Covered reservoirs have not provided the public health benefits open reservoirs provide. Covered

reservoirs are cleaned every five (5) years or longer allowing for sedimentation, increased disinfectant demand and disinfectant byproduct formation, and microbial issues.

> "Although the storage facility is normally an enclosed (covered) structure, numerous access points can become entry points for debris and contaminants. These pathways may include roof top access hatches and appurtenances, sidewall joints, vent and overflow piping." (EPA) (Ref. 55)

> "Microbial contamination from birds or insects is a major water quality problem in storage tanks (covered reservoirs). One tank inspection firm that inspects 60 to 75 tanks each year in Missouri and southern Illinois reports that 20 to 25 percent of tanks inspected have serious sanitary defects; and eighty to ninety percent of these tanks have various minor flaws that could lead to sanitary problems (Zelch 2002). Most of these sanitary defects stem from design problems with roof hatch systems and vents that do not provide a watertight seal. Older cathodic protection systems of the hanging type also did not provide a tight seal. When standing inside the tank, daylight can be seen around these fixtures. The gaps allow spiders, bird droppings, and other contaminants to enter the tank. (Zelch 2002) reports a trend of positive total coliform bacteria occurrences in the fall due to water turnover in tanks. Colder water enters a tank containing warm water, causing the water in the tank to turn over. The warm water that has aged in the tank all summer is discharged to the system and is often suspected as the cause of total coliform occurrences." (EPA) (Ref. 55)

The premise of covered reservoirs reducing risk has proven to be widely unfounded. Toxic and carcinogenic materials have been widely used in and on covered reservoirs. These materials are NOT used on open reservoirs.

Portland open reservoirs have not had any deaths or public health outbreaks from chemicals or microorganisms. One alleged outbreak of waterborne Giardia illness in Portland took place in 1954. However, "failure to isolate *G. lamblia* from suspect water strongly influenced investigators to reject drinking water as the possible vehicle of infection." (Ref. 60)

Water samples from the Oregon Health Authority remain within EPA standards. Viruses, Cryptosporidium, and Giardia have not been identified in Portland's open reservoirs. Algae are not a public health issue in our open reservoirs and are limited in growth from the nitrogen and phosphorous fertilizers originating from the Columbia South Shore Well field water. Bull Run water has minimal levels because there is no agricultural chemical exposure.

V. CONCLUSION

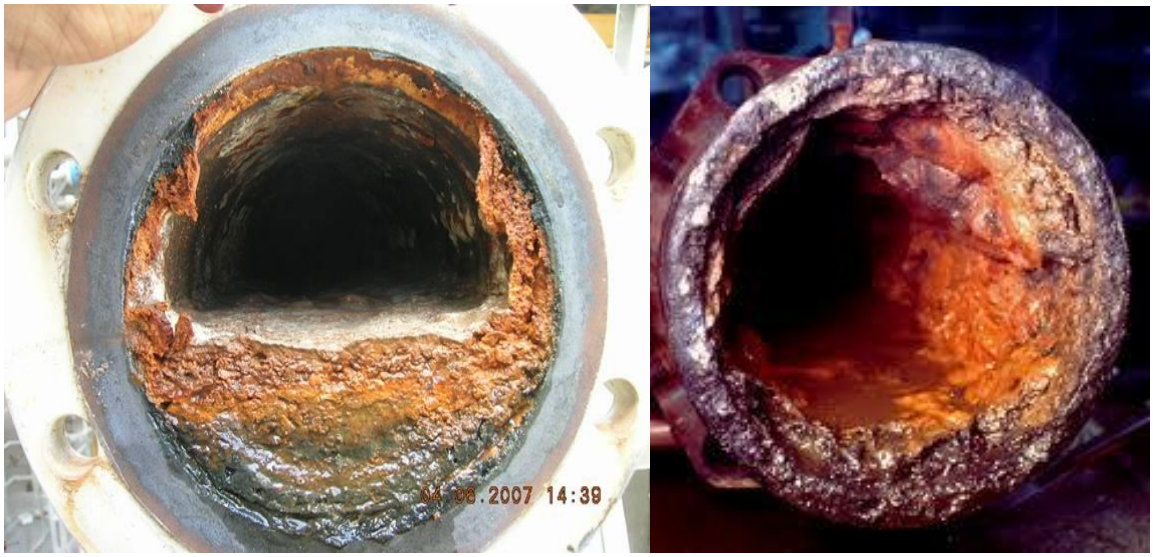
KGW News: ***"So will a closed system prevent future boil alerts?"***

David G. Shaff, Portland Water Bureau Administrator: ***"It can still happen."***

–May 25, 2014

The public health benefits of open reservoirs at Mt. Tabor Park and Washington Park are profound. Citizens of Portland have adopted and agreed to the EPA Administrators' "LT2 Rule" position: "Science will determine the ultimate outcome" and "We're just trying to get at the public health impacts and if there's a better way to do that we'll be wide open to it" of our open reservoirs. This has been historically illustrated by the City of Portland's Open Reservoir Independent Review Panel 2004 majority vote that supported retaining the open reservoirs. **The open reservoirs provide a complex ecological tapestry of benefits showing many levels of scientific interactions that must occur to retain the public health of our community.** Sunlight, water aeration, and oxygen-loving microorganisms create an ecosystem that keeps our drinking water safe and healthy.

The Portland Water Bureau just this month placed the third of three "boil water" alerts allegedly based on the bacterium Escherichia coli, blaming it on the open reservoirs. Because of a decade-long record of water distribution system deferred maintenance water quality concerns – as acknowledged by City of Portland Auditor reports – and along with a consistent breach of acceptable microbiological water sampling protocol, there can be no expectation the reservoirs are a true source of contamination. The ongoing deferred maintenance problems – cross-connection, backflow, low pressure zones, flushing taking place upstream in SE Portland, pipe breaks, biofilm and sediment build up. etc. – are more likely to have been the source of the alleged contamination event, not the open reservoirs.



Example of water pipeline biofilm & sediment accumulation from years of Portland Water Bureau deferred maintenance and system neglect as source of alleged contamination resulting in "boil-water" notice on May 23, 2014

Additionally the PWB water sampling process has no scientific basis and breaches acceptable microbiological “aseptic technique” protocol. Probability of water contamination when sampling without gloves as a barrier is extremely high and unacceptable, leading to rejection of water sample results. Hand sanitizers are not appropriate in public use situations because they do not remove dirt and organic material that can hide contaminants. (CDC 2002)

Unacceptable water sampling procedure used by the Portland Water Bureau. Sample should be rejected as there is high contamination risk due to no gloves as barrier and water stream splash

EPA water sampling procedure using gloves as contaminant barrier and controlled flow

During the last century open reservoirs throughout the United States have provided a long and well documented history of safe drinking water. Microbiological scientists in the 1800's and 1900's such as Louis Pasteur and physician John Snow furthered the understanding of healthy drinking water by unraveling the relationship between identifiable microorganisms and disease. They determined that separation of fresh drinking water from water filled with sewage is important for public health.

One of the many Bull Run system benefits is providing safe drinking water free of sewage in contrast to the previous Portland source, the increasingly contaminated Willamette River. Consistent with our open reservoirs, scientists of the 19th and early 20th centuries recognized the many benefits of sunlight in promoting public health. European scientists discovered by chance that sunlight could kill bacteria. Media grown without sunlight exposure became cloudy from organism growth, while media grown with sunlight remained clear because of organism mortality. Later experiments from the 1900's confirmed that the presence of oxygen as well as sunlight is critical to this destructive microbial process. Soon it was accepted by the scientific community: "sunlight and fresh air are the enemies of disease".

A decade of experience under the 1986 Safe Drinking Water Act revealed several areas where responsible, science-based flexibilities and a better prioritization of effort could improve protection of public health compared to the one-size-fits-all approach of the 1986 statute. (EPA 1996) As an example 1996 SDWA, Portland's open reservoirs' existence is not to be based on a "one size fits all" EPA regulation, but on their historical public health value and recognition of future chemical and microbial challenges they have successfully overcome for more than 100 years.

The central reason for maintaining Portland's open reservoirs is that they are best for public health. There is a recognized scientific need to reduce/eliminate environmental toxic and carcinogenic chemicals that have no place in drinking water. **Portland can already meet EPA microbiological standards without the corollary health hazards resulting from covered reservoirs.**

Citizens of Portland and other local Bull Run customers are addressing their concerns about added exposures of toxic and carcinogenic chemicals in their drinking water. EPA regulates 11 disinfection byproducts and now has identified +600 more chemicals present in drinking water that are of concern but are not regulated.

The open reservoirs provide the most important and critical public health benefit of the Bull Run water system. Open reservoirs ***act as a stop sign and thus a barrier to toxic and carcinogenic chemicals*** that would otherwise enter the distribution system ending up in our homes, schools, and work places. We have seen the negative air quality outcome when closed drinking water systems allow toxic aerosol gases such as radon and chloroform exposures into everyday living situations. The shower/bath induced chloroform places the household health at risk because EPA long term toxin standards are not based on children or pregnancy exposures, only adults. There is no safe level of radon and its radioactive progeny exposure in the household air and water.

Covered reservoirs cannot efficiently provide the chemical mitigation public health process of open reservoirs because they are significantly anaerobic (without oxygen), principally enclosed, and in an environment without sunlight. Because of their public health and toxic chemical mitigation shortcomings, ***covered reservoirs act like an express lane for contaminants on their way to the distribution system and into indoor plumbing systems. For the benefit of public health and continued commitment by the City of Portland to the Precautionary Principle, the open reservoirs must be retained and maintained as they are today with the addition of improved security measures.***

While all Americans now carry many synthetic chemicals in their bodies, women often have higher levels of many toxic substances than do men. Some of these chemicals, such as chloroform, have been found in maternal blood, placental tissue, and breast milk samples from pregnant women and mothers who recently gave birth. Thus, chemical contaminants are being passed on to the next generation, both prenatally and during breastfeeding. Some chemicals (e.g., radon) indirectly increase cancer risk because they can be influenced by the effect of carcinogens. Children of all ages are considerably more vulnerable than adults to increased cancer risk and other adverse effects from virtually all harmful environmental exposures. In addition, some toxics have adverse effects not only on those that can be exposed directly (including *in utero*), but on the offspring of exposed individuals.

The Portland Utility Review Board (PURB) in July 2002 voted unanimously to pursue an EPA Waiver from the Long Term 2 Enhanced Surface Water Treatment Rule. That voted position remains in force today. The Portland City Council and Portland Water Bureau to date have not followed up on that mandate. ***Council has only asked EPA "if a waiver was available?" without providing EPA with properly documented scientific evidence or reasoning. Nor has the City of Portland made a formal waiver request.***

"Science will determine ultimate outcome" has been clearly and consistently stated by the EPA regarding case-by-case application of the "LT2 Rule." Yet the Portland City Council and the Portland Water Bureau have generally ignored the primary scientific public health benefits of open reservoirs as barriers to distribution system toxic chemical contamination. Scientifically supported public health benefit examples could have been easily presented to the Oregon Health Authority (OHA) such as: sunlight UV (AWWARF 3021), nitrification mitigation (EPA 2002), and gas volatilization (radon).

The City of Portland needs to restart the process of working transparently and in good faith with Oregon's Congressional delegation, the Oregon Health Authority, the Governor's Office, and citizens of Portland familiar with the science and advocacy administrative experience in keeping the reservoirs open. The scientific information and principles outlined in this document are intended to provide the foundation for that effort.

Portland's open reservoirs utilize the principles of chemistry, physics, and microbiology to support a safe and healthy drinking water outcome that covered reservoirs cannot meet. Contemporary science is building on the new way of thinking that reduction and elimination of drinking water environmental chemical exposure is the new future of open reservoirs to provide the best outcomes for drinking water and public health.

A. Final Thought

Joe Meyer of KBOO Radio on May 10, 2011, interviewed Dr. Gary Oxman, highly-respected Multnomah County Public Health Director (retired 2013), about Portland's open reservoirs

Q. **What about Portland's current water?**
Dr. Oxman: "I think Portland's water is superb. We have a wonderful water source in Bull Run watershed. Well designed system and responsibly run system and we have excellent water."

Q. **Are there any known public health issues today?**
Dr. Oxman: "No there really aren't. If you are talking, are there diseases caused by our water – environmental diseases, chemical diseases, bacterial diseases, microbial diseases – no we have not been aware of or detected any diseases or sign of illness associated with our water system."

Q**. If Portland does cover reservoirs will you expect fewer illnesses?**
Dr. Oxman: "We are not detecting any illnesses associated with water in Portland. *No I would not expect we would get fewer illnesses after covering reservoirs.*" (emphasis added)

Q. **Anything else to say?**
Dr. Oxman: "Great drinking water system here in Portland. Levels of citizen involvement that we have in the debates, of what the directions are a very positive thing. What we need to do as a community is to come together and debate the issues honestly, debate them openly, a lot of different factors that will influence the decisions that our policy makers will make. Council and other elected officials, and I think we need to be an active part of that process, part of the gift we can give to future generations here in Portland."

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VII. APPENDICES

Appendix 1

Excerpts from City of Portland Auditor's Reports re: Portland Water Bureau

Documenting neglected maintenance and poor management that risk public health and unnecessarily increase costs

For complete copies of these reports see: City of Portland Auditor, Audit Report Index by year – http://www.portlandonline.com/Auditor/Index.cfm?c=27096

1.1 "Portland's Water Distribution System: Maintenance Program Needs Improvement"
Office of the City Auditor, Portland, Oregon, August 2004 – Report #299

"Water mains are flushed and replaced infrequently, valves receive minimal exercising and maintenance, and meters are repaired and replaced slowly. In addition, the backlog of needed repairs has grown. Although water quality and reliability have not yet been adversely affected, we believe continued decline in the maintenance of the water distribution system assets could negatively affect water service performance in the future."

"The Bureau lacks a clear and comprehensive maintenance plan, complete and reliable information on the nature and condition of its assets, and adequate methods to organize and schedule maintenance work."

"The AWWA indicates that periodic flushing of main water lines is needed to remove bacteriological growth, sediment, and corrosion, to improve flow, and to introduce fresh water with higher chlorine residual. The most effective form of flushing is unidirectional flushing, which entails comprehensive flushing of large areas of pipe in order to systematically cleanse the pipes of debris. The Bureau's ability to perform unidirectional flushing is also hampered because the Bureau does not regularly exercise and maintain valves and does not have a complete and accurate inventory of valve status and location."

"The feet of mains replaced dropped from 46,500 to 9,800 feet, a 79 percent decline. If main replacement continues at the same rate as the past five years, it will take the Bureau over 400 years to replace all the City's 2,000 miles of water mains."

"Fire hydrants, water meters, water valves being paved over and all being neglected by Portland Water Bureau maintenance"

"A recently completed analysis of outstanding work orders by Construction and Support supervisors indicates the work order backlog may currently represent in excess of 26,000 hours of needed repairs and maintenance."

1.2 "Spending utility ratepayer money: Not always linked to services, decision process inconsistent"
Office of the City Auditor, Portland, Oregon, March 2011 – Report #398

"The City of Portland operates water and sewer utilities, and is required by City Charter to spend ratepayer money from water and sewer operations on these utilities. Recent concerns about the use of utility ratepayer money for non-utility purposes led us to conduct this audit. Our objectives were to determine whether utility ratepayer money is used for non-utility purposes, and whether the decision making process and uses of ratepayer money are transparent to the public. The audit scope included utility ratepayer money spent by the Bureau of Environmental Services (which operates the sewer system) and the Water Bureau."

"Most City spending of ratepayer money was both related to providing a utility service and approved through the complete public budget process. However, we identified other examples where this was not the case. We found that ratepayer money spent by the City falls into three categories:

1. Ratepayer money spent for purposes directly linked to providing water and sewer services that also followed the City's complete fi nancial planning and budget process.
2. Ratepayer money spent for purposes not directly linked to providing water and sewer services, but followed the City's complete financial planning and budget process.
3. Ratepayer money spent for purposes not directly linked to providing water and sewer services, and did not follow the City's complete financial planning and budget process."

"The items to consider when making decisions regarding the spending of ratepayer money are whether the utility charges are just and equitable and based on reasonable cost-of-service principles, whether the revenue is spent on utility service related purposes, and whether the utility system is operated in an efficient and effective manner."

1.3 "Portland Water Bureau: Further advances in asset management would benefit ratepayers"
Office of the City Auditor, Portland, Oregon, June 2012 – Report #405

"Water users depend on Portland Water Bureau assets – pipelines, pump stations, tanks, and other equipment that supply homes and businesses with clean water. These physical assets are valued at $7 billion. The Bureau supplies ~100 million gallons of water a day. Asset failures such as pipe breaks could result in health emergencies and significant repair costs."

"City policy requires bureaus to maintain assets in good working order to minimize future costs of maintaining and replacing them, especially to avoid costly deferred maintenance."

We found that the Bureau has developed an overarching data management strategy, but has not yet implemented key tasks to meet general Bureau needs nor to meet specialized asset management needs. For many years the Bureau has known about its data limitations. These limitations impact the data quality used for decision-making, and the efficiency of its business processes."

“Improving data management depends on leadership, dedicated technical resources, and assigning responsibility for making data management improvements.”

“We found that although the Bureau has defined its service levels, it is not using essential service levels systematically in budgeting.”

“The Bureau has not gotten agreement from representative customers that the identified service levels are appropriate for decision making. In addition, many of its 27 defined service levels do not clearly express which service is delivered, and some are not clear about what is actually measured.”

“Without plans decisions are made on a case by case basis by individual managers and the Bureau may not perform asset maintenance repair and replacement at the best times to save costs.”

“We also found that even when the Bureau had plans for asset groups, the extent of implementing the plans was unclear. Plans were partly implemented, but lacked elements needed for accountability.”

“City of Portland Auditor’s Office recommends that Commissioner in Charge direct the Portland Water Bureau to:

- Deploy resources, formalize leadership, and develop accountability structures to implement a data management approach that meets the Bureau’s asset management needs.

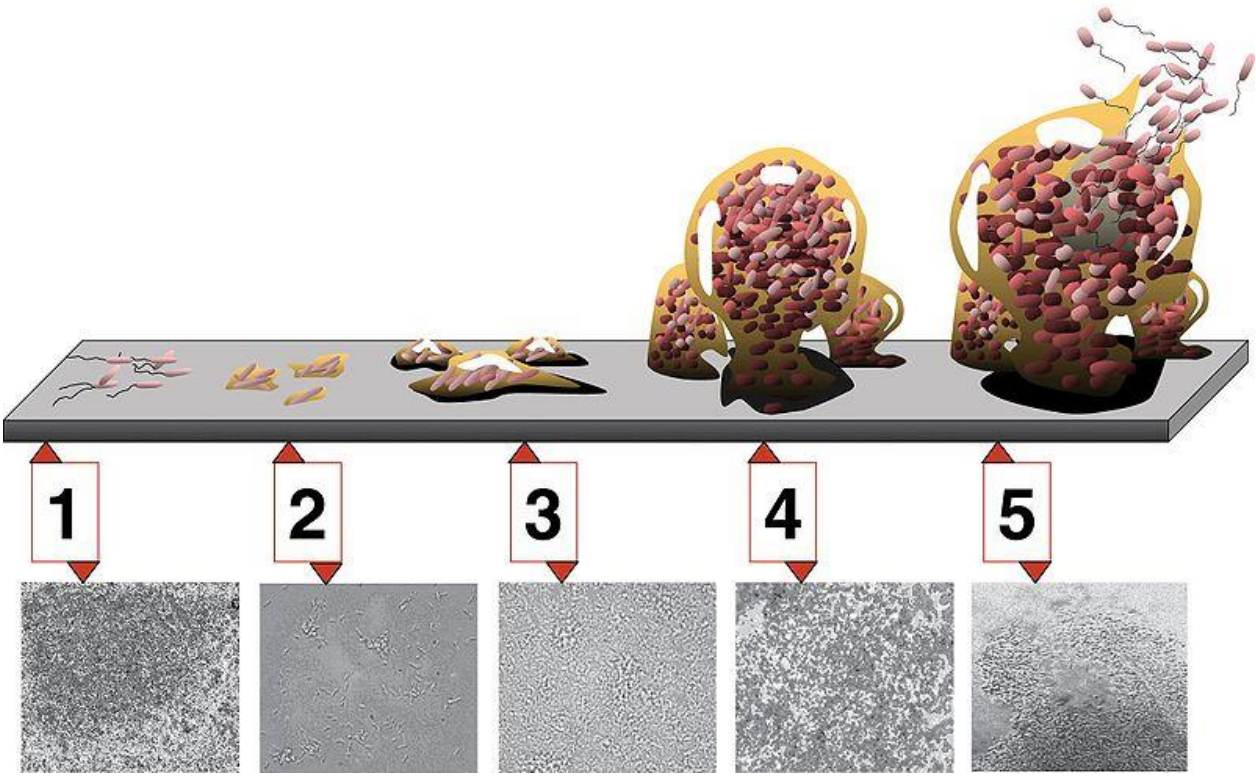
- Identify and clarify the essential required service levels, obtain confirmation from representative customers so that required service levels can be more useful in decisions about resource allocation, and apply service levels as budget criteria.

