# US Drinking Water: Fluoridation Knowledge Level of Water Plant Operators

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**Abstract**

***Objectives:*** *We determined the knowledge level of water plant operators who fluoridate drinking water, and we compared small and large water plants.* ***Methods:*** *A pretested survey was sent to 2,381 water plant operators in 12 states that adjust the fluoride concentration of drinking water. A z-test for proportion was used to test for statistical difference between small and large plants at $\alpha=0.05$. Small water plants were those treating less than 1 million gallons of water daily.* ***Results:*** *Eight hundred small and 480 large water plant operators responded, resulting in a response rate of 54 percent. Two-thirds of water plant operators correctly identified the optimal fluoride level, but more than 20 percent used a poor source for choosing the optimal level. Only one-fourth of operators were able to maintain the fluoride concentration to within 0.1 mg/L of the optimal concentration. A significantly greater proportion of operators at large water plants than at small water plants reported that they were able to maintain a fluoride concentration to within 0.1 mg/L of the optimal concentration (33.5% vs 21.3%, $z=4.74$, $P<.05$).* ***Conclusions:*** *Although most operators correctly identified the optimal fluoride level, small water plant operators were less likely to use accurate reasoning for choosing that level and in maintaining fluoride concentrations within 0.1 mg/L of that level than large water plant operators. [J Public Health Dent 2001;61(2):92-98]*

*Key Words: drinking water, water fluoridation, fluoride concentration, fluoride.*

Fluoridation has long been the cornerstone of preventive dentistry in reducing dental caries. Presently, over 145 million residents in more than 10,500 communities throughout the United States have access to fluoridated public water supplies (1). The widespread availability of both topical and systemic fluorides have reduced differences in caries rates between fluoridated and nonfluoridated communities; nevertheless, those differences are still significant (2). The only known undesirable effect of water fluoridation at concentration levels above the recommended optimal range is enamel fluorosis.

Historically, enamel fluorosis can be traced to the early 1900s in the United States, when a young dentist, Dr. Frederick S. McKay, opened a dental practice in Colorado Springs, Colorado, and discovered that many of his patients' teeth presented with permanent brown staining of enamel. With the discovery that high concentrations of fluoride in drinking water caused enamel fluorosis, Dr. H. Trendley Dean was appointed by the US Public Health Service (PHS) in 1931 to conduct epidemiologic investigations. As had been observed by Drs. McKay and G. V. Black, Dean noted that persons with enamel fluorosis often had less dental caries than those without this condition. Dean investigated the inverse relationship between enamel fluorosis and dental caries. His "21 Cities Study" was conducted to determine the fluoride concentration in drinking water associated with a low prevalence of dental caries and insignificant levels of enamel fluorosis. His study showed that the optimal fluoride concentration in temperate climates was 1.0–1.2 mg/L (3-4). Even at this optimal concentration, however, approximately 10 percent of children developed very mild to mild enamel fluorosis (5), which Dean accepted as a necessary tradeoff for the decreased dental caries prevalence. By the mid-1950s, Galagan and Lamson demonstrated that air temperature was a factor in the amount of tap water consumed: more tap water was consumed in hotter climates (6). These researchers recommended that the optimal fluoride concentration range from 1.2 mg/L in the coldest areas of the United States to 0.7 mg/L in the warmest areas. The Public Health Service has endorsed these recommendations (7).

The PHS recommends an optimal or target fluoride concentration for each water system in each state, which is based on the annual average of the maximum daily air temperature for that location. In practice, the optimal concentration is established by the state health department. Although the PHS may recommend up to three fluoride concentrations for a state due to differences in temperature, most states set only one (8). Regardless of the number of target concentrations, it is not always possible to maintain an exact fluoride concentration in water systems; therefore, states require water systems to operate within an acceptable control range. The control range surrounds the state optimal fluoride concentration and is established by individual state environmental health programs. These programs vary among the states and can be under the health department or a stand-alone agency responsible for natural resources, drinking water, waste water, solid waste, and air. Current recommendations by the PHS set the control range at 0.1 below to 0.5 mg/L above the optimal level.

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Our purpose in conducting this study was (1) to determine the knowledge level about fluoridation of US water plant operators who fluoridate drinking water; and (2) to compare small and large US water plants by their selection and maintenance of the optimal fluoride concentration, factors responsible for variation in optimal fluoride level, and type of fluoride compound used.

