Welcome to the Operator’s Guide to Water Fluoridation. My name is ___________

and I am the ________________

for the state of ____________________.
This course was prepared to provide operators with essential knowledge related to water fluoridation. There is certainly more to the field of water fluoridation than can be covered in a 1-day course, but this course will present the principles and practices of water fluoridation for water facility operators.

The course is based on a training program prepared by the Centers for Disease Control and Prevention and was customized to include specific content based on the state program.

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Although the water treatment industry is a complex one, with many different parties contributing to the results, the “rubber hits the road” at the operator level. The treatment facility operator ultimately determines the success or failure of any water treatment process. Good operator training is essential. This includes the need for both formal classroom training, like this session, and standard operating procedures (SOPs) for the staff that can include detailed instructions and guidance on best practices. To protect the public and ensure that water is safe, it is essential to have operators with the correct training and knowledge, which leads to appropriate operator certification for the facility.
Studies by the United States Environmental Protection Agency, also referred to as the EPA, have found that one-half of operating problems are a result of inadequate operator training and/or incorrect process understanding or application by an operator. It makes sense that, if operators are not shown how to do their job correctly in the first place, they may not be doing it right. This course provides important information on water fluoridation so that water plant operators can successfully promote and protect the public’s health.
The objectives of this course are to provide operator-focused training, explaining the reason for fluoridation while addressing some of the numerous false allegations about the dangers of fluoridation. This course will not make you a fluoridation expert. The information is presented on a “need-to-know” context and is presented with respect to other related operator responsibilities. You should not have a separate safety program just for fluoridation; instead, you should have a facility-wide safety program that will include water fluoridation as part of a wider program. This course will direct you to other information sources that will help you develop your own specific facility fluoridation program.
The topics we will cover today include

Health benefits and why we fluoridate water

Regulatory perspective on water fluoridation

Water fluoridation additives

Water fluoridation equipment and facilities

Laboratory analysis of the fluoride content in water

Personnel safety considerations about handling water fluoridation additives

And where it all comes together, water fluoridation operations
Here is our schedule. two breaks in the morning and afternoon. We will have a break for lunch. There should be sufficient time to answer your questions, so please ask questions about things you don’t understand.
This presentation will cover water fluoridation by discussing it in topic areas. Let’s start with the reason we add fluoride to drinking water and the health benefits.
Let’s start by looking at the who, what, where, why, and how of water fluoridation.

Water fluoridation is the adjustment of the water’s natural fluoride concentration to a level that results in optimum oral health benefits.

The U.S. Centers for Disease Control and Prevention, also known internationally as the CDC, included it as 1 of 10 great public health achievements of the 20th century. Water fluoridation has a 60-year history of success, having first been implemented in Grand Rapids, Michigan, in 1945.
Scientific study of water fluoridation started with Dr. Frederick S. McKay, a dentist from Massachusetts, who relocated to Colorado Springs, Colorado. He noticed that some people in the community had stained teeth. He had never encountered that type of stain before, so he initiated a study in 1908 to analyze “Colorado brown stain.”

Over time, he reached important conclusions…

First was that the affected teeth were more resistant to dental caries, which was different from what he had expected.

Over time, the “Colorado Brown Stain” became known as dental fluorosis.

Second, some life-long residents had the stain, but more recent residents did not.

McKay became convinced that an agent in the drinking water was causing the stain. In 1931, once spectrographic analysis became available, McKay sent water samples to an Alcoa chemist named H. V. Churchill, who determined that the samples contained high levels of fluoride (2–12 mg/L).
In the 1930s, Dr. H. Trendley Dean of the U.S. Public Health Service collaborated with McKay. They studied the water fluoride content of many communities and the incidence of tooth decay.

Some important conclusions:

Dean found increased benefit with increasing levels of fluoride. He observed that, with fluoride levels up to 2 mg/L, the incidence of tooth decay progressively decreased. However, most of the decrease occurred as fluoride levels reached 1 mg/L.

Dean also observed that when fluoride exceeded 1 mg/L, and especially after the fluoride levels exceeded 2 mg/L, the incidence and severity of dental fluorosis increased.

Dean graded the cosmetic effects, calling white spots on the teeth a “mild” fluorosis and teeth with a mottled brown stain moderate to severe fluorosis.
Water fluoridation is the adjustment of fluoride to an optimum range of 0.7–1.2 mg/L. The optimum level is based on annual average air temperature, recognizing that people in warmer locations consume more water than people in colder climates. People in warmer climates need only 0.7 mg/L, while people in colder climates may need 1.2 mg/L.

Because it may be difficult to maintain an exact level of anything at a water treatment facility, CDC recommends a control fluoride range of 0.1 mg/L below to 0.5 mg/L above optimum. So if the optimal level for a state is 0.8 mg/L, the control range will be 0.7 to 1.3 mg/L. This can vary from state to state. Operators should consult with their state water fluoridation program for specific requirements in their state.

The benefits of water fluoridation decline as the concentration falls below optimum. As the concentration exceeds 2.0 mg/L, there is very little additional tooth decay prevention benefit and a greater potential for fluorosis.
Fluoridation has contributed to a remarkable decline in the prevalence and severity of dental caries (tooth decay). It is a remarkable legacy that water industry professionals have been leaders in promoting and implementing this important public health intervention that has resulted in a significant improvement in the health of our country.

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Data sets on this chart are from national surveys of tooth decay, and include the following data sets.

NHANES 1971-1973 ages 5 to 17
NIDCR 1979-1980 ages 5 to 17
NIDCR 1986-1987 ages 5 to 17
NHANES 1988-1994 ages 6 to 19
NHANES 1999-2004 ages 6 to 19

NHANES – National Health and Nutrition Examination Survey
NIDCR – National Institute of Dental and Craniofacial Research
Approximately 67% of the U.S. population on community water systems, which is greater than 170 million people, currently enjoys the benefits of water fluoridation. This percentage has increased every year since 1945 when fluoridation began in Grand Rapids, Michigan. The chart on this slide presents trends in total U.S. population growth, people on public water systems, and people who have optimally fluoridated water. It is interesting to note that the number of people drinking naturally fluoridated water has not increased, which can be explained by the fact that most naturally fluoridated waters are groundwater systems serving smaller populations.

The goal for 2010 is that 75% of the U.S. population on public water systems will be served with water fluoridation.

Water or salt fluoridation is practiced in many countries on every continent and continues to increase in coverage, just as it does in North America.
The percentage of the population receiving fluoridated water from public water systems is not uniform among the states. Very high percentages of the population have this benefit in some states, whereas in some states the percentage is much lower.
The halo effect refers to the spread or diffusion of fluoride from communities with fluoridated water (fluoridated communities) to communities without fluoridated water (nonfluoridated communities).

Foods and beverages processed with fluoridated water are shipped to nonfluoridated communities. For example, beverages such as Coke, Pepsi, and beer and processed food products are commonly produced in larger cities with fluoridated water, and the fluoride content benefits consumers regardless of where they live. So water fluoridation benefits the residents of the community as well as people in other places.

Are people getting too much fluoride? The consensus is that people who live in fluoridated communities today get about the same amount of fluoride as residents who lived in fluoridated communities 60 years ago. All the locally produced products they used were influenced by fluoride content in the local water and that allowed us to recognize the benefit to oral health. So the halo effect does not increase the fluoride exposure to people in fluoridated communities since they are only replacing one fluoridated product with another fluoridated product, but it does extend the benefit to unfluoridated communities.

The difference in caries occurrence is now only 20%–40% between fluoridated and nonfluoridated communities as a result of the spread of fluoride. However, there continues to be a significant difference and benefit to fluoridated communities.
Fluoridated communities have 20%–40% fewer caries. The difference used to be greater, but with the increasing sources of fluoride in our diet, the benefits of fluoride are spreading across all areas. However, even with more sources of fluoride, there is still a significant difference between fluoridated and nonfluoridated communities.

Fluoridation is very cost-effective: every dollar spent on water fluoridation avoids $38 in dental care, while drinking water costs to consumers increase by less than 1%. The cost to fluoridate water for one person for their lifetime is less than the cost to have one dental filling.

Water fluoridation benefits all consumers across the socioeconomic spectrum. Water fluoridation benefits all age groups, from children to senior citizens. Some people allege that water fluoridation benefits only children, but it benefits adults as well. Senior citizens are a case in point: many of them take medications that result in dry mouth (reduced saliva), compromised diets, and physical impairments that decrease their ability to maintain ideal oral hygiene. Additionally, they may have receding gums, which exposes enamel to decay. Water fluoridation helps to counteract these conditions.
Your teeth are in an active environment of change, and tooth decay is caused by multiple factors, with fluoride only being one of them. A tooth can experience demineralization and remineralization with fluoride in the saliva and plaque acting as a nutrient in the remineralization process. Your diet, oral hygiene, and the bacteria in your mouth can all influence your oral health. Your saliva flow is very important as it conveys the fluoride to the tooth surface and supplies other vital nutrients. People with chronic dry mouth syndrome generally experience more severe problems with tooth decay.

Plaque levels alone are not associated with caries because plaque itself does not cause cavities. There must be specific bacteria within the plaque—particularly *Streptococcus mutans* and, to a lesser degree, lactobacilli.

Contrary to what many people believe, the tooth does not have to be clean for fluoride to work, because plaque actually helps to keep fluoride available to remineralize the tooth surface. Consuming fluoridated water throughout the day has a strong value in replenishing the fluoride content.
How does fluoride work? It helps tooth surfaces resist decay by inhibiting demineralization and promoting remineralization.

Acid released from food and beverages releases fluoride from the plaque reservoir, which ultimately minimizes demineralization. Acid attacks the tooth enamel, releasing calcium and phosphates, and then the fluoride released from the plaque reservoir combines with calcium and phosphates to remineralize the tooth and can form a stronger and more decay resistant enamel.
This is the spectrum of tooth decay and remineralization that is always in progress in your mouth. The enamel can re-form and it does remineralize. Fluoride is an essential nutrient in the remineralization of teeth. This is why water fluoridation benefits people of all ages, not just children. It is true that having sufficient fluoride available for children under age 9 results in stronger teeth, but all adults benefit from the continual remineralization that fluoride facilitates.

One of the reasons water fluoridation is the most effective fluoride delivery method is that we consume small quantities of water throughout the day, and not just a couple of times when we brush our teeth or eat. Therefore, water fluoridation replenishes small quantities of fluoride, which contributes to good oral health.
Fluoridation has resulted in a remarkable decline in the prevalence and severity of dental caries (tooth decay).

Despite this reduction, dental caries is still the most common preventable chronic disease in the United States, affecting

1 of 4 elementary school children
2 of 3 adolescents
9 of 10 adults
Decline in tooth decay has been uneven across the general population.

Populations with increased risk include people with:

Low socioeconomic status (SES)

Low level of parental education

Little, if any, access to “dental care”

But water fluoridation benefits all members of a community—young, old, rich, and poor.
Fluoride is naturally occurring, but surface waters tend to have lower fluoride content and groundwaters can have higher fluoride content. Most surface waters typically have fluoride levels below 0.2 mg/L. Groundwaters can have extremely low to very high fluoride content and can vary seasonally if the groundwater is influenced by surface waters. Sea water typically has a naturally occurring fluoride content of 0.8–1.4 mg/L.

So, with water fluoridation we are adjusting the natural level of fluoride to a level that is optimal for oral health.
A little fluoride is good. But at levels that are higher than optimal for oral health, fluorosis can occur.

Enamel fluorosis occurs when children with developing teeth (less than age 9) consume excessive fluoride. The excessive fluoride may be incorporated into the enamel as it is initially formed, leading to hypomineralization. Once teeth are developed by age 9, the potential for enamel fluorosis ends. Adults do not experience enamel fluorosis by consuming water with a high concentration of fluoride.

Ingestion of toothpaste containing fluoride at >1,000 mg/L by young children is a major cause of enamel fluorosis. Parents should be instructed to never give more than a “pea-sized” dab of toothpaste to young children because up to age 5 or 6, children have a poorly developed swallowing reflex. Parents should supervise tooth brushing to encourage children not to swallow toothpaste, which generally tastes good.

EPA considers enamel fluorosis, a cosmetic influence. There is an increased potential for enamel fluorosis when the fluoride content of drinking water exceeds 2 mg/L. Skeletal fluorosis can occur if water with extremely high levels of fluoride is consumed for many years. This has been observed in some other countries, but, in the United States, there have been only six reported cases of skeletal fluorosis, and none was related to fluoride in drinking water at the optimal levels.
This is a case of mild fluorosis. If you look closely, you will see areas of white speckles near the biting edges of the teeth. That is the fluorosis. Fluorosis is not harmful to the teeth, and in fact results in stronger teeth, which are more decay resistant. However, cosmetic expectations by consumers compels us to avoid fluoride levels that would lead to fluorosis.
With increasing fluoride content, hypomineralization of the enamel surface can progress to the point that the teeth can become stained, which is symptomatic of moderate fluorosis. Fluorosis can occur when children under age 9 are exposed to higher levels of fluoride while their teeth are developing in a preeruption stage. It is important to keep the fluoride water content below 2 mg/L to minimize the potential for this staining. Once the teeth are formed and emerge, the potential for fluorosis ends. Adults and children over age 9 do not develop dental fluorosis, even at levels above 2 mg/L. The incidence of enamel fluorosis increases as the fluoride level increases in the water.
Different fluoride delivery vehicles have been tried. Salt fluoridation is the second most common means for fluoride delivery. The World Health Organization (WHO) has stated that salt fluoridation is not a substitute for water fluoridation but should be used when water fluoridation is not practical. So the international consensus is that water fluoridation is the best practice when feasible. WHO recommends that a country implement either a water program or a salt program, but not both.

Salt fluoridation requires detailed knowledge of natural fluoride in water supplies so that the consumers do not get excessive fluoride exposure from the combination of water and salt. It is easier to manage a water fluoridation program, because the fluoride content of local water supplies can vary within a geographic region from city to city.

Water fluoridation is comparable to addition of iodine to salt, vitamin D to milk, and folic acid to breads and pastas. Water has been proven to be the most effective means for fluoride delivery for optimal oral health benefits.
Opponents of water fluoridation often claim that fluoride additives in the water negatively affect our health. Typically, they point to individual studies or parts of studies as evidence of a harmful effect. These claims are based on half truths and innuendo and are not substantiated by the body of credible scientific evidence that exists.

The list you see on this slide is only a partial list of the diseases and maladies that opponents claim are related to water fluoridation. Claims are made that fluoride contributes to life-threatening diseases such as cancer, heart disease, diabetes, and AIDS. Birth and developmental problems have been asserted. In fact, claims of damage to every one of the main body systems—digestive, immune, excretory, reproductive, muscular, skeletal, circulatory, and nervous systems—have been made.
We are fortunate that fluoride and water fluoridation have been studied extensively. For the 60 years that water fluoridation has been in existence, and for many years before that, the effects of fluoride in the water supply have been studied.

Occasional studies have suggested an association between fluoridation and one adverse effect or another; however, these individual studies typically have failed to account for confounding factors or have had other flaws, and the findings have not been replicated by other independent researchers.

Good science relies on the weight of the evidence, not the results of one study. Water fluoridation has been examined by panels of scientists chosen for their expertise. These scientists examine the cumulative evidence. They consider not only the findings from the many studies but also the quality of the studies, taking into account study design, statistical analysis used, and biological feasibility of the results.

There are people who feel that science is not enough, and allow themselves to be alarmed by ideas without scientific merit. Dr. Marie McCormick, Chairwoman of a 2004 Institute of Medicine panel on immunizations, reflected on the increasing number of people who make unfounded decisions as a result of scientific illiteracy. This is certainly true of other contaminants in drinking water in addition to fluoride.
Every expert panel that has considered the issue of water fluoridation has come to the same conclusion: it is a safe and effective public health practice. These are some of the more recent expert panels considering water fluoridation practices.
Safe and Effective

- Expert scientific panels, medical and professional organizations, and public health officials have concluded that water fluoridation is safe and effective.
- Water fluoridation has been endorsed by the past five Surgeons Generals of the United States including the current one, Dr. Richard Carmona.

Some Web sites on the Internet make remarkable allegations about the dangers of fluoride. Their claims typically come from sources based on discredited studies, studies that did not have satisfactory controls or epidemiological input, and statements that are taken out of context. They are not intended to educate or inform; in fact, they are carefully worded to alarm and scare the reader. Even when experts have refuted these claims, opponents of fluoridation continue to repeat them.

In spite of the various allegations on Web sites that water fluoridation is a dangerous practice with no medical benefit, the facts clearly show that expert scientific panels, medical and professional associations, and public health officials have concluded that water fluoridation is safe and effective. The past six Surgeon Generals of the United States, including the current one, Dr. Richard Carmona, have all endorsed water fluoridation and encourage communities to add fluoride to the optimal level for oral health.
Experts have studied fluoridation very carefully. That is why more than 100 scientific, professional, and medical associations have recognized the benefits and safety of water fluoridation.
You will have people ask questions based on erroneous information obtained from the Internet. Many questions are answered in the American Dental Association publication *Fluoridation Facts*, available for purchase at www.ADA.org; you should consider obtaining one or more copies of this useful and informative publication. A second source of reliable and correct information is the CDC and their Web site at www.CDC.gov/OralHealth.

In addition to these important resources, you should consider your state water fluoridation program and state dental director as your primary resource to address these erroneous claims.
Impact on Water Bill

- Average water and wastewater bill for a typical family is $41.95/month (source: 2004 AWWA Raftelis Survey)
- Average annual cost to fluoridate water supply for typical household of 2.4 people $4.25 (source: Griffin, J. Public Health Dentistry, 1992 adjusted for inflation)
- Results in equivalent cost to fluoridate typically less than 1 percent of annual utility bill

How much does water fluoridation cost? We can compare a water and wastewater bill for a typical family at approximately $42 a month according to the 2004 American Water Works Association (AWWA) Raftelis (Raff-tell-us) Survey with the average annual cost to fluoridate the water supply for a typical household at $4.25, which includes the operating cost, the cost of the additive, and the amortized bond cost of constructing the improvements, with an equivalent cost to fluoridate equal to less than 1% of the annual utility bill.
This is good time to engage the class with a discussion on health benefits. Use a flip-chart to record their comments.
Why do we fluoridate water?