- Document management decisions and directions for action in Asset Management Plans to increase accountability and the likelihood of implementing the plans to benefit customers. Consider an overall asset management plan or other means of clarifying management policy and providing guidance for decision making.

- Incorporate an accountability framework throughout the Bureau to increase the likelihood of successfully meeting its objectives.”

Appendix 2

Portland Water Bureau Deferred Maintenance Leads to Biofilm Buildup and Puts Public Health At Risk



Process of water pipe biofilm development: 1. Attachment – 2. Permanent Attachment – 3. Maturation1 – 4. Maturation2 – 5. Dispersal of Microbes into Water System

✓ **What is biofilm in a drinking water pipe?**

Biofilm is a thin coating containing biologically active agents such as a slimy film of bacteria sticking to a surface of a structure. Biofilm has the consistency of an egg white. Some microorganisms may be primary pathogens that cause disease in healthy individuals or may be opportunistic that may affect immunocompromised individuals. (1) (2)

✓ **How does water pipe biofilm impact water quality?**

Biofilms can negatively impact water quality by increasing in size as a result of neglected water system maintenance. Colonies of biofilm bacteria continue to grow giving them protection from disinfectants such as chlorine and ammonia. Construction projects or changes in water pressure during a fire event can result in pieces of biofilm breaking off and contaminating the water system. Biofilms can also retain sediments harboring disease causing microorganisms adding to health risks if pipes are not scheduled for proper maintenance.

✓ **How does biofilm get into pipes and stay there?**

Biofilm microorganisms are present and found everywhere in a water system from the watershed to the faucet. They are part of a natural ecosystem and food chain structure except when water pipes are not properly managed.

✓ **Why do we want it removed routinely?**

Once microbial colonization of the pipe surface begins, the biofilm grows between a combination of cell division and recruitment. The microorganisms multiply and begin to draw other microorganisms into biofilm. We want to manage the biofilm volume and public health risk by routine flushing so biofilm build up does not interfere with water flow, microorganism build up, and disinfectant breakdown. City of Portland Auditor reports indicate Portland Water Bureau does not currently meet industry standards for distribution system maintenance. (3)

✓ **How does pipeline biofilm impact relate to covered reservoirs?**

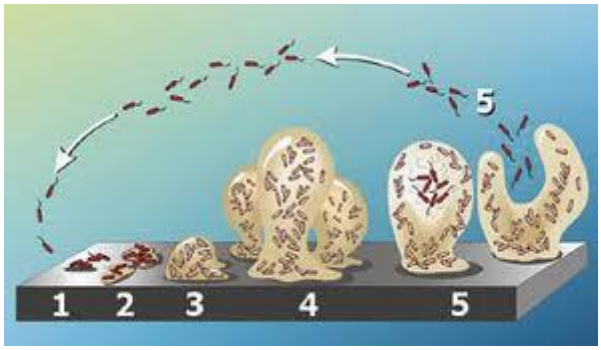
Poorly maintained water systems like Portland's have natural buildup of biofilm. As the biofilm increases because of prolonged PWB deferred maintenance chlorine demand increases leading to chloramine break down resulting in free ammonia. The free ammonia then begins to be metabolized by nitrifying bacteria leading to nitrification. Drinking water chloramine nitrification episodes in distribution systems occur in the dark (**in covered reservoirs, pipelines, taps, etc**.) leading to unwanted nitrate, nitrites, and NDMA toxic and carcinogenic chemicals. (4)

✓ **How does pipeline biofilm relate to open reservoirs**?

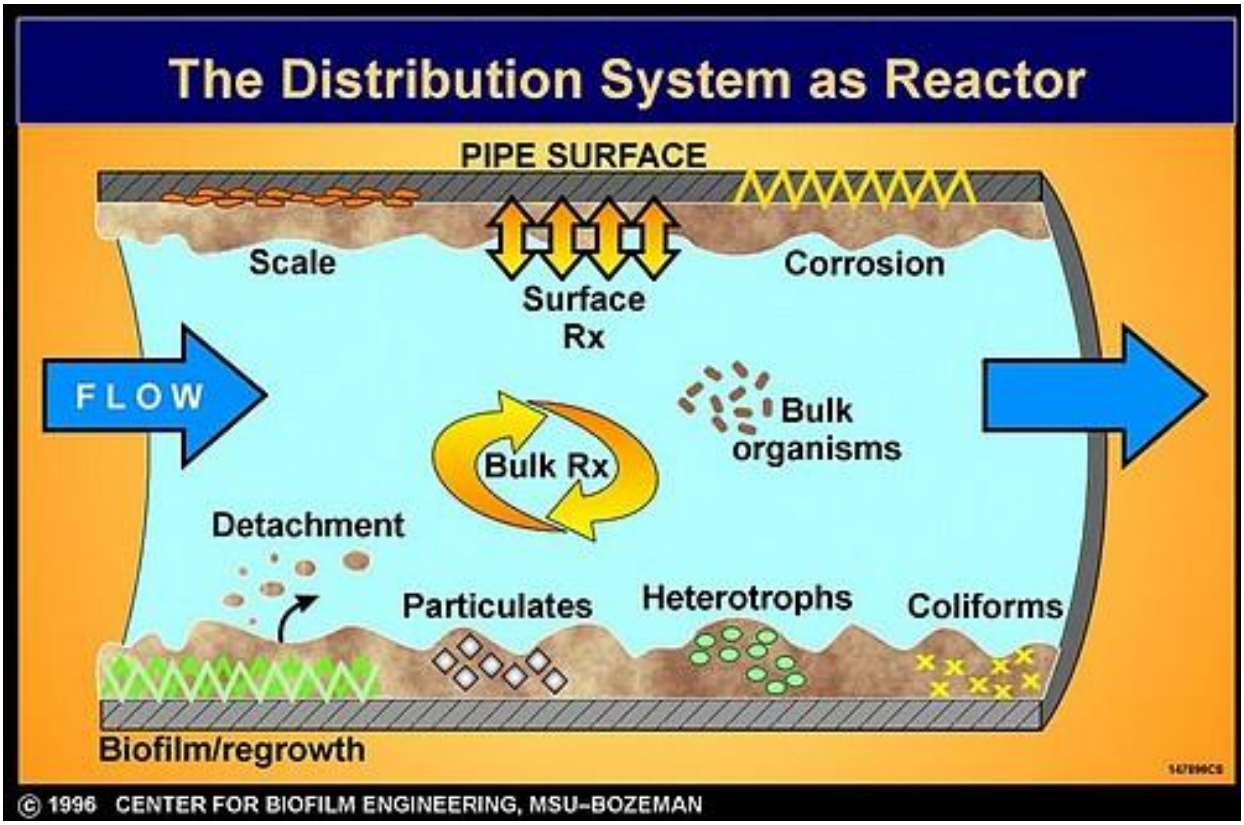
Because the open reservoirs have sunshine exposure that inhibits the bacterial nitrification process there is no relationship to the covered reservoir public health deficiencies. The sunshine also helps break down the unwanted toxic and carcinogenic chemicals; nitrates, nitrites, and NDMA that were generated in the dark pipes.

Notes:

1. Farlex Medical Dictionary, 2014
2. EPA, Health Risks from Microbial Growth and Biofilms, 2002
3. City of Portland Auditor, Portland Water Bureau Reports
4. EPA, Nitrification, 2002



Expansion of biofilm bacteria throughout unmaintained pipe system



Biofilm build up harbors disease causing microrganisms as was seen in the Fall 2013 fecal contamination event throughout the Portland drinking water system. The news story was reported by journalist Carla Castaño, KOIN 6 CBS. Illustration shows biofilm bacteria and other microorganism build up and sediment buildup on inside of water distribution system pipes

Appearance of biofilm buildup in water distribution pipes due to neglected flushing

Neglected pipe. Portland Water Bureau maintenance management has been below industry standards for more than a decade. Biofilm slime can exert a great demand for chlorine which further puts water quality and public health at risk.

Scheduled routine flushing of system can remove microorganisms. Above is an example of properly maintained water pipe that has been routinely flushed.

Appendix 3

News Report: Portland's Covered Reservoir Construction, ca. 2012–Present

Carla Castaño, journalist from KOIN 6 News, reported in February 2014 that the Powell Butte Reservoir has more than 1,000 cracks leaking thousands of gallons of water each day. Using emails from the Portland Water Bureau obtained through a public information request, KOIN 6 also learned the reservoir is four months behind schedule

Excerpts from the KOIN 6 News broadcast, "Powell Butte Reservoir failing leak tests" – Feb. 26, 2014 – http://koin.com/2014/02/26/powell-butte-reservoir-failing-leak-tests/

"It appears our reservoir leaking is increasing. We are at roughly 200,000 gallons per 24-hour day in the east and 80,000 gallons per day in the west," project manager Jim Hall wrote in one email. Hall agreed to speak with KOIN 6 News — until he spoke with the Portland Water Bureau."

"PWB has requested that all interview requests be coordinated through Tim Hall of the P-W-B," he wrote Wednesday."

"[Official PWB spokesman Tim] Hall spoke briefly with KOIN 6 News, but declined an interview. He released this statement:"

" 'Working with our contractor to find and seal these hair-width cracks is a normal and expected activity, and one of the final steps before the reservoir is put into service.' "

"Design and engineering groups who worked on reservoirs in this area told KOIN 6 News 1,200 cracks sounds like a high number and could be a design flaw. However, they also declined on-camera interviews."

"PWB said they are not over budget on the project and said they were behind schedule due to the unexpected rain."

"The Portland Water Bureau plans to have this reservoir online by March."

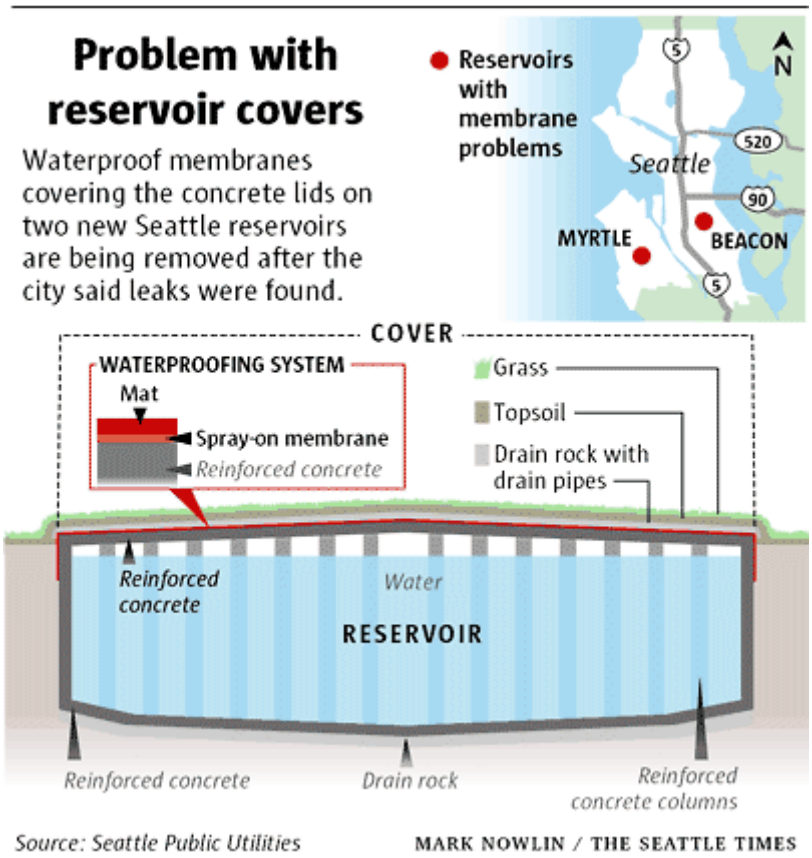
Appendix 4

News Reports: Seattle Covered Reservoirs, ca. 2009–Present

Construction concerns from poor planning and workmanship

4.1 "Major do-over for two Seattle reservoirs" – July 17, 2009
http://seattletimes.com/html/localnews/2009485902_reservoir17m.html

"As Carlos Balansay stood inside the cavernous new underground reservoir that would soon hold 50 million gallons of drinking water, the last thing the construction manager expected to see was water, dripping from a roof that was supposed to be watertight. The drops, first detected last August, have triggered a massive do-over project involving the removal of waterproof coating applied to Beacon Hill's new covered reservoir. A second new reservoir, in West Seattle, had the same orange coating applied to its concrete cover, and it, too, is being blasted off with pressure washers."



–Water proof membranes were removed and replaced with rubberized asphalt, a petrochemical that contains toxic and carcinogenic chemicals such as benzene.
–Microorganisms over time begin to biodegrade petrochemicals into smaller components that can enter drinking water through cracks.

4.2 "Hundreds of waterproofing leaks found at Myrtle, Beacon Reservoirs; 'membranes' now being dug up and redone" – July 13, 2009
http://westseattleblog.com/2009/07/wsb-exclusive-hundreds-of-waterproofing-leaks-found-at-myrtle-beacon-reservoirs-membranes-now-being-dug-up-and-redone/

"West Seattle Blog has learned that Seattle Public Utilities has ordered waterproofing work dug up and redone at two newly covered city reservoirs — Myrtle Reservoir here in West Seattle (photo) and Beacon Hill Reservoir — because of hundreds of leaks discovered in the 'membranes' applied to both projects."

4.3 "Questions over whether 4 buried reservoirs can withstand quake" – Nov. 16, 2012
http://seattletimes.com/html/localnews/2019692615_reservoirs16m.html

"Four years after discovering leaks in what were supposed to be waterproof reservoir covers, the city is investigating whether four new underground reservoirs were adequately built to withstand earthquakes."

Appendix 5

Correcting the Record: Annotated Portland Water Bureau documents

5.1 Excerpt from Portland Water Bureau Letter to the Oregon Health Authority RE: Public Health Risk Evaluation, Feb. 10, 2012

The established standard for all EPA drinking water utility decisions for years has been: "Science will determine the ultimate outcome." It is the benchmark for administering a waiver from the EPA "LT2 Rule". Yet in the case of Portland Water Bureau communications to the Oregon Health Authority to retain the open reservoirs, the relevant scientific approach to chemistry and microbiology has been consistently omitted or misstated.

In one such letter to the OHA, PWB was ostensibly making the case for the safe and reliable public health record of Portland's open reservoirs. Yet in a closing summary the PWB contradicts itself and undermines its own case with an incorrect disclaimer about the testing method used to detect microorganisms in the water samples.

Independent verification shows that AWWARF staff used a rigorous, inclusive testing method (EPA 1623 HV 1000) along with HCT 8 cell cultures during Portland's year-long "American Water Works Association Research Foundation 3021 Study" (AWWARF 3021) from 2008-09. The "HV 1000" modification of EPA's 1623 testing protocol refers to high-volume (1000-liter) samples that provide a *more* accurate assessment than standard 1623 testing. Therefore the disclaimer, shown in bold in the excerpt below, is erroneous.

Portland's AWWARF 3021 sponsored study verified zero (0) Cryptosporidium over a year-long testing period. Additionally, NO Cryptosporidium oocysts and Giardia oocysts were detected in any samples taken in 1994/1995 from Reservoir 6 and Reservoir 4 (PWB 1/28/10).

Excerpt from the PWB's 2/10/12 letter to OHA, with misleading disclaimer highlighted in bold:

> The current observable risk to public health is low. This conclusion is supported by the following:
>
> • No waterborne disease outbreaks in PWB's service area since inspections began – One criterion for maintaining a water supplier's unfiltered status is evidence that the water source "has not been the source of a waterborne disease outbreak." This criterion has been verified each year by the State of Oregon Drinking Water Program for the Bull Run source since 1991, the effective date of the Surface Water Treatment Rule.
>
> • A disease surveillance system sensitive enough to identify outbreaks – Oregon's disease surveillance, investigation, and reporting system has been used as a benchmark of excellence for foodborne outbreaks. The protocols, structures and reporting that make Oregon well-known for foodborne investigations are identical to those used for waterborne illness. Despite the challenges inherent in cryptosporidiosis surveillance, the systems in Oregon are sensitive enough to identify local outbreaks. For example, a 1998 outbreak was traced to a swimming pool in Multnomah

County. No cryptosporidiosis outbreaks in Multnomah County have ever been attributed to PWB drinking water as a source.

• Expert opinion is that the water system presents a low risk for cryptosporidiosis – A 2011 public health expert panel 10 examined the available data on cryptosporidiosis within the service area. The panel concluded that the data show no indication of an endemic disease burden due to Cryptosporidium from the water system and that no cryptosporidiosis outbreaks have ever been attributed to the Portland water supply.

• Record of safe operations – Because there is no sewage exposure in Bull Run, Portland has an outstanding record of safe operations. Yearly watershed inspections conducted by the State of Oregon since 1992 have also rated the water supply system as being in good operating condition. To ensure the continued safety of the system, many water quality parameters are monitored at the source and throughout the distribution system far more frequently than is mandated by law. In the event of a total coliform or E. coli detection, PWB has a rigorous response plan that includes a plan for notification, protocols for actions at the reservoir and in the distribution system, record-keeping, and follow-up actions.

• Water quality data collected from two of Portland's uncovered reservoirs indicated no presence of pathogenic Cryptosporidium – 36 water samples totaling 7,000 liters were collected from Reservoirs 4 and 5 between June 2008 and April 2009 as part of Water Research Foundation study 3021. **The testing method employed was not EPA Method 1623 and was instead designed to detect only the presence of infectious Cryptosporidium.** (emphasis added) Zero infectious oocysts were detected in the 36 samples.

5.2 Transcript of Very Important Letter from Friends of the Reservoirs to Portland City Council, Jan. 17, 2010

Mayor Sam Adams and City Commissioners
1120 SW Fifth Ave.
Portland, Oregon 97204-1926

RE: SDWA Open Reservoir Alternative Compliance

Dear Mayor Sam Adams and City Commissioners,

On December 16, 2009 EPA replied [1] to Commissioner Leonard's November 2009 request for clarification regarding the reservoir Variance application process. In this reply the EPA contends that the Variance provided for by Congress within the Safe Drinking Water Act (SDWA) is not available for the open reservoirs.

Ten months ago in March 2009 EPA responded in the same manner to New York City, another city seeking to retain their large Hillview open reservoir. New York was not deterred by EPA's response [2] and New York's legal team advised the Portland Water Bureau that the EPA's interpretation of the variance applicability is in fact wrong. We agree EPA is wrong.The SDWA clearly authorizes EPA to grant a variance from the LT2 "cover or treat" Cryptosporidium " treatment technique" requirement.

New York's Department of Environmental Quality spent more than a year compiling data, 161 pages, to support the retention of its Hillview reservoir. Unfortunately, during that same period of time the Portland Water Bureau focused a majority of its resources on developing and implementing fast-tracked reservoir burial projects, doing so without any public involvement.

New York City's extensive undeterred efforts to preserve their open reservoir provide a clear blueprint for action by the City of Portland. The community expectation is that the City makes a serious effort to secure the available SWDA reservoir variance, an effort evidenced in part by a Water Bureau work product. A single late-date letter to the EPA regarding a reservoir variance is not enough.

The Friends of the Reservoirs offer the following advice:

- Stop approving consultant contracts. The plan filed with the EPA in March 2009 gives YOU, City Council the power to alter the plan or the pace at which it is implemented. As noted in the fine print, the reservoir burial plan is contingent upon City Council approval of individual projects; it can be renegotiated with the EPA if the City Council does not approve the current schedule for any particular project within it.

- Require the Portland Water Bureau to prepare a detailed report documenting relevant scientific data in support of a reservoir variance.

- Seek an extension or deferral from the EPA from the burial projects. Community stakeholders have long recommended this action for both the open reservoirs and the source water requirement.

- Engage the assistance of the City Attorney and/or outside counsel Foley Hoag.

- Seek further assistance from Senator Jeff Merkley who has demonstrated his support for retention of the open reservoirs.

- Submit the data to the EPA or state of Oregon if the state has assumed Primacy for the regulation; in 2006 the state legislature unanimously approved and the Governor signed into law a state provision for variances with the full knowledge that Portland would be seeking such a variance for its open reservoirs.

- Do not rule out legislation. The opportunity for further Congressional intervention is not only possible but also likely in light of the acknowledged flaws with EPA's source water variance plan [3].

The American Water Works Association Research Foundation 3021 study preliminary report addresses the flaws of EPA's LT2. This report is discussed in the Friends of the Reservoirs September 2, 2009 letter to City Council.

In an internal EPA memo (3/31/09) addressing the reservoir applicable SDWA variance provision EPA's legal counsel states "The alternative treatment technique is available but not approvable because the only alternative EPA is aware of is a risk mitigation plan … (emphasis added)" EPA states that it wants to be consistent in its denial. Scientific data is an "approvable" way of demonstrating that our open reservoirs pose no greater risk to public health than covering or additionally treating [4].

The goal of the rule is to reduce disease incidence associated with Cryptosporidium and other disease-causing microorganisms in drinking water through "treatment techniques".

Scientific data from the recent American Water Works Association Research Association Foundation study AWWARF 3021 testing large volumes of water at the outlets of Portland's open reservoirs demonstrated that there are zero infectious Cryptosporidium in our open reservoirs. Burying, covering, or additionally treating the open reservoirs will not reduce the level of infectious Crptosporidium to below Zero. Portland's Total Coliform Rule data meets EPA standards. Our reservoirs are not subject to surface water runoff; they are cleaned twice a year.