## Methods

We asked the Division of Oral Health at the Centers for Disease Control and Prevention (CDC) to choose 12 states that would in their opinion be representative of all 50 states. The criteria used by CDC were based on four guidelines: (1) there was an active statewide fluoridation program; (2) a minimum of 50 percent of the population was drinking fluoridated water; (3) each area of the country was represented, as near as possible; and (4) both rural and urban states were represented. The states selected were Alabama, Arkansas, Colorado, Connecticut, Illinois, Iowa, Maine, Massachusetts, Missouri, Nebraska, Tennessee, and Texas.

CDC furnished the name of a contact person for each representative state. The contact person could be a fluoridation coordinator, director, or engineer. During the summer of 1997, we sent each of these 12 persons a survey questionnaire for their state, asked them to endorse our study, and asked them to provide us with mailing addresses for that state's water plant operators who fluoridate water. By early 1998, we had sent all water plant operators who fluoridate within the 12 states a two-page questionnaire that had been previously used in a mail survey of water plant operators in Ohio. Copies of the survey questionnaire are available from the first author. We also sent a cover letter explaining the survey and a preaddressed return envelope. Second and third mailings were used to help attain an adequate response rate.

Data from the completed questionnaires were entered into a database and a z-test was computed to test for differences in proportions between small and large water plants. Significance was assessed at $P<.05$. We defined small water plants as those treating less than 1 million gallons of water daily (MGD) (which generally serves a population of 6,000–7,000) and large water plants as those treating more than 1 MGD.

**TABLE 1**
**Participating State Water Plants**

| State | Total *n* | Large Plants *n* | Large Plants (%) | Small Plants *n* | Small Plants (%) |
|---|---|---|---|---|---|
| Alabama | 92 | 64 | (70.0) | 28 | (30.0) |
| Arkansas | 36 | 22 | (61.1) | 14 | (38.9) |
| Colorado | 45 | 26 | (57.8) | 19 | (42.2) |
| Connecticut | 19 | 17 | (89.5) | 2 | (10.5) |
| Illinois | 419 | 70 | (16.7) | 349 | (83.3) |
| Iowa | 199 | 35 | (17.6) | 164 | (82.4) |
| Maine | 35 | 12 | (34.3) | 23 | (65.7) |
| Massachusetts | 57 | 41 | (71.9) | 16 | (28.1) |
| Missouri | 91 | 36 | (39.6) | 55 | (60.4) |
| Nebraska | 44 | 13 | (29.5) | 31 | (70.5) |
| Tennessee | 141 | 84 | (59.6) | 57 | (40.4) |
| Texas | 102 | 60 | (58.8) | 42 | (41.2) |
| Total | 1,280 | 480 | (37.5) | 800 | (62.5) |

## Results

**Sample Response.** We mailed questionnaires to 2,391 water plant operators, of whom 1,280 (53.5%) responded. The response rates for the 12 participating states were as follows: Alabama, 76.7 percent; Arkansas, 48.6 percent; Colorado, 62.5 percent; Connecticut, 57.6 percent; Illinois, 41.5 percent; Iowa, 78.7 percent; Maine, 57.4 percent; Massachusetts, 70.4; Missouri, 56.5 percent; Nebraska, 71.0 percent; Tennessee, 65.3 percent; and Texas, 41.1 percent. Eight hundred (62.5%) of those responding operated small water plants, and 480 (37.5%) operated large water plants (Table 1).

In addition to size, as determined by MGD, we were able to include both primarily rural states—e.g., Arkansas and Maine—as well as urban states—e.g., Illinois and Massachusetts. Three of the sample states had mandatory fluoridation laws (Connecticut, Illinois, and Nebraska). Another aspect well represented in the sample was the location of the fluoridation program, i.e., the health department, the engineering/environmental unit within the health department, or in the environmental department. While Arkansas, Connecticut, and Nebraska have the fluoridation program located in the engineering/environmental unit within the health department, three other states (Maine, Missouri, and Tennessee) have their fluoridation programs housed in the environmental department. In the remaining six states, the fluoridation programs are housed in the health department. Two of the sample states (Colorado and Massachusetts) require training for their water plant operators, but the remainder do not require any training. While there is no difference in training for small and large plants, Colorado conducts fluorida-

**TABLE 2.**
**Optimal Fluoride Concentration and Acceptable Control Range in Participating States According to Individual State Policy**

| States | Optimal Fluoride Conc.* (mg/L) | Accept. Control Range* (mg/L) |
|---|---|---|
| Texas | 0.7 | 0.6–1.2 |
| Arkansas | 0.8 | 0.7–1.2 |
| Colorado | 0.9–1.1 | 0.7–1.3 |
| AL, CT, MO, NE | 1.0 | 0.8–1.2 |
| Illinois | 1.0 | 0.9–1.2 |
| MA, TN | 1.0 | 0.9–1.3 |
| Iowa | 1.0 | 0.9–1.6 |
| Maine | 1.2 | 1.0–2.0 |

*Optimal fluoride concentration and acceptable control range were provided by the fluoridation coordinator, director, or engineer of each state.

tion training yearly and Massachusetts requires training every other year.