• Fluoride is a necessary naturally occurring nutrient for good oral health.
• Not all communities have sufficient naturally occurring fluoride.
• Fluoride is essential in the tooth enamel demineralization and remineralization cycle.
• Water fluoridation benefits people of all ages and all socioeconomic groups.
• CDC has named it 1 of 10 great public health achievements of the 20th century.
• The cost to fluoridate water for one person for their entire lifetime is less than the cost of one dental filling, with a cost-benefit of avoiding over $38 dollars for every $1 spent.
Are there any questions about why we fluoridate water or the health benefits of fluoridation?
Now that we have discussed the health benefits of water fluoridation, let’s consider the regulatory perspective for drinking water.
When we talk about EPA drinking water regulations, we are really talking about regulations put forth by the Safe Drinking Water Act (SDWA), passed by Congress on December 16, 1974. The driving force behind the SDWA was reports showing the wide range in quality of drinking water across the nation. The SDWA had some major amendments in 1986, and, more recently, was reauthorized in 1996.

The purpose of the SDWA is to ensure that drinking water supplied to the public is safe. We are fortunate to live in a country where you can visit any community, of any size, and have confidence that you can turn on the tap and safely take a drink of water. That’s a statement you just can’t make in most other countries in the world.

Although the EPA promulgates the safe drinking water requirements, the programs are administered by the individual states that adopt the federal requirements. As long as a state adopts requirements equal to or exceeding the federal EPA requirements, it can assume what is referred to as “primacy” for administration in the state.
The regulations define a contaminant as “Any physical, chemical, biological, or radiological substance or matter in water.”

Basically, anything in water is a contaminant. EPA must periodically assess the various contaminants and identify which ones should be regulated to minimize unfavorable health effects and outcomes.

Knowing this, some contaminants are good to have at low levels for their nutrient value and we want them in the water; we just don’t want too much. Copper and iron are both examples, along with fluoride, of contaminants that have positive health benefits with a nutrient value. You can probably think of other examples.
In the earliest days of water fluoridation, EPA and the Public Health Service (PHS) were partners in promoting water fluoridation. EPA wrote the original engineering guidance for water fluoridation, which was the predecessor to the current AWWA Manual of Practice No. 4 and, at one time, had regional water fluoridation engineers to support local communities and states in each EPA region. The 1974 SDWA implicitly defined water fluoridation as a state program. At that time, state programs began to be established and CDC became the federal support agency for those programs.
The EPA focus is on safe water and contaminant levels that result in unfavorable health outcomes. In 1984, EPA decided other entities should be responsible for providing standards covering water additives. Consequently, the American Water Works Association and the National Sanitation Foundation International are responsible for providing standards to cover water additives. These standards will be discussed later in this presentation.

No federal entity regulates water fluoridation. Water fluoridation programs are managed at a state government level and, in some cases, at a local government level.
EPA studies the health effects of various contaminants in water and identifies what levels are acceptable and what levels may result in unfavorable health results. To avoid unfavorable health results, EPA sets a maximum contaminant level (MCL). MCL is defined as the maximum permissible level of a contaminant in a community water system. MCLs are set to provide a margin of safety and ensure that drinking water does not pose either a short-term or long-term health risk.
Another term you may have heard of is the maximum contaminant level goal (MCLG).

It is important for you to know the definition of MCLG and understand its importance. The MCLG is defined as the maximum level of a contaminant in drinking water at which no known or anticipated adverse effect on the health of persons would occur and that allows an adequate margin of safety.

These goals are nonenforceable and are based on health criteria, regardless of the economics or technology available for meeting the goal.
So what are the maximum concentrations of fluoride allowed in drinking water by the primary standards? The MCL has been set at 4 mg/L. The MCLG value is also 4 mg/L.

Some opponents of water fluoridation allege that EPA is against fluoridation. However, the fact that the EPA has set both the MCLG and MCL at the same concentration, which is considerably higher than the level that is optimal for oral health, demonstrates that such allegations are unfounded.

EPA, in setting a value of 4 mg/L for the MCLG is stating, by definition of the MCLG, that there is no scientific evidence to indicate ANY known or anticipated adverse effect on the health of persons. Although several communities in the United States have consumed water with fluoride levels up to 10 mg/L with only dental fluorosis as an undesirable cosmetic effect, the MCL and MCLG were both set to allow an adequate margin of safety for people with sensitive responses to contaminants.
There are two types of standards: primary and secondary. Let’s take a look at the National Secondary Drinking Water Regulations.

Secondary standards apply to public water systems and specify MCLs that address the aesthetic quality of water, not the direct health qualities. Secondary standards are based on the judgment of the EPA administrator and apply to any contaminant that:

- Adversely affects the odor or appearance of such water and consequently may cause some persons to discontinue its use, or
- May otherwise adversely affect the public welfare.

An example is iron, which can cause cosmetic staining of plumbing fixtures even though there are no associated health effects. Secondary standards are not enforceable and are intended as guidelines for states.
The standard is known as the secondary MCL (SMCL). For fluoride, this has been set at 2 mg/L.

What is the aesthetic quality of water being addressed by this secondary standard for fluoride? Dental fluorosis. As explained earlier, dental fluorosis is a concern only for children before the teeth erupt; in other words, those less than 9 years old. Older children and adults are not at risk for dental fluorosis and can safely consume water with a higher fluoride content without the risk of developing fluorosis. The EPA Web site indicates that this SMCL was promulgated for waters naturally high in fluoride.

Public notification is covered in the primary drinking water regulations.
There are sampling requirements under the SDWA.

For groundwater sources, the fluoride concentration must be checked at least every 3 years.

For surface water sources, the fluoride concentration must be determined at least on an annual basis.
By regulation, when a water system is found to be out of compliance with the primary drinking water standards, the owner of the system must notify consumers of the violation through a mechanism called public notification.

Violation of the fluoride MCL is a Tier 2 violation and requires public notification within 30 days of the violation. An annual notice must be sent/posted to consumers. The regulations contain information on the types of information that must be contained in the notice and how the notice must be sent or posted. Some states may have a different requirement that has been promulgated by the state drinking water regulatory program.

For fluoride violations, specific health-related language must be used, which is also in the regulations.

The notice must also explain steps that are being taken to bring the system into compliance.
The primary drinking water regulations also specify that the public notification must also take place for exceedance of the secondary standards.

Public notification is required for any single exceedance of the 2.0-mg/L secondary standard. Exceedance of the 2.0-mg/L secondary MCL triggers Tier 3 notification requirements. The public should be notified as soon as possible, but always within 12 months of exceedance.

Secondary standards apply to all CWSs. Some confusion exists because the primary standards, which apply to all PWSs, state that exceedance of the 2.0-mg/L secondary MCL requires public notification.

Specific language must be used; it is in EPA’s public notification handbook.
Water fluoridation is not a national program but is organized as a state or local program. Consequently, the state program is the most important management level for proper control and management to ensure the public health.

Although 12 states have mandatory fluoridation laws, most states have left the decision to fluoridate to local policy makers, with state programs providing support and promotion of oral health benefits. CDC provides technical assistance and support to the state programs.
This is good time to engage the class with a discussion on the regulatory perspective. Use a flip-chart to record their comments.
What are the regulatory considerations?

Water fluoridation programs are managed at the state level to promote good health. The optimal level for good oral health is [0.8] mg/L for [Georgia] with a control range of [0.1] mg/L below to [0.5] mg/L above the optimal level.

EPA has established regulatory levels that are considerably above the levels for optimal oral health benefits.

The maximum contaminant level (MCL) is set at 4.0 mg/L, which is the highest tolerable level to avoid adverse health effects.

The maximum contaminant level goal (MCLG), which is the desirable level to avoid adverse health effects, is set at 4.0 mg/L.

The secondary maximum contaminant level (SMCL) is nonenforceable but is a level that requires public notification. It has been set at 2.0 mg/L to avoid the cosmetic effects related to enamel fluorosis.
Are there any questions on regulatory perspective related to water fluoridation?
10-minute break.
We have covered the health benefits of water fluoridation and regulatory perspective for drinking water. Now we can begin to discuss the topics directly related to water plant operators starting with the fluoride additives that we use.
Theoretically, any compound that forms fluoride ions in a water solution can be used to adjust the fluoride concentration in drinking water.

Three compounds are commonly used in the United States:

sodium fluoride;

sodium fluorosilicate, also called sodium hexafluorosilicate or sodium silicofluoride (“sodium sil”); and

fluorosilicic (floor-oh-sill-liss-ick) acid, also called FSA, hydrofluorosilicic acid, HFS, and hexafluorosilicic acid

Other fluoride products have been considered in the past as possible additives but have not been used and no standards exist for their use in drinking water facilities.

Note to Instructor: this is good time to engage the audience and ask each of them which additive is used at their facility.
The raw material for fluoride additive production is the mineral apatite. This is a type of limestone that is a mixture of calcium compounds with relatively high phosphate and fluoride content including:

- calcium phosphate,
- calcium carbonates, and
- calcium fluorides.

Apatite contains 3%–7% fluoride depending on the ore deposit, and it is the primary source of fluoride for water fluoridation in the United States. Florida, North Carolina, the Gulf Coast area, and Mexico are all sources of fluoride used for water fluoridation. After the United States, China is the second largest source of apatite quarrying.

One photo shows milled apatite (a type of limestone) that is used in manufacture of phosphate fertilizers, next to a photo showing calcium fluoride, also known as fluorite or fluorspar. Calcium fluoride deposits were the historical source for fluoride products before the fertilizer industry and apatite became the principal source. Notice that the calcium fluoride crystal is transparent to opaque.
This is the basic flow chart of FSA production. Apatite, a limestone with high phosphate content, is refluxed (mixed and heated) with sulfuric acid resulting in a phosphoric acid-gypsum slurry, the starting point for making pelletized phosphate fertilizers. Gypsum is the material that is used to manufacture drywall or sheetrock type wallboard. This process also produces gases, silicon tetrafluoride, and hydrogen fluoride, which are collected and then condensed into the FSA mixture used for water fluoridation.

The hydrogen fluoride and silicon tetrafluoride that otherwise would be released to the atmosphere or left in the gypsum slurry is deliberately recovered from the slurry by evaporators and condensed to FSA used for water fluoridation. The recovered fluorosilicic acid is a high-purity, low-cost source of fluoride. Some sources may tell you that fluorosilicic acid is hazardous waste material that the industry wants to dispose of, but that is not true.

There is also a small amount of FSA formed when hydrogen fluoride gas is combined with silica. This is possible from the etching of silicon wafers in the manufacturing of electronic components. The acid derived from this route is of high purity. Less than 1% of the FSA used for water fluoridation is derived from this method.
FSA is a straw-colored, transparent liquid. FSA is a fuming corrosive acid, with a pungent odor and irritating action on the skin. FSA is actually a mixture of water, FSA, and free acids, which include hydrogen fluoride. The largest faction, approximately three-quarters of the total, is water, mixed with FSA (H$_2$SiF$_6$), which is a dissolved solid and is the other quarter of the mixture. A trace quantity, typically less than 1%, of the mixture, is in the form of free acids. This free acid fraction includes hydrofluoric acid, also known as hydrogen fluoride (HF), along with silica tetrafluoride, phosphoric acid, sulfuric acid, hydrochloric acid, and other trace acids.

Hydrofluoric acid is volatile, which means it is a gas in solution. This is like the relationship of oxygen gas dissolved in water. The volatile hydrogen fluoride gas will leave the solution if it can reach a surface, and it is the tiny portion of volatile hydrogen fluoride that gives the characteristic odor to FSA. Hydrogen fluoride is also the portion of the mixture that produces the corrosive attack on materials and electronic devices. The rate of hydrogen fluoride formation is very slow, and this makes it possible to store the FSA in tanks for long periods.

This explanation is a simplification of the chemistry of FSA but is sufficient for the purposes of understanding the product for use in water treatment facilities.
FSA has a solution pH of 1.2.

It is commercially available in purities ranging from 20% to 35%, with a typical purity of 23%–25%.

The density of a 25% acid is 10.1 pounds per gallon, which is more than the 8.34 pounds per gallon that water weighs. The chart shows how the density of the FSA increases as the concentration of the acid increases.

FSA is corrosive and care is needed when handling it.

The volatile fumes, which are hydrogen fluoride, are lighter than air. Hydrogen fluoride is less than 1% of the mixture.

If an acid has a purity of 25%, what is the remaining 75%? Water. Because the acid contains a large quantity of water, shipping is a major component of its cost. Even so, it is typically still the least expensive to use for many facilities.

FSA is the most commonly used additive.
Sodium fluorosilicate, previously called sodium silicofluoride, is widely used for water fluoridation. It is a white, odorless, crystalline powder.

Sodium fluorosilicate is produced by neutralizing FSA with sodium carbonate or sodium chloride. During the process, sodium fluorosilicate precipitates out of solution. The acid solution is a weak hydrochloric acid (when sodium chloride is used), so heavy metals remain in the acidic stream solution and not with the precipitated sodium fluorosilicate. The heavy metals do not precipitate with the sodium fluorosilicate.

Unlike sodium fluoride, which has a constant solubility, sodium fluorosilicate has a solubility that varies with temperature; this requires a special effort to correctly dissolve the additive before feeding.
Sodium fluoride was the first compound used for water fluoridation, and its toxicity and physiological effects have been thoroughly studied.

Sodium fluoride is a white odorless salt, available in powder or crystalline form. It is the ideal additive for use with saturators for small systems because of its relatively constant solubility.

It is most commonly produced by neutralizing FSA with caustic soda (NaOH), but can also be produced by combining hydrogen fluoride with caustic soda. It is the most expensive of the fluoride additives because of the high cost and large amount of caustic soda required to produce it. As a result of the high cost of production, all production sources are currently located outside the United States.
There are a couple of standards you should be aware of for fluoride additives.

AWWA has standards for materials and additives used for the treatment and distribution of drinking water. The AWWA specification covers the manufacturing, quality, and verification of the fluoride additives. All facilities should have the AWWA standard for the additive they use for fluoridation.

The NSF International (National Sanitation Foundation) standard covers distribution and impurities of drinking water treatment additives. A key concept is that an additive should not add more than 10% of the maximum allowable level (MAL), which is based on the EPA MCL of any regulated contaminant. This standard replaced the former EPA Water Additives Program in response to a request by EPA in 1984 for requirements for distribution and purity of products added during water treatment, thereby ensuring the public’s protection. It was developed by a consortium of associations, including AWWA, the American National Standards Institute (ANSI), the Association of State Drinking Water Administrators, and the Conference of State Health and Environmental Managers. Many state drinking water programs now require that water treatment additives meet NSF International Standard 60 and 61.

The U.S. Food and Drug Administration (FDA) does not regulate additives to drinking water because their regulatory purview concerns only food, drugs, and cosmetic-related products. There is a 1979 Memorandum of Agreement between EPA and FDA that gives EPA all authority for drinking water regulations and FDA all authority for beverages. Commercially bottled water is considered a beverage, but potable drinking water is not considered a beverage.
AWWA specifications control the quality and manufacturing of the additives. Although you can and should require a supplier to provide a certified copy of all these tests on each batch delivered, facilities can in fact run the tests themselves.

If you suspect the additive delivery may not conform to the specifications, then by all means you should conduct the tests on the additive yourself and verify that the additive meets the specified criteria. For example, the percent fluoride content of FSA can vary from batch to batch; it is sold as 23% but can vary between 18% and 30%. Another example has to do with moisture; excessive moisture content of dry additive can suggest handling problems and the potential for poor solubility.

The test procedures are specified in the AWWA specification, and most water treatment laboratories should be able to conduct these tests. All facilities should have a copy of the specification on hand.

Particularly important for plant personnel is the hydrogen titration test for FSA, along with the specific electrode method for the dry additives, to verify fluoride content of the additives. With an increasing amount of imported sodium fluoride on the market, the insoluble matter and saturated solution turbidity tests are important for that product.
Currently, shortages of fluoride compounds occur in isolated local areas, typically related to depletion of supplies in a regional depot. Discussions with producers and suppliers indicate that there is no reason to expect any shortages at the national level.

Because fluoride compounds used in water fluoridation are produced as a coproduct of the phosphate fertilizer industry, any problems in that industry could affect fluoridation. The year 2004 is an example of a rare disruption as several hurricanes required the fertilizer industry to power-down and then restart operations on several occasions. There was one month when some regional depots in the Midwest and eastern states depleted supplies before new deliveries could resume. Very few facilities were actually affected because there were sufficient on-site inventories in bulk storage tanks, and only a couple dozen facilities nationwide were affected. This type of regional depot depletion does not happen every year.

Dry additives can be imported, and currently, most sodium fluoride comes from China; there is no domestic producer.

You do need to be careful about some imports; utilities have reported that some foreign supplies have debris and purities of less than 50%. You may think you are getting a good deal, but you may use twice as much additive to get the same fluoride concentration, and you have the maintenance headaches of dealing with impurities and debris, particularly in saturators. The AWWA tests can verify the purity of the additive you are using.
FSA can be delivered in different sized containers, including 20,000-gallon rail cars, 4,000- to 6,000-gallon truck tankers, tote tanks with 300–400 gallons, 55-gallon drums, and even 13-gallon carboys.
FSA Delivery Issues

• Most problems occur after shipment leaves manufacturing location or depot
• Typical problems
  − Breakdown and release from transfer hoses
  − Delivery in damaged containers
  − Improperly or inadequately equipped delivery personnel
  − Attempted delivery to wrong storage area
  − Transport related trash including black particles attributed to breakdown of vehicle tank liners, plastic bags, other trash

There are not a lot of problems with additive delivery, but they do occur, and you need to be prepared for them. Most problems associated with FSA delivery are related to causes that occurred after it leaves the manufacturing location or the regional distribution depot. The typical problems are

• Breakdown and release from transfer hoses, so be prepared to contain and neutralize materials discharging onto driveways and neighboring structures.

• Attempted delivery of chemicals in damaged containers of all types, so include an inspection of the containers before you allow delivery personnel to unload.

• Improperly equipped and trained delivery personnel. Verify their delivery manifest documentation and ask to see their checklist of practices before allowing them to unload to ensure that best practices are followed and that agents understand how to perform their job.

• Attempted delivery to the wrong storage location in the facility, which might endanger facilities and personnel when the vehicle must be repositioned. Also, it is not uncommon for a facility to have a truck discharge location with multiple chemical connections for different additives. Make sure your connection line is clearly marked and locked, and unlock the connection only when you are sure the agent is prepared to make the correct connection.