As Commissioner Saltzman said last July about LT2, "this is a regulation in search of a problem... we should continue to pursue all alternative options beyond a large capital project."

Given the extensive scientific data in support of retaining Portland's open reservoirs, the broad-based community support for retaining our open reservoirs, the exorbitant cost of burial ($403million, $800 million with debt service) and the new public health risks [5] associated with covered reservoirs, it is incumbent on the City to push back and push back hard.

Sincerely,

Floy Jones
On behalf of The Friends of the Reservoirs

Cc Interested parties

[1] On January 12 during a Council session the community was told that a reply from the EPA on a reservoir variance had not been received; then on January 13 the Water Bureau issued a press release advising of the December 16 EPA response indicating that the original letter was somehow lost.

[2] Based on extensive review of water-quality data and other information collected by the Department of Environmental Protection, New York believes they can make the requisite showings required by the variance from the reservoir cover or additionally treat requirement. Portland's data is superior to that of New York. Portland can make the requisite showing that our open reservoirs have not caused Cryptosporidium or other drinking water related disease.

[3] EPA moved the goal post twice on the source water variance plan, which consumed more than 17 months. If EPA refuses to accept the new science that supports genotyping, confirming

whether any oocyst is harmful (dead or alive, "viability of the oocyst), and insists on sampling away from our source water out in the tributaries then further federal intervention will be necessary.

[4] While EPA has documented public health illness and deaths only with buried and covered storage, EPA failed to establish the general level of contamination in buried and covered storage thus EPA cannot factually state that buried and covered storage is more protective than open storage. See EPA white paper
http://www.epa.gov/safewater/disinfection/tcr/pdfs/whitepaper_tcr_storage.pdf

[5] EPA in its own white paper acknowledges that cancer-causing nitrification could be an unintended consequence of its LT2 reservoir requirement. Nitrification occurs in the absence of sunlight in chloraminated systems, see section 3.2 Absence of sunlight, pg.11
http://www.epa.gov/ogwdw000/disinfection/tcr/pdfs/whitepaper_tcr_nitrification.pdf

5.3 Transcript of Letter from Portland Water Bureau to the Oregon Health Authority, Aug. 23, 2011

Mr. David Leland, Program Manager
Oregon Health Authority Drinking Water Program
P.O. Box 14450
Portland, OR 97293-0450

Dear Mr. Leland:

Last Friday in a letter from Administrator Lisa Jackson, the EPA reversed its longstanding refusal to review the requirements of the federal LT2 rule as they pertain to uncovered finished drinking water reservoirs. The reversal came in response to a July 20th request from Senator Chuck Schumer to the agency.

In the letter, the EPA states:

"…as part of the Agency's Final Plan for Periodic Retrospective Review of Regulations, as well as the Safe Drinking Water Act (SDWA), the Agency will review the LT2 rule. In doing so, EPA will reassess and analyze new data and information regarding occurrence, treatment, analytical methods, health effects, and risk from viruses, Giardia, and Cryptosporidium to evaluate whether there are new or additional ways to manage risk while assuring equivalent or improved public health protection."

In light of this significant and unanticipated change in federal drinking water policy, the City requests an indefinite suspension in Portland's uncovered drinking water reservoir compliance schedule during EPA's review of the federal LT2 rule. It is critical to the City to remain in regulatory compliance with the LT2 rule during EPA's review and it therefore seeks written approval from the Oregon Health Authority Drinking Water Program of Portland's request for a suspension of the City's state approved schedule.

While it is uncertain what opportunities for alternative compliance may emerge from EPA's review, the City may choose not to proceed with its current plans for constructing additional storage at Kelly Butte until the implications of EPA's review and any subsequent changes in the federal LT2 rule are known.

Once the EPA's review is complete and Portland is given the opportunity to explore any alternative compliance methods that may become available, the City will propose a detailed amended schedule for compliance with the rule.

Please do not hesitate to contact me to discuss this matter further.

Sincerely,

David. G. Shaff
Administrator

5.4 Q&A: Refutation of Incorrect Portland Water Bureau Positions

Q1. *Why is Portland required to discontinue using the open reservoirs at Mt. Tabor Park and Washington Park?*

PWB Position – In 2006 the Environmental Protection Agency finalized the Long Term 2 Enhanced Surface Water Treatment Rule (LT2). The rule requires that water utilities discontinue the use of open finished water reservoirs or treat the water as it exits the reservoir for Cryptosporidium, Giardia, and viruses.

Correction – Since the 2004 comment period, 2006 final rule, and 2012 LT2 review, the EPA regulation has been challenged by water utilities such as New York City because it is scientifically unsupported. The EPA regulation is currently being reviewed for another two years, yet Portland City Council continues to unnecessarily fast-track closure of the safe and healthy water from the open reservoirs. City Council has replaced one reservoir with a covered reservoir that is poorly engineered and constructed that leaked millions of gallons of water per week. Cryptosporidium, viruses, and Giardia have never been detected in Portland's open reservoirs and water samples for bacteria support the safety of the water supply. Portland City Council has not referenced the public health science provided by citizens and documented in scientific literature in making its decisions about the open reservoirs.

Q2. *What about getting the "waiver" people are talking about?*

PWB Position – There is no such thing as a "waiver." When advocates speak of getting a "waiver" they are talking about legislative action by Congress to amend the federal Safe Drinking Water Act and exempt Portland from the rule which would then have to be signed by the President in order to become law. Commissioner Randy Leonard did ask our Congressional

representatives about the likelihood of obtaining legislative action on behalf of Portland and was told there was no support in Congress for such an amendment.

Correction – The "waiver" option always exists with EPA. It is a simple agreement between the EPA and the water utility. Portland has been under a "waiver" from EPA for decades under the Filtration Avoidance Determination – it is a waiver from filtering in effect today. The current situation regarding a waiver for Portland's open reservoirs is that City Council has never presented the scientific argument and formal request to EPA, as they have been repeatedly asked by advocates to do. If the "waiver" does not exist, then why are the New York City mayor, their Council and Congressional delegation asking for an EPA Waiver to keep their open reservoir? The waiver option definitely exists and is available to Portland if City Council will simply coordinate with the Oregon Health Authority to formally ask EPA for it. A waiver is the only permanent solution – Portland City Council needs to adopt the 2004 decision of Open Reservoir Independent Review Panel's majority vote outlining the well-defined scientific basis, asking for the EPA Waiver we so justifiably deserve.

Q3. *Does covered storage increase risks of gas buildup in the reservoirs?*

PWB Position – No. All reservoirs, covered or uncovered, have an air gap above the water surface that is vented into the atmosphere. For nearly 30 years, almost every customer of the Portland Water Bureau has consumed drinking water that has been stored in a covered reservoir or tank, and the water quality consistently meets or exceeds that of the open reservoirs.

Closed reservoirs, because they continue to have air exchange above the water surface, allow venting to occur. Screened vents in closed reservoirs are sized to ensure adequate air flow through the reservoir to prevent pressurization and also prevent "off-gas" buildup. Air quality has not been a problem at any of the Water Bureau's many closed reservoirs and tanks. The Water Bureau inspects and maintains vents and reservoir access points on a regular basis to prevent intrusions from animals, birds, or humans. Additionally, the State Drinking Water Program performs inspections at these sites every three years.

Correction – Another PWB answer that is false and has little scientific basis. Gas build-up such as methane in covered reservoirs has caused death from inhalation. Because covered reservoirs are so poorly maintained – being cleaned from 5-25 years – anaerobic (oxygen absent) bacteria in sediments and debris generate toxic gases. The open reservoirs acting as a barrier to toxic chemicals provide 100% efficiency and volatilization/vaporization of gases before they enter schools, homes, and businesses. Covered reservoirs cannot provide the same efficiencies in removing gasses. The vents of covered reservoirs are mostly allowing air IN to the reservoir to allow a smooth flow of water to the outlet and not allowing vacuum interference of water flow. Contrast in air efficiencies is shown by Open v. Powell Butte 2 inefficiency. For example: open reservoir at Mt. Tabor 6 is 100% efficient with open air and fountains. Powell Butte 2 at 5 acres ~ 218,000 sq. ft. with small vents at ~ 80 sq. feet opening is ~ .00037% of outside air communication venting footage efficiency.

Because of aeration, the quality of Portland's drinking water is excellent from open reservoirs. Changing to a covered drinking water system quickly degrades water quality with unwanted toxic and carcinogenic chemicals.

Q4. *Is radon an issue in Portland drinking water that will be affected by eliminating open drinking water storage?*

PWB Position – No. Radon is not detectable in Portland's main supply, the Bull Run watershed, which contributes on average over 97% of the total water supply. Radon gas naturally occurs in the western United States from underground rock formations. Portland has detectable amounts of radon it its water system from the Columbia South Shore Well Field which is used for emergency backup and to augment the Bull Run source to provide summer supply and constitutes an average of approximately 3% of the total water supply. However, these amounts do not cause the drinking water to exceed the proposed rule for radon.

Correction – Radon in drinking water at any level is very serious. EPA states "there is no safe level of radon, any exposure poses some risk of cancer."(EPA 2013) Portland receives radioactive radon water from Columbia South Shore Well field every year during maintenance or supplemental needs. CSSW can be used for emergencies at any time. Radon exposure for unknown periods of time can be expected to add public health risk entering homes, schools and work places. Radon in drinking water is not regulated by EPA. PWB does not have to disclose it exists in our water, but it is still there anyway producing radioactive materials we breathe and drink. That is why we need to retain open reservoirs for active ventilation and removal of radon gas before it enters homes, schools, and workplaces. EPA acknowledges radon to be the highest cancer causing risk of any drinking water contaminant. (EPA 1998)

Q5. *What is nitrification, and are closed reservoirs a risk in Portland's system?*

PWB Position – Nitrification is a biochemical process that in excess can interfere with the disinfection process in drinking water systems. The conditions within Portland's open finished drinking water reservoirs are more conducive to causing nitrification than the conditions within closed reservoirs. In Portland's drinking water system, the first step of the nitrification process – decomposition of chloramine disinfectant – is accelerated by loss of chlorine residual as drinking water passes through the open reservoirs. Exposure of chloraminated water over a large surface area to wind and sunlight and airborne pollutants such as pollen, dust, and animal waste has a significant role in this decomposition of the chloramines. Closed water storage facilities (i.e. tanks or covered reservoirs) do typically have the type of bacteria which are capable of feeding on ammonia and contributing to nitrification. However, without significant availability of ammonia from chloramine decomposition, or high temperatures, it is difficult for such bacteria to multiply and interfere with disinfection.

Correction – According to EPA, "consequently, nitrification episodes in distribution systems occur in the dark, i.e., in covered reservoirs, pipelines, taps, etc."(EPA 2002)

Open reservoirs inhibit nitrification, not encourage it; thus the explanation from PWB is far from truthful or accurate. Because PWB has neglected and deferred pipeline system maintenance, buildup of biofilm and sedimentation has increased the chlorine demand part of the chloramine molecule. This leads to ammonia/nitrogen exposures in the dark resulting in nitrification, as EPA has already acknowledged. Sunlight from open reservoirs disrupts the microbial nitrification process seen in the pipes and covered reservoirs. Unwanted nitrogen based chemicals like NDMA, nitrite, nitrate, etc. are also broken down by sunlight.

Q6. *What role does sunlight play in disinfection of drinking water in open reservoirs?*

PWB Position – Exposure to sunlight raises water temperatures and encourages the growth of algae and bacteria, which has been a recurring problem at open reservoirs. Sunlight can also contribute to an increase in disinfection byproducts, loss of chlorine, reduction of pH (which can cause corrosion in home plumbing), increased total coliform production, and taste and odor issues. Additionally, elevated water temperatures in the open reservoirs increases nitrification and growth of total coliforms. In highly controlled settings, processes similar to sunlight are used to provide water treatment; however, natural sunlight is not strong enough to provide demonstrable improvement in water quality. The exposure to sunlight actually has a greater number of negatives than positives. Sunlight is not a controllable treatment method, and cannot not be relied upon to adequately disinfect drinking water.

Correction – Sunlight has been recognized over the centuries as an important and valuable asset to drinking water safety and health referred to as "solar disinfection". The natural disinfection premise of open reservoirs was built on this principle. Algae and bacteria are growth based on the nutrients present such as nitrogen and phosphorous coming up from CSSW, not sunlight. Chloramine is a stronger molecule than chlorine and lasts longer in sunlight. (WHO 2004) Sunlight breaks down disinfection byproducts and other unwanted chemicals. Sunlight adds to the oxygenated water creating oxides for natural microbial control much on the principle of hydrogen peroxides. Algae are naturally present and remove acidic chemicals helping make water pH balanced. PWB's position does not align with fundamental principles of microbiology, physics, or chemistry.

"In addition surface waters are exposed to natural UV irradiation in sunlight which may damage oocyst (Cryptosporidium) DNA thereby inhibiting DNA replication and reducing infectivity." (AWWA RF 3021 2008)

Q7. *Why have waterborne disease outbreaks been associated with closed drinking water reservoirs?*

PWB Position – Portland has never had a disease outbreak caused by its closed storage reservoirs. Closed reservoirs that have had waterborne outbreaks have been in systems that experienced operational or mechanical failures and which have typically been infiltrated by animals. Open reservoirs, on the other hand, with their large water surface areas are much more vulnerable to animals entering, swimming, defecating, or dying in them. It is fairly common for Portland Water Bureau maintenance workers to find dead animals, excrement, and other contaminants in the open reservoirs – this water goes directly to the customers' tap without further treatment. Many of the documented outbreaks associated with closed reservoirs have been tracked to animals that have made their way into closed reservoirs. Animals are able to enter a closed reservoir through a broken or missing screen on its vent or overflow. Due to the screening of vents and overflow piping, evidence of animal access has never been discovered in our closed storage tanks. In Oregon, the State Drinking Water Program reviews the function of vent screens and overflows. The Water Bureau inspects and maintains vent screens and access points to its closed reservoirs and tanks on a monthly basis.

Correction – Portland's open reservoirs have never had a microbiological, chemical, or disease issue resulting in illness or death. Portland Water Bureau has never been able to demonstrate the debris they claim to find has a chain of custody originating from the open reservoirs. All we see is material placed on a tarp in the area outside the open reservoirs. Portland's open reservoirs have never had a negative impact on water quality as shown by no Cryptosporidium, viruses, or Giardia. Water samples for bacteria meet EPA and Oregon Health Authority standards. Covered reservoirs in Portland have had vandalism and dangerous chemicals thrown in them. As an example, the covered reservoir at the top of Mt. Tabor had hydrochloric acid and other debris dropped in it on May 28, 2012. This incident was never reported by Portland Water Bureau to the public.. Other covered reservoirs in Missouri and Colorado have had deaths from bacteria. Unlike the covered reservoirs, other open reservoirs across the United States do not have public health detriments either. Open reservoirs continue to provide safe and healthy drinking water for the citizens of Portland.

Q8. *What about rubberized asphalt coatings leaching into the water on a new reservoir?*

PWB Position – The new reservoirs planned at Powell Butte and Kelly Butte will be built of reinforced concrete. No rubberized asphalt coatings will be placed inside the reservoirs next to the drinking water. However, it is standard practice to apply waterproofing to the exterior of concrete structures of this type.

Correction – Rubberized asphalt is a toxic petrochemical based sealant used on concrete reservoir roofs and elsewhere on the covered reservoirs. As we have seen in the Powell Butte 2 construction, there are problems with hundreds of cracks in the roof and elsewhere. Applying the rubberized asphalt compound becomes a public health problem when it can permeate through cracks in the concrete. The caps are sealed with hot mopped coal tar that is also petrochemical based and has polycyclic aromatic hydrocarbon (PAH) cancer causing component. Rubberized asphalt has a benzene component that may be released through microbial degradation of the petrochemicals, thus reaching the drinking water through the many cracks in concrete.

These toxic component health issues are overlooked or dismissed by those who are decision makers in constructing these poorly planned and developed covered reservoirs. Standard practice in construction has little value to those who are at risk for toxic and carcinogenic chemical health issues. Rubberized asphalt is listed in California Proposition 65 as a cancer causing agent.

Q9. *Wouldn't it be cheaper to maintain the open reservoirs than build covered storage?*

PWB Position – The open reservoirs range from 100 to 117 years old. While they may look fine when full, they are in poor condition. The concrete is deteriorated, with cracks and chunks missing, the lining panels have eroded, and the steel pipes and valves are corroding. In the last 10 years $40 million dollars have been spent on reservoir maintenance, and the costs continue to climb. Perhaps most importantly, the reservoirs and pipes are not structurally sound enough to withstand an earthquake, and would be unusable for water storage at a time when they would be most needed. It has been estimated that the reservoirs would need over $125 million dollars in improvements to seismically reinforce them. This would still not meet the EPA's regulatory requirement to cover them or treat the water exiting them.

Correction – The public health benefits of the open reservoirs far outweigh the minor costs to restore and maintain them. Regular architectural and engineering reports from 1990 to 2009 confirm their condition as good with a small amount of restoration needed. The reservoirs are built soundly and have withstood earthquake activities. We reviewed the earthquake discussion during the 2004 Open Reservoir Independent Review Panel and it was confirmed that earthquakes are not a structural issue. There is no scientific or engineering reason the reservoirs cannot last many decades longer for our public health benefits. The PWB has unnecessarily spent hundreds of millions of dollars more than it would cost to maintain the open reservoirs to build covered reservoirs we do not need because water usage is declining. The engineering of Portland's open reservoirs was ahead if its time and has been shown to remain structurally solid.

Q10. *What was the AwwaRF Project 3021 sampling at Portland's open reservoirs and how does it relate to the requirements of the LT2 rule or a Variance for Open Reservoirs?*

PWB Position – In 2008 and 2009 the Portland Water Bureau participated in the Water Research Foundation (WaterRF) Project 3021, Detection of Infectious Cryptosporidium in Water. The purpose of the WaterRF project was to "examine conventionally filtered surface water for the presence of infectious Cryptosporidium using both cell culture techniques and molecular methods," and "attempt to repeat a recent study that reported a risk of infectious Cryptosporidium in filtered drinking water so that a scientifically sound consensus may be reached."

The Water Bureau's sample volumes ranged from 83.5 liters to 305.6 liters, for a total volume of about 7,000 liters during the study. Eighteen samples were collected approximately twice per month from June 2008 to April 2009. The results of the study were that no infectious Cryptosporidium oocysts were detected in any of the Water Bureau's samples. Additionally, no infectious oocysts were detected for any utility participating in this study.

EPA has indicated that variances are not available for the open reservoir requirements of LT2. Even if a variance to the open reservoir requirements of LT2 were available, the WaterRF study would not be adequate to achieve a variance.

The WaterRF study does not document the absence of Cryptosporidium and other public health risks in the open reservoirs. It simply shows that no infectious oocysts were detected in any of Portland's samples collected on 18 occasions. Given the literature that addresses the potential for direct microbial and chemical contamination and other forms of water quality degradation associated with 5 open finished water reservoirs, the data from the WaterRF study would not be considered convincing evidence for EPA, public health officials, or the scientific community in general.

Furthermore, the WaterRF study would not suffice as an adequate variance application (if one were available) for the following reasons:

1. The Water Bureau's sampling frequency and total number of samples from this study is insufficient compared to what EPA requested for the source water variance.
2. The Water Bureau's sampling location was only from Reservoir 4 (and occasionally from Reservoir 5) and not representative of all open reservoirs.
3. The WaterRF project did not use EPA Method 1623 for analysis. Method 1623 is required for LT2 monitoring.

4. LT2 samples must be analyzed by an EPA approved laboratory. The laboratory in the Texas Agrilife Research center used in the WaterRF study is not an EPA approved laboratory for Cryptosporidium.
5. The WaterRF research project did not sample for Giardia or viruses. The LT2 rule states that public water systems "using uncovered finished water storage facilities must either cover the storage facility or treat the storage facility discharge to achieve inactivation and/or removal of 4-log virus, 3-log Giardia lamblia, and 2-log Cryptosporidium." The open reservoir requirements of the LT2 rule are not solely concerned with Cryptosporidium.

Correction – In 2008 and 2009 the Portland Water Bureau participated in the American Water Works Association Research Foundation (AwwaRF) Project 3021 "Detection of Infectious Cryptosporidium in Water."

The Portland Water Bureau sampled 7000 liters at the outlet of Portland's open reservoirs with zero detects of cryptosporidium while utilizing a sampling method superior to that recommended by the EPA.

The EPA's 1623 HV sampling method has been widely criticized by municipalities and national professional associations because the agency's approved sampling method fails to distinguish between harmless and harmful Cryptosporidium, dead or alive Cryptosporidium, and between infectious and noninfectious varieties.

In a 2008 conference presentation AwwaRF 3021 researchers made this statement regarding the current EPA sampling method, "The detection of non-infectious oocysts or oocysts belonging to a species that is not infectious to humans could cause unwarranted concern for a contaminant that may not be significant public health risk."

Portland was one of 19 utilities participating in the study and, according to the study researchers; all utilities including Portland already meet the goal of the LT2 rule based on the statistically significant sampling. The goal of the LT2 rule is to reduce the level of disease in the community.