When we analyzed the response rate of the individual states based on the existence of mandatory fluoridation laws, location of fluoridation program, or requirement for operator training, no trend was evident. For example, those water plants located in states with mandatory fluoridation laws responded from a low of 41.5 percent to 71.0 percent, while those plants in states without mandatory laws responded similarly from 41.1 percent to 78.7 percent.

**Optimal Fluoride Concentration.** Overall, 63.8 percent of the 1,280 water plant operators knew the correct optimal fluoride concentration for their plant (Table 2), and an additional 24.8 percent of operators gave the correct answer to within 0.1 mg/L. Overall, there was no difference in knowledge level between operators at large water plants and operators at small plants about the optimal fluoride concentration. Only in Iowa and Nebraska were there significant differences between small and large water plants. In Iowa small water plant operators were more likely to identify the correct optimal fluoride concentration than operators at large water plants (61.6% vs 42.9%, $z=2.04$, $P<.05$). On the other hand, in Nebraska large water plant operators were significantly more knowledgeable about the correct optimal fluoride concentration than small water plant operators (100% vs 80.7%, $z=2.73$, $P<.05$).

**Source of Information for Choosing Optimal Fluoride Concentration.** Respondents were asked what source of information was used to determine the optimal fluoride concentration. We considered highly accurate sources to be a water fluoridation manual for engineers or water plant operators, or the policy of the dental division at the state health department or regional Environmental Protection Agency office. We considered the average or middle of the fluoride range as established by the state environmental health program to be a moderately accurate source of information. We considered inaccurate methods of determining the optimal fluoride concentration to be historical concentration, selecting one that is easy to remember, trial and error, operator's decision, experience, cost, or choosing what works best. Overall, 70.1 percent of the water plant operators cited highly accurate sources for choosing the optimal fluoride concentration, and an additional 8.1 percent cited the moderately accurate source. On the other hand, 21.7 percent of water plant operators used the least accurate sources for choosing their optimal fluoride concentration. Overall, operators at large water plants were significantly more likely than operators at small water plants to cite the highly accurate sources (73.3% vs 68.1%, $z=2.00$, $P<.05$). This finding did not hold true for Connecticut or Arkansas. In Connecticut, small water plant operators were more likely than large plant operators to use the most accurate information for choosing their optimal fluoride concentration (100% vs 76.5%, $z=2.29$, $P<.05$). In Arkansas, large water plant operators were significantly more likely to rely on the least accurate information (18.2% vs 0.0%, $z=2.21$, $P<.05$).

**Ability to Maintain Optimal Fluoride Concentration.** Only 25.9 percent of water plant operators responded that they were able to maintain the fluoride level in drinking water to within 0.1 mg/L of their optimal or target fluoride concentration. Another 49.3 percent of operators claimed they were able to maintain the fluoride concentration from between 0.1 to 0.2 mg/L of optimal concentration, 19.5 percent felt they were able to maintain between 0.2 and 0.3 mg/L of optimal concentration, and 4.5 percent felt they were capable of maintaining it at >0.3 mg/L of optimal concentration. A significantly greater proportion of operators at large water plants than those at small water plants were able to maintain the optimal fluoride concentration to within 0.1 mg/L of optimal concentration (33.5% vs 21.3%, $z=4.74$, $P<.05$). No individual state showed any significant differences.