• Although NSF International includes provisions for certification of transport and depot deployment of delivery, on rare occasions contamination can still occur. The delivery vehicles are rubber-lined tanks and the liner can break down, resulting in black particles that can enter your system and damage equipment or block pipes or equipment. Plastic bags and other debris can also enter the delivery vehicle and result in problems. Verify that you have a strainer in the system and that the strainer is clear of debris. If you discover black particles, report it to the additive supplier promptly. Many facilities have the truck driver present a liter of additive before unloading to inspect for black particles and to conduct the AWWA tests.
The preferred storage location is inside a building or under cover. FSA can freeze at approximately 4°F. In moderate climates, the tank can be outside if it is insulated and heat-wrapped, but this is not recommended.

Because this is liquid, it is important to have spill containment for 110% volume (double-walled tank or barrier). If concrete is used, a protective coating should be applied to minimize acid attack on the concrete in the event of a spill. Check with your coating supplier, but normally a good grade of epoxy undercoating with a top coat of high-quality urethane will be satisfactory. Be sure that you use standard operating procedures (SOPs) for filling and withdrawing from the storage tank to ensure that operators are careful and do the job right.

Keep the storage containers sealed with air vented to the outside. Terminate the vent with an inverted “U” and an insect/bird screen. FSA will produce a small quantity of hydrogen fluoride gas, which is corrosive and will etch glass, attack concrete, damage electrical circuits, and stain many things with which it comes into contact. Ensure that the containers are sealed and vented to the outside so the hydrogen fluoride gas is not released inside the storage room.

The bulk storage container, which is the large storage tank, should never be used for additive feed supply. The system should include a day tank that is used for actual feed of fluoride additive.
Some operators have incorrectly speculated that, because hydrogen fluoride gas released from storage tanks results in corrosion, then by extension, water fluoridation will corrode pipes.

EPA and University of Michigan (Ann Arbor) researchers have proven that at the temperatures and concentrations used for water fluoridation, FSA achieves virtually complete dissociation when added to water to the product ions of fluoride, hydrogen, and silica (which is sand) and cannot produce corrosive hydrogen fluoride gas after it is diluted. So, once FSA is added to drinking water, hydrogen fluoride is no longer a problem.

Silicates are actually used as a water stabilizer reducing water corrosion, and sodium silicate is referred to in the water industry as “activated silica”.
A common delivery mode for FSA is a 55-gallon drum. These have been used as day tanks in some cases but normally should not be used in such a fashion. A properly sized tank made for that purpose should be used instead. This polyethylene tank shows that a tank can be easily vented with a flexible hose. The second photograph demonstrates corrosion in the vicinity of an incorrectly vented tank.
Tote tanks can provide a larger volume of FSA than a 55-gallon drum. However, a tote tank should be stored on a containment pallet to hold FSA in the event of spill.
Polyethylene tanks are available in sizes from 10 to 10,000 gallons. Polyethylene is a good material for storage of FSA as it has excellent corrosion resistance. Larger storage volumes are available by grouping several polyethylene tanks together. The cross-linked polyethylene tanks have better environmental resistance, but the linear polyethylene tanks have a better chemical resistance to hydrogen fluoride. Both types of polyethylene tanks have given satisfactory service.

Some facilities have reported discoloration of polyethylene (HDPE) tanks by FSA. This can be considered normal. Strong acids, such as hydrogen fluoride, can have a superficial adsorption, resulting in a scorching of the surface layer leaving a characteristic light brown or light pink stain. This surface scorching leaves a protective film (patina), which then protects the HDPE from further scorching unless the patina film is damaged or scratched. It does not affect the integrity of the tank structure.
Fiberglass tanks provide the potential to store large volumes. There is mixed opinion about the suitability of these tanks. Some locations have used them successfully, but there is speculation that the glass fibers used as a reinforcement may be prone to attack by the hydrogen fluoride gas. If the gel-coat surface is intact, then the glass fibers probably have reasonable protection. Ensure that the resins and coatings used in such storage tanks are suitable for exposure to hydrogen fluoride. Periodically inspect these tanks for structural integrity. The formation of new stains can often identify leaks that are developing. Repairs are relatively inexpensive if caught early. Always use experienced contractors for such work. These tanks have some discoloration as a result of hydrogen fluoride exposure.

Always remember to have a sealed tank that is adequately vented to the outside.
This tank is not correctly vented to the outside. Ensure that the tank is sealed and vented to the outside and that it does not release within the building. This installation will experience corrosion problems within the building.

If a tank is poorly vented, or if there is a leak in the vent piping, there are two visual signs that will indicate that the operator should take action. The first as we have discussed is evidence of corrosion, and the second is a fine white powder covering the piping and other surfaces. This white dusting is silica resulting from decay of the silica tetrafluoride in the FSA releasing HF and silica.

The venting system can be confirmed by air testing. Piping contractors typically have a air test system that can be used for this. The vent system can be pressurized to 2 psig and monitored for air loss. If the system loses more than 1 psig over a 2 minute period, then there is a leak and corrosion will result. The bubble method should help in identifying the leak. Do not exceed 4 psig in the test as the PE tank will not support pressures exceeding 5 psig. It is good practice to check for leaks at least once every 5 years.
FSA will damage concrete surfaces. Along with the use of corrosion-resistant pipe materials, provide surface protection to the concrete where leaks could occur.

A dual application of epoxy undercoat with urethane topcoat normally provides suitable protection for minor leaks.

Consult with reputable coating manufacturers for acceptable products.
Dry additives can be delivered in 50- and 100-pound bags, in 125- to 400-pound drums, and even in 2,500-pound supersacks.

Handling of bags requires special consideration. Use correct lifting technique to avoid personnel injury, and never tear bags open. Always use a knife to slit bag to minimize release of loose dust. After use, wrap bag inside a plastic bag for disposal and use secured placement to avoid exposure to someone else. Don’t just toss bags into a dumpster. Coordinate with the trash hauler and landfill operator so their personnel do not have exposure to fluoride dust.
Dry Additive Delivery Issues

• Most problems occurred after shipment leaves manufacturing location or depot
• Typical problems
  − Delivery in damaged packaging
  − Improperly or inadequately equipped delivery personnel
  − Attempted delivery to wrong storage area
  − Mixing with other chemicals
  − Degradation of product during transport

There are not a lot of problems with additive delivery, but they do occur. Most problems associated with dry additive delivery occur after the additive leaves the manufacturing location or the regional distribution depot.

• One problem is attempted delivery of chemicals in damaged or punctured bags, so include an inspection of bags and pallets before you allow delivery personnel to unload. Often pallets are wrapped in plastic at the manufacturing location, so if you purchase by the pallet, ensure that the shipping wrap is undamaged. Inspect for evidence of rough handling and fork lift punctures.

• Improperly equipped or untrained delivery personnel is another problem. Verify the delivery manifest documentation and ask to see a checklist of practices before you allow unloading to ensure that best practices are followed and that the agent understands how to correctly perform their job.

• Another problem is attempted delivery to the wrong storage location in the facility, which might endanger facilities when the vehicle is repositioned.

• Although NSF International includes provisions for certification of transport and depot deployment of delivery, contamination can still occur. Especially for smaller facilities, all the chemical additives used in the facility may be supplied by a single supplier and they might mix bags of different additives on a common pallet. Verify that no damage has occurred to the bags and that the additives maintain their integrity.

• Another problem can be degradation of product during transport. If the additives are exposed to weather during transport, they can hydrate (adsorb water), which can change their properties and handling characteristics. Do not accept delivery of product exposed to the elements.
Dry additives should be kept in a separate room with secure access that is convenient to the feed location. Avoid storing other additives, lubricants, yard-care fertilizers, etc., in the same room. Do not mix additives.

The room should have good ventilation in the event of dusting.

It is best to have an elevated platform, and keep the dry additives on pallets so they are not in contact with the floor.

Limit stacks to six bags high and protected from the elements. Additives cake when compressed and exposed to moisture. Do not overbuy as the additives will slowly adsorb moisture from the air and hydrate, resulting in “fish-eyes” that may never be successfully dissolved. Limit purchases to a maximum 6-month supply.
Supersacks are a 2,500-pound delivery package that is common in the bulk handling market, and sodium fluorosilicate is available for delivery in supersacks. They hold the equivalent of one pallet of bags. Supersacks have forklift loops for lifting and transporting. For facilities that use a lot of sodium fluorosilicate that can be designed with a large storage hopper, this can be a cost-effective means of handling the additive.

Supersacks should be stored on an elevated platform so that they are not in contact with concrete floors. They must be protected from the elements, and should not be stacked.
What do you do if you have a spill of your fluoride products?

With your dry compounds, shovel them up and, if not contaminated, use them.

If the compounds are suspected of contamination, then they should be properly disposed of in a landfill. Follow local and state codes and regulations. Sodium fluorosilicate is a regulated hazardous substance, and you do not want to expose a landfill operator to excessive sodium fluoride even though it is not a regulated substance. Check with your state water fluoridation program specialist for advice.
Liquid spills require a little more effort. Proper preparation starts by having a containment barrier such as a corrosion-coated concrete curbing surrounding the tank sufficient to hold 110% of the contents of the tank, or drums and totes can be stored on containment pallets. Even with good containment, it is possible for a release to occur (broken pipe, etc.), so you should keep on hand spill control pillows or dams that adsorb acid to contain liquid from spreading in the event of a spill. “Spill kits” are commercially available and many utilities have them. Conduct an annual inspection of your spill kits to ensure that the contents are up to date. If there are multiple chemicals in the tank form, clearly label all spill kits as to their application.

Once contained, neutralize and then consult with authorities about disposal requirements. Avoid “flushing” to a public sewer or on-site septage (septic tank) system. Local jurisdictions have sewer use ordinances prohibiting discharge of non-domestic chemical releases and states have septic tank regulations prohibiting unauthorized use of subsurface leach systems for chemical disposal.
If a spill occurs, as a result of either a leaking pipe or tank or a burst hose, the first thing to do is to contain the acid. Small quantities of acid can be cleaned up with spill control pillows that absorb the acid, and lime can be used to create a dike to contain the spill.

Lime is the best choice for neutralizing acid, and lime is another additive that is available at many water treatment plants. A good practice is to have several bags of powdered lime in storage near to the delivery point so that if a spill occurs, it can be quickly deployed to prevent spreading. Replace the bags yearly so that they don’t cake with excessive moisture over time.

In the reaction of acid and lime, the calcium fluorosilicate is unstable, and almost everything formed will be calcium fluoride (CaF₂) and silica (SiO₂).

These two products are accepted at most landfills, as they are nonhazardous chemicals. However, be sure to consult with the local landfill operator so that no employees at the landfill are exposed to excessive fluoride during placement.

For an acid strength of 25%, you need about 0.39 pound of lime to neutralize a pound of acid.
If lime is not available for neutralization, then caustic soda or soda ash can be used for FSA spills. However, use of these agents will result in formation of either sodium fluorosilicate or sodium fluoride, which may be considered hazardous materials. Special caution is required to clean up these residues, and disposal may involve special licensing. Check with your state hazardous waste regulatory group and consult with the local landfill and fire chief.
This is good time to engage the class with a discussion on fluoride additives. Use a flip-chart to record their comments.
What fluoridation additives are used?

Three additives are used for water fluoridation. Fluorosilicic acid (FSA) is the most commonly used additive. Sodium fluorosilicate is the second most commonly used additive. Sodium fluoride is often used with smaller systems because of its consistent solubility.

There are important AWWA standards that govern the quality and manufacturing of the additives and all facilities should have a copy of the standard for the additive in use at that facility. In addition, NSF International standards govern the impurity levels and transportation of the additives.

Delivery and storage considerations of the additives include the need for a segregated storage area, spill containment, use of corrosion-resistant materials, and venting of volatile hydrogen fluoride resulting from the acid. Separate secured storage protected from the elements needs to be provided. And there are considerations on delivery problems.

How to handle and clean up spills.
Do you have questions on fluoride additives?
10-minute break.
Now that we covered the fluoride additives, we can discuss the equipment and facilities needed for water fluoridation.
There is no one specific type of equipment that is used solely for one type of water system. All the fluoridation equipment, with the exception of a saturator, can be used on any system.

Historically, large water systems typically use FSA, a medium-sized system can use either FSA or dry additives with a feeder, and a very small system uses dry additives with either a saturator or a feeder.

FSA systems are more frequently used because many utilities believe that because the acid is contained in tanks and pipes, there is less hazardous exposure to the operator and require less operator involvement and time. Larger systems typically have found FSA more cost-effective than dry additives in the larger delivery capacities. Some locations with hard water have found that using FSA avoids scaling and plugging from fluoride precipitation products.

Some utilities have chosen the dry additives because they have fewer impurities than FSA, or because they believe that exposure of personnel to dry additives and the resulting solutions present less hazardous conditions than FSA. So dry additives and FSA advocates can both argue that there is less resulting exposure, depending on assumptions, and they can both be right.

In fact, there are reasons to select any of the systems or additives, and a community should consider all the factors before deciding which system to use.
The number of fluoridation systems to serve a community depends on several factors. If the water system has a surface water supply, like a lake or a river, then there may be only one treatment facility, requiring a single fluoride addition location. If the community has two or more treatment facilities, then each location requires a separate feed system.

If the community is served with a groundwater system, then there may be multiple wells, resulting in a distributed feed to the distribution system. If that is the case, then each well requires a separate feed system.

Two equally sized communities, but one with a surface water plant and the other with a distributed well system, might have completely different fluoridation systems. The single surface water plant might use an FSA feed system, whereas the well system might be better off with a saturator or volumetric feeder for dry additive at each wellhead.
How do you design a water fluoridation system?

First, you select the additive and then select the equipment. The compatibility with the water system and other equipment may be a factor, such as using the same brand of metering pump or volumetric feeder that other chemical additive locations use in the facility. The type of flow, such as variable feed or steady state, and the pressure at the discharge point (gravity discharge into a tank or flume versus injection to a pipe) are other considerations. The number of treatment sites can also figure into the decision.

The natural fluoride level must be checked along with the optimum level for addition of fluoride.
Cost is a major—and, in many cases, the deciding—factor in the design of a fluoridation system, especially capital costs.

Of course, state rules and regulations have to be followed and may affect the design a great deal. Sometimes there is a preference by state engineers for a certain additive or installation, so check with the drinking water program for the state for their opinion.
Water fluoridation needs to be understood in relation to other water treatment processes and objectives. First, it must be compatible with the other processes, and it must not contribute to water quality violations. The top priority of the water system is to ensure safe water for the community, and that should not be compromised. On these points, water fluoridation meets the requirements.

Water fluoridation is different from other water treatment processes in that it is unrelated to safe drinking water standards but is comparable to fire fighting in that it promotes a community benefit and has a very high benefit-to-cost ratio for the community. Remember that the cost to fluoridate drinking water for one person for their lifetime is less than the cost of one dental filling.

The EPA perspective is interesting in that EPA recognizes that fluoride is a beneficial nutrient at concentrations that are optimal for good oral health, but, like copper, fluoride has beneficial nutrient levels that are close to undesirable levels. In the case of fluoride, it may result in dental fluorosis.
The objectives of water treatment are

• Disinfection, for pathogenic organisms
• Reduction of contaminants for health effects
• Oxidation of undesirable reduced compounds
• Aesthetic improvements: taste, odor, and color
• Fire fighting, which is not treatment but is an important use of the water system and was the original reason for many community water systems, along with other community benefits such as irrigation, support of industry, and water fluoridation.
Here is a simplified schematic diagram of water treatment. The top line is a conventional surface water treatment facility process train, and the bottom one is a groundwater system that requires some processing of the extracted water. You will see that water fluoridation is often like corrosion control in that it is done as part of effluent finishing as the water is delivered to the water system for distribution.

In this example, chlorine is added at the beginning of the facility. This does not happen at all facilities, but many facilities do add chlorine at the beginning so that they can include the detention time in the facility when computing their C-T (concentration-time) statistics for disinfection management.
Fluoridation Design Basics

- Basic design principles for fluoridation same as for other water treatment processes
- Equipment and process design same as for other standard water treatment processes

The design principles for water fluoridation are the same as for other water treatment processes. The calculations are the same as for other additives and the equipment and process design are the same as for other standard water treatment processes. Fluoride additives, whether purchased in a liquid or dry form, are almost always fed, or added, into the drinking water supply in a liquid form.
It’s really very simple; you need a tank to hold the solution and you need a pump. But, as with most things, there are certain details to get right.
The standard reference guide is the AWWA Manual of Practice No. 4, *Water Fluoridation Principles and Practices*. The current version is the fifth edition, which was published in 2004. If you are adding fluoride to your system, you should consider purchasing this manual of practice from AWWA as a reference. It contains a wealth of information on the practices and operations related to water fluoridation.
I think every operator can tell you that what works at one location may not work in a different situation. So in this class, we can discuss what has been the operating experience at most locations, but you need to learn what unique issues you have at your facility.
Fluoride Additive Feed Equipment Requirements

- Precise Delivery
- Small Quantities/Capacities
- Reliable
- Safety in Handling Hazardous Products
- Corrosion Resistance

Adding fluoride to water involves precise delivery of small quantities of additives. It is always important in water treatment to have reliable facilities and equipment to ensure that the process is maintained with low operator supervision. Because the fluoride additives are corrosive in the concentrated state, we need to use materials with suitable corrosion resistance. And operators are important people, so we need to ensure their safety in handling the concentrated fluoride additives, which are hazardous products.
First, let’s look at how the different additives we discussed are fed into the water. Depending on which product is used, there are different methods for feeding the additives.

FSA can be fed into the water supply with a metering pump.

Saturated solutions of sodium fluoride (NaF) can be produced in a saturator and then fed into the water system with a metering pump.

Unsaturated solutions of either sodium fluoride or sodium fluorosilicate (NaFS) measured using dry feeders, on either a volumetric or a weight basis, are then added to water in a mixing tank, and then added to the water stream.
When FSA is the additive of choice, the process can be quite simple. If the facility is sufficiently large, then delivery can be by tanker truck and the FSA storage tank, with a 3-month supply, is filled by the tanker truck. A transfer pump would refill a day tank with a maximum 3-day storage volume. The final step is a solution metering pump to deliver a precise quantity to the water flow. Each step along the way would have a backflow preventer and anti-siphon device to minimize accidents. Unless a leak occurs, there is very little operator exposure.
Pumps used to deliver fluoride products to drinking water must be accurate and consistent in their delivery rate. We want to maximize benefits and minimize the risk of fluorosis.

Metering feed pumps used in water plants vary in their actions and design but often are of two mechanical categories.