Both the Safe Drinking Water Act and Oregon state law provide for a reservoir "treatment technique" variance. It has long been recommended by community stakeholders that the Portland Water Bureau follow NYC's lead with regard to pursuing a reservoirs variance: collect and submit the AwwaRF 3021 cryptosporidium data (zero detects) along with Giardia and other necessary data to the State as part of a reservoir variance application.

Public health officials agree that there will be no measurable public health benefit from additionally "treating or covering" Portland's open reservoirs. The State Drinking Water Program now has primacy over the rule but can only consider a reservoir variance application if one is submitted. The City Council should act to ensure that the PWB applies for such a variance.* (*This statement was obtained from the Friends of the Reservoirs. The documents from the AWWA RF 3021 study have been read and agree with their position.)

"LT2 Rule" Waiver Supporters at Portland City Hall, Earth Day 2011

Drinking Water Public Notification

Public notification changes – Quick Look

EPA published revised public notification regulations on May 4, 2000 (65 FR 25981), as required by the 1996 SDWA Amendments. These changes make notification easier and more effective for:

Consumers - Faster notice in emergencies, fewer notices overall, notices that are easier to understand.
The new public notice requirements direct water suppliers to let people know within 24 hours of any situation that may immediately pose a health risk. Formerly, water systems had up to 72 hours to provide this notice. This change will make it easier for consumers to avoid drinking contaminated water. Water suppliers can now also combine notices for less serious problems and make notices shorter and easier to understand.

States & water systems - concise standard language and notices.
The new public notification requirements make the standard health effects language more concise. The new rule also gives water systems a standard set of procedures to follow, to make notices easier for water systems to issue, while providing better information for consumers.

Public notification helps to ensure that consumers will always know if there is a problem with their drinking water. These notices immediately alert consumers if there is a serious problem with their drinking water (e.g., a boil water emergency). For less serious problems (e.g., a missed water test), water suppliers must notify consumers in a timely manner. Public notice requirements have always been a part of the Safe Drinking Water Act; EPA recently changed these requirements to make them even more effective.

Water suppliers across the United States consistently deliver drinking water that meets EPA and state standards. Systems also test regularly for approximately 90 contaminants to make sure that no contaminant is present at levels which may pose a risk to human health. Water suppliers serving the same customers year-round summarize this information in an annual report which provides consumers with a snapshot of their everyday water quality.

Unfortunately, water quality can sometimes change. Despite the efforts of water suppliers, problems with drinking water can and do occur. When a problem with drinking water happens, the people who drink the water have a right to know what happened and what they need to do. The public notice requirements of the Safe Drinking Water Act require water suppliers to provide this notice.

As water suppliers test their water, they may discover that levels of certain contaminants are higher than the standards set by EPA or states. This might happen due to a change in local water conditions, heavy rainstorms, or an accidental spill of a hazardous substance. Water suppliers may also fail to

take one or a series of their required samples. Any time a water supplier fails to meet all EPA and state standards for drinking water (including missing required samples or taking them late), the water supplier must inform the people who drink the water.

How quickly do water systems have to send notices?

Depending on the severity of the situation, water suppliers have from 24 hours to one year to notify their customers after a violation occurs. EPA specifies three categories, or tiers, of public notification. Depending on what tier a violation situation falls into, water systems have different amounts of time to distribute the notice and different ways to deliver the notice:

- **Immediate Notice (Tier 1):** Any time a situation occurs where there is the potential for human health to be immediately impacted, water suppliers have 24 hours to notify people who may drink the water of the situation. Water suppliers must use media outlets such as television, radio, and newspapers, post their notice in public places, or personally deliver a notice to their customers in these situations.
- **Notice as soon as possible (Tier 2):** Any time a water system provides water with levels of a contaminant that exceed EPA or state standards or that hasn't been treated properly, but that doesn't pose an immediate risk to human health, the water system must notify its customers as soon as possible, but within 30 days of the violation. Notice may be provided via the media, posting, or through the mail.
- **Annual Notice (Tier 3):** When water systems violate a drinking water standard that does not have a direct impact on human health (for example, failing to take a required sample on time) the water supplier has up to a year to provide a notice of this situation to its customers. The extra time gives water suppliers the opportunity to consolidate these notices and send them with annual water quality reports (consumer confidence reports).

What information must be included in a notice?

All notices must include:

A description of the violation that occurred, including the potential health effects
The population at risk and if alternate water supplies need to be used
What the water system is doing to correct the problem
Actions consumers can take
When the violation occurred and when the system expects it to be resolved
How to contact the water system for more information
Language encouraging broader distribution of the notice

How often do violations occur that require a public notice?

Serious water quality problems are rare. Approximately 25 percent of the nation's 170,000 public water suppliers violate at least one drinking water standard every year and are required to provide public notice. In fiscal year 1998, there were more than 124,000 of these violations. Ninety percent of these violations are due to the failure of water systems to complete all sampling in a timely manner. About one percent of the time, water systems incur a violation for a serious situation where notification must be provided immediately (Tier 1).

EPA 816-F-00-021

May 2000

CITY OF

PORTLAND, OREGON

MONDAY, JUNE 3, 2013 – The City of Portland has been turned down several times over the years in its request to avoid or delay complying with public health requirements regarding open drinking water reservoirs. In May 2013, the Oregon Health Authority refused our latest request for a delay.

Faced with no other legal options and with deadlines looming, the city will move forward to meet the compliance timeline.

In approving the 2013-14 budget, we will continue moving forward on a multi-year plan for Portland's drinking water reservoirs.

The Environmental Protection Agency rule – known as the Long Term 2 Enhanced Surface Water Treatment Rule, or LT2 – is an unfunded federal mandate to not use uncovered reservoirs to store finished drinking water in order to reduce the risk of exposure to contaminants.

The city has been fighting LT2 since its inception.

- In 2006, the city appealed the EPA rule in federal court and lost.
- In 2009, the city sought EPA guidance on how to obtain a variance, and was told no variance was possible.
- When the EPA later moved regulatory oversight to the Oregon Health Authority, the city again asked for a variance and was turned down.
- In 2011, the city asked the state if a variance was possible and was told it was not.
- Later in 2011, the city asked the state to suspend enforcement of the provision until federal regulatory review was completed, and was turned down.
- In 2012 and again in 2013, the city asked the state for a delay. The city was turned down each time.

The reservoirs at Mount Tabor will be disconnected when new reservoirs, being constructed at Powell Butte and Kelly Butte, are completed. This is projected to take effect by December 31, 2015.

At Washington Park, one reservoir will be decommissioned and the other renovated and covered, gaining a reflecting pool similar to the current appearance atop the buried tank.

We are looking to the community to help us preserve these historic structures, and will conduct an inclusive public process to plan the future of our world-class parks. Recognizing the impact that compliance will have on rates, we will heighten scrutiny of all capital projects and contracts to keep rate increases as low as possible.

Portland is blessed with one of the best drinking water sources in the world. Therefore, the city will continue its strong advocacy in support of the Bull Run sourcewater treatment variance under a separate LT2 provision.

Charlie Hales
Mayor

Nick Fish
Commissioner

Dan Saltzman
Commissioner

Steve Novick
Commissioner

Main Identity

From: "Commissioner Fritz" <amanda@portlandoregon.gov>
To: "'Kate & Chris'" <samsa@pacifier.com>
Sent: Saturday, June 15, 2013 10:36 PM
Subject: RE: Please Ask for EPA Safe Drinking Water Act Waiver

Dear Katherin,

Thank you for your message. Unfortunately, I am the only one on the Council willing to keep seeking any kind of federal relief on the reservoirs, and there is no way for me to stop Mayor Hales from moving forward with disconnecting and covering them. I tried my best, for four years. Commissioner Fish is now in charge of the Water Bureau, so further community advocacy on this matter should be directed to him. He signed the letter authored by Mayor Hales calling a halt to efforts to avoid or defer action to take the open reservoirs off line, however.

Amanda
Amanda Fritz
Commissioner, City of Portland
The City of Portland is a fragrance free workplace. To help me and others be able to breathe, please avoid using added fragrances when visiting City offices.
To help ensure equal access to City programs, services and activities, the City of Portland will reasonably modify policies/procedures and provide auxiliary aids/services to persons with disabilities. Call 503-823-2036, TTY 503-823-6868 with such requests or visit http://www.portlandonline.com/ADA_Forms

From: Kate & Chris [mailto:samsa@pacifier.com]
Sent: Thursday, June 13, 2013 12:50 AM
To: Commissioner Fritz
Subject: Please Ask for EPA Safe Drinking Water Act Waiver

Dear Commissioner Fritz:

Thank you for your commitment to stopping the burial of Portland's reservoirs.

The voters understand that the corruption behind this project runs deep, and that standing up for the truth puts you in a difficult position.

The voters understand, as you do, that the LT2 rule is unscientific and likely to be overturned by the EPA within the next few years.

The voters understand, as you do, that LT2 was only passed because of strong pressure from Portland politicians whose campaign contributors stand to gain from reservoir burial contracts.

The voters understand, as you do, that this latest round of posturing with the Oregon Health Authority was yet another charade and a waste of taxpayers' money.

The voters understand, as you do, that this pork-barrel project was home grown, and that many of their own representatives and the City Attorney's office have been working against citizens' interests all along.

Most importantly, the voters understand, as you do, that it can all be stopped by simply asking the EPA for a Safe Drinking Water Act Waiver.

We are counting on you, Commissioner Fritz. Please don't let us down. Please fight the corruption in City Hall and do everything in your power to ensure that Portland's citizens get the EPA waiver they need

Katherin Kirkpatrick
1319 SE 53rd Avenue
Portland, OR 97215
(503) 232-8663
samsa@pacifier.com

Mon 6/17 2pm

Called Comm. Fritz' front desk & spoke to Jasmine 503.823.3008. Thanked her for email & asked her to have staff person contact me. It was her first day - she sounded young & didn't know what Mt Tabor was - but she was friendly. I id'd myself as a Mt Tabor resident also commented to stopping reservoir burial & expressed wish to speak w/ & offer help to Commissioner's staff person involved in the Commissioner's decision NOT to sign the Mayor's 6/3/2013 letter. She said she would try to ID the appropriate staff person & have them call me back tomorrow.

Parsons, Susan

From: Kate & Chris <samsa@pacifier.com>
Sent: Thursday, May 28, 2015 2:18 AM
To: Council Clerk – Testimony
Cc: Hales, Mayor; Commissioner Fritz; Commissioner Fish; Commissioner Novick; Commissioner Saltzman
Subject: LU 14-218444-HR-EN Testimony of Katherin Kirkpatrick 2015-05-28 -- Email 5 of 11
Attachments: LU 14-218444-HR-EN Testimony of Katherin Kirkpatrick 2015-05-28 -- Exhibit P.pdf

Dear Karla:
Please accept my attached testimony for submission into the record of LU 14-218444-HR-EN on the Mt. Tabor Reservoirs Decommissioning, scheduled for hearing this afternoon at 2:00 p.m.
This batch consists of Exhibit P in support of my legal brief. Kindly send me an electronic receipt when this document is are entered.

Thank you,
Katherin Kirkpatrick
1319 SE 53rd Avenue
Portland, OR 97215
samsa@pacifier.com

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 85, NO. B6, PAGES 3079-3088, JUNE 10, 1980

Radon Anomalies and Microearthquakes at Lake Jocassee, South Carolina

PRADEEP TALWANI, W. S. MOORE, AND JIN CHIANG[1]

Geology Department, University of South Carolina, Columbia, South Carolina 29208

Continuous low-level seismic activity was found to occur at Lake Jocassee after the impoundment of the reservoir in 1975. In addition to monitoring seismic activity we began (in January 1976) a series of geochemical measurements in an effort to search for precursors to $M_L \sim 2$–2.5 events. Discrete water samples were collected from wells and a spring, and their radon content was determined by scintillation counting. These data were comparable to those obtained from a continuous Rn monitor in the spring using an ionization chamber. Soil Rn measurements in track etch cups were started in 1977. The results of the data collected so far indicate (1) that long-term fluctuations occur in the radon concentrations in the spring water with a period of ~44 weeks (the radon content being 50–100% lower in summer and fall), (2) that anomalous changes in the radon concentrations have occurred both before and after earthquakes, the timing of the anomaly being dependent on the distance of the epicenter to the radon sample site, (3) that both high and low anomalous radon values occur, and (4) that the soil randon method using track etch cups is useful in determining areas of high and low Rn concentration but not for a study of short-term temporal changes.

INTRODUCTION

Following the M_L 3.2 earthquake near Lake Jocassee on November 25, 1975, we have continuously monitored that area for seismic activity. We have recorded continuous, low-level ($M_L \leq 2.6$), shallow (<4 km) seismicity. Several parameters suggest that the seismic activity at Lake Jocassee is induced by the impounding of water behind the 109-m-high Jocassee dam in the early 1970's [*Talwani et al.*, 1976].

At Lake Jocassee we monitored some seismic parameters (*ts/tp* and *P/Sv* amplitude ratio values, frequency, and location pattern in time and space of foreshocks) that can be useful as earthquake predictors. In January 1976 we also began to monitor the radon content in groundwater, and in 1977 we also began to monitor soil radon.

Although we are dealing with small earthquakes ($M_L < 2.6$) with small precursor times (≤15 days), their relative abundance (compared with, say, M 6 events) makes this study a large-scale laboratory experiment, the results of which can, perhaps, lead to a better understanding of the phenomena and be extrapolated to regions of large tectonic earthquakes.

In this paper we present results of over 3 years of simultaneous monitoring of radon concentrations in the Jocassee area and compare them with some seismic observations. We have detected periodic changes in radon concentration with a period of about 44 weeks. We have observed two kinds of radon anomalies: long-duration anomalies, which start several days before a $M_L \geq 2.0$ earthquake, (these are observed if the monitored site is in the epicentral area), and short-period anomalies, which occur a few hours before or after an event when the monitored site is outside the epicentral area. Increases and decreases in the radon concentration have been noted prior to seismic events.

In this paper we briefly note some of the recent research involving the monitoring of radon concentration as an earthquake predictor (a theme dealt with in detail in this special issue) and review some of the factors that affect these concentrations. Our results are then presented together with an example of the observation of a radon anomaly that was accompanied by a precursory change in the *ts/tp* ratio values before a M_L 2.3 earthquake on February 23, 1977.

[1]Now at City Services Company, Tulsa, Oklahoma 74102.

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0148-0227/80/009B-1481$01.00

After the first reported precursory increase in radon concentration in a deep well in the hypocentral region of the 1966 Tashkent earthquake (M = 5.3) [*Ulomov and Mavashev*, 1968], anomalous precursory changes have been reported for other large earthquakes in China [*Liu et al.*, 1975; *Raleigh et al.*, 1977] and for moderate earthquakes in California [*Craig et al.*, 1976]. *Liu et al.* [1975] with probably the largest data base, found both an anomalous increase and an anomalous decrease in the radon concentration in groundwater precursory to some Chinese earthquakes. They noted an anomalous increase in the radon content for wells on fractures or for wells located in the compression quadrant (for a strike slip fault). This increase was followed by a decrease in the radon content. Imminent earthquakes were preceded by a short-duration anomaly, while large events were associated with long-duration anomalies.

Using the track etch counting method, a method developed for the prospecting of shallow uranium deposits, the radon content in soil gas and its association with earthquakes is being studied in California [*Birchard and Libby*, 1976, 1978; *King*, 1976, 1978*a*, *b*], in the New Madrid region [*Steele et al.*, 1978], and in New York [*Mogro-Campero et al.*, 1978]. *King* [1978*a*, *b*] has reported observing possible radon anomalies associated with moderate earthquakes ($M \geq 4$). Similar changes were reported by *Birchard and Libby* [1976] for four southern California earthquakes ($M > 3$).

In the various examples cited above, the distance from the sensor to the epicenter has varied from tens (in California) to hundreds (in China) of kilometers. The observations were in different geologic settings and occurred in different seasons. Until recently, the effects of various factors that influence radon concentrations were not considered.

FACTORS THAT AFFECT RADON CONTENT IN GROUNDWATER AND SOIL GAS

Several factors are thought to affect the concentration of radon in groundwater and soil gas. These can be divided into two broad classes, environmental and geological.

Environmental Factors

Radon is soluble in many liquids: the solubility depends upon the liquid, temperature, and pressure. *Rogers* [1958] found that increasing the temperature decreased the solubility

of radon in water. Rogers' observations in the laboratory were corroborated by field data by *Chen et al.* [1973], who found that the radon content in a spring decreased when its temperature was increased. *Arndt and Kuroda* [1953] found that spring lost about 40% of their radon in the first meter from the point of emergence in the direction of turbulent flow. *Belin* [1959] suggested that the radon concentration in water depends on the transit time of fluid through the radon-producing region and the extent of differential leaching of subterranean rocks by acid water. A general correlation between high radon content and periods of high rainfall was documented by *Andrews and Wood* [1972].

Kovach [1945] suggested an inverse correlation between atmospheric pressure and radon content in soil. He also found that high wind velocities reduce the radon content in the upper meter of the soil and that frozen, snow-covered soil traps and accumulates radon.

Geological Factors

Chinese geologists found that acid igneous rocks had the highest emanation of radon among their samples [*Chen et al.*, 1973]. *Barretto et al.* [1975] indicated that radon emanation occurred not only from the pores of rocks but also by a diffusion of radon from the production sites within crustal structure to grain surfaces. They also found that the percentage of radon which escaped from minerals is not correlated to the uranium concentration but to the stability of the mineral structure and crystallinity. Xenotime and monazite, although they have higher uranium content, lost less radon than did zircon, sphene, and biotite, which have much lower uranium content.

Arndt and Kuroda [1953] and *Jurain* [1960] have found that the radon concentration of a stream was dependent on the geological formations that it passed over. The difference in radon concentration has been used for the possible exploitation of potassium-rich brines and prospecting for oil and gas [*Sterrett*, 1944; *Mazor*, 1962]. More frequently, it has served as an indicator of uranium deposits [*Wennervirta and Kauranen*, 1960; *Dyck*, 1969; *Dyck et al.*, 1976; *Gingrich and Fisher*, 1976]. *Stothart* [1948] and *Israel and Bjornsson* [1966] used an increase in radon emanation as a method to detect faults.

GEOLOGICAL SETTING

Water samples are collected for measurement of their radon content from different sites in the vicinity of Lake Jocassee (Figure 1). The locations of sampling sites and their radon contents are listed in Table 1. All these sites are located in the Henderson augen gneiss unit, which is the predominant country rock in the area. Its mineral analysis (Table 2) from *Hatcher* [1971] reveals that it contains 10.09% biotite, 0.29% sphene, and 0.29% zircon. These three minerals have high radon escape rates [*Barretto et al.*, 1975] and possibly account for the observed radon concentrations in the waters in the Jocassee area.

EXPERIMENTAL MEASUREMENTS

Most of our measurements of ^{222}Rn are based on discrete samples collected in the field in evacuated 125-m bubbling flasks. These are returned to the geochemistry laboratory, where radon is stripped and then measured in a scintillation cell. This procedure is that described by *Broecker* [1965] and modified by *Moore* [1969]. The radon system has an efficiency of about 75% and a sensitivity of less than 0.1 pCi/l (picocuries per liter). Precision is estimated to be ±5%.

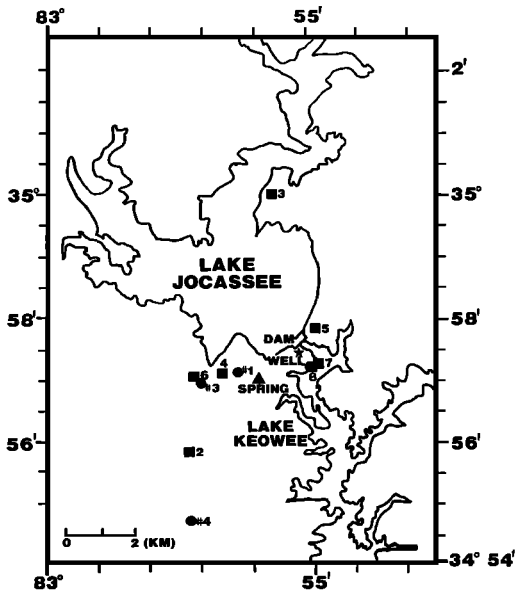

Fig. 1. Location of radon sampling sites. The wells (circles) and spring (triangle) were monitored regularly. Single test sample sites are shown by squares.

Data for some wells and springs and the lake water are given in Table 1. These data indicate that the wells and springs are significantly enriched in radon relative to lake water. Well 3 is about 20 times richer in radon than the well associated with the 1966 Tashkent earthquake. We concentrated our efforts on wells and a spring.

Continuous Monitoring

L. Cathey of the Physics Department, University of South Carolina, designed, built, and field tested a continuous radon monitor [*Cathey*, 1977]. This was first deployed at the spring on November 10, 1976. The sample of radon is stripped from the water with nitrogen bubbles. The flow is directed into an ionization chamber, where the induced ionization is collected as a current and fed to an electrometer circuit to measure the current. Since the current is proportional to the number of alpha decay events per unit time, we can record the concentration of radon in the ionization chamber on a multipoint recorder. If the flow rates of springwater through the bubbler and of gas bubbles into the ionization chamber are constant, the concentration of radon in the ionization chamber will be proportional to the radon concentration the springwater. Temperature affects the proportionality constants for both these rates. The recorder also records the water and chamber temperatures so that appropriate corrections can be made. The response time of the instrument is from 2 to 4 hours. This instrument was in continuous operation from January to March 1977, during the time of a $M_L = 2.3$ event on February 23, 1977.