The centrifugal action pumps are widely used in water treatment plants and are sometimes used for other compounds but are not used for feeding fluoride into the water system, because their delivery can be variable and not very precise. You may recognize these as the small utility pumps you buy at the store or the sump pump in your basement. A centrifugal pump may be used as a transfer pump to move FSA from a bulk tank to a day tank but, as a rule, should not be used to feed into the system.

The other category of pump is the positive displacement pump, and the one we will discuss next.
As the name implies, positive displacement pumps are designed to deliver a constant amount of solution over a wide range of system pressures. There are three main categories of positive displacement pumps that traditionally have been used for water fluoridation.

The most common fluoride feed pump is the diaphragm pump.

The peristaltic metering pump is gaining somewhat in popularity. A peristaltic pump is also called a hose or tube pump, because a hose is squeezed by a rotating element, resulting in delivery of a precise quantity of solution.

The piston pump has a piston that moves back and forth to pump the fluoride solution into the water main. Its main advantage is for high-pressure applications. Its main disadvantages are a high purchase cost and high operating and maintenance costs. Some are still in use, but for the most part they are used less frequently for water fluoridation.

There are other positive displacement pumps, including the progressive cavity pump, the screw pump, and the rotary lobe or gear pump. These generally are not used for fluoride solutions, mainly because of the limitations of incompatible corrosion of the materials used to fabricate those pumps.

Best practice is to have the pump fed by a day tank and not from the bulk storage tank. The pump should not have a flooded suction as these can tolerate a suction lift, and that minimizes the potential for an overfeed event.
The piston pump and diaphragm pump offer control of flow over a very wide range. Historically, these may be the more common pumps used for chemical delivery in water treatment plants. The quantity of discharge can be varied in two ways: first in the speed of the stroke and second in the length of the stroke. The diaphragm or piston head is replaceable on these types of pumps and should be replaced annually with a fluoride-compatible material. This picture also shows the pumps mounted with calibration columns to verify the quantity of the delivery and with the pumps installed with containment in the event of leaks. This installation would be suitable for a dry additive solution feeder since the calibration columns are not vented to the outside to minimize fugitive volatile HF, which would result in corrosion if it were used with FSA.
Diaphragm pumps have an oscillating membrane head, which alternately sucks the solution into the pump and then discharges the solution. Inlet and discharge check valves ensure that the fluid moves in one direction. The diaphragm pumps have a replaceable head, which should be replaced annually as a preventive maintenance measure. Also, the check valves need to be inspected and replaced if necessary.
Peristaltic pumps are also known as hose or tube pumps. They have a rotating element that squeezes the hose, delivering a precise quantity of solution. The hose is replaceable and is the only wearing part. These pumps can provide a variable delivery by changing the speed of the rotating element—the faster it rotates, the more solution can be delivered. Some models can operate with large suction lifts. Typically, the hose is replaced annually. Although these have not been used as often in the past, they are gaining in popularity because of their ease of use and maintenance.

Peristaltic pumps have two main groups. The Tube Pumps have a relatively low discharge pressure of less than 40 psi limiting their usage to low-head applications. The reinforced hose pumps are able to achieve discharge pressures of up to 200 to 300 psi, but are more expensive and has a smaller range of capacities.
It is recommended that the storage tanks be enclosed in a designated room. This installation has a view window so that key controls and operations can be monitored without entering the room. This room also includes a depressed floor to provide firm spill containment in the event of a leak or spill. Not all treatment facilities have such a containment, but if your facility is considering an expansion or redesign, this is something to consider.
Dry additives typically are fed into the water system as a saturated or unsaturated solution. Either a saturator or a feeder can be used.

A fluoride saturator is a device to dissolve the dry additive, much like salt or sugar dissolving in water, forming a saturated solution. The most common type of saturator is the upflow saturator, which is typically used in the United States. The downflow saturator is rarely used and is not available in the United States. The venturi saturator has not been sold for many years, but occasionally you may encounter one. Saturators normally are used only with sodium fluoride, because it provides a saturated solution of known concentration, whereas sodium fluorosilicate has a variable solubility based on temperature, so the concentration of the saturated solution is difficult to predict.

Dry feeders are more expensive than saturators, but they offer greater flexibility and can be used for either sodium fluoride or sodium fluorosilicate. Dry feeders are commonly used at water treatment facilities for dry additive feeds other than fluoride additives. They are commonly used to feed dry additive to a solution tank for mixing before addition to the flow. You need to discuss dry feeders with the manufacturers, either volumetric or gravimetric.
A fluoride saturator, either the downflow or the upflow type, maintains a bed, or layer, of sodium fluoride in a tank. Water flows through the bed and dissolves the sodium fluoride.

If operated properly, the solution is completely saturated by the time it passes all the way through the bed. For very small communities, the upper portion of the tank can serve as a day tank and the lower portion of the tank as the saturator. Every day, the operator verifies that there is sufficient additive in the bed and then turns on the water to fill the upper portion to the fill line. This displaces the saturated solution in the bed into the day-tank upper portion of the tank.

For larger flows, the saturator is inadequate for use as a day tank, and, in those cases, the saturator should be coupled with a day tank that is filled from the saturator. Although a standard saturator is roughly the size of a 55-gallon drum, very large saturators can be custom fabricated for use on larger facilities. However, a more typical application would be to use a dry chemical feeder for larger facilities.

The minimum depth of the sodium fluoride in the saturator should be 12 inches, although a deeper bed of 16 to 18 inches is better, and this can be marked on the outside of the tank so that the operator can determine the depth of the additive at a glance. The saturator should never be filled high enough to allow some undissolved additive to reach the pump suction line. Only granular sodium fluoride should be used in a saturator, because the powdered additive tends to plug or allow short-circuiting of the water without becoming fully dissolved.

A chemical feed pump is then used to add a precise quantity of saturated solution to the drinking water supply.
By the 1980s, the downflow saturator had been replaced by the upflow saturator mainly because of operation and maintenance problems with the downflow saturator. One big advantage is that the sand and gravel were eliminated. But the inlet waterline is plumbed directly to the distribution piping at the bottom of the tank and, with no air gap possible, a vacuum breaker and backflow preventer are needed. This is one type of upflow saturator, but there are different varieties on the market.

Saturators typically are used for sodium fluoride, because that additive forms a uniform solution of approximately 40,000 mg/L, or 4 g per 100 mL. With a typical available fluoride content of 45% (55% of the weight is sodium and 45% is fluoride), the saturated solution is a constant 18,000 mg of fluoride ion per L. Saturators can also be used with sodium fluorosilicate, but the solubility of sodium fluorosilicate varies according to water temperature, so the actual solution concentration is inconsistent. This would require constant testing of the concentration of the solution strength. Therefore, it is advisable to avoid using saturators for sodium fluorosilicate as the operational problems can be significant.

The inflow rate on the water makeup line needs to be regulated so the water does not travel through the sodium fluoride bed in less than about 10 minutes.

One of the things you should notice in the photo is the small footprint or area required for the feed equipment. It can literally be put in the corner or along the wall—anywhere you have some open space.

The manufacturer of this saturator has a molded spot on the lid for the pump to sit on, but here it is mounted on a shelf. This makes it easier to reach the saturator for inspection and maintenance.

An electrical outlet should be in series with the high-service or well pump motor starter. Having a flow switch is a good idea.
In areas with high hardness, a water softener is often needed on the make-up water feed to minimize the potential for calcium fluoride scale formation. To avoid scale formation in hard water, either a water softener is needed, or FSA would be the system to minimize scale formation.
Dry Additive Feeders

- Dry Volumetric Feeders
  - Delivers a constant volume of fluoride additive
  - Generally sodium fluorosilicate, but also used with sodium fluoride

Dry feeders deliver a constant volume of fluoride additive and generally are used with sodium fluorosilicate; they can also be used with sodium fluoride.
There are several varieties of dry feeders. These are useful if you are handling large quantities of dry additive and are also available for very small dry additive feed rates. They are more mechanically complex and are more expensive than a saturator. Although a saturator is a simpler operation, it is suitable for use only with sodium fluoride because sodium fluorosilicate does not have a constant solubility. The saturated solution of sodium fluorosilicate is temperature dependent.

A typical installation has the dry feeder deliver the additive to a solution tank. Dry feeders are fundamentally different than a saturator. A saturator prepares a saturated solution, whereas a feeder will add additive to excess dilution water in the dissolving tank. Consequently, a dry feeder does not require softened water, whereas a saturator often requires softened water.

A feeder is a better application for larger facilities and can provide more flexibility, with a choice of either sodium fluoride or sodium fluorosilicate feeds. If you think you want to use a dry additive and this is the type of feeder you want to use, then discuss the options with the various manufacturers.
Unlike sodium fluoride, which has a constant solubility, sodium fluorosilicate has a solubility that varies with temperature, from 0.44 g per 100 mL (which is 1/10th that of sodium fluoride) at 32°F to 2.45 g per 100 mL at 212°F. When the water temperature is 77°F, the solubility is approximately 0.762 g per 100 mL, or 1/5th the saturated solution strength of sodium fluoride at the same temperature. Consequently, it requires a lot more water to form a solution.

Experience has shown that sodium fluorosilicate requires a minimum of 5 minutes to fully dissolve into solution. However, hard water, water temperatures colder than 60°F, and a crystalline form of the additive instead of a powdered form can increase the time necessary to fully dissolve sodium fluorosilicate into solution. If any of these conditions exists, double the time for solution to 10 minutes, and if two or all three exist, then triple it to 15 minutes.

If a dry feeder is used for sodium fluoride, a 5-minute solution tank detention is normally satisfactory. However, it would be prudent to design the dry feeder to be suitable for either sodium fluoride or sodium fluorosilicate feed to give an operator the advantage of being able to use either additive. If the feeder is suitable for sodium fluorosilicate, it will be satisfactory for sodium fluoride. However, a system designed for sodium fluoride might not work properly for sodium fluorosilicate.
It is important that the dry additive be fully dissolved and not fed to the water flow as a partially dissolved slurry. If the solution is not a clear, homogeneous solution, then one of several things likely needs to be changed.

First, check the size of the dissolving chamber. Is it adequately sized? It is necessary to have at least 5 minutes, but as discussed on the previous slide, it might be necessary to have 10 minutes or even 15 minutes. Next, check on the required amount of dilution water and verify that there is excess dilution water delivered. Because the dilution water must mix with the additive, verify that the mixer has suitable power and is in working order. A last thing to verify is that the flow is not short-circuiting the tank, resulting in insufficient detention time.
A volumetric feeder can be a simple installation with a standard chemical feeder and a top loading bin hopper. The feeder will dispense a precise quantity of additive to the solution tank. The feeder and bin in this installation are mounted on a scale so that the amount of additive used can be precisely measured each day. If you have a high erroneous fluoride measurement, the scale allows the operator to verify the actual amount of additive that was used and compare the calculated and measured rates. The water supply has a backflow preventer and vacuum breaker to prevent backflow or siphoning of the solution into the water system.

This type of installation is typical of a sodium fluorosilicate feed. Because the solubility of the fluorosilicate varies with temperature, the solution pump is sized to deliver a constant feed rate based on the maximum quantity of solution at the lowest operating temperature for the largest facility flow rate, and the quantity of fluoride feed is precisely controlled by the speed of the feeder. The top loading bin hopper is sized for a 1- to 3-day supply of sodium fluorosilicate. The minimum time for mixing sodium fluorosilicate is 5 minutes, but sizing the solution mixing tank for a 10- to 30-minute detention will ensure good dissolution.
Here is another feeder installation. It has a slightly larger bin hopper, and there is a loading platform so the operator can have easy access to the bin feed location. For even larger facilities, the bin loading location might be on the floor above the one with the hopper, or you can get bin loaders with elevator lifts as part of the bin loading so the bags can be added at ground level of the building.
A complete system needs vacuum breakers, anti-siphon valves, and day tanks; it may also include water meters, pacing meters, mixers, scales, and continuous analyzers. As with any process, the more ability the operator has to operate and manage the system, the better will be the results.
Whether you are installing a new system or rebuilding an older system, be sure to include the piping fittings and other auxiliary items to make your job easier.
Piping Considerations

- Use fluoride-compatible materials such as PVC, HDPE
- Include numerous shut-off valves and unions at key locations to facilitate pipe repairs
- Identify the pipe

Use fluoride-compatible materials such as polyvinyl chloride (PVC), chlorinated PVC (CPVC), and HDPE in pipe manifolds. Be sure to include numerous shut-off valves and unions at key locations to facilitate pipe repairs. Use a color-coding system to clearly mark that the supply is a fluoride solution. A recommended painting scheme is light blue with red bands, with an arrow indicating the direction of flow and the word “Fluoride” on the pipe.
Backflow prevention and air-relief valves in key locations can preclude draining or siphoning tanks, which could result in overfeeds or solution spills.
Calibration cylinders installed in the piping manifold allow pump discharges to be checked so that flows are accurate. This is particularly important with fluoride, as the flow rates tend to be very small.
When adding solution to a pipe, an injector can enhance the mixing of the solution with the water flow. The injector should be placed in the lower third of the pipe and extend into the pipe approximately one-third of the pipe’s diameter.

Some contractors will install the injector into the crown (top) of the pipe due to easy access, but this will result in poor mixing. The fluorosilicic acid solution is denser (heavier) than water, so if the injector is pointed down towards the pipe invert (bottom), then the solution will sink to the bottom of the pipe and the solution plume will be poorly mixed.
A static mixer is a screw-like vane pipe insert to promote mixing of the solution with the water flow. This is particularly important if the first customer is only a short distance downstream from the facility.
Instrumental analysis has shown significant improvements in quality and reliability. This is also true for continuous online fluoride analysis. These units are available from $5,000 on the low end to $10,000 on the high end. The difference can be summed up by the adage “you get what you pay for.” However, these devices are becoming more common, and operators find that they are important operational tools to manage the fluoride level. They can also initiate actions at preset alarm points, which can be valuable at water facilities that are not manned 24 hours per day. In many facilities, the use of these devices ultimately saves operator time and improves the results. There will be increasing reliance on the use of these as well as other devices in the future.
If FSA is delivered in a drum or a tote, it will be necessary to transfer from the bulk storage to a day tank. Because the volume transferred from a drum or a tote is likely to be small, a simple hand pump may be satisfactory.
In addition to hand pumps, small electric pumps can also be used. However, never have an automatic transfer pump from bulk storage to the day tank actuated by a float or level controller. The transfer pump to the day tank should also be manually controlled so that operator presence is required to transfer and overfeeds are prevented.
Scales for drums and tanks are an excellent means of accurately documenting the use of fluoride solution. An advantage of using scales is that there is nothing extending into the atmosphere of the tank so hydrogen fluoride corrosion is avoided. If your installation does not have a scale, consider adding one for improved management and verification of precise fluoride feed. Scales can be obtained for any size, including for an entire tank. Normally, only a day tank needs to be weighed.

Electronic scales use an electronic load cell to measure weight. A load cell is based on a Wheatstone Bridge to provide precise measurement. One load cell provides accuracy to within 1 % and for typical solution day tanks would be a satisfactory measurement. For a typical small to medium sized plant with a day tank of 50 gallons or less, an electronic scale would cost approximately $3,000. For a dry chemical feeder with the feed bin mounted on top, a scale with three load cells would be accurate to within 0.1 % and could cost $3,500 to $5,000.
All tanks should have containment in the event of a spill. Commercially available containment pallets can provide secure protection for various sizes of tanks and totes. Be sure to have a containment pallet sufficient to hold the entire contents of the drum or container in the event of a spill.
For handling bags of dry additive with hopper bins, a bag loader can minimize dusting, reducing operator exposure. The bags should not be torn open, but slit the top with a knife after it is secured in the loading swing-door to minimize loose dust.
CDC recommends a storage capacity equal to 3 months of additive. With times greater than 6 months, there can be some degradation of product, particularly with the dry additives; with less 2 months capacity, you may have insufficient quantity to extend over shortages. Consult with vendors in your area for their advice about the appropriate level of storage.
It is always recommended that chemical additions be fed from a day tank, not the larger storage tank. The reason is that, in the event of an accident or error, a very large amount of additive could be accidentally added from the larger storage tank. However, use of a day tank avoids accidentally adding excessive fluoride. You will need to check your state regulations on the size of day tanks, for the recommendations can vary. 10-State Standards specifies a maximum of 30-hours, with AWWA suggesting that a day tank can be sized for up to a 3-day supply. Some state programs may have a smaller maximum permissible capacity. The CDC recommends that a day tank be sized for a 1- to 2-day capacity.

The saturator can also be sized to double as a day tank. The upper portion of the tank above the additive bed can serve as the day tank if it is sized appropriately. A volumetric feeder can also be sized with a feed hopper that can hold a designated amount of additive that is less than a 3-day supply.

The solution pumps should also be appropriately sized. If you are using a metering pump to deliver a precise quantity of saturated solution, then you want a high-quality pump with reliable delivery. The pump should not have excess delivery capacity. By matching the maximum delivery to only that needed for maximum delivery of the required fluoride solution at a peak design event, excessive feed of fluoride is avoided.

If you are using a volumetric feeder with unsaturated solutions, then the pump might be sized to deliver the peak flow needed to convey the fluoride additive at the peak flow event with the lowest operating temperature at the treatment facility.
If you are planning on changing or modifying your fluoridation system, check on your state requirements for prior approval. Typically, if the work is more maintenance in character—fixing or replacing what already exists—then you can often proceed. But many states require submission of plans and specifications, some requiring the seal of a professional engineer, before giving approval to proceed with work that goes beyond what would be considered maintenance. Many states also require inspection of new installations before putting them in service. Know your state requirements.
This is a good time to engage the class with a discussion on equipment and facilities. Use a flip-chart to record their comments.
What fluoridation equipment did we discuss?

We discussed FSA storage tanks and pumps.

Dry additive feeders.

Saturators.

Backflow preventers, anti-siphon devices, and day tanks to avoid overfeed incidents. Scales and level monitors to verify usage of additives.

Suitable materials for corrosive exposure.
Are there any questions about equipment used for water fluoridation?
We have covered that we fluoridate water for the remarkable oral health benefits, that it is safe and effective, the regulations on water quality related to water fluoridation, and the additives and equipment used. We are going to take a lunch break and when we pick up, we will consider laboratory testing, personnel safety, and water fluoridation operations.

60- to 90-minute lunch break depending on availability of restaurants. Attempt to identify a sponsor to provide lunch so that the participants do not leave the location.
Fluoride is one of the more difficult things to measure in water. Although we do not have time in this class to give you detailed hands-on instruction in laboratory technique, we will cover the considerations that you need to know to conduct an accurate analysis. Be sure to work with colleagues and the sales representatives of your laboratory equipment for precise instruction on the use of your equipment. It is only with hands-on experience that you learn proper technique.
The three methods used for fluoride analysis in water are colorimetric, which is used most frequently, specific ion electrode, which is more accurate but requires a slightly higher level of operator attention, and inductively coupled plasma spectroscopy, or ICP-MS, which requires an expensive specialized analytical tool and is rarely used.
Fluoride Testing Methods

- **Colorimetric** - Compares reduction of indicator solution color influenced by ions
- **Specific Ion Electrode** - Measures ionic activity as a relative indicator
- **Inductively Coupled Plasma Spectroscopy (ICP-MS)** - Measures the number of ions in a fixed volume on basis of mass to charge ratio

How do these methods work?

The colorimetric method compares reduction in the color of an indicator solution that is reduced by the presence of ions. There are competing ions that can introduce errors in measurement. Sometimes a more precise answer can be obtained by using a spectrophotometer instead of a colorimeter. This method can suffer from many operator errors in methodology.

The specific ion electrode measures the activity of ions by measuring electrical potential. This is less influenced by competing ionic interference than the colorimeter and experiences fewer method errors that are operator related.

Inductively coupled plasma spectroscopy (ICP-MS) measures the number of ions in a fixed volume on the basis of mass-to-charge ratio. We will not be discussing this method because it is rarely used by water treatment facility laboratories, and it requires an expensive device. If there is a need for accurate measurement of many samples, or if your laboratory has a reason to have this type of instrument for other purposes, it would be a method that you should consider.
When you are selecting a method to use for fluoride analysis, you need to compare the methods based on certain criteria. If you are making only one or two measurements a day to verify the operating fluoride level and have few interferences, then the colorimetric method may be the best choice. If you need better accuracy, if interfering substances are present, or if you are making numerous tests in a day to obtain a better operating control, then the specific ion electrode method is a better choice. The colorimetric method may be a lower cost option if you are measuring only once per day, but if you make more frequent measurements, the cost of the supplies for the colorimetric method will result in it being the more expensive option.

Another consideration might be the ability to verify product purity. In the additive and operation sections, we discussed that the purity of the fluoride additive can vary and that the AWWA standard provides a means to verify additive purity. The specific ion electrode is the method prescribed for sodium fluorosilicate and sodium fluoride, so you might want that test procedure just so that you can verify product purity. All additives can vary in characteristics, but experience has found that imported additives, particularly sodium fluoride products, can differ greatly from batch to batch.
The colorimetric method is a simple method. The basic parts are

- a source of radiant energy or light source,
- an energy detector to measure how much of the energy passes through the sample, and
- the adsorption body, which we refer to as the sample.
Why do we see color in something? This is a complex topic, but for the purpose of understanding the concepts of colorimetry, we will simply say that an object has both reflectance and transmittance characteristics. Light is composed of different colors, with each color being a different wavelength. An object reflects certain colors and retains others. An object can adsorb certain colors of light, meaning it can allow certain colors of light to pass through. The apple is red, because it reflects the red color and adsorbs the other colors.
How something appears includes the shade of black and white, as seen by the rods in an eye, and the color, as seen by the cones. The colors are a function of the wavelength of the light. We use 570 nanometers, located in the green portion of the color spectrum, as the reference for measuring fluoride, which is fortunately different than the red spectrum and which, as a complementary color, could confuse the observer.
People see colors differently. Approximately 10% of all males are color blind to some extent, and many people see colors with hues and shades in a different way than others. The original colorimetric methods relied on a person’s perception of the color compared with a color chart. This could result in a lot of interpretation, or even outright guesses. Using a colorimeter to measure color is more accurate and reproducible than relying on a person’s perception.
There are two types of instruments we can use to measure the color properties of a sample: a photometer, also known as a colorimeter, and a spectrophotometer.
The older style filter photometer used a white light source and a color filter. White light includes all the color spectrum, and the color filter might transmit the green spectrum without attenuation, but it would transmit a portion of other colors as well. The result was that the light source was less specific and gave a less precise measurement with potential interference from other color wavelengths. Recently, colorimeters have used a light-emitting diode (LED) as a specific green wavelength light source. Use of an LED allows a narrower wavelength spread from the light source, and this has improved the accuracy of the newer colorimeters.
The best accuracy using a colorimetric test is obtained with a spectrophotometer. Whereas a photometer using an LED source has a narrower spectral range than a filter photometer, it still has a wider range than the specific color wavelength that is needed for a precise measurement. A more precise measurement is obtained if a spectrophotometer is used to select the precise wavelength of the test procedure.
For a colorimetric method to work, you need a reference reagent with color. For fluoride, this is SPADNS. In addition to fluoride, SPADNS is also used to measure zirconium and thorium, which occur rarely in water and so they don’t interfere with this test. The test procedure is accepted by EPA and is explained in *Standard Methods for the Evaluation of Water and Wastewater*.

[sodium-pair-aw-sull-for-fee-null-la-zoe-die-high-droxs-ull-nap-full-lean-die-sull-for-nate]
If you want to economize, you can mix your own SPADNS reagent, but that takes a certain deliberate effort and needs to be done periodically so that the solution is fresh. More commonly, a laboratory will purchase premade SPADNS. Purchasing the premade reagent is more expensive than mixing your own, but it eliminates some of the potential operator error related to improper mixing.

HACH sells a specialty product named AccuVac Ampules, which are vacuum-packed ampoules ready for sample filling and testing with premeasured reagent already included. AccuVac can minimize operator handling errors, but is the most expensive choice.

Please note that CDC does not endorse any single product or manufacturer, but information on this HACH product is included for there are many facilities using this product. Check with other suppliers on the availability of competitive products.

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SUPPLEMENTAL NOTES FOR REFERENCE ONLY

2005 HACH prices
Carton of 25 AccuVac Ampules $17.55, so 70 cents per test.
SPADNS reagent 500 mL $22.10, so at 4 mL per test, about 125 tests per bottle or 18 cents per test.
So AccuVac is approximately 3.5 times more expensive per test.
When SPADNS is added to a water sample, a “color lake” is formed in the sample. For fluoride measurement, SPADNS actually measures the amount of zirconium in the sample. Zirconium reacts with fluoride, and, in the absence of SPADNS, the solution is colorless. However, if SPADNS is added to the solution, the zirconium-fluoride complex reduces the color of the “color lake” and the observed reduction in color is an indication of the amount of fluoride in the solution. A deep red color indicates an absence of fluoride, and a light red color indicates a high fluoride concentration.
Colorimeters are programmed so that you calibrate them by testing a fluoride standard, which is water with a known concentration of fluoride, and a “blank,” which is distilled-deionized water with no fluoride. This calibrates the device, and then the test is repeated, this time with the sample collected. The difference in the sample color is the fluoride concentration. Colorimeters are programmed so that this calculation is done for the user automatically, with a direct readout of the fluoride concentration.
The colorimetric method of analysis can introduce the largest number of potential errors. Let’s review the types of errors that can be experienced with the colorimetric method.
For sources of error with the colorimetric method in sample collection, is the sample collected from a location where the fluoride solution is fully mixed? It might be appropriate to take samples at the same time from multiple locations and see if the value changes as you move downstream. If it does change, that may well indicate that the solution is not adequately mixed. Either find a different sampling location or promote better mixing by using a device such as a better nozzle or a static mixer in a pipe or by moving the fluoride addition point upstream of a good mixing location such as a weir.

Is the container used for collection clean? A lot of plants have difficulty collecting a sample directly and must use an intermediate container such as a bucket to collect a sample. If so, verify that the intermediate device is not introducing a sampling error.

And don’t forget that the person collecting the sample can introduce contamination. If additive was just poured into the hopper, then there may be a slight residual from fingers or clothes, which would influence the sample results.

Contamination might result from chlorine. Be sure to use sodium arsenite to minimize chlorine interference.
After the sample is collected, sample handling can introduce more potential errors.

If the operator is not using a HACH AccuVac Ampule, then it is necessary to use pipettes for measuring sample quantity and the SPADNS solution. Use of a pipette requires skill and practice to achieve accuracy. Also, if you are using a suction bulb to fill the pipette, make sure the bulb is clean and not introducing error. The pipette itself might not have been correctly washed or rinsed from the previous use. Be sure to use an acid wash for pipettes.

If you are using an AccuVac Ampule, invert the ampoule and immerse the tip under the water surface. Then carefully snap the tip by placing pressure against the sample container, and ensure that you keep the tip under the water surface until the ampoule is completely filled. There is a tendency to lift the ampoule while filling, and that breaks the ampoule vacuum, which renders it useless. A certain percentage of the ampoules will be wasted, further increasing the cost of the procedure.

Parallax can also introduce error. Parallax is the visual distortion that results from a different viewing angle. As shown in this illustration, the measurement must be made from eye level, not looking down or up at the measuring line.
If HACH AccuVac Ampules are used, then the errors from a testing cell, or cuvette, are minimized. But many locations use reusable cuvettes for testing with the sample and SPADNS measured for each test to save money. If so, there are certain actions to avoid introducing error with cuvettes.

Most importantly, ensure that the cuvette is cleaned and is not smeared with fingerprints or other substances. This can also be a problem with AccuVac Ampules. Keep your fingers cleaned, and ensure the cuvette or ampoule is clean. Sometimes use of latex gloves, such as disposable medical exam gloves, can help avoid this type of exposure as well as potential sample contamination.

Is the cuvette clean? Many detergents contain phosphorus compounds for cleaning, and those and other potential residuals can interfere with the results. Use an acid wash or rinse thoroughly with SPADNS reagent, which includes hydrochloric acid.

Another factor is the optical clarity of the cuvette and ampoule. If you are using two cuvettes, one for the blank or reference sample, and another for the sample to be tested, you might want to ensure that they have a consistent optical clarity. Scratches, etching, and discolorations can all interfere with an accurate measurement.
The colorimetric method requires comparison to a standard, and this can introduce other errors.

Always use fresh standards. Standards can go bad for various reasons, including contamination, evaporation, and other causes. The SPADNS solution can also change in character such as evaporation of the hydrochloric acid, which is part of the solution. It is good practice to replace the standards at least yearly, but once every 6 months is better. Also, are the standards appropriate for the concentration range that will be measured?

Another error can be if the colorimeter is not correctly calibrated with the standard. The colorimeter must be recalibrated against a standard every time the device is turned on, at least once a shift, or if it is being used at a different location.

Another potential source of error is if true, deionized water is used. The water must be fluoride-free, or zero fluoride. When was the last time the distillation still was cleaned? The conductivity meter may not register that a high level of conductance is passing, but fluoride is one of the first ions to begin passing the exchange medium as it progressively exhausts in capacity. Consider purchasing zero fluoride water from the supply house when you purchase your standards.
The colorimeter relies on electronics to operate. There can be several causes of electronic errors.

The batteries used in a colorimeter are good for only 300–400 tests, and that presumes the batteries were fresh with a full charge to begin with. If the batteries are weak, the results will be inconsistent, even if the indicator still shows charge left in the battery, so establish a replacement cycle before the battery begins to lose its charge. Another problem can be leaking batteries. The chemical can seep into the electronics and damage the circuits, or sometimes the voltage can continue to interfere with the circuit when the unit is plugged into a power source, so remove the batteries if you are using a different power source.

The electronics can also experience deterioration due to oxidation corrosion, heat, or abuse. Dropping the instrument or bumpy rides in a truck can damage the instrumentation. Leaving instruments in a car or other container in the sun can result in heat damage. Chemical corrosion can result from several sources, but the most common source is hydrochloric acid, which is a component of the SPADNS solution. Although many cases have a space to hold a vial of SPADNS, the best practice is to store the SPADNS solution remotely from the colorimeter so that slight fumes from hydrochloric acid are avoided.

How can you tell if the electronics are in working order? Compare the results using standards against other measuring devices including colorimeters, specific ion electrodes, or a split sample with the state reference laboratory.
Calibration is essential for accurate measurements. The colorimeter must be calibrated at least once each time it is turned on and should be verified if the device has been inactive for a period.

It is also important to use the device only within the range in which it is reliable and within the range in which the calibration has been set. Although the manufacturers of colorimeters claim that they are accurate from 0.1 to 2.0 mg/L, Standard Methods for the Examination of Water and Wastewater recognizes a range of only 0.1–1.4 mg/L. The reason is that the test procedure has a linear response only up to 1.4 mg/L. The test relies on a nonlinear calibration above 1.4 mg/L.

The accuracy of the test is a function of ±0.1 mg/L ± 50%, or as much as a 0.15-mg/L deviation from the true value, without chemical or other interferences.

Background color or turbidity can also influence results. Verify that there is no background color or turbidity.

Another interference can be the sample temperature. The standards and the sample must be at the same temperature for results to be comparable.
Besides chlorine, there are certain compounds that can result in interferences. These include aluminum, iron, hexametaphosphate (from corrosion control), phosphate, and sulfate. You can still use the colorimetric method, but it is necessary to distill the sample. A distillation apparatus can be purchased for the SPADNS test, and the procedure is explained in *Standard Methods for the Examination of Water and Wastewater*. Distillation is effective but requires close control, is hazardous, and easily overruns the end point. If these interferences exist, it might be better to choose a different test procedure such as specific ion electrode.
The 2005 price for a single function pocket fluoride colorimeter is about $350, with cost of the more capable multifunction colorimeters around $600. If you use the HACH vacuum ampoules, the cost for each test will be about $0.75. If you use the SPADNS solution instead of the ampoules, then the cost is less than 20 cents for each test.

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SPADNS reagent 500 mL $22.10, so at 4 mL per test, about 125 tests per bottle or 18 cents per test.
The SPADNS can also be run with a spectrophotometer and the results should be more accurate. However, the cost of the device may be $2,000–$6,000 depending on the manufacturer and the features of the unit you purchase. If you already have a spectrophotometer for other testing in your laboratory, then you do not need to purchase a specialty device.
The second most common type of fluoride measuring instrument is the specific ion electrode. Fluoride is measured by the ionic activity in the solution. The electrode is composed of an electrode body, an ionic membrane using a lanthanum fluoride (LaF) crystal, which is connected by a wire to the opposite end of the electrode, and a filling solution. The electrode is connected to a specific ion meter, which indicates the ionic strength of the solution.
In the simplest terms, the specific ion electrode method uses a specific ion meter with a sensing electrode coupled with a reference electrode. The sample is mixed with a buffering solution and then the sample must be stirred. The reason is that, without stirring, the fluoride content of the water in immediate contact with the probe membrane will change, so stirring ensures that the probe is always in contact with fresh solution. Some devices use a “combination” probe, which combines both electrodes into one unit. The combination probes are more expensive but less expensive than the two separate probes. However, the reference probe has a longer life than the specific ion probe, so some users think the use of two separate probes is less expensive in the long run.
The specific ion electrode method has the advantage of a greater range than the colorimetric method, it has fewer interfering substances and tolerates them at a higher concentration, and it is less susceptible to technique errors if you are making a lot of measurements and will be less expensive. The disadvantages are that it can be more expensive and time-consuming, and it requires a little higher operator attention to the procedure.
The specific ion electrode method uses a total ionic strength adjusting buffer, also known as TISAB. It adjusts pH to the range 5–5.5 to optimize fluoride ion availability, adjusts the overall ionic strength of the solution, and complexes iron and aluminum.
There are various forms of buffer used. The most common form for fluoride analysis is TISAB II, which uses an equal part of buffer to sample. It complexes up to 5 mg of aluminum or iron content per liter.
There are two other forms of TISAB that can be used but are not often used. TISAB III is a concentrated form of TISAB II. The reason it is not often used is that many laboratories find it is easier to measure equal volumes of TISAB and sample rather than different volumes of TIASB III and sample. TISAB IV is rarely used but it can handle a higher level of impurities.
A specific ion meter ranges from $1000 to $2000. Orion fluoride electrodes are about $500, or $600 for a combination electrode.
Specific Ion Electrode Analysis

This is a typical setup for a two-electrode system with the meter, the two probes, and the sample on a magnetic stirrer.
The first step is to calibrate the specific ion electrode and meter against reference samples.
Because it is important to verify calibration of the instrument every 2 hours, laboratories often set up a gang of reference samples that can be left on the bench. This can facilitate instrument calibration verification.
After calibration with reference standards, rinse with deionized water to avoid carryover, which might yield erroneous results.
Then measure the sample fluoride. Many of the modern specific ion meters are programmed to remember the calibration and then give you a direct read of the fluoride level.
There are fewer sources of potential error with the specific ion electrode method, and it is less subject to technique errors. However, as with all things, there remains a potential for error, so let’s review those starting with sampling.
The potential sampling errors are the same as for the colorimetric method.

Is the sample collected from a location where the fluoride solution is fully mixed?

Is the container used for collection clean?

And don’t forget that the person collecting the sample can introduce contamination. If additive was just poured into the hopper, there may be a slight residual from fingers or clothes, which would influence the sample results.

Contamination might result from chlorine. Be sure to use sodium arsenite to minimize chlorine interference. This can happen whenever chlorine is added ahead of fluoride, which is often the case if the facility is relying on the detention time within the plant facilities to achieve the C-T ratio.
Specific Ion Analysis

Sources of Error

Sample Handling or Method Related
- Parallax in measurement
- Improper stirring
- Bubble
- Induced EMF
- Complexation (TISAB)
- Concentration out of range

Potential errors can be introduced during sample handling or can be related to the method procedure. There is less chance for error here than in the colorimetric method.

Care needs to be taken when measuring the sample and TISAB II buffer so that they are equal volumes. Any accurate container will do. A beaker with a clearly defined measurement line can be used to measure two equal volumes. Remember the parallax error and measure at eye level.

The solution must be adequately stirred while the electrode probe is measuring the fluoride level. The water immediately in contact with the membrane at the bottom of the probe will have a varying concentration of fluoride, so you need to scour the membrane with fresh solution. A related issue can be if a bubble is captured at the membrane. Then the electrode probe will not be in contact with the solution.

It is possible for measurement to be influenced by an induced EMF if the wire leads are crossed. Be careful of the wire placement on the bench, and move the wires to minimize the EMF interference.