Soil Radon

We have also experimented with track etch cups to measure soil radon. We have deployed arrays of 25 cups. These were similar to the cups described by *King* [1977*a*] and were buried at depths of 0.7 m for periods of 14–50 days.

RESULTS AND DISCUSSION

We began to monitor the waters in the Lake Jocassee area in February 1976. Duke Power Company monitored the ra-

TABLE 1. Free Radon in Jocassee Water Area

Site Description	Latitude, N	Longitude, W	Date Collected	Radon Concentration, pCi/l
Lake Jocassee water at boat dock	34°57.16′	82°56.84′	Feb. 12, 1976	6.2
Well 1 (20 m deep)	34°57.22′	82°56.38′	Feb. 12, 1976	$1.40 \times 10^3 \pm 1.0 \times 10^2$
Well 3 (56 m deep)	34°57.02′	82°57.01′	Feb. 12, 1976	$2.07 \times 10^4 \pm 1.45 \times 10^3$
Well 4 (78 m deep)	34°54.55′	82°57.15′	Feb. 27, 1976	$1.44 \times 10^4 \pm 1.0 \times 10^3$
Spring	34°57.01′	82°55.84′	May 19, 1976	$5.58 \times 10^3 \pm 3.9 \times 10^2$
Stream at ODL (2)*	34.55.82′	82°57.65′	Nov. 11, 1976	$3.86 \times 10^3 \pm 2.7 \times 10^2$
Spring near BG3 (3)	35°00.00′	82°55.65′	Nov. 11, 1976	$1.30 \times 10^3 \pm 9.1 \times 10$
Well 5 (4)	34°57.12′	82°56.78′	Dec. 8, 1976	$5.26 \times 10^2 \pm 3.7 \times 10$
Microwave tower (5)	34°57.79′	82°54.95′	Jan. 6, 1977	$2.13 \times 10^3 \pm 1.5 \times 10^2$
Holcombe spring (6)	34°57.10′	82°57.04′	Jan. 28, 1977	$2.23 \times 10^3 \pm 1.6 \times 10^2$
Trailer's water (7)	34°57.19′	82°54.74′	Feb. 10, 1977	$5.06 \times 10^3 \pm 3.5 \times 10^2$
Well near trailer (8)	34°57.16′	82°54.81′	Feb. 15, 1977	$3.61 \times 10^3 \pm 2.5 \times 10^2$

One picocurie per liter (pCi/l) is equal to 2.2 disintegrations per minute per liter (dpm/l).
*Numbers in parentheses refer to locations in Figure 1.

don content in wells 1 and 3 by gamma counting radon daughters for the period January–April 1976. Our data which are in good agreement with theirs were used to obtain the natural background (Figure 2). These data indicate that the background radon concentrations in wells 1 and 3 about 1.5×10^3 and 2.0×10^4 pCi/l (1 pCi = 2.22 dpm), respectively. Some anomalous changes from the background values are discussed below.

Although we observed anomalies, we could not be certain that some of the variations were not caused by the fact that the wells fed holding tanks where the water remained for indefinite lengths of time. As these wells were being used for domestic purposes, this time was dependent on many factors. Since we were unable to sample the water before it entered the holding tank, we abandoned the well-monitoring program in favor of monitoring a free-flowing Spring (Figure 1). The spring samples were collected within 30 cm from the point of its emergence from the ground.

Figure 3 shows radon data for the spring along with rainfall, lake level, and seismic activity plotted in number of days from May 1, 1976. We have also measured the temperature of the springwater and found it to be constant at 14 ± 1°C in all seasons.

We find no systematic correlation (correlation coefficient 0.06) between the radon concentration in the spring and lake level, suggesting that they are hydrologically independent. However, on comparing the variations in the radon level (from a background value of $4.6 \pm 1.1 \times 10^3$ pCi/l) with rainfall we note a decrease in radon concentration immediately after a heavy rainfall. This is probably caused by shallow recharge of the spring (cf. Figure 4).

Rainfall Effects

To study the effect of rainfall on the radon concentrations of the springwater, the two were compared for the period May 1976 to October 1978. It was soon apparent that there were long-term fluctuations in the radon values. Radon concentrations in the periods September–October 1976, August–September 1977, and May to early July 1978 were lower than at other times and have been grouped as the 'low period'; the remaining data constitute the 'high periods.'

Rainfall values (to the nearest 0.05 in.) are daily readings at 0800 (local time) and represent the total rainfall in the previous 24-hour period. These are plotted (Figure 5) against radon concentrations (to the nearest 0.1×10^3 pCi/l) of samples collected within 24 hours. If there was an earthquake with $M_L \geq 1.5$ located within 6 km from the spring, it is indicated by an open circle. The radon concentrations for periods of no rain are shown on a frequency plot (inset Figure 5). Those radon readings which were taken within 24 hours of a $M_L \geq 1.5$ event are shaded on the frequency plots.

From Figures 5 and 6 we note that the radon concentrations can be divided into two periods—those of high and low values. These changes we believe to be long term, and they are discussed below.

In both periods there is a large scatter in the radon values, which is maintained as the radon values decrease with an increase in rainfall—the decrease being marked for water samples collected within 24 hours of a $M_L \geq 1.5$ earthquake have extreme radon concentrations—suggesting a possible relationship. The short-period anomalies are discussed in a later section.

Long-Term Changes

In addition to short-period changes in radon concentration due to seismic events or rainfall we have also noted long-term fluctuations. To observe these, we obtained weekly averages of radon concentrations, eliminating those that showed an obvious decrease due to rainfall.

These data, which are averages of one to four discrete measurements (from May 19, 1976, to October 24, 1978, 127 weeks), are shown in Figure 6. The larger earthquakes ($M_L \geq$

TABLE 2. Average Modal Analysis of Henderson Augen Gneiss [after *Hatcher*, 1971]

Mineral	Analysis, %
Quartz	35.56
Microcline	23.57
Microperthite	
Oligoclase	20.86
Myrmekite	5.29
Biotite	10.09
Muscovite	2.81
Chlorite-biotite	
Epidote	1.10
Sphene	0.29
Zircon	0.29
Amphibole	
Carbonate	
Garnet	
Opaque	0.09

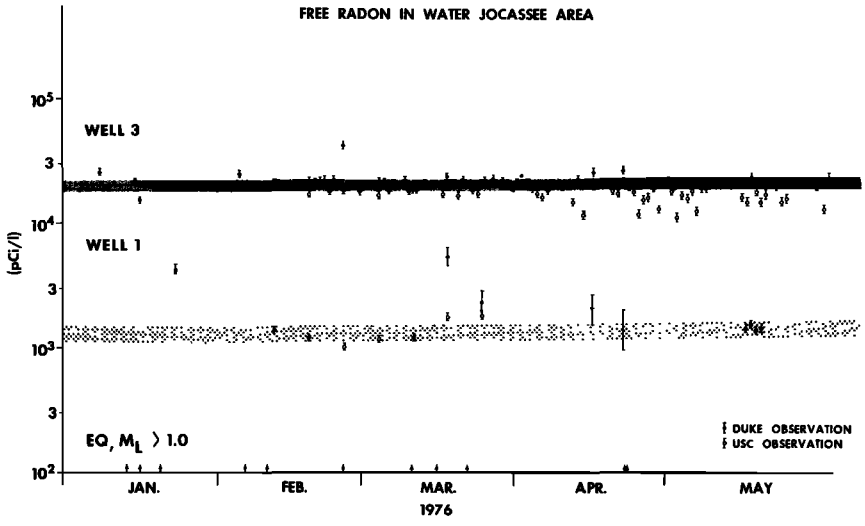

Fig. 2. Radon concentrations in wells 1 and 3 for the period January–May 1976. Earthquakes with $M_L \geq 1.0$ are indicated by arrows.

2.0) that occurred during this period are indicated by vertical bars. From May 1976 to the end of August 1976 (week 15) the radon values remained fairly consistent at about 5000 pCi/l. Between September and mid-October 1976 (weeks 15–21 in Figure 6 and days 105–150 in Figure 3) there was a factor of 2 decrease in the radon concentration, and these values stayed low until the beginning of November 1976 (week 24). This was also a period of decreased seismic activity in the Lake Jocassee area, and the radon decrease was not associated with rainfall (Figure 3). At that time it was not clear whether this decrease was seasonal and due to possible changes in the water table (and/or temperature) or was related to a decrease in seismicity [*Talwani et al.*, 1977].

We noted that around July 27, 1977 (week 63), the radon values decreased again and stayed low for about 8–9 weeks. During this period of low radon values there was a brief period of increase, which we associated with a M_L 2.6 event on September 7, 1977 (in week 68). Two of the radon concentrations ($\geq 5.0 \times 10^3$ pCi/l) occurred during the low period (Figure 5). The next period of decreased radon concentration was between weeks 103 and 112 (May–June 1978).

Thus we note three prolonged periods of radon decrease,

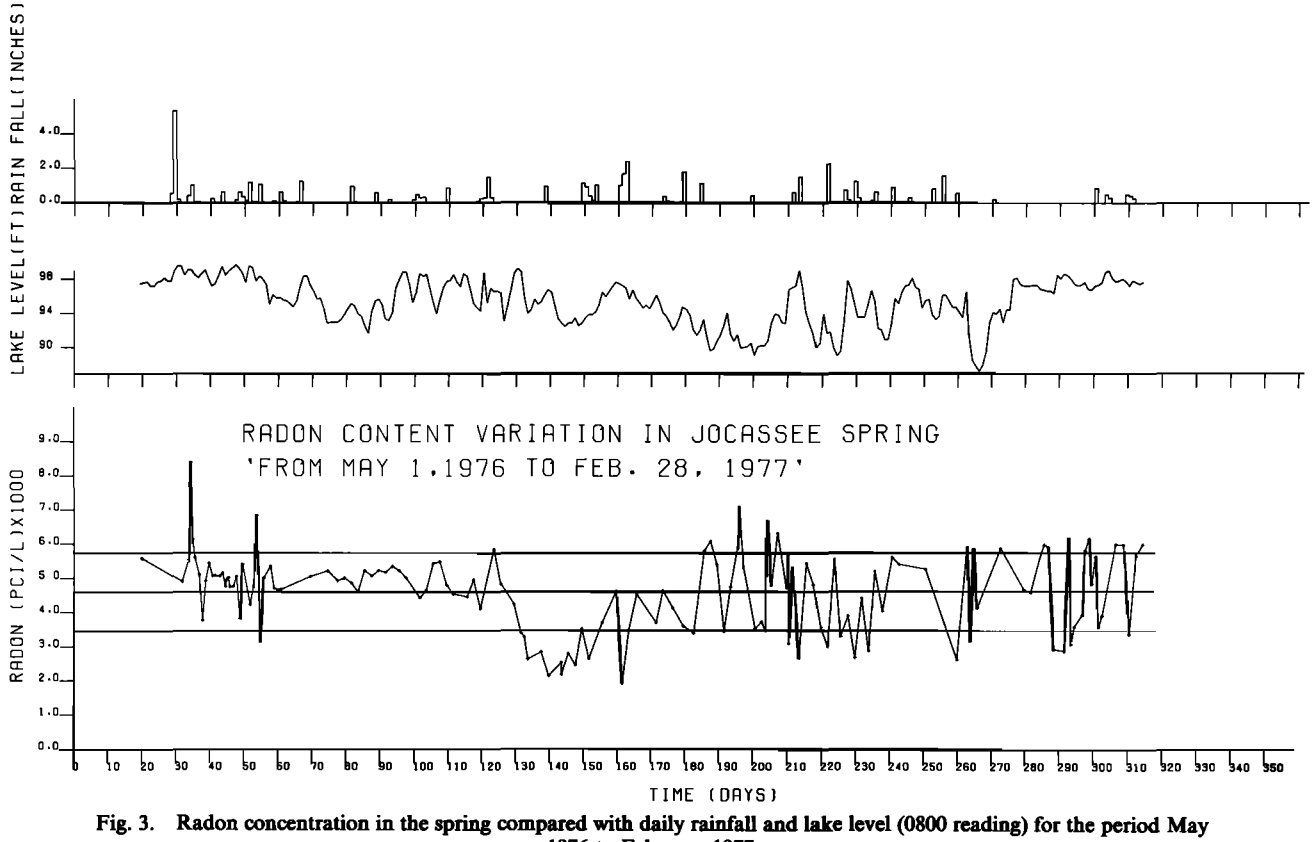

Fig. 3. Radon concentration in the spring compared with daily rainfall and lake level (0800 reading) for the period May 1976 to February 1977.

which do not appear to be related to water temperature (which stayed constant at 14° ± 1°C), lake levels, or rainfall. These periods (between weeks 15 and 24, 63 and 71, and 103 and 112) are separated by an average of 44 weeks. They occur in different parts of the year, namely, September–October 1976, July–September 1977, and May–June 1978. It is possible that they reflect some seasonal changes, for example, changes in the water table, or that they are related to a low seismic energy release observed during these periods.

Interestingly, *King* [1978*a*] finds a periodicity of 46 weeks for high radon concentrations in his data (soil radon over the San Andreas fault), which he attributed to seismic causes. In light of our finding approximately the same period between peak radon values (lows) we suggest that the effect of seasonal changes needs to be examined and to be removed from observed data to seek correlation of observed radon changes with seismic causes.

Short-Period Anomalies

At Lake Jocassee we are attempting to predict small (M_L = 2.0–2.5) seismic events, and thus the radon anomalies are expected to be sharp (7–15 days long). We need to collect samples at short intervals (6–8 hours) to detect some of these anomalies. However, sometimes our samples have been collected near the time of an event, and possible effects have been noted.

For example, there was a drop in well 3 from 2.20×10^4 pCi/l on January 15, 1976, to 1.56×10^4 pCi/l the next day. The latter reading was taken 8 hours after a $M_L = 2.2$ event, located about 2 km south of the well. Some of the other observed anomalies are shown in Figure 7. The level of radon on February 26, 1976, rose to twice the normal value (to 4.2×10^4 pCi/l), a M_L 1.5 event occurred at 1312 hours (EST) and at 1430 hours the radon count had decreased to 1.85×10^4 pCi/l. Next day the radon level returned to normal.

Two felt events that occurred on April 23, 1976, seem to have been preceded by an anomalous change in radon about half a day earlier at well 3, located about 2 km away (Figure 8). In the case of a $M_L \simeq 2$ earthquake on June 2, 1976, a radon anomaly was detected at the spring after the event which occurred about 6 km away. We did not observe any anomalous changes associated with some $M_L > 1.0$ events in March 1976 (Figure 6), as no samples were collected close to their times of occurrence. Interestingly, the events on February 26 and April 23 were located within 2 km of well 3, and the radon anomalies were observed within 12 hours of the events. We suggest that this observation indicates that both the epicentral area and the well were located in the 'region of earthquake preparation.' However, the event on June 2 occurred 6 km from the spring, and the anomaly was observed after the event. This observation indicates that if the two are related, a stress pulse emanating from the hypocenter traveled to the spring and there caused excessive radon to be released. (Unfortunately, we did not collect water samples from wells 1 and 3, data which could have tested our hypothesis.)

Thus the time of occurrence of the short-period anomaly appears to depend on its distance (among other factors) from the hypocentral region. This conclusion is in agreement with an observation reported by *Liu et al.* [1975], who monitored the radon content of a well and large blasts ($M \simeq 4^+$) at different distances from the well. The response which was found to be delayed depended on the distance to the blast. However, if the blast and the well were located on the same 'fracture,' the response was almost instantaneous.

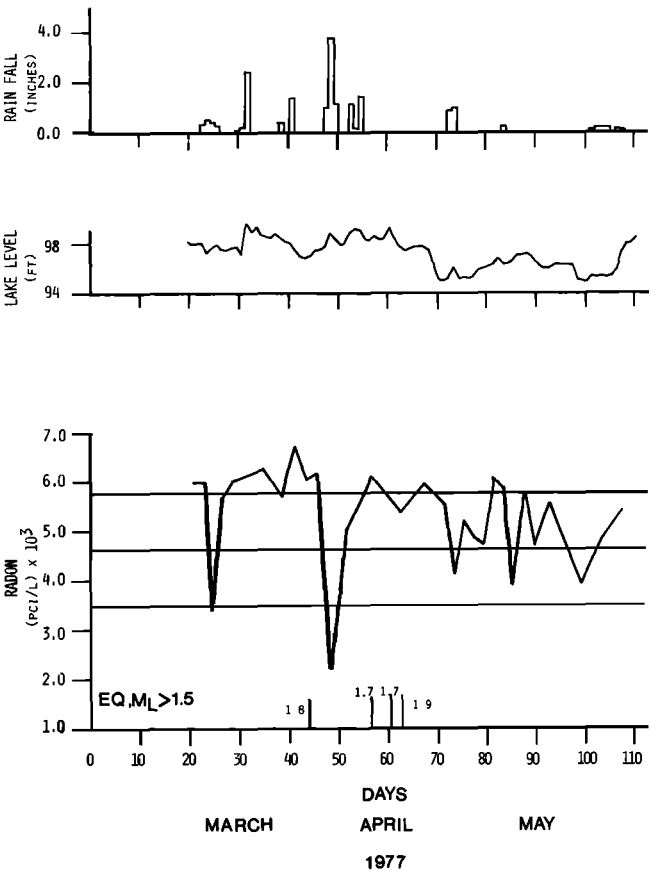

Fig. 4. Radon concentration in the spring compared with daily rainfall and lake level (0800 reading) for the period March–May 1977 to show the effect of dilution of springwater by rainfall runoff. Earthquakes with $M_L > 1.5$ are also indicated.

A Long-Period Radon Anomaly

As was mentioned earlier, we have been monitoring various seismic parameters at Lake Jocassee in search of precursors. A magnitude 2.3 event at 0850 UTC on February 23, 1977, provided us a test of our prediction program. This was the first instance that we know of (outside China) where an earthquake was predicted by both *ts/tp* ratio and radon anomalies [*Talwani*, 1979]. The earthquake was located within 1 km from both the spring and Lake Jocassee (Figure 8).

Besides monitoring radon (both continuously and discretely), lake levels, and seismicity we also obtained *ts/tp* ratio values for each located earthquake.

Some of the parameters that we are monitoring are shown in Figure 9, which covers the period from January 1 to February 28, 1977. The top row shows the continuous radon data at the spring plotted on an arbitrary scale. Diurnal fluctuations are readily seen. Discrete radon data (squares) have been superimposed on the continuous curve, and its scale in picocuries per liter is shown on the right-hand side. Daily rainfall recorded at the Jocassee dam is shown in the next row; *ts/tp* ratio values obtained from Wadati plots using three to five points are shown in the next row. The lake level (100 feet corresponds to 1100 feet above sea level) is shown in the next row. The magnitude 2.3 event on February 23 is shown by a vertical line.

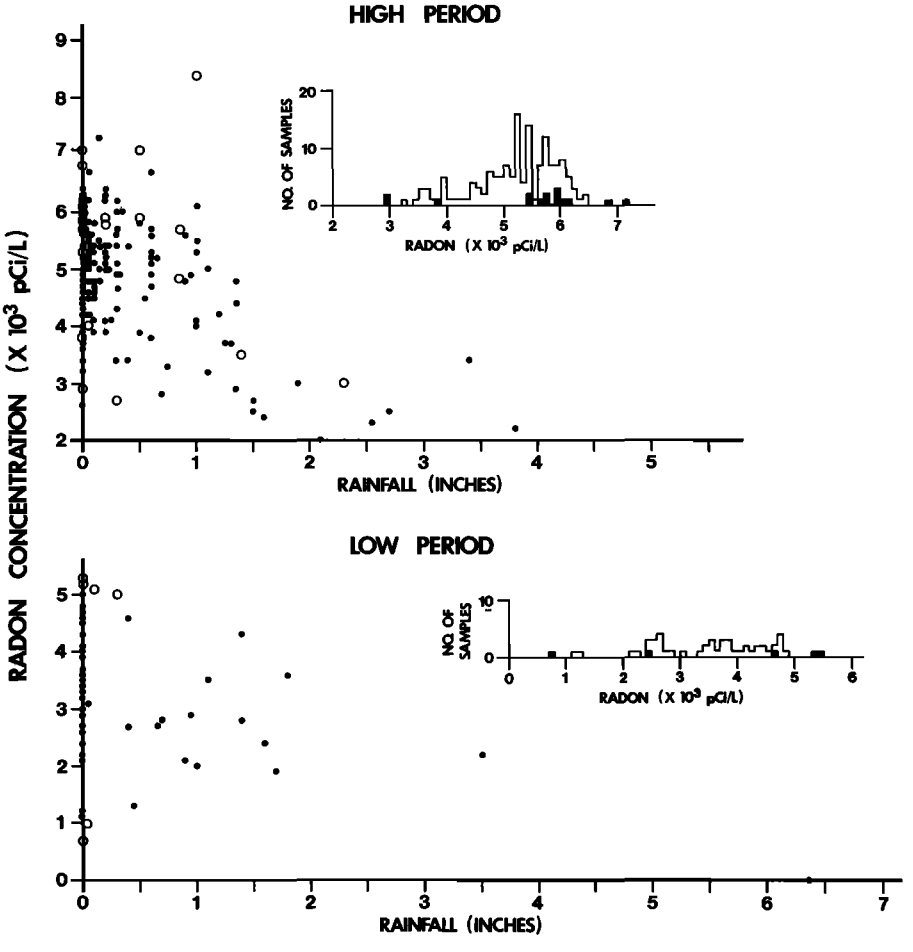

Fig. 5. Radon concentration in the spring plotted as a function of rainfall for the period May 1976 to October 1978. Data for 'low periods' of radon concentration (September–October 1976, August–September 1977, and May–July 8, 1978) have been separated (bottom) from the remaining data (top). Insets show frequency plots of radon concentrations for no-rain periods. Open circles and solid bars (inset) show radon concentrations of water samples collected within 24 hours of $M_L \geq 1.5$ earthquakes.