The TISAB buffer has an important influence on the outcome of the test. Ensure that the TISAB is fresh and the correct quantity and type of TISAB are used. TISAB II is commonly used, but types III and IV are sometimes appropriate.

Always remember that the results are not accurate if the concentration is out of the operating range of the test procedure.
The specific ion method requires comparison to a standard, and this can introduce other errors. Much of this is the same as was discussed for the colorimetric method, but in review …

Always use fresh standards.

Ensure appropriate calibration of the instrument using the standard. The specific ion meter must be recalibrated against a standard every 2 hours.

Use true, deionized water.
The specific ion meter relies on electronics to operate. There can be several causes of electronic errors.

The batteries used in a portable specific ion electrode probe are good for only a limited time. If the batteries are weak, the results will be inconsistent, even if the battery indicator still shows charge left in the battery, so establish a replacement cycle before the battery begins to lose its charge. Another problem can be leaking batteries. The chemical can seep into the electronics and damage the circuits, or sometimes the voltage can continue to interfere with the circuit when the unit is plugged into an AC power source, so remove the batteries if you are using a different power source.

The electronics can also experience deterioration due to oxidation corrosion, heat, or abuse. Dropping the instrument or bumpy rides in a truck can damage instrumentation. Leaving the instrument in car or other container in the sun can result in heat damage. Chemical corrosion can result from several sources, so avoid storing fuming acids or chemicals near the instrument.

The specific ion method can also suffer an instrument drift, with varying results, if there are weak batteries or if the temperature changes or varies in the different solutions.

How can you tell if the electronics are in working order? Compare the results using standards against other measuring devices including colorimeters, specific ion electrodes, or a split sample with the state reference laboratory.
The fluoride electrode is a delicate part of the specific ion method. Many facilities find that the specific ion electrode can be good for a period of 2 or more years, with luck. However, it is not uncommon to need to replace an electrode after 6 months for a number of reasons.

First, the fine-wire electrical lead that connects the membrane at the “working end” of the probe to the connections at the top of the element can break, and this will render the electrode unusable.

Another group of problems are related to the filling solution, whether a leak has developed in the body, whether the incorrect filling solution is used, or whether the correct amount of filling solution is maintained within the electrode body. Check the manufacturer’s information on the probe to ensure that the correct filling solution and the correct amount are used.

The membrane can also be damaged, either as a result of crystallizing or if the membrane is otherwise plugged.

Another item to verify is whether you are using the correct reference electrode. The reference electrodes are not as expensive as the specific ion electrode, and they tend to have a longer life span, but they can wear out.
If you suspect the fluoride electrode is not giving you accurate readings, check the slope of the electrode potential. Although the specific ion meter is normally set to indicate the fluoride level, it is really measuring the electrode potential. You can reset the device to display the electrode potential, and if the slope is not a 56-millivolt drop per decade against the fluoride concentration, such as between 0.1 and 1.0 mg/L, or between 1.0 and 10.0 mg/L, then you need to replace the probe. Also the reference probe can be verified by pairing it with a pH electrode and performing a pH calibration.
Besides chlorine, there are certain compounds that can result in interferences. These include aluminum, iron, hexametaphosphate (from corrosion control), phosphate, and sulfate. If these are present, the specific ion method can eventually have interference but, as a practical matter, can give erroneous readings.
If you need to store the electrodes for a period of time, check the manufacturer’s recommendations. As a general rule, the specific ion probe is stored dry, while the combination probe and the reference probe have filling solution.
This is good time to engage the class with a discussion on laboratory analysis of fluoride. Use a flip-chart to record their comments.
For laboratory analysis

We covered the colorimetric method (SPADNS), which can provide satisfactory results but is subject to many interferences and operator methodology errors.

We covered the specific ion electrode method, which provides more reliable results but requires greater operator effort.

Whichever method you choose, care and attention to methodology details and correct procedure are essential to achieve satisfactory results.
So what questions do you have on laboratory analysis?
10-minute break.
You have probably heard that fluoride additives are hazardous. We will review the facts on fluoride handling, and cover what personnel safety gear you should use.
Why is safety a consideration in a water fluoridation program? Because people are our most important resource. All people have the right to work in safe conditions, and there are regulations to mandate safe conditions.
We cannot separate water fluoridation efforts from other safety programs at a water treatment facility. So let’s review the principles of safety and planning for safety. There are four principles of occupational safety according to the *Handbook of OSHA Construction Safety*:

- All accidents are preventable
- All levels of management are responsible for safety
- All employees must be properly trained to safely perform their work
- All employees are responsible for their own safety and the safety of their co-workers
A safe practice comprises three things:

- Knowledge,
- Action, and
- Attitude.

Let’s look at these a little closer.
The first part of safe practices is knowledge.

It is important for both the management and the staff to understand the risk. Identify the unsafe conditions in advance, and if you encounter something late, act on it then. Anticipate situations that could occur in your plant.

Be sure you have the material safety data sheets (MSDS) for the chemicals you use in your facility. Have them available for the staff, index them for easy retrieval, and verify that everyone knows how to read them.

Learn the rules that cover safe working practices at your facility. The Occupational Safety & Health Administration (OSHA) in the United States has many specific safety requirements that need to be implemented, and a facility may choose to hire a specialist to assist in identifying hazards and the appropriate OSHA rules. Some states have their own requirements that exceed OSHA requirements, and, of course, union and labor agreements might also have certain requirements. Make sure you know what they are.
Action is the next part of safe practices. Action requires having a safety plan. A facility can contract with a consultant to prepare a safety plan, but most plants prepare their own. An excellent resource in preparing a safety plan for a water treatment facility and the larger water utility system is the AWWA Manual of Practice No. 3, *Safety Practices for Water Utilities*. 
Attitude is another part of safe practices. All employees must value safety for themselves and others, and safety should be integrated into all activities and actions.
Water Fluoridation Safety

- Hazards are the same as water facility operators experience in other aspects of facility operation
- Specific hazards are related to material handling considerations

The hazards water facility operators experience due to water fluoridation are essentially the same as those they encounter with other parts of the water treatment facility. So, a safety plan that addresses the hazards in a water treatment plant will directly address the hazards associated with operating a water treatment system. The specific hazards in water fluoridation relate to material handling of the fluoride additives.
The OSHA hazard communication standard establishes the minimum requirements to ensure employees know chemical hazards and the appropriate protective measures. Employers have a requirement to provide all relevant information to employees, and employees should expect to obtain information on how to protect themselves against hazards.
MSDS must be provided by chemical suppliers for their product, and employers have the responsibility to ensure that employees have access to that information. Commonly, employers compile the MSDS and then maintain them at a central location for employees to review. Although a few institutions provide generic MSDS, virtually all manufacturers prepare their own content. Use the manufacture specific sheet from your additive supplier, not a generic sheet. Also, verify that you have the most recent update. Manufacturers typically review their sheets annually and periodically reissue the MSDS.
To ensure personnel safety, it is important to learn the rules. Obtain the correct personnel respirators and train your staff on proper use. Obtain the correct personnel protective gear and train your staff on proper use. Learn about the additive you use and the material handling considerations. Develop SOPs and best practices for your facility. Plan ahead by formulating response plans for spills and to avoid excessive exposure of your staff.
We need to understand the risk, so let’s review it. A toxic substance is something that is considered harmful to the body, often with undesired side effects. This can range from as little as experiencing symptoms from which the person fully recovers, to severe cases when death is possible. What is important between these extremes is the dose, or exposure.

There are two types of exposures: acute and chronic. Acute exposures are singular, rare, and more severe than chronic exposures. Acute exposures should not be minimized or underestimated. They require rapid response and follow up by medical personnel. In contrast, chronic exposures often go ignored or unnoticed for years until symptoms develop.

Our bodies can generally tolerate some exposure to everything, but increasing amounts may result in toxic exposure. An example is aspirin. Medical authorities suggest that one or two baby aspirin (or approximately half an adult pill) per day is beneficial, particularly for cardiovascular health, and two pills when necessary can relieve pain, promote healing of tissue, and reduce a fever. However, if you consume a larger quantity of pills daily over a long time you might develop stomach pain and bleeding (a chronic exposure) and if you take enough pills at one event (approximately 40 aspirin for a typical adult male), it could lead to death (acute). So the dose is what is important.

Most fluoride product exposures in water treatment plants come from poor work habits or accidents involving careless handling of fluoride products. Splashes, spills, exposure to fluoride dust, and even emergency situations, such as fires, can lead to exposure. Routinely wearing National Institute for Occupational Safety and Health (NIOSH) approved breathing apparatus and protective clothing will help workers avoid exposure.
There are three ways to be exposed to fluoride. A person can breathe it in, have it splashed on the skin, or ingest it.

Ingestion, or eating or drinking, is how the public relates to fluoridated water. However, water plant employees are most concerned about inhalation and dermal exposure. There may be occasions when employees accidentally ingest dry chemicals, although that would be rare. By not putting your hands in your mouth or eating food in the vicinity of fluoride products, you can avoid ingestion.

Note that, in the case of a fire, dry chemicals are not flammable but will release hydrogen fluoride gas. When FSA is heated, it reacts with many metals to produce flammable and explosive hydrogen gas.
Exposure to fluoride at low levels, such as those used for water fluoridation, has not been found to cause adverse effects in humans. A comprehensive U.S. Public Health Service Report (1991) found no indication that organ systems are affected by chronic, low-level fluoride exposure and that claims cannot be substantiated for associations with allergic reactions, cancer, birth defects, genetic disorders, or any other adverse claim.

Long-term exposure to higher than recommended levels can lead to health effects such as those noted on this slide. Most people have intakes of 1–3 mg of fluoride per day from food, diet, air, etc. When exposures become considerably higher than these levels over long periods of time, symptoms can develop. For example, it is generally accepted that exposures of 15–20 mg of fluoride per day can put a person at risk of developing skeletal fluorosis, a bone disease. It is important to point out that, during the past 40 years, only six cases of skeletal fluorosis have been diagnosed in the United States, and none was related to water fluoridation at optimal levels or due to water facility operators handling additives.
Inhalation and dermal exposure are linked. Splashes with liquid acids can burn, especially when hydrogen fluoride is inhaled or makes contact with the delicate tissues of the respiratory system, including the trachea, bronchia, and alveoli. Likewise, contact with exposed skin surfaces can result in serious burns. The skin is delicate and can ulcerate if the exposure is sufficient. When either dermal or inhalation exposure occurs, it is best to suspect that both types of exposure occurred. Appropriate actions to take for all exposures are detailed later in this presentation.

Because dermal and inhalation exposure are often linked, it is usually difficult to determine how much each contributed to the toxic exposure. In instances in which fatalities have occurred due to exposure to hydrogen fluoride gas (none of these incidences has occurred in water plants), it is unclear how much exposure the person suffered. Dermal exposure is more of a concern with FSA as the skin tissue is sensitive to the acid, but the dry additives have little direct dermal exposure risk as the adsorption rate through skin is minimal.

For external burns, medical personnel may apply magnesium oxide paste to skin or soak exposed skin in cold solutions of magnesium or calcium salts or quaternary ammonium compounds. Mild or moderate burns may be massaged with a penetrating calcium gluconate gel.
Acute exposures take place when an individual is exposed to a single, large dose.

A number of symptoms may develop after exposure, including all those shown on the slide, but not everyone develops all symptoms.

Symptoms may vary depending on the route of exposure. For example, inhalation is highly irritating and would be accompanied by nasal and eye irritation, sore throat and cough, shortness of breath, and airway burns and ulcerations.

The symptoms that develop from exposure to excessive amounts of ingested fluoride may include gastric distress, weakness, excessive salivation, etc. The advent of any symptoms should be taken seriously and medical assistance should be sought immediately. Call the poison control center.

SUPPLEMENTAL NOTES FOR REFERENCE ONLY

5 mg/kg body weight
77.27 mg for 170-lb person (kg = lb/2.2)
Not possible with optimally fluoridated water
Ingestion of 386 liters (102 gallons) for 170-lb person
5 liters of 1 ppm water/kg body weight
Tetany = clinical neurologic syndrome characterized by muscle twitches, cramps, and carpopedal spasm, and, when severe, laryngospasm and seizures.
After exposure, the first concern is to move the affected person from the source of the exposure. Next, immediately consult a poison control center or medical toxicologist. Contacting 911 may be an appropriate action. Then provide first-aid treatment—rinsing eyes and skin with water and washing affected skin with an alkaline soap—to help relieve symptoms.

The main objectives of medical treatment are to limit further absorption and to complex or remove free fluoride ions from the blood while maintaining electrolyte balance. In other words, attempts are made to disrupt the action of fluoride and remove it from the body while keeping other bodily functions operating at an acceptable level. Free fluoride is bound by elements with positive charges, such as calcium, magnesium, phosphorus, and aluminum, so strategies to reduce the effects of excess fluoride use compounds containing these elements. For example, gastric lavage (washing) has been conducted with calcium gluconate, calcium carbonate, calcium lactate, calcium chloride, calcium hydroxide, calcium- or magnesium-based antacid, and aluminum hydroxide gel. Skin burns have been treated with pastes made of calcium gluconate and magnesium oxide. Skin has been soaked in iced solutions of quaternary ammonium, alcohol, or magnesium sulfate. Intradermal and intraarterial injections of calcium gluconate and other compounds have been used.

The major route of fluoride excretion is via kidneys and urine. Two methods are NOT recommended: (1) neutralizing the acid with orally administered sodium bicarbonate, which will create an exothermic (heat producing) reaction, and (2) inducing vomiting, which will form hydrofluoric acid in the stomach. Administer milk, calcium carbonate, and aluminum- and magnesium-based antacids to bind fluoride. Hospital workers will administer calcium chloride intravenously to correct calcium deficiencies.
When toxic doses are listed for fluoride, they are listed for pure fluoride. It is important to remember that 5 mg of fluoride is equal to 11 mg of sodium fluoride and 8 mg of sodium fluorosilicate. Therefore, it takes 11–22 mg of sodium fluoride per kg of body weight and 8–16 mg of sodium fluorosilicate per kg of body weight to cause toxicity. Similarly, it takes 70–141 mg of sodium fluoride and 51–102 mg of sodium fluorosilicate per kg of body weight to create a lethal dose.

To achieve a toxic dose of pure fluoride, which means experiencing symptoms, a 170-lb person would need to ingest 386–773 mg, or something nominally equal to the volume of two to four aspirin tablets. To achieve a potentially lethal dose, a person would need to consume a dose of pure fluoride in an amount equal to a volume of 8 to 18 aspirin tablets.

Based on this, the amount of sodium fluoride needed for a potentially lethal dose has a volume that is one-seventh to one-third the volume of aspirin for a lethal dose.

SUPPLEMENTAL NOTES FOR REFERENCE ONLY
Symptoms may appear with 3–5 mg/kg of body weight

Regular strength aspirin has 325 mg of active ingredient. Aspirin has a toxic dose of 150–300 mg/kg body weight and a potentially lethal dose of 500 mg/kg body weight.

\[
\begin{align*}
(\text{kg} = \text{lb}/2.2) \\
5 \text{ liters of 1-ppm water/kg body weight} \\
5 \text{ mg/kg body weight (lowest level)} \\
170-\text{lb person} = 77.27 \text{ kg} \\
77.27 \times 5 \text{ mg} = 386.36 \text{ mg} \\
\text{Not possible with optimally fluoridated water} \\
\text{Ingestion of 386 liters (102 gallons) for 170-lb person}
\end{align*}
\]
Now that we have reviewed the hazard, we need to consider what actions a plant operator can and should take to minimize risk. What protective gear is appropriate for handling fluoride additives? The typical routine exposure an operator would encounter is quite low, but CDC recommends that people in potential contact with fluoride products wear safety gear at all times in the event of unanticipated large exposure as a result of unforeseen events, such as a bag dropping or a pipe or pump hose breaking.

A respirator is important to avoid inhaling dust or hydrogen fluoride. In addition to a respirator, long rubber or neoprene gloves will protect a worker’s hands, and the gloves should have a sleeve gauntlet so that if the hands are raised, the additive that comes down is captured by the gauntlet and does not continue to run. A rubber or neoprene apron will protect the worker from splashes, and rubber boots will keep shoes away from contact with loose additive. General body protection can be provided by long-sleeve overalls. Don’t use bib overalls without sleeves or short-sleeve overalls as the arms are left without protection. Never forget eye protection so that dust and acid do not irritate the eyes.
Handling fluoride additives presents a respiratory exposure. So let’s take a moment and discuss respirators. Everything has a dose-response relationship; in other words, you can tolerate some exposure to everything, but there is a limit to the amount of exposure to anything your body can tolerate. OSHA requires using a respirator when the permissible exposure limit (PEL) is exceeded for the time period to conduct the work task for a particular hazard.

For fluoride additives, the dry additives sodium fluoride and sodium fluorosilicate both offer principally a dust exposure, whereas FSA exposure results from the release of volatile hydrogen fluoride. The actual exposure in routine operations, such as adding a bag of additive, connecting hoses when filling tanks, or adjusting equipment, is typically within the PEL for both the fluoride additive dust from dry additives and the volatile hydrogen fluoride that is released from FSA. However, although the exposure is inherently low, the best practice is to mandate the use of respirators whenever potential exposure could occur in the event an UNEXPECTED higher exposure is encountered. This can happen if a bag is dropped, with the resulting dust, or if a bag has deteriorated, assuming more of a powder character than the granular character required by the specifications, or if there is a large spill of FSA that allows a large release of volatile hydrogen fluoride. You need to be prepared to respond to such an incident, which may exceed the PEL, which is a compelling reason to use a respirator at all times.

You should also be aware that some lots of dry additive may have a lower fluoride content and a higher insoluble content. When this happens, it is often a case of having too much silica content. Very fine silica can also present a respiratory hazard, so the respirator is important with those lots as well.
There are two major types of respirators.

The first is an air purifying respirator, which removes or reduces specific particulate, vapor, and gas contaminants. These are not suitable if the oxygen content of the atmosphere is less than 19.5%.

The second is an air supplying respirator, which provides protection independent of conditions in the room. These can be supplied from a stationary gas source or they can be a self-contained breathing unit, also known as a SCBU, which some people refer to as “scuba.”
Which respirator is appropriate for use with fluoride additives?

A good clue about which respirator is appropriate is how the additive manufacturers view their products and what they recommend for an 8-hour exposure limit in handling the product. Remember that very few water plant operators will ever have an 8-hour exposure to fluoride additives, because most activities require 5–30 minutes daily, so the MSDS recommendations, which are based on 8-hour exposure, exceed the likely exposure that an actual water facility operator would incur for less than 30 minutes a day. The consensus of the additive supplier MSDS guidance, and the recommendations by Mine Safety Appliance, a major manufacturer of safety gear, is that an air purifying respirator with a hydrogen fluoride rating is appropriate for standard exposure for both dry additives and FSA.

The exception to the use of an air purifying respirator is in the event of fire. Then, a SCBU is necessary because of the potential for the oxygen content of the air to be less than 19.5%. There are some advocates of SCBU for all exposures. This can be considered an ultimate solution, and it may be appropriate if it is consistent with other safety practices at that facility and if the operator is comfortable and familiar with use of SCBU.
Typically, the better quality respirators come in different sizes, to fit different sizes of individuals. You should consider procuring a respirator for each individual on your staff so each person has firm protection. If the respirator does not fit well, then the user will not have full protection. Also, although using a respirator may seem intuitive, in fact, there are instructions on correct use. Make sure that each person has the appropriate training on correct use of the respirator.

Note to Presenter: Bring a respirator to the classroom and demonstrate.
Although some respirators can be elaborate with integrated face masks and other features, a NIOSH approved air purifying respirator is satisfactory. Don't think that a simple fabric face mask is an acceptable respirator for fluoride products. It will not provide satisfactory protection to the user.
Let's review what we have discussed about respirators. An air purifying respirator is satisfactory for most situations at a water treatment facility with fluoride additive exposure, with a fire exposure requiring an air supplying respirator. Ensure that the mask is correctly sized for the individual using it. Respirators that include integral eye protection are preferred. It is important that the user get training on proper use of the device. The air purifying respirators use a replaceable canister that should be both particulate and hydrogen fluoride rated. Make sure you have a scheduled replacement period for the canister. CDC recommends that canisters be replaced every 6 months as a precaution and immediately after any major event such as a cleanup of spilled material. This is because the media will eventually degrade or become saturated, and you always want to have a unit that is not subject to exhaustion or failure when you need it the most. Also, when the filtering canisters are replaced, give the respirator unit a complete inspection. Replace seals and other features such as a scratched eye protection lens or elastic mounting strap to ensure a snug fit. If there is any question about the unit, replace it with a new one.
Skin exposure is more hazardous than breathing the vapors of FSA, so it is important to have a rubber or neoprene apron and long-sleeve gloves with gauntlets. When FSA comes into contact with skin, it does not initially respond with a burning sensation, but it is a very strong acid and will do damage. If you have contact with acid, wash or shower immediately, and then remove your clothes and repeat the washing or rinsing. People who have had skin contact with FSA indicate they did not initially feel a burning sensation, but the chemical burn did occur, so, if exposed, be sure to wash immediately for about a 15 minute duration to avoid skin damage. Acid in the clothing fabric can result in significant burns if it is not removed.

Good quality gloves and aprons can be obtained from many sources, but the commercial safety catalogs have a wide selection at a reasonable price. This is an inexpensive protection that is easy to provide. Do not use leather, thin latex, or fabric gloves; only neoprene, PVC, and heavy rubber products will provide protection.

When wearing gloves, be sure to turn back the cuff.

NOTE TO PRESENTER: bring an apron, gloves, and boots to the classroom for demonstration.
When handling FSA, a full-face shield in addition to goggles is recommended. Use of a respirator with integrated eye goggles is an alternative to separate goggles, but a full-face shield would still be needed.
Even with a full face shield and safety goggles, there is a remote possibility of eye irritation, particularly if there is failure of the safety gear. For that unlikely situation, you need a safety shower and eye wash station.

Here is a safety shower with a pull-chain handle. And here is a typical eye wash station. You can get integrated safety shower/eye wash combinations that provide both features. These should be tested on a regular schedule to ensure that they are in proper working condition. Note that this eye wash station is not working correctly and would be virtually useless in an emergency situation.
So let's review safety gear for fluorosilicic acid.

- Face shield and safety goggles
- Heavy rubber apron and gloves
- Rubber boots are also important. Rubber boots provide protection to shoes and will help avoid tracking solution to other locations outside the fluoride additive storage area.
- And have a safety shower and eye wash station at the location of potential contact.
- Long-sleeve coveralls will also provide some additional protection, by minimizing the amount of acid splashed directly on your skin. But if the overalls are splashed, remove them immediately.

This operator has appropriate FSA safety gear, but he is not wearing a long-sleeve overall for arm protection. Also, an air purifying respirator would provide better protection in the event of an unexpected spill.
If you are handling dry additives, you don’t want to use a face mask. Goggles will provide much better protection. The CDC recommends that you consider having a respirator with integrated goggles.
Here is a properly equipped operator handling bags of dry additive. Note the respirator with integrated eye goggles, long-sleeve overalls, and rubber gloves. In this application, an apron is not necessary because the operator is not being exposed to solutions.

The long-sleeved overalls are important when handling dry additives to minimize contact of the additives with the skin. Although there is very little skin adsorption of the dry additive in normal contact, it is important to wash off the dry additive if you experience an unintended exposure as soon as is practical. Your skin is the first line of protection to keeping things out of your body, and if you have an open cut or wound, substances have an easy entry into your body. Wearing overalls protects the skin from abrasion or cutting that could accidentally occur while handling the additives, resulting in unwanted exposure. Remember that the normal exposure to fluoride additive in typical situations by a water plant operator is inherently low, but we need personnel protection gear for the UNEXPECTED high exposure that can occur when we don’t expect it to happen.

Notice that the operator is using a knife to slice the bag open. This minimized loose dust that would potentially occur if the bag was ripped open. Also think about disposal of the bags. Do not drop them in a dumpster, but secure them in plastic bags and dispose of them in a manner that does not expose another person the hazard.
You should keep your gear in a designated location convenient to the point-of-use. A locker or a storage cabinet can serve this function. Avoid contamination with other gear or clothing.
A good facility will prepare SOPs for every aspect of operations. This is particularly true with respect to safety. A SOP can represent a consensus of several people’s experience, resulting in guidance for less experienced staff. It also reminds all staff members of correct procedures and promotes best behavior in addition to best practices. SOPs also preserve the institutional memory as to why something is done and how to do it so that, if key individuals leave, the practice continues in their absence.
Here are examples of things to include in the practice area of best practices:

Always use personnel protective gear.
Never eat or smoke in additive storage area.
Always clean up additive storage area promptly after spill.
Always wash clothes and body after excessive exposure.
Always wash hands after entering fluoride storage area.
Always have a backup buddy when entering additive storage area.

Use a checklist and document its use.
Proper Signage and Markings

- Ensure appropriate warning signs are installed
- Install barriers to minimize unauthorized entry to controlled spaces – doors, fences, etc.
- Use floor markings to manage use of space – lines to demarcate limits of storage locations or perimeter of special safety precautions

Another safety action that can be quite effective is the use of appropriate warning signs to alert people to hazards. This is not only to serve as a reminder to the staff, who can grow tolerant to hazards, but also to orient new employees or visitors, who otherwise might be unaware of the hazard. Barriers to minimize unauthorized entry to controlled spaces can include doors and fences. Also, floor markings can effectively identify limits of storage areas or the perimeter of special safety precautions. Sometimes a painted line on a floor can remind someone not to enter an area without the appropriate personnel safety gear.
Safety signage can be custom ordered to meet the needs of your facility. The cost of a few signs may be repaid many times over in avoiding an accidental exposure to a person.
This is good time to engage the class with a discussion on personnel safety. Use a flip-chart to record their comments.
The safety of operators was discussed, including

That every plant should have a safety program to protect our most important resource, the operator.

Hazards to water facility operators from water fluoridation are like other operational and chemical hazards already present at the facility.

Excessive exposure to concentrated chemicals can result in illness or death.

Personal safety gear should always be worn for the unexpected excessive exposure incidents, which is where operators experience most injuries and toxic exposures.
Do you have questions on operator safety related to water fluoridation?
10-minute break.
Operations is where everything we have learned today comes together.
We are adding these compounds to the water so that we can adjust the fluoride concentration to the optimal level for preventing tooth decay. The optimal fluoride level for a location is based on the average maximum daily air temperature, and we use data from a 5-year period. This average is for the entire year; we do not recommend changing the optimal level to account for seasonal temperature variations.

It is important to remember that benefits to oral health decline as fluoride levels drop below optimum, and only a small incremental benefit is gained as fluoride levels rise above optimum. The CDC recommends a control range of 0.1 mg/L below the optimal level to 0.5 mg/L above the optimal level, but some states have different control ranges.
For the full benefits of fluoridation to be realized, fluoride must be maintained at or near the optimal level. For [Georgia], the optimal level is [0.80] mg/L. The principal reason for low or erratic fluoride levels is poor operation and maintenance.

Everything to do with water fluoridation is something a water plant operator already does for another process, so there are no new skills to master. But, it is important to understand what types of things an operator should be doing to resolve problems when they occur.
For operators to successfully do their job, they must understand the job and what is required to achieve success. This includes providing good operator training on the job objectives and requirements, guidance on best practices to conduct the work, SOPs specific to the facility, and demands of the job.
To the operators, guidance means they have all the information needed to do the job correctly.

SOPs should always be prepared for all job elements so operators have the information for the job at hand.

SOPs should be written presuming that high employee turnover could jeopardize operational continuity when new people show up.

SOPs should include operational considerations, safety, performance measures, best practices, reporting, and documentation on all aspects of a job. Check with other facilities to see if they have SOPs for process management, which you might be able to use for a head start in preparing your own SOPs. If you can't find another facility, then either contract with a firm to assist you, or begin writing down everything that is relevant to a process, and, over time, you will have prepared your SOP.
Here is the simplified process control scheme. To control the fluoridation process, the steps include:

- Raw water sampling;
- Fluoride analysis to know how much additive is in the solution, such as FSA or dissolved dry additive;
- Determination of the fluoride dosage;
- Calculation of the proper feed rate;
- Calibration of the feeder; and
- Sampling of the treated water to verify operation.

Many operators may ask if it is necessary to calculate the feed-rate if they can control it by adjusting the feed-rate and observing the result without doing the confirming math. That approach is a reactive approach, and typically leads to unanticipated swings in operation that can result in a water quality violation. It is only by having the calculated feed rate as a comparison that the operator can anticipate changes in operation that need to be addressed before they result in uncontrolled swings in operation. The reactive form of plant operations will lead to bigger problems as the operator struggles to recover from an event that they are unclear as to the cause.

Best Practices in operation are to document all Standard Operating Procedures (SOPs). This would include the calculations necessary for monitoring the plant operation. The first time the calculations are prepared will take some time, but once prepared, the daily review should only take a minute, which is time well-spent.
To get the right dosage of fluoride additive, it is necessary to know how much to add. This requires some math, but the calculations are the same type as those required for other chemical additives at a treatment facility. So let's review the simple math calculations that are needed for any process control in a water facility. As is the case with other calculations, it is normally necessary to express the calculations in units of measurement.

For the plant flow, million gallons per day (MGD), or gallons per day (gpd) for smaller facilities, and cubic meters per day (m³/day) in the metric system.

For the dosage, either milligrams per liter (mg/L) or parts per million (ppm), which is approximately the same thing.

The additive feed rate is normally expressed as pounds per day (lb/day) or pounds per hour (lb/h) for dry additives, or as milliliters per minute (mL/min), gallons per day (gpd), or gallons per hour (gph) for FSA feed.
Process Calculations

- Desired dosage
  - Amount of fluoride chemical needed to attain optimal level
- Optimal level
- Natural level

\[
\text{Dosage} = \text{Optimal level} - \text{Natural level} \\
\text{(mg/l)} - \text{(mg/l)} = \text{(mg/l)}
\]

To determine the amount of fluoride additive, you need to know the optimal level for your location and what the natural fluoride level is for your source water. The optimal level can be determined by consulting with your state water fluoridation program, and the natural level must be measured. Some locations will find the natural level to be stable, but other locations will find it changes based on seasonal influences. Once you know the target optimal level and the natural level, you can determine the necessary dosage by simple subtraction. For example, if the optimal level is 0.8 mg/L, and the natural level is 0.2 mg/L, then the dosage is 0.6 mg/L.
Once the dosage has been calculated, then the quantity of fluoride additive can be calculated. This requires knowledge of the treatment facility capacity. Here is a listing of various capacity measurements for one treatment facility. Typically, a water facility is rated to have the capacity to produce the maximum month demand, and that is often the measurement we think of as a facility capacity. But, in fact, there are other measures of capacity including maximum hour, maximum day, annual average, and minimum capacity that the facility can operate; each is a factor of the capacity. On this list, the maximum month capacity is listed as a factor of 1, and the others have the factor you would multiply by to get that rating. So the annual average capacity is 80% of the maximum month capacity. When doing your calculations, you might need to run several calculations depending on what you are trying to determine. Often, the most important calculation is the actual operating rate, which is the measured flow through the facility.

Groundwater wells can present a unique case in that some groundwater pumps are constant speed pumps, so they deliver the amount of water only when they are pumping. Then you have a simpler calculation.

Please note that not all water treatment facilities operate on a 24-hour basis. If a water plant only operates 8 hours per day, then the calculations will need to be adjusted appropriately.
The chemical purity of the additive is also important. For the three fluoride products, the available fluoride ion depends on the chemical purity. However, some additives may not meet AWWA specifications and therefore would deliver a different quantity of available fluoride ion than shown in this table. One example is that FSA is nominally sold on a 23% purity basis, but, in fact, each batch might have a different purity. You need to verify the purity of your batch—is it 22% or 25% pure? And some dry additives can have a lower purity, such as excessive silica in sodium fluoride, which is often the case with imports from other counties that might not meet the AWWA specification. Make sure you verify the purity of each shipment. The supplier should be able to provide you with a certified test of the batch you receive; you can also run a test of the purity to verify what was delivered.

The available fluoride ion content is based on a 100% purity, so verify the purity of your additive using the AWWA test.
Here is an equation with which you should already be familiar. It’s our old friend, the water formula. As you have learned in other courses, this equation is prepared to allow easy-to-use units, pounds per day, milligrams per liter, and million gallons per day, and the factor 8.34 includes all the conversion factors to make the units resolve. We also include the available fluoride ion and the chemical purity, which we saw on the previous slide.

The first time you run this calculation for your facility, it may take a while to get the calculation correct. But Best Practices for water plant operations are to document all your work in a Standard Operating Procedure, and once you do that, then a daily verification of the calculated feed rate should only take you minute to prepare.
If we rearrange this equation to calculate the dosage, we need to multiply both sides of the equation by the AFI and the chemical purity, and divide both sides by the capacity and the 8.34 conversion factor. This results in the lower equation.
With this equation, which is a familiar friend, we can calculate how much additive is required to treat the flow. As a comparison, to treat 1 million gallons per day with 1 mg of fluoride per liter, presuming the water does not contain any naturally occurring fluoride, the following amount of additive is required:

Sodium fluoride (98% verify the purity, particularly if it is imported), 18.8 lb

Sodium fluorosilicate (98%), 14.0 lb

FSA (23%, and this can vary from delivery to delivery), 45.7 lb/≈4.6 gallons.
Calculation Problem 1

- Plant 1 has an average daily flow of 1.4 MGD and the source water has a natural fluoride level of 0.15 mg/L. The optimal level for oral health is 0.9 mg/L. If the FSA has a concentration of 25%, what is the dosage required and how many gallons will be necessary?

You will have to compute the usage of fluoride additive at your own facility for the flows and concentrations you will be dealing with. Let’s take a little time to do a few sample calculations. We will do one calculation each for FSA, sodium fluorosilicate, and sodium fluoride, but even though you need to deal with only one of these at your plant, the practice of making the calculation for each example will help you in your management of fluoride levels in your plant.

For the first example, we have a plant that is treating 1.4 MGD. The natural fluoride in the source water is 0.15 mg/L and the optimal level for oral health for the state is 0.9 mg/L. The FSA has been evaluated by using the hydrogen titration method from the AWWA standard for FSA and has been determined to be 25%. Let’s discuss how to calculate dosage and gallons of solution to be fed.
We have a plant that is treating 1.4 MGD. The natural fluoride in the source water is 0.15 mg/L and the optimal level for oral health for the state is 0.9 mg/L. So 0.9 minus 0.15 is 0.75 mg/L of fluoride to be added.

Now that we know how much fluoride product to add, we can calculate the number of gallons we need to add each day.
So we calculated that we needed a dosage of 0.9 minus 0.15 which is 0.75 mg/L of fluoride to be added. We put that dosage into the equation, and then substitute the capacity with 1.4 MGD. The FSA has a purity of 25%, which means it has 25% acid and 75% water. And from the earlier table, we know 0.792 mg of fluoride ion is available for each mg of pure acid (assuming 100% purity). Using the standard water treatment equation and substituting the known values in the equation, we can compute that we need to feed 44.22 lb of solution per day. From other math courses, you have probably learned the concept of significant figures in calculations; because the 1.4 MGD has only two significant figures, we can rely on only two significant figures in the final calculations, so we round it to 44 lb/day.

So that is how much fluoride additive is needed in one day.
Calculation Problem 1 (step 3)

Average daily flow of 1.4 MGD
Optimal minus natural is

\[
\begin{align*}
0.9 &- 0.15 = 0.75 \text{ mg/L} \\
44 \text{ lb/day} &
\end{align*}
\]

\[
\begin{align*}
\frac{44 \text{ lb/day}}{0.792 \times 0.25} &= \frac{0.75 \text{ mg/L} \times 1.4 \text{ MGD} \times 8.34}{0.792 \times 0.25}  \\
44 \text{ lb/day divided by 24 hours is 1.8 lbs per hour} \\
\text{FSA at 25 percent purity weighs 10.1 pounds per gallon to give} \\
0.18 \text{ pounds per hour} \\
\text{The total feed rate is} \\
4.4 \text{ gallons per day (44 lb/day divided by 10.1 pounds per gallon)} \\
0.18 \text{ gallons per hour (4.4 gal per day divided by 24 hours)} \\
690 \text{ mL per hour (4.4 gal multiplied by 3.78 liters per gallon)}
\end{align*}
\]

So we have calculated that we need 44 lb/day.

Pounds of solution may be difficult to use as a control amount because the pump is calibrated in gallons, so let’s divide 44 by 10.1, which is how much each gallon of fluorosilicic acid at 25% purity weighs. This gives us 4.4 gallons, which is equal to 0.18 gallon per hour (dividing by 24 hours in a day). This is also 690 mL per hour. That is how much we need to set our pump to deliver.