The top row in Figure 9 shows the continuous and discrete radon data at the spring. The background value at this location obtained from discrete data is $4.6 \times 10^3 \pm 1.1 \times 10^3$ pCi/l. In the continuous data there are two sharp decreases, one on January 10 and another on January 14, which are probably caused by shallow recharge of the spring by rainwater runoff. However, on or about February 8, 1977, there is a steady decrease in the radon concentration, becoming lowest on February 12, almost increasing back to its normal value on February 16, decreasing rapidly, and then returning to the background value on February 22. The discrete data are in excellent agreement with the continuous data. Samples collected on February 8, 9, and 10, 1977, have radon concentrations of 5.75×10^3, 5.97×10^3, and 5.93×10^3 pCi/l, respectively (Figure 9, top row), which are within the background range. On February 12 the radon concentration dropped to 2.93×10^3 pCi/l and stayed low until February 15. This was also a period of low *ts/tp* ratio values. These two anomalies occurring simultaneously alerted us to the possibility of an earthquake. From February 20 we collected the discrete water samples every day. The radon concentration returned to a high value on February 21 (5.81×10^3 pCi/l) and increased to 6.16×10^3 pCi/l on February 22. The next day a M_L 2.3 earthquake occurred at 0850 UTC. No rainfall was observed during the anomalous period, so the observed low was not due to dilution by rainfall runoff. A decrease in the radon values after the earthquake was probably associated with rainfall.

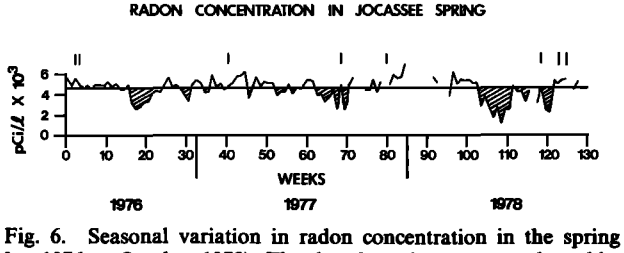

Fig. 6. Seasonal variation in radon concentration in the spring (May 1976 to October 1978). The data have been averaged weekly, and those affected by rainfall, disregarded. Vertical bars indicate times of $M_L \geq 2.0$ earthquakes.

When we talk of precursory radon anomalies associated with earthquakes, especially in light of Russian data at Tashkent [*Ulomov and Mavashev*, 1968], most authors [*Press*, 1975; *Scholz et al.*, 1973; *Mjachkin et al.*, 1975; *King*, 1976; *Craig et al.*, 1976] anticipate a radon high as a precursor. However, *Liu et al.* [1975], with a much larger data base, pointed out that the distribution of the shape of the anomaly on the ground surface has some definite relationship with the source mechanism. For the Lu Ho (magnitude 7.9), Bo Hi (magnitude 7.4), Fung Nan (magnitude 5.2), and Sa Hu (magnitude 5.2) earthquakes, positive radon anomalies were observed before the earthquake when the observation points were located in the

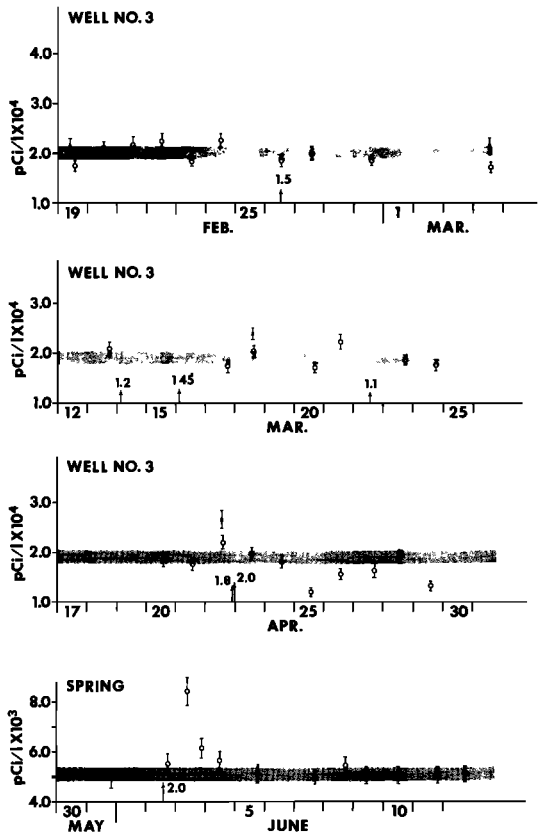

Fig. 7. Short-period anomalous changes in radon concentration in groundwater, possibly related to seismic events.

compression quadrant (Figure 10*a*). For observation points located in areas of dilatation, low radon values (or negative anomalies) are obtained. They pointed out that 'this phenomenon has been observed by many institutions....'

Another example taken from *Liu et al.* [1975] is also shown in Figure 10*b*. Here we note that the response of two wells is opposite, a positive radon anomaly at Hown-Sun well 1 and a negative radon anomaly at Jin Ti well. The locations of the two wells with respect to the epicenter were not given.

Thus we conclude from the Chinese examples that a negative radon anomaly is observable and depends on the location of the sampling site with respect to the epicenter.

A decrease in the radon content in the water coming out from rocks could be accounted for by closure of cracks and a decrease in the surface area from which radon emanates. An alternate explanation might be that even if more cracks and surface area are produced, releasing more radon, water with lower radon concentration (lake or stream water in the hypocentral area) penetrates, diluting the radon concentration of in situ water. This dilution would have an overriding effect on the increased radon produced by opening cracks and could account for the observed negative anomaly. The exact cause of this observed low radon anomaly is not very well understood.

An interesting aspect of this earthquake is that besides a radon anomaly it is also associated with a simultaneous *ts/tp* ratio anomaly.

The *ts/tp* ratio values obtained from Wadati plots showed a systematic decrease (from a background value of 1.69) on or about February 9, the same time as the onset of the radon anomaly. There was no marked increase in seismicity; however, in view of the simultaneous onset of the radon and velocity anomalies we term the seismic events between February 8/9 and the main shock on February 23 foreshocks. Interestingly, the *ts/tp* ratio values increased to 1.68 on February 22, the same time at which the radon values increased to the background value.

This long-period radon anomaly was observed in a spring located near the epicentral area. We suggest that the stresses responsible for the earthquake were also responsible for the radon anomaly. The duration of the radon anomaly (14 days) is consistent with the precursor time for a M_L 2.3 earthquake [*Talwani*, 1979].

Soil Radon

At the suggestion of C. Y. King of the U.S. Geological Survey we installed track etch cups in the vicinity of Lake Jocassee (Figure 11). Over a 1-year period these cups were changed at different intervals. In general, they were useful in documenting spatial and temporal differences in the soil radon as illustrated by the following example. Track counts for two time periods are shown in Figure 12. For the period September 2–16, 1977, for 25 samples the mean value is 703 with a standard deviation of 453. For December 13, 1977, to February 1, 1978, the mean value is 321 with a standard deviation of 200. There are two interesting aspects of these results. First, cups in the same region have high values (solid circles), indicating that the natural radioactivity there is higher than at other sites. Second, the radon count in September for a 2-week period is about twice that for a 7-week period in Decem-

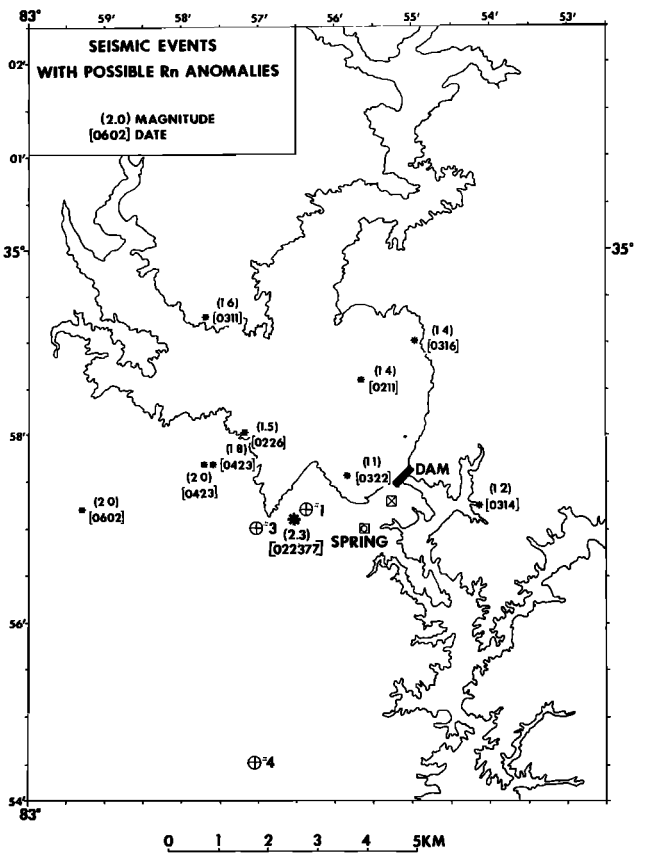

Fig. 8. Locations with magnitude and date of the seismic events shown in Figures 7 and 9 together with recording sites—wells 1 and 3 and the spring.

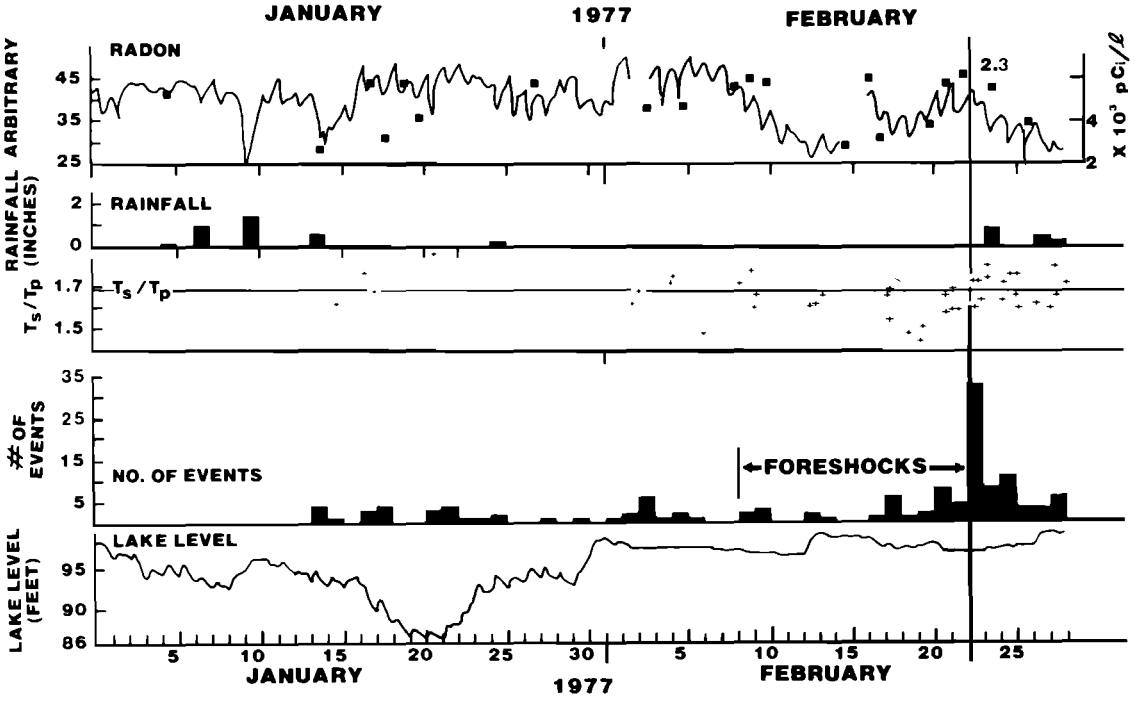

Fig. 9. Various parameters for January and February 1977 and their relationship to a magnitude 2.3 event on February 23, 1977 (see text for details).

ber 1977 to February 1978. The track count being an integrated sum, this implies large differences in the two periods. There was a magnitude M_L 2.6 earthquake in the middle of the lake on September 7, 1977 (Figure 11), with no comparable activity in the later period. This suggests that a general increase in the radon value in September 1977 may have been associated with an increase in seismic energy release. We note here that the radon concentration in the spring had also

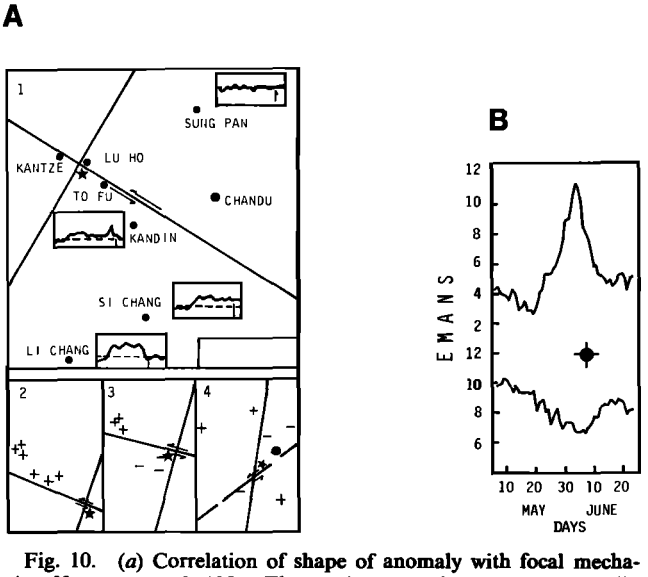

Fig. 10. (*a*) Correlation of shape of anomaly with focal mechanism [from *Liu et al.*, 1975]. The star indicates the epicenter, the solid circle the radon observation well, and the pluses and minuses the signs of the radon anomaly. The data are for (1) February 6, 1973, Lu Ho earthquake, M 7.9, (2) July 18, 1969, Bo Hi earthquake, M 7.4, (3) May 15, 1970, Fung Nan earthquake, and (4) October 12, 1972, Sa Hu earthquake. (Distance scales were not given.) (*b*) Hew-Jin earthquake (solid circle) and associated radon anomalies: (top) Hown-Sun well 1; (bottom) Jin-Ti well.

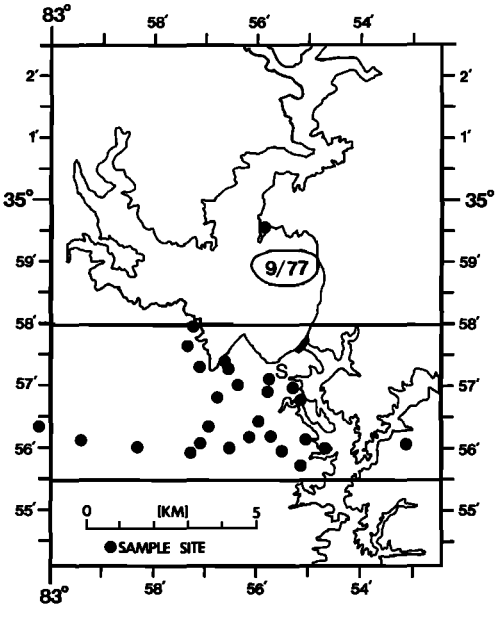

Fig. 11. Location of track etch cups used to detect soil radon. The epicentral area of a M_L 2.6 earthquake on September 7, 1977, is also shown. S indicates a cup in the vicinity of the observation spring.

TABLE 3. Location of Large Events in Lake Jocassee Area and Associated Radon Anomalies

Event	Date	Time, UTC	M_L	Latitude, N	Longitude, W	Depth, km	Possible Radon Anomaly
1	Nov. 25, 1975	1517	3.2				
2	Jan. 14, 1976	0057	2.5	34°59.85′	82°55.58′	0.45	
3	Jan. 16, 1976	0543	2.2	34°56.12′	82°56.34′	1.42	S
4	Feb. 6, 1976	0612	1.8	34°57.85′	82°58.95′	1.70	
5	April 23, 1976	0139	2.1	34°57.67′	82°57.71′	0.05	S
6	June 2, 1976	1816	2.0	34°56.80′	82°59.16′	0.86	S
7	Feb. 23, 1977	0850	2.3	34°57.19′	82°56.43′	1.55	L
8	Sept. 7, 1977	1441	2.6	34°58.93′	82°55.64′	2.67	L
9	Nov. 25, 1977	2223	2.2	35°00.97′	82°55.09′	0.70	
10	Aug. 21, 1978	1353	2.3	34°59.21′	82°55.59′	1.91	
11	Sept. 21, 1978	0707	2.3	34°59.68′	82°57.68′	1.82	
12	Oct. 5, 1978	1231	2.1	34°56.64′	82°57.32′	0.88	

S is short period (≤1 day), and L is long period (>10 days).

increased at about this time (Figure 5) and had been attributed to the September 7, 1977, earthquake.

CONCLUSIONS

Our conclusions after about 3 years of simultaneous monitoring of the radon concentration and low-level ($M_L \leq 2.6$), shallow (<4 km) continuous seismicity in the vicinity of Lake Jocassee can be summarized as follows:

1. There are long-term fluctuations (in the form of a 50–100% decrease over an 8- to 9-week period) in the radon concentrations in the spring with a period of about 44 weeks. Whether these are related to soil temperatures, water table depth, and/or other environmental factors or to periods of decreased seismicity is not clear. The radon concentration in the spring is diluted by rainwater runoff, although it is not affected by lake level fluctuations.

2. We have detected some positive and negative radon anomalies possibly associated with the larger seismic events (cf. Table 3).

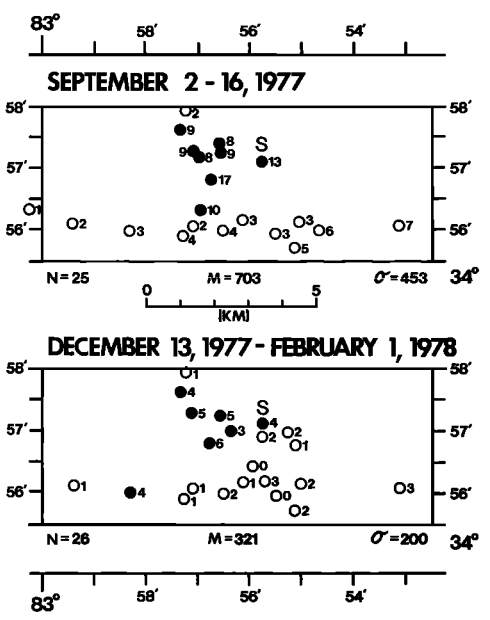

Fig. 12. Radon counts for two periods (September 2–16, 1977, and December 13, 1977, to February 1, 1978). The numbers indicate one tenth of the track count. N is the number of samples, M is the mean value, and σ is one standard deviation. Solid circles are for cups with a track count greater than the mean value. S is for the location of a cup, near the spring.

3. When the monitoring site is in the epicentral area, for example, February 1977 (or on the same fracture system?), stress changes responsible for the earthquake may cause detectable long-period (over 10 days for $M_L \geq 2.0$ events) precursory radon anomalies.

4. When the monitoring site is distant from the epicentral area, short-period (<1 day) changes are observed both before and after the event. These are liable to be missed if samples are not collected within 12 hours of an event. Our discrete sampling does not allow us to preclude the possibility of the changes being coseismic rather than precursory.

5. The source of the anomalous radon lies in the immediate vicinity of the sensor rather than in the epicentral area.

6. The exact time of onset of the radon anomaly is probably controlled both by the distance to the source and by the geological conditions.

7. The soil radon method was found to be useful in determining areas of high and low radon concentrations and possibly in detecting long-period anomalies.

8. To be useful in an earthquake prediction program, continuous monitoring of radon (as well as other environmental factors) at several sites is necessary.

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Parsons, Susan

From: Kate & Chris <samsa@pacifier.com>
Sent: Thursday, May 28, 2015 2:20 AM
To: Council Clerk – Testimony
Cc: Hales, Mayor; Commissioner Fritz; Commissioner Fish; Commissioner Novick; Commissioner Saltzman
Subject: LU 14-218444-HR-EN Testimony of Katherin Kirkpatrick 2015-05-28 -- Email 6 of 11
Attachments: LU 14-218444-HR-EN Testimony of Katherin Kirkpatrick 2015-05-28 -- Exhibit Q.pdf

Dear Karla:
Please accept my attached testimony for submission into the record of LU 14-218444-HR-EN on the Mt. Tabor Reservoirs Decommissioning, scheduled for hearing this afternoon at 2:00 p.m.
This batch consists of Exhibit Q in support of my legal brief. Kindly send me an electronic receipt when this document is entered.