If the water facility does not operate 24-hours per day, then the calculation would need to be adjusted accordingly. If there is only an 8-hour operation, you would divide 4.4 gallons per day by 8 hours to get 5.5 gallons per hour.
For our second example, we have a plant that is treating 5.8 MGD. The natural fluoride in the source water is 0.2 mg/L, and the optimal level for oral health for the state is 0.8 mg/L. The sodium fluorosilicate purity has been evaluated by the specific ion electrode method from the AWWA standard and has been determined to be 98%. So let’s discuss how to calculate dosage and pounds to be fed.
We have a plant that is treating 5.8 MGD. The natural fluoride in the source water is 0.2 mg/L and the optimal level for oral health for the state is 0.8 mg/L. So 0.8 minus 0.2 results in a dosage of 0.6 mg/L of fluoride to be added. Now, we can calculate the amount of additive to be added based on the dosage.
So we calculated that we needed a dosage of 0.8 minus 0.2 which is 0.6 mg/L of fluoride to be added. We put that dosage into the equation, and then substitute the capacity with 5.8 MGD. The NFSA has a purity of 98%. And from the earlier table, we know 0.607 mg of fluoride ion is available for each mg of additive. Using the standard water treatment equation and substituting the known values in the equation, we can compute that we need to feed 49 lb of solution per day. From other math courses, you have probably learned the concept of significant figures in calculations; because the 5.8 MGD has only two significant figures, we can rely on only two significant figures in the final calculations, so we round it to 49 lb/day.

So that is how much fluoride additive is needed in one day.
Calculation Problem 2 (step 3)

Average daily flow of 5.8 MGD
Optimal minus natural is \(0.8 - 0.2 = 0.6\) mg/L

\[
\frac{49 {\text{lb/day}}}{0.607 \times 0.98} = \frac{\text{Dosage} \times \text{Capacity} \times 8.34 \text{mg/min}}{\text{mg/L} \times \text{MGD}}
\]

The feed rate is 49 pounds per day, or 2.0 pounds per hour (dividing by 24 hours)
0.92 kilograms per hour (divide pounds by 2.2 to get Kg)
15 mg per minute (1000 mg in a Kg, and 60 minutes in an hour)

So we need to add 49 lb/day. That is how much we need to set our dry feeder to deliver. You can set it based on a calibration test to deliver the precise amount.

If the water facility does not operate 24-hours per day, then the calculation would need to be adjusted accordingly. If there is only an 8-hour operation, you would divide 49 pounds per day by 8 hours to get 6.1 pounds per hour.
For our last example, we have a plant that is treating 0.45 MGD. The natural fluoride in the source water is 0.4 mg/L and the optimal level for oral health for the state is 1.1 mg/L. The sodium fluoride purity has been evaluated by the specific ion electrode method from the AWWA standard and has been determined to be 96%. Let’s discuss how to calculate dosage and pounds to be fed.
We have a plant that is treating 0.45 MGD. The natural fluoride in the source water is 0.4 mg/L and the optimal level for oral health for the state is 1.1 mg/L. So 1.1 minus 0.4 is 0.7 mg/L of fluoride to be added. So now we know the dosage we want, we can calculate the feed rate.
So we calculated that we needed a dosage of 1.1 minus 0.4 which is 0.7 mg/L of fluoride to be added. We put that dosage into the equation, and then substitute the capacity with 0.45 MGD. The sodium fluoride has a purity of 96%. And from the earlier table, we know 0.452 mg of fluoride ion is available for each mg of dry additive. Using the standard water treatment equation and substituting the known values in the equation, we can compute that we need to feed 6.1 lb of solution per day. From other math courses, you have probably learned the concept of significant figures in calculations; because the 0.45 MGD has only two significant figures, we can rely on only two significant figures in the final calculations, so we round it to 6.1 lb/day.

So that is how much fluoride additive is needed in one day.
Calculation Problem 3 (step 3)
Average daily flow of 0.45 MGD
Optimal minus natural is
\[ 1.1 - 0.4 = 0.7 \text{ mg/L} \]
\[ \frac{6.1 \text{ lb/day}}{0.45 \text{ MGD}} \times 8.34 = 0.452 \times 0.96 \]
The saturator would need an additional 6.1 pounds per day. If a dry feeder is used, then 6.1 pounds divided by 24 hours is 0.25 pounds per hour (or 4 ounces or 120 grams).

So we need to add 6.1 lb/day. That is how much we need to set our dry feeder to deliver, or the amount that would need to be added to a saturator each day. You can set the dry feeder based on a calibration test to deliver the precise amount.

If the water facility does not operate 24-hours per day, then the calculation would need to be adjusted accordingly. If there is only an 8-hour operation, you would divide 6.1 pounds per day by 8 hours to get 0.76 pounds per hour.
Calculation Problem 3 (step 4)

Average daily flow of 0.45 MGD
Optimal minus natural is

\[
1.1 - 0.4 = 0.7 \text{ mg/L}
\]

\[
6.1 \text{ (lb/day)} = \frac{0.7 \text{ mg/L} \times 0.45 \text{ MGD} \times 8.34}{0.452 \times 0.96}
\]

The saturator would need an additional 6.1 pounds per day.

An saturated solution of sodium fluoride is 40,000 mg/L, which is 18,000 mg/L of fluoride ion.

6.1 pounds per day is 2,770 grams per day, or 2,770,000 mg. Divided by 40,000 mg/L is 69 liters per day.

69 liters per day is 2.9 liters per hour or 18 gallons per day.

18 gallons per day is 0.76 gallons per hour.

With this being a saturator, we need to know how much solution to pump in addition to how much sodium fluoride to add to the saturator. 6.1 pounds per day can be multiplied by 454 to get grams per day, and with 1,000 mg per gram, we need 2,770,000 mg of sodium fluoride each day. Since the solution is 40,000 mg/L, if we divide by 40,000, we get 69 liters per day, or 2.9 liters each hour. This is also equal to 0.76 gallons per hour.
There are some simple actions an operator can follow for process control.

First, understand the process and how it works.

Second, read the manual.

Understand the operating cycle, when the equipment operates, and when the equipment shuts down,

Know what things sound like when it is working well, and when it is not working well.
Sampling is an essential activity. The minimum EPA sampling for fluoride presumes that a facility does not adjust fluoride and has only the natural level. Consequently, EPA may require only annual testing. But when you are adding fluoride, you need additional information to verify operation. Both the AWWA and CDC recommend daily sampling of product water, and some of the better operated larger facilities may also practice hourly testing of product water to optimize chemical usage.

Make sure you use good locations for collecting samples. Verify that your sampling provides a representative concentration of the added fluoride. Occasional spot-sampling at random locations in the distribution system can identify other problems with the system such as storage tanks.
Accurate and consistent records are essential to good facility operations. Always check on what requirements your state may have on records and reporting requirements for water treatment facilities. For your facility, you need to maintain complete operational records, laboratory records, maintenance records, and customer comments.
Operational records for fluoridation include both the source and the product water fluoride level. The product water should be measured daily, but the source water may need to be sampled only quarterly if the fluoride concentration is reasonably consistent. Be sure to record where each sample is taken, who collected the sample, and the date and time of each sampling event. Also record the amount of fluoride additive used daily, for it is important to document how much was actually added, particularly if you have a sample that is excessively high as a false reading, along with a record of how much water is used if you are using a dry additive. Some states may have a requirement to record fluoride pounds or solution used for the measured water produced.

There are also records important for the operator adjustments. These can include calibration curves for pump or feeder settings. The calibration curves should be verified quarterly to account for changes in product quality and wear of equipment. As has been pointed out previously, the characteristics of the additive can change from batch to batch, so verify the chemical purity with each new delivery.

Ask your state program if they have any special records that are requested by the state.
To correctly operate the fluoridation system, certain tests must be prepared on the finished water to verify correct operation. Every water plant operator should then submit those results to the state water fluoridation program. The reason is that the results can then be compiled in a national database that is available to public health officials, medical doctors, dentists, and other health care providers to make good decisions for communities and patients on oral health based on actual fluoride levels. These results should be submitted at least monthly. Some states require weekly submissions.
Laboratory Records
- Dates, times, technician, location, methodology, etc. for sampling events
- Results of split-sampling with state proficiency laboratory
- Verification of analytical procedure against standards
- Maintenance of laboratory equipment

Be sure to record where each sample is taken, who collected the sample, and the date and time of each sampling event. Split sampling and testing with another reference laboratory are important to verify that your laboratory technicians are conducting the tests correctly and to reveal if there are interfering ions. Include tests on known reference standards to verify your analytical procedure. Also, maintain records on the laboratory equipment.
As part of a complete records program, certain maintenance records should be kept. It is good to know when parts such as hoses and pump diaphragms were last replaced, when changes to the electrical system that might affect the fluoride system were made, where parts can be procured for maintenance, and other relevant documentation. Remember that preventive maintenance is the best policy, and that does not mean what repairs were made. The objective of a good maintenance program is to provide continuous, dependable operation.
On a daily basis

Watch for trouble

Inspect system, listen to sounds
Look for leaks or differences

Liquid systems

Check solution levels, check level switch
Check hoses for air locks
Check pump for prime
Refill day tank

Dry feeders

Check for compaction
Refill additive hopper
For FSA systems, every 3 months

- Check all piping for leaks, and gas venting for integrity
- Check pipes/hoses for encrustations
- Inspect tank level measurement (floats, gauges, etc.)
- Calibrate pump delivery rate
For dry feeders, every 3 months

- Thoroughly clean, remove cinders/encrustations
- Check belts; adjust if necessary
- Lubricate bearings
- Calibrate feeder dispensing rate
- Rotate your inventory; check to ensure no bags in storage are older than 3 months, and use the oldest bags first to avoid product deterioration.
For a saturator, every 3 months

• Thoroughly clean, remove cinders/encrustations
• Verify uniform flow through additive bed: no short circuiting or piping (piping is when a flow channel like a “pipe” allows water to travel through bed without contact with additive)
• Verify water softener in working order
• Clean water strainer
• Check all piping for leaks
• Inspect tank level measurement (floats, gauges, etc.)
• Calibrate pump delivery rate
• Rotate your inventory; check to ensure no bags in storage are older than 3 months, and use the oldest bags first to avoid product deterioration.
Every 6 months

Motor driven pumps
  • Check lubrication, adjustments

Foot valves, lines, hoses, injector
  • Check for crystalline deposits
  • Disassemble and clean

Vacuum breaker, anti-siphon valve
  • The International Plumbing Code stipulates that all backflow prevention valves, anti-siphon valves, and vacuum breakers must be tested at the time of installation; after they are moved, relocated, or reinstalled; and a minimum of once every year. Replace any worn parts.

Saturator
  • Drain, disassemble, and clean
Suggested Maintenance

- **Annually**
  - Metering pump
    - Disassemble and replace worn parts
    - Replace hoses, diaphragms, seats, etc.
    - Clean valves
  - Foot valve
  - Suction, discharge valves
  - Anti-siphon valves; vacuum breaker
  - Injection check valves
  - Dry feeder
    - Check for worn gears, replace worn parts
    - Lubricate, change gear oil

Annually

Metering pump
- Disassemble and replace worn parts
- Replace hoses, diaphragms, seats, etc.
- Clean valves
  - Foot valve
  - Suction, discharge valves
  - Anti-siphon valves; vacuum breaker. The International Plumbing Code stipulates that all backflow prevention valves, anti-siphon valves, and vacuum breakers must be tested at the time of installation; after they are moved, relocated, or reinstalled; and a minimum of once every year; replace any worn parts.
  - Injection check valves

Dry feeder
- Check for worn gears, replace worn parts
- Lubricate, change gear oil
Troubleshooting is when you need to identify why there is a problem and solving it. Things to begin with in troubleshooting include:

- Changes in the equipment,
- Deviations in sound or smell,
- Change in the amount of chemical fed, or
- Change in the fluoride concentration.
Trouble Shooting – continued

- Pump won’t pump
  - Check hoses & fittings
  - Test check valves, foot valve
  - Check back pressure
  - Verify float/level controller operation
- Pump won’t pump like it used to
  - Clogged foot valve or strainer
  - Ruptured diaphragm
  - Worn seals
  - Change of pump stroke or speed
  - Pumps or pipes clogged with impurities
- Softener
  - Verify water hardness before/after softener
  - Check backwashing/regeneration

Some things you might have to do in troubleshooting include these common problems:

Pump won’t pump

Check hoses and fittings
Test check valves
Check foot valve—must be in vertical position
Check back pressure
Verify that pump is primed
Verify float/level controller operation

Pump won’t pump like it used to

Clogged foot valve or strainer
Ruptured diaphragm
Worn seals
Change of pump stroke or speed
Pumps or pipes clogged with impurities
Check pump adjustment knobs—they tend to loosen on their shaft

Softener

Verify water hardness before/after softener
Check backwashing/regeneration
If you experience excessive output

Siphoning
  Pumping downhill without an anti-siphon valve
Little or no pressure at injection point
Change of stroke length or speed
Dry feeders may have these problems:

Feed helix not turning but power ON
  Check for obstructions
Chemical will not feed
  Increase frequency of hopper agitator
  Check moisture content (fish eyes)
  Is material bridging or packing in bin?
Erratic feed
  Binding of drive shaft or helix
  Low speeds
If you have low fluoride readings in a saturator

Inadequate chemical depth

Incomplete mixing, verify no short circuiting or piping in bed

Inconsistent chemical addition

Accumulation of cinders, encrustations

Verify no slimes or grease layers in gravel or additive bed

Verify softener working properly; test solution strength to verify that the solution is saturated
If you have high fluoride readings, check the following:

**Phosphates**
- When using sodium 2-(parasulfophenylazo)-1,8-dihydroxy-3,6-naphlene disulfonate (SPADNS) method
  - Verify with ISE meter

**Sample chlorine residual**

**Check natural level**
- Fluctuations due to
  - Runoff
  - Low river flows
  - Seasonal variations
With variable fluoride readings,

Check feeder or pump for variable output, and recalibrate the settings.

Check for air binding in the metering pumps.

Has the saturator chemical bed been partially depleted, or is there insufficient material in the bin hopper?

Does your plant operate with intermittent operations; if so, are the electrical interconnections wired properly?

You may want to check your calculations and compare the calculated amount of chemical additive fed with the measured amount. Are the calculated levels comparable to the actual additive being consumed?
Some other considerations with variable fluoride readings include these items:

Verify additive purity, water content, or silica content

Verify chemical not bridging or packing in bin

Verify additive does not have excessive moisture or fish eyes

Incomplete mixing, verify that mixing tank has adequate volume for hydration/saturation

Is tank experiencing stratification of concentrations? (Different batches, complete dissolution, storage tanks?)
Additional considerations with variable fluoride readings.

Maintenance can result in unintended changes to controls and wiring.

Are controls and process working as intended?

Is wiring correct?

Does solution pump activate with one service pump but not the other?

Is there a changing flow rate that might result in variable fluoride readings?
There can also be laboratory influence results for low fluoride readings.

- Interference with lab tests
- Poor glassware
- Improperly cleaned glassware
- Phosphate detergent
- Rinse with distilled water
- Sample temperatures
- Improper laboratory methodology
- Instrument errors, damage
Calibration of equipment to verify rate of feed has been mentioned as an essential part of accurately controlling the system. You probably already do this, but let’s review the steps involved.

First, you close the valve to the pump, and open the valve to the calibration column and fill it. Don’t open the valve all the way at once or you might overfill the calibration column—allow it to fill slowly.

Then close the valve from the storage tank, and open the valve to the calibration column and pump to full-open position.

Then measure the time to pump a measured flow for several pump settings, including a rate below your normal feed rate and above your normal feed rate in addition to flow rates around the expected feed rate. If you don’t have a calibration column, consider adding one to the piping. The columns are relatively inexpensive, and the piping modifications can probably be accomplished in a couple of hours.
Calibration of dry feeders involves use of a pan test. Here is how a pan test is conducted.

Fill the hopper to a normal depth

Set the machine to low feed rate, collect discharge over a measured time

Repeat for several higher feed rates, including rates above and below your expected feed rate

Measure weight of pan with material and subtract pan weight to obtain material feed rate for each equipment setting
Once you have collected the discharge rate from the pump or the feeder, you can plot the results on a chart. Draw a line between the dots, and you have the result. This chart is prepared plotting the feed rate settings, normally 0%–100%, against either the pumping rate in gallons per minute or the discharge rate in pounds per hour.
Some considerations on calibrating a feed rate:

Calibration curve must be prepared for each pump or feeder.

Verify curve accuracy quarterly, more frequently if additive character change or maintenance is performed on equipment. The equipment will have wear and tear that will influence the operating characteristics over time. Also, the additive can change in character such as having a moisture content or higher silica content, so verify the nature of the additive during the calibration test.

Curve should be based on four or five settings over the full range.

Always include the date of the calibration test and compare the results with previous calibration tests.
Overfeed

- CDC provides overfeed recommendations, verify state specific requirements
- Water treatment facilities should have overfeed instructions with operator instruction on procedures
- For overfeeds less than MCL, continue operation while problem is identified
- For overfeeds exceeding MCL
  - Temporarily stop operations while problem is identified
  - Notification of state personnel
  - Flush lines
  - Notify the public

In actual experience, overfeeds are rare; many facilities will never have an overfeed incident in the life of the facility, but they do occasionally happen. CDC provides overfeed recommendations; verify what are the specific requirements in your state.

Each water treatment facility should prepare overfeed instructions with specific operator instructions on procedures for the plant. This might include flushing lines or some other appropriate activity. Each community should identify in advance what needs to be done. Consult with your state program to learn their policies on overfeed events.
This is good time to engage the class with a discussion on water fluoridation operations. Use a flip-chart to record their comments.
For fluoridation operations, we discussed

That process calculations are important and are the same type of calculation an operator should already be doing to optimize and manage the processes in the facility

What records should be maintained and what should be reported to the state

Maintenance of facilities

How to calibrate feed delivery

Some common troubleshooting problems
That covers water fluoridation operations. Are there any questions?
We have covered a lot of information today, but let us review what we have learned.
The course content included the following major topic areas.

• Why we fluoridate water
• Health effects
• Regulatory considerations
• Fluoridation additives
• Fluoridation equipment
• Fluoridation operations
• Safety considerations
• Laboratory analysis
Has this course provided you with the information you needed?

We want your suggestions on how to improve this course.
Thank you for your attention.