Thank you,
Katherin Kirkpatrick
1319 SE 53rd Avenue
Portland, OR 97215
samsa@pacifier.com

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Experimental Assessment of the Short- and Long-Term Effects of ^{222}Rn from Domestic Shower Water on the Dose Burden Incurred in Normally Occupied Homes

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Previous studies of the effects of ^{222}Rn in drinking water have centered on the long-term or chronic exposure to ^{222}Rn and its decay products. In this study, the possible effects that the transient increase caused by the release of ^{222}Rn from shower water can have on the ^{222}Rn concentration have been studied. In addition, the increment in the lung dose incurred by the occupants of a normally occupied home and the long-term increase in the ^{222}Rn concentration and the associated dose in the home has also been examined. Various parameters are of interest including the release of the ^{222}Rn from the shower water, the role of ventilation as a removal mechanism, and the behavior of the aerosol present in the home. Experimental work was performed in a shower stall constructed in the laboratory and in a bathroom in a normally occupied home. The home was supplied with water containing around 550 kBq m^{-3} of ^{222}Rn. A transfer coefficient around 0.70 and equilibrium factors up to 0.69 were measured in the laboratory. The ventilation rates measured in the home were in agreement with those found in the literature, 0.5–4.0 h^{-1}. The dose incurred was assessed using the lung dose model developed by the International Commission on Radiological Protection (ICRP). Calculations indicated that for homes with ^{222}Rn in the domestic water similar to the experimental home, the short-term exposure during showering could contribute a 17% increase in dose over the average daily dose. However, the increase in the long-term average concentration caused by the release of ^{222}Rn from water use in the home could more than double the average daily dose. Thus, the focus of concern regarding radon in domestic water should be primarily on its effects on the long-term airborne ^{222}Rn concentration.

Introduction

The impact of ^{222}Rn on human health has received much attention in the last 15 years (*1*). In conjunction with this increased attention has been a concomitant increase in interest in a number of related subjects such as ^{222}Rn sources, entry pathways, and ^{222}Rn mitigation methods. Many different sources have received attention. The most commonly encountered source is soil gas entering a structure from the substructure geological features. For this source, there are a large number of possible entry pathways, such as through cracks in the floor or around built-in openings such as around water pipes.

This work examines the effects that radon-laden water and one particular entry pathway, showering, can have on the radon environment in a house. While radon is a noble gas, it is soluble in many substances. The solubility of ^{222}Rn in 'medium hard' water, expressed as the Ostwald coefficient, varies between 0.315 and 0.214 as the temperature varies from 288.15 to 308.15 K (*2*). If the water is extracted from an aquifer, then the elevated pressures and the low temperatures experienced by the water in the aquifer will lead to increased ^{222}Rn solubility. If a building is supplied with water that has a high radon concentration and there are water heating devices, then the water heated in these devices form a potential source of ^{222}Rn contamination. In typical homes, water heaters heat water in an enclosed system that does not provide an opportunity for the ^{222}Rn in the water to escape. When the water is released from the system such as in a shower, the ^{222}Rn is free to escape from the water, and so the heated water can make an effective ^{222}Rn source. Therefore, it is useful to determine the potential contribution of radon-bearing shower water to the ^{222}Rn decay product exposure and the resultant radiation dose accumulated by the occupants.

Previous studies have concentrated on the contribution that water utilization has on the long-term ^{222}Rn concentrations within a structure (*3–5*). There is also the short-term impact of ^{222}Rn concentration transients due to water usage to be considered. This work was undertaken in two distinct phases. First, there is the experimental investigation of this phenomena in a laboratory model system and in a normally occupied home. The experimental work is presented here. A dynamic model was also developed to extend this work from specific homes to more general situations (*6*).

Experimental Investigations

Experiments were performed in both a laboratory system and a normally occupied home to examine the effects of the transient nature of showering as a source of ^{222}Rn exposure and dose. An overview of the experimental setup and procedures for the laboratory and field studies is presented herein. More details are provided in the Supporing Information (see paragraph at the end of this paper).

Laboratory-Based Investigations. A shower stall was constructed with dimensions of 0.79 m × 0.79 m × 1.8 m (L × W × H) with a volume of 1.1 m^3 and a surface-to-volume ratio of 6.2 m^{-1} (Figure 1). Ventilation occurred either by forcing air through an entrance in the top or by drawing air from a port at the bottom. The ventilation rate was determined using a dry test meter to measure the air flow. The stall was thoroughly sealed to achieve a low natural ventilation rate.

The fraction of radon transferred from the water at various temperatures and shower head configurations was measured. Different shower heads provide different droplet sizes and shower stream configurations. ^{222}Rn in the water was measured by sampling before the shower head and after the drain and liquid scintillation counting (*7*).

The ^{222}Rn decay products were monitored by taking samples on Millipore 0.8-μm pore filters. Each filter was gross α-counted using a ZnS(Ag)-coated Mylar disk coupled to a photomultiplier tube. Counts were taken in a series of equal length, equally spaced intervals. The ^{222}Rn decay product

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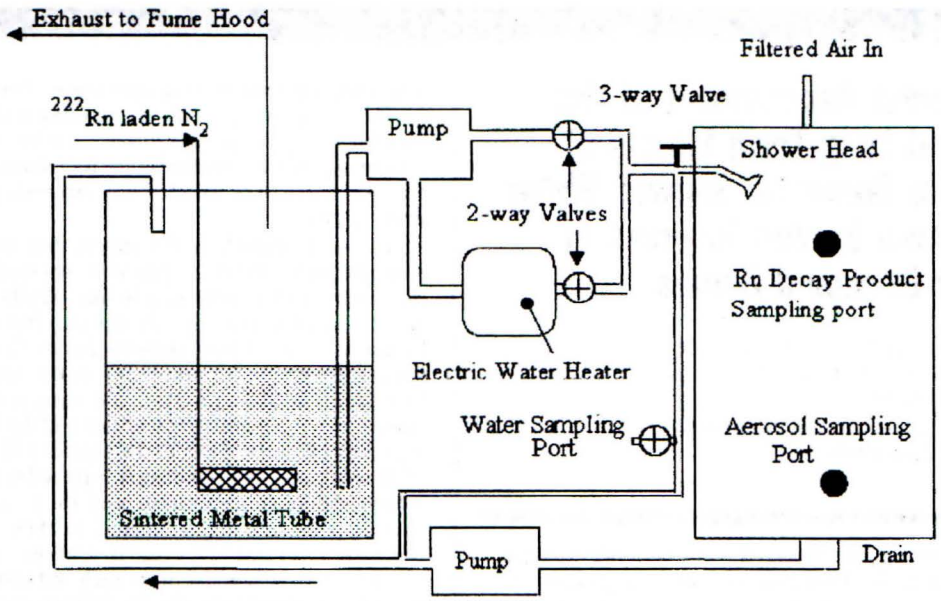

FIGURE 1. Schematic of the laboratory shower system used.

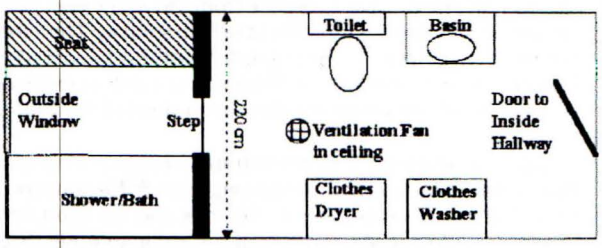

FIGURE 2. Layout of the test bathroom.

concentrations were calculated using the Raabe–Wrenn least-squares method (*8*).

The deposition of submicron particles was measured under typical showering conditions for various size particles at different ventilation rates with and without the water running. The heat from the water may increase the turbulence and promote thermophoresis. High humidity can cause hygroscopic growth. The droplets can cause particle washout. The experimental particles were carnauba wax, so hygroscopic growth was not expected. Washout is not significant for the submicron particles. The deposition rates were determined by measuring the decay of the particle concentration with time. The initial concentration was kept below 30 000 cm^{-3} to eliminate coagulation. The deposition rates were calculated by subtracting the ventilation rates from the overall removal rates.

Field Measurements. A normally occupied dwelling was found that was supplied with water from a drilled well containing 518 000–555 000 Bq m^3 of radon. The dwelling was a one-story wooden house of a type common in northern New York state. A schematic diagram of the bathroom is given in Figure 2, and the placement of the equipment in the bathroom and home is shown in Figure 3.

Measurements of ventilation were made using SF_6 gas. The SF_6 gas was released into the room, and a fan was used to produce a uniform distribution throughout the room. Using a MIRAN IB2 portable infrared spectrometer, the SF_6 concentration was followed over time, and the decay rate was determined. The only removal process is assumed to be ventilation.

The ventilation rate was also extracted from the decay of the ^{222}Rn released into the bathroom from the shower water. The technique is the same except that the removal rate calculated from the concentration and time data must be adjusted for the radioactive decay of the ^{222}Rn. However, the radioactive decay of ^{222}Rn is negligible for these short experiments. However, the ^{222}Rn was not dispersed uniformly throughout the room with a fan.

The temperature gradients within the bathroom were measured using three 0.1 °C resolution mercury thermometers placed as shown in Figure 3. The thermometers were placed against the surfaces and read sequencially each minute. The measurement results are shown in Figure 4.

Short- and long-term measurements of the ^{222}Rn concentrations were made using both a passive scintillation cell (Thompson and Nielsen Model RN 2900) and an active cell (Eberline RGM-3). These devices contain a ZnS(Ag)-lined scintillation cell. The α-particles emitted in the cell strike the coating and cause flashes of light that are detected by a photomultiplier tube. The RN2900 has no pump and relies on diffusion of the ^{222}Rn gas into the cell whereas the RGM-3 samples rely on a fixed 18-min cycle with an active pumped flow. The decay product concentrations in the bathroom were monitored in the same fashion as in the laboratory measurements.

The particle size distributions were measured with a TSI Model 3071 electrostatic classifier operating in the scanning mode with a TSI Model 3025 particle counter. The size distributions were accumulated in a continuous series of 5-min scans.

Other experiments measured the effect that the showering activity would have on the adjoining rooms of the house. The ^{222}Rn concentrations were monitored with both the RGM-3 and the RN2900. Long-term measurements were also made with commercial LR-115-II detectors. LR-115-II is cellulose nitrate, which is easily damaged by the passage of α-particles. These tracks are visualized by chemical etching and counted. The number of tracks per unit area is proportional to the ^{222}Rn concentration. Particle sizes were monitored using the same instrumentation as above.

Measurement Results

Laboratory-Based Measurement Results. Table 1 shows some results of the investigation of the radon release fractions. As can be seen, the release fraction is relatively independent of both the water temperature and the choice of shower head. These values are in agreement with previous values reported in the literature given in Table 2. This uniformity of results allows the assumption that 0.70 is a generally representative value for the fraction of radon released.

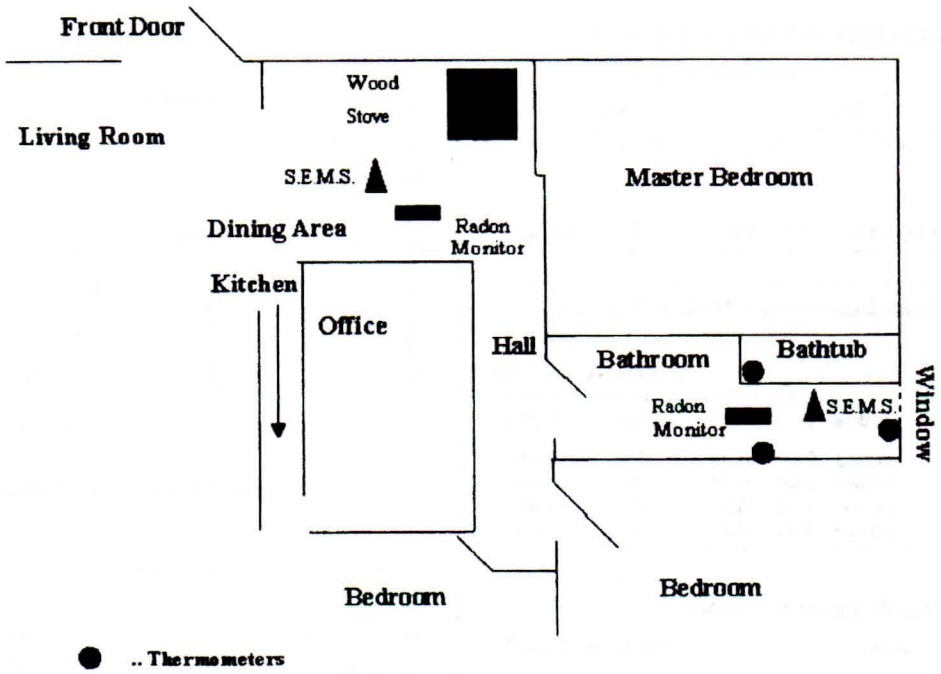

FIGURE 3. Positioning of the equipment during some of the experiments.

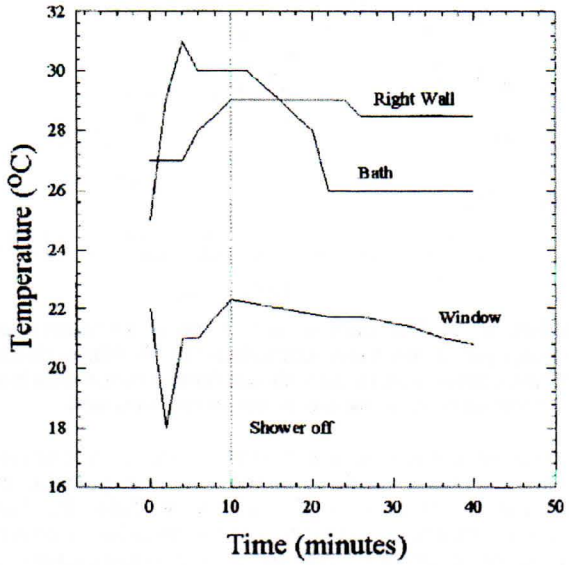

FIGURE 4. Temperature variations around the bathroom.

TABLE 1. Laboratory Measured Emanation Fraction

shower head	water temp (°C)	^{222}Rn in water concn before shower (kBq m^{-3})	^{222}Rn in water concn after shower (kBq m^{-3})	emanation[a] (%)
head 1	32	374	108	71
	32	773	233	70
	21	375	124	67
	21	207	58	72
head 2	32	254	69	73

[a] Errors in these values are approximately ±2%.

Table 3 illustrates the ingrowth of the radon decay products by following the equilibrium factor (F). The equilibrium factor is defined as the ratio of the total potential α-energy for the actual ^{222}Rn decay product concentrations to the potential α-energy concentration of the decay products if they were in full equilibrium with the ^{222}Rn concentration. The equilibrium

TABLE 2. Transfer Coefficients for Some Domestic Devices

device	emanation fraction	ref
commode	23.6%	4
dish washer	98.5%	4
showering	>60%	3

TABLE 3. Effect of Ventilation Rates on Measured Equilibrium Factors

time (min)	0.3 h^{-1}	1.0 h^{-1}
5	0.06	0.05
30	0.26	0.17
55	0.40	0.29
80	0.53	0.41
105	0.54	0.41
130		0.54
207.5	0.69	

factor rises to 0.692; this is considerably in excess of the normally measured indoor equilibrium factors of 0.4 (*11*). This result may appear unusual in that the surface-to-volume ratio in the laboratory shower stall is large (approximately 6 m^{-1}), the aerosol particle size spectrum is typical of indoor air, and the particle number concentration is low. It would be expected that there would high wall deposition rates and relatively low equilibrium factors. The discrepancy can be understood if it is remembered that as the decay product levels are growing, the ^{222}Rn levels are falling. This discrepancy will impact on calculations of dose since this is a non-steady-state environment and the usual simplifying assumptions of the existence of a steady state are not valid. The individual system components must be treated in a time-dependent manner. In a companion paper (*6*), a dynamic room model to predict the general behavior is presented.

Initially, the radon appears to be relatively free of decay products. This result indicates that there is little release of decay products from the water. This finding is contrary to that of Bernhardt and Hess (*12*), who indicated the possibility of appreciable decay product activity released from the shower drops. Therefore, in our measurements, any change in the decay product levels is due only to the ventilation and the

TABLE 4. Measured Deposition Rates in Shower Stall

	ventilation rate (λ_v)			
	0.5 h^{-1}		4.0 h^{-1}	
shower	off	on	off	on
aerosol size (nm)				
90	0.11 ± 5%	0.11 ± 5%	1.32 ± 5%	1.51 ± 5%

TABLE 5. Ventilation Measurements Made in Field Test Bathroom

door	ventilation fan	window	λ_v:SF_6 (h^{-1})	λ_v:^{222}Rn (h^{-1})	time to max ^{222}Rn concn (min)	max ^{222}Rn concn (Bq/m^3)
closed	off	closed	0.64	0.33	85	1300
closed	on	closed	2.44	0.76	25	850
open	off	closed	4.54	0.67	25	1100
open	on	closed	3.41	0.71	31	810

TABLE 6. ^{222}Rn Levels around Test Home

room	^{222}Rn concn (Bq/m^3)
bathroom (near shower)	636 ± 67
bathroom (near washing machine)	270 ± 56
master bedroom	178 ± 56
kitchen	248 ± 56
living room	152 ± 48

decay of radon within the shower stall and not to the release of decay products from the water droplets.

The data (Table 4) would appear to indicate that the presence of the water stream and the resulting combined effects of the high relative humidity and elevated temperatures have a minimal effect on the measured deposition rates, especially when compared with the effects of ventilation alone. A detailed discussion of particle deposition and exhaust ventilation is given by Nomura et al. (*9*) and is beyond the scope of this paper.

Field Measurement Results. The results of the ventilation rate measurements are given in Table 5. A discrepancy is observed between the two sets of ventilation measurements. It can be explained in the following fashion. If the natural mixing of the room is poor, then there will be a concentration gradient from the bathtub into the room. Thus, the higher radon concentration in the bathtub forms a source of radon and will cause the apparent ventilation rate measurement to be low relative to the SF_6 measurement. This observation was also seen by Bernhardt and Hess (*12*). The true ventilation rate for the bathroom appears to vary between 0.6 and 4.5 ACH (air changes h^{-1}), which is in agreement with estimates of typical domestic ventilation rates (*13*). However, this effect will mean that the radon in the shower stall will serve as a ^{222}Rn source after the water has been turned off and cause the elevated levels in the rest of the bathroom to persist for longer than would be expected on the basis of the SF_6 measurements. In order to obtain some information on the long-term effects of this uneven mixing of the ^{222}Rn, two LR-115-II detectors were placed in the bathroom; one beside the bath and the other in the part of the bathroom near the washing machine. These results are presented in Table 6.

The temperature measurements given in Figure 4 indicate a transitory difference of 13.5 °C between the window and the bath wall. This particular result is probably close to the most extreme case that would be likely to occur in this home as the external temperatures were below 0 °C. Calculations using the model developed for this work indicate that, ignoring thermophoretic forces, a change in the temperature from

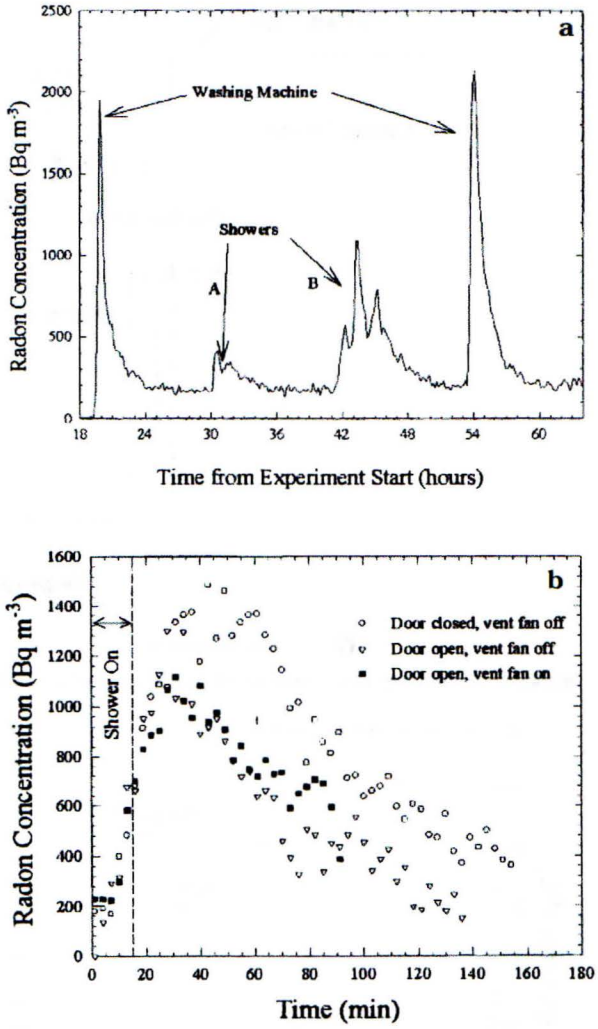

FIGURE 5. (a) ^{222}Rn levels in the bathroom as a function of time during a period when it was occupied normally. (b) ^{222}Rn as a function of time and ventilation in the bathroom during a period when it was unoccupied or occupied only by the investigating staff.

293 to 303 K has an negligible effect on the deposition rates. This calculated result is supported by deposition rate measurements made in the laboratory (Table 4). These experimental results indicate that the deposition rate is not substantially affected by the shower water temperature. One feature of the plot in Figure 4 is the sharp decrease in the window temperature and the sharp increase in the bath wall temperature. This observation may be in some way indicative of convective transport patterns within the room.

Figure 5a,b shows the radon concentration as a function of the time for normally occupied use of the room (panel a) and specific ventilation experiments (panel b). There are two interesting features in Figure 5a. Peaks are observed during the afternoon that can be identified with the use of the washing machine in the bathroom. There are peaks also caused by sequential showers. Other similar measurements consistently show similar profiles. Beside illustrating the cumulative effect of multiple showering, the shower peaks show the effect of the ventilation. The peaks marked A correspond to showers taken in the morning when the ventilation fan was used whereas those marked B correspond to showers taken without using the fan. It is clear that the ventilation fan can help mitigate the high ^{222}Rn concentrations. Also Figure 5a shows that devices such as the washing machine also can be significant sources of ^{222}Rn. The side peak on A may be an example of backwash when the fan is switched off

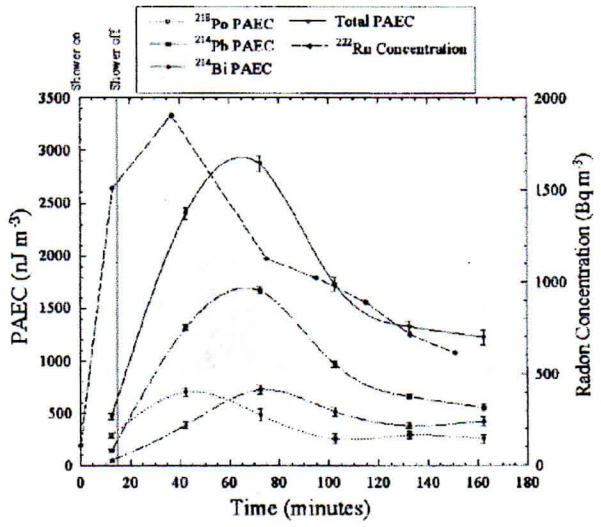

FIGURE 6. Airborne concentrations of ^{222}Rn, ^{222}Rn decay products, and PAEC during an experiment on showering in the bathroom of the experimental home.

and the radon from around the bathtub mixes into the room, but it also may be subsequent water use, for instance, at the hand basin.

Figure 5b further illustrates some of the effects of the ventilation fan on the ^{222}Rn concentrations within the bathroom. When the ventilation fan was operated, it was run for the entire period of the experiment. Increased ventilation not only lowers the maximum radon concentration but it also causes the maximum concentration to be reached in a shorter time. From Figure 5b, it is evident that the open door forms the dominant removal mechanism and that the ventilation fan is less effective in removing ^{222}Rn from the bathtub area when the door is open. It is important to note that the SF_6 tracer gas measurements of ventilation would indicate that the door open and the ventilation fan off created the best ventilation conditions and so should be the most effective removal technique. However, the ^{222}Rn gas measurements indicate the opposite; that the fan with a closed door is most effective in removing the radon.

The differences observed here are probably the result of the lack of initial mixing of the ^{222}Rn within the bathroom, the location of the ventilation fan in the portion of the bathroom where the washing machine is placed (see Figure 2), and the ^{222}Rn measurements being made near the bathtub. Thus, the apparent ventilation rate as seen by the ^{222}Rn is more a function of mixing into the whole room than transfer from the room. The open door appears to allow air from the rest of the house to enter the bathroom. The effect of the open door is that the fan efficiency is diminished in terms of moving radon-laden air from the bathtub measurement location. Clearly, just opening the door provides mixing of radon-laden air into the rest of the home. The presence of some means of ventilation clearly reduces the maximum exposure to ^{222}Rn. Clearly it is best to vent the ^{222}Rn from the room and, thus, not add to the average indoor ^{222}Rn in the house.

Table 6 contains the results of the long-term LR-115-II detector monitoring over the 5 months from October to March of the average radon levels within various rooms. Those rooms where water is used or close to rooms with water use have elevated radon levels. This particular house has high radon concentrations primarily because of the effect of the radon in water. Measurements taken in the middle of the day when the house is unoccupied and well after the water use periods found the airborne radon concentrations in the living room of the house to be below 40 Bq m^{-3}.

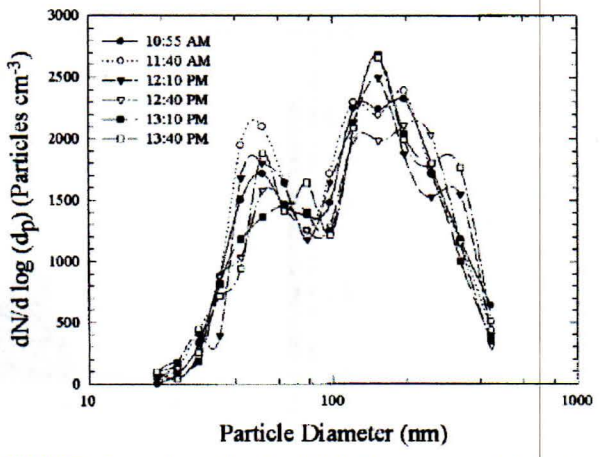

FIGURE 7. Aerosol particle size distributions measured during the experiment for which Figure 6 presents the airborne activity measurements.

Figure 6 illustrates one example of the buildup of both the ^{222}Rn and the ^{222}Rn decay products when the bathroom door was closed and the fan was turned off. Although the figure shows measurements extending to 180 min from initiation of the shower water flow, the exposure would only come during the first 30 min (15 min in the shower and 15 min after). It can be seen that at this time these are still very low concentrations of the decay products relative to the ^{222}Rn concentration. Experiments in both the laboratory and the field indicate similar patterns. Increasing the ventilation rate has the same effect on the decay products as it does for the ^{222}Rn. As the ventilation rate increases, the time to reach the maximum concentration decreases and the maximum concentration decreases.

A number of measurements of the particle size distributions were performed in the bathroom. Figure 7 shows the number-weighted size distribution before, during, and after the shower for one set of experiments. The particles may undergo some hygroscopic growth. Other experiments show this growth more clearly. The growth of domestic aerosols has also been seen by other investigators (*14*). Their experience shows, however, that not all indoor domestic aerosols grow, and those that do, can grow by varying amounts. The behavior depends on the exact nature of the aerosol in the bathroom since at least part of any bathroom will reach approximately 100% relative humidity for at least a short period of time.

The growth of the aerosol particles means that any calculations of dose must allow for the possibility of hygroscopic growth of the aerosol. The aerosol size distribution and hence the activity-weighted size distributions may shift in size before, during, and after the shower. If the aerosol particle can grow to a larger size, then this increase will result in a larger decay product attachment rate. Also if the aerosol can grow in the high humidities achieved during showering, then it can grow in the respiratory tract. However, if it has already reached its maximum size, it will not grow further in the respiratory tract. Depending on how close the bathroom humidity is to 100%, the amount of possible growth when the particles enter the lungs is reduced, further altering the deposition patterns within the lung.

Changes in particle size will have two effects. First, the changes in the sizes will affect the deposition of the particles onto the room surfaces and thus affect the amount of decay products available for inhalation. Second, the change in size will alter where the particles deposit within the respiratory tract. The effect of humidity on the dose delivered to the lung is discussed in more detail by Dua and Hopke (*14*).

From these number-weighted size distributions (Figure 7), activity-weighted distributions can be calculated using

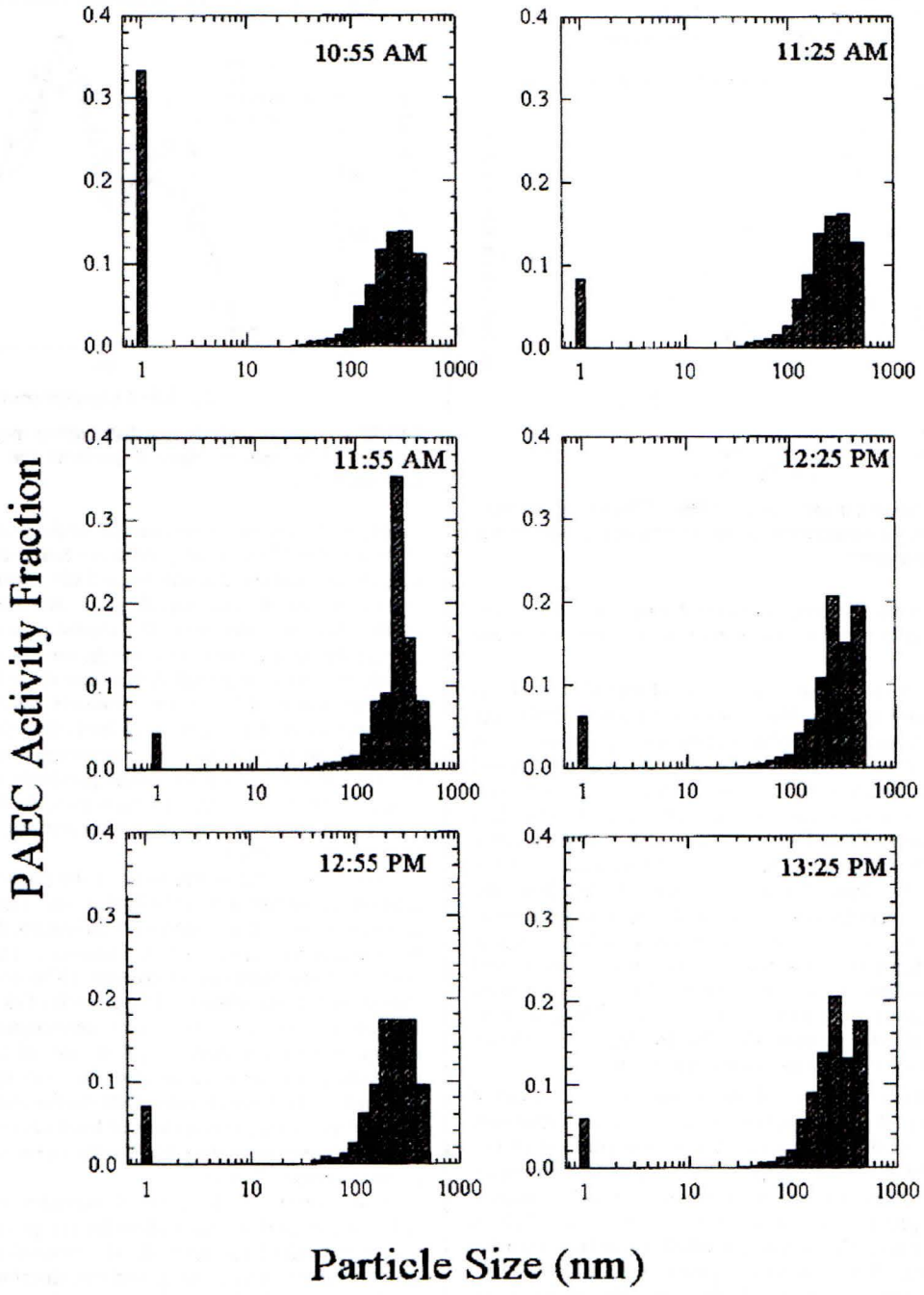

FIGURE 8. Calculated activity weighted (PAEC) size distributions from the airborne activity concentrations shown in Figure 6 and the number-weighted size distributions shown in Figure 7.

the attachment coefficients of Porstendörfer et al. (*16*). From the attachment rates, the unattached fraction can be estimated (*13*). Figure 8 presents these estimated activity-weighted size distributions. Tu and Knutson (*17*) have shown that this method provides a reasonable approximation to the directly measured activity-weighted distributions.

Measurements in the dining area showed an increase in the radon levels after showering. However, measurements indicated there is apparently no change in the aerosol size spectrum, so the only effect would be an increase in the dose due to the increase in ^{222}Rn and its decay products. There is a short-term effect of the increased airborne activity concentration. However, it is small, and the primary effect is the long-term elevated levels that appear in the measured averages given in Table 6.

Dosimetric Calculations

The most current and widely accepted lung dosimetry model is that proposed by the International Commission on Radiological Protection (*15*). This model predicts the dose to various regions of the lungs on the basis of the size of particles inhaled into the respiratory system. The conversion factors, from size and activity to dose, are derived from this model assuming an adult male subject with a breathing rate of 0.79 $m^3\ h^{-1}$. The dose as a function of particle size is shown in Hopke et al (*11*). To fully utilize use the ICRP model to predict dose, it is necessary to have the radon daughter product activity size spectra.

It is feasible to make direct activity-weighted size distribution measurements (*18*). However, the system available for such activity-weighted size distribution measurements

TABLE 7. Estimated Dose Rates in Bathroom during and following a 15-Min Shower Starting at 10:40 AM

time of end of sample	min after start of shower	dose rate (μSv h^{-1})	dose rate per unit ^{222}Rn (nSv h^{-1} Bq^{-1} m^{3})
10:00 AM	−40	14	15
10:55 AM	15	22	15
11:25 AM	45	51	31
11:55 AM	75	48	39
12:25 PM	105	33	35
12:55 PM	135	28	39
13:25 PM	165	24	44

draws 90 L of air/min and so would substantially alter the aerosol size distribution in a volume as small as the bathroom. As it is not feasible to make direct measurements of activity-weighted size distributions, they were calculated as described above, resulting in distributions as shown in Figure 8. While this calculation is adequate to a first approximation, it is preferable to make direct activity-weighted size distribution measurements both to provide better information on the dosimetrically important ultrafine particles and to eliminate any uncertainty introduced by the use of the steady-state attachment equations. The steady-state approximation gives an upper bound to the calculated values, and the dynamic model (*6*) calculations are lower for the same aerosol conditions.

Figure 8 clearly shows how the activity-weighted size distribution shifts during showering toward larger sizes that are less efficient at delivering dose to the bronchial tissues. Thus, while the activity suspended in the air increases, the dose does not increase as sharply. The period of time during which the size shifts is short, of the order of 5−10 min, and the particles return to their original size within approximately 15 min.

As a representative example of the changes observed in the bathroom, Table 7 gives the calculated dose and dose per unit radon concentration for one particular decay product atmosphere (Figure 8) in the experimental bathroom using this steady-state approximation. The ventilation rate during the experiment was measured using SF_6 to be 0.4 h^{-1}. The surface-to-volume ratio of the bathroom was relatively large, and the aerosol particle concentration was 3000−4000 particles cm^{-3} so a deposition rate of 40 h^{-1} was assumed for the ^{222}Rn decay product activity. This value is the upper limit of the deposition rates suggested by Knutson (*13*). More accurate and rigorous calculations of the dose in this non-steady-state environment were performed as part of the studies with the model developed in tandem with this experimental work as well as making a comparison to the steady-state model, and these results are presented elsewhere (*6*).

The experiment illustrated in Table 7 was one of a number of sequential experiments performed on one day. Because of time constraints, the room was not fully vented back to the background concentration, and thus the initial ^{222}Rn concentration was higher than typically present in the room in its normal occupancy (111 Bq m^{-3}). However, the the ^{222}Rn and decay products increase sufficiently to examine the effects of the water run during the experiment.

Using the background (−40 min) and the 15- and 45-min measured hourly dose rates in Table 7, the daily dose increment to a person in a home with a bathroom identical to that used in this work with water containing ^{222}Rn at 381 kBq m^{-3}, the measured value for the experiments shown in Table 7, is calculated to be 23 μSv. Assuming that the radon emanated will scale linearly with the radon concentration in the water, the equivalent dose for 550 kBq m^{-3} would be 33 μSv. This bathroom was in a house in the northeastern United States. It is possible to put the values in Table 7 in context based on similar homes. Hopke et al. (*11*) presented the

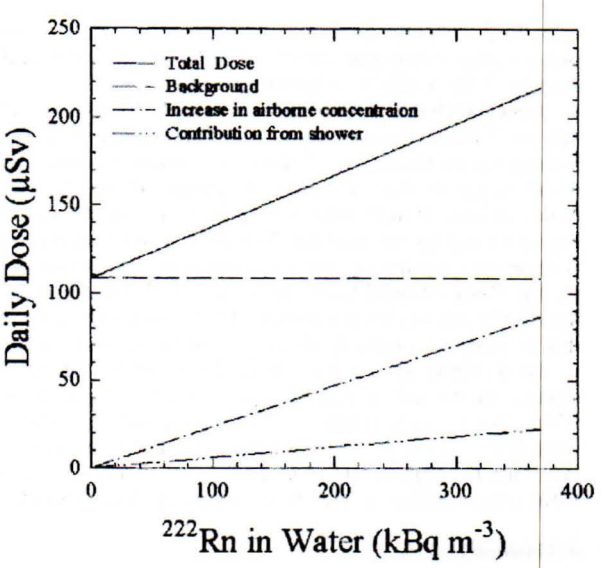

FIGURE 9. Calculated contributions to the average daily dose from showering and the increase in airborne radioactivity through the use of radon-laden water.

results of 565 measurements of activity-weighted size distributions made in normally occupied homes in the northeastern United States and southeastern Canada. They obtained a value for the median dose per unit ^{222}Rn concentration of 130 nSv h^{-1} (Bq^{-1} m^{-3})$^{-1}$ from activity-weighted size distribution measurements using the current ICRP lung model and dosimetry factors (*15*). It can be noted that although the dose rates given in Table 7 were higher during and immediately after the shower water was run, the dose rates per unit ^{222}Rn concentration were much lower than the median value observed in homes because of the limited amount of decay product ingrowth.

The U.S. National Residential Survey measured an average ^{222}Rn concentration of 46.3 Bq m^{-3} (*19*). This value is taken as representative for the average home and assuming 75% as the time occupancy factor, the daily dose is 108 μSv. Taking 108 μSv as being representative of an 'average' home, the occupant would experience an average daily dose increase from 108 to 141 μSv day^{-1}, a 31% increase.

Furthermore, if the average transfer factor measured by Nazaroff et al. (*20*) of 10^{-4} is used, then the ^{222}Rn released by all of the water usage will increase the average ^{222}Rn concentration in the home. For water containing 555 kBq m^{-3}, the indoor airborne radon concentration would increase by 55.5 Bq m^{-3}. The long-term increased ^{222}Rn concentration in the house will have the effect of raising the daily dose by 130 μSv, an increase of 120%. The combined effect of showering and the increased average concentration arising from all of the water use in the house would be 271 μSv or a 151% increase in the daily equivalent dose. Thus, while the transient effects of the increase in ^{222}Rn within the bathroom and the relatively short stay in there can lead to elevated doses, it is clear that it is the effect of the radon-laden water on the average ^{222}Rn concentration within the whole home that has a larger impact on the dose. This result is due to the higher occupancy times and the higher *dose per unit ^{222}Rn* in the whole home as opposed to the bathroom.

These results are summarized in Figure 9. This figure was developed using the experimental data gathered in this work. The horizontal line is the background daily dose of 108 μSv. The two lines at the bottom are the increase in dose arising from both the showering itself and from the increase in the airborne ^{222}Rn concentration caused by the radon from the water. It can be seen that the increment of dose scales linearly with the radon concentration in the water. The top line is the sum of the three lower lines. As can be seen, the short-

term dosimetric effects of showering are not entirely negligible but are small as compared to the effect of the increase in the average ^{222}Rn levels throughout the home.

It is clear that high concentrations of ^{222}Rn in water (550 kBq m^{-3}) can contribute over twice the average daily dose from domestic exposure to ^{222}Rn and its decay products. This result suggests that, in such situations where the ^{222}Rn concentration is high, efforts to reduce this contribution to exposure will be worthwhile. However, as indicated by the ventilation experiments, the most efficient removal pathway for the ^{222}Rn released from the shower is through the door into the house, so efforts to reduce the transient dose increase due to showering must be designed not to increase the dose in the dwelling as a whole. It is also clear that domestic devices such washing machines can also lead to increased ^{222}Rn doses. This result may also indicate that various workplaces such as gymnasiums and laundries may be locations for high occupational exposure if there is a high ^{222}Rn concentration in the water supplied to the facility.

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Supporting Information Available

Details of the experimental investigation (5 pp) will appear following these pages in the microfilm edition of this volume of the journal. Photocopies of the Supporting Information from this paper or microfiche (105 × 148 mm, 24× reduction, negatives) may be obtained from Microforms Office, American Chemical Society, 1155 16th St. NW, Washington, DC 20036. Full bibliographic citation (journal, title of article, names of authors, inclusive pagination, volume number, and issue number) and prepayment, check or money order for $15.00 for photocopy ($17.00 foreign) or $12.00 for microfiche ($13.00 foreign), are required. Canadian residents should add 7% GST. Supporting Information is also available via the World Wide Web at URL http://www.chemcenter.org. Users should select Electronic Publications and then Environmental Science and Technology under Electronic Editions. Detailed instructions for using this service, along with a description of the file formats, are available at this site. To down-load the Supporting Information, enter the journal subscription number from your mailing label. For additional information on electronic access, send electronic mail to si-help@acs.org or phone (202) 872-6333.

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