**Reasons for Variations in Optimal Fluoride Concentration.** The survey question on the factors responsible for any variation from the optimal fluo-

**TABLE 3**
**Factors Responsible for Variations from Optimal Fluoride Concentration**

| Factor | Total n (%) | Large Plants n (%) | Small Plants n (%) |
|---|---|---|---|
| *Problems with equipment or chemicals* | | | |
| Problems with feeder | 236 (18.4) | 88 (18.3) | 148 (18.5) |
| Variation in chemical purity or density | 36 (2.8) | 11 (2.3) | 25 (3.1) |
| *Poor training of water plant operator* | | | |
| Operator error* | 74 (5.8) | 16 (3.3) | 58 (7.3) |
| Fluoride feeder maintenance | 24 (1.9) | 14 (2.9) | 10 (1.3) |
| Physically changing fluoride drums* | 11 (0.9) | 1 (0.2) | 10 (1.3) |
| *Existing condition* | | | |
| Variation in main water flow | 164 (12.8) | 59 (12.3) | 105 (13.1) |
| Fluctuation in raw water fluoride concentration | 82 (6.4) | 38 (7.9) | 44 (5.5) |
| Problems with process control* | 52 (4.1) | 13 (2.7) | 39 (4.9) |
| Variation in temperature | 16 (1.3) | 3 (0.6) | 13 (1.6) |
| *Other or combined problems* | | | |
| Problems with filter backwash recycle or filter | 17 (1.3) | 10 (2.1) | 7 (0.9) |
| Problems with feeder + main water flow | 49 (3.8) | 22 (4.6) | 27 (3.4) |
| Problems with feeder + other factors* | 126 (9.8) | 64 (13.3) | 62 (7.8) |
| Variation in main water flow + other factors* | 71 (5.6) | 41 (8.5) | 30 (3.8) |
| Other | 103 (8.1) | 37 (7.7) | 66 (8.3) |
| *No response* | 219 (17.1) | 63 (13.1) | 156 (19.5) |

*Significantly different between large and small water plants ($P<.05$).

ride concentration allowed for open-ended responses. We categorized the responses as equipment or chemical problems, lack of water plant operator training, existing conditions, and other or combined conditions. We determined these categories based on problems previously reported to the state and CDC. The equipment problems included not having the correct equipment (e.g., buying the wrong size metering pump), not maintaining the equipment properly, not replacing worn out equipment, misuse of equipment, and not maintaining spare parts for the equipment. The chemical problems include purchasing the wrong chemical (e.g., sodium fluorosilicate [$Na_2SiF_6$] instead of sodium fluoride [NaF] for a saturator), obtaining the wrong grade or size of chemical (e.g., buying powder instead of granular sodium fluoride), and purchasing the incorrect purity of chemical. Existing conditions included variations in the main water flow (e.g., because a certain kind of well pump was used or a field of wells converged into one line), variation in outdoor temperature, and fluctuations in the fluoride concentration in the raw water (e.g., the water carried to the city of Los Angeles in the Owens Aqueduct varies from 0.2 mg/L to 0.8 mg/L of fluoride during the year, and the fluoride content in the Ohio River varies depending on the industrial discharge). Other conditions that may cause variation from the optimal fluoride concentration included earthquakes, floods, or other natural disasters or accidents. There also may have been a combination of factors, such as a poorly trained operator trying to use a poorly designed fluoride feeder system with a highly variable concentration of natural fluorides.

Equipment problems and variations in the main water flow were the most common reasons cited for variation from the optimal fluoride concentration (Table 3). Compared with operators at large water plants, operators at small water plants noted significantly more variation caused by operator error (7.3% vs 3.3%, $z=3.19$, $P<.05$) and process control (4.9% vs 2.7%, $z=2.04$, $P<.05$). Process control is the water treatment process, e.g., filtration, over which operators have no control.

**Fluoride Compounds Used.** Three types of fluoride compounds are presently in use by water plant operators: NaF, $Na_2SiF_6$, and fluorosilicic acid ($H_2SiF_6$). Overall, 11.6 percent of water plant operators reported that they used NaF, 10.9 percent used $Na_2SiF_6$, and 75.7 percent used $H_2SiF_6$ (Table 4). Operators at large water plants were significantly more likely than those at small water plants to use $Na_2SiF_6$ (20.2% vs 5.4%, $z=7.42$, $P<.05$). Conversely, operators at small water plants were significantly more likely to use NaF (15.5% vs 5.0%, $z=6.48$, $P<.05$) or $H_2SiF_6$ (78.3% vs 71.5%, $z=2.69$, $P<.05$).

**Other Factors Affecting Knowledge Level of Operators.** Factors other than the size of water plants also may contribute to the knowledge level of water plant operators who fluoridate US drinking water. Among those factors are: (1) the existence of a state law mandating fluoridation, (2) the physical location of the fluoridation program, and (3) the requirement of fluoridation training for water plant operators by state officials. Although CDC chose states that were primarily rural or urban for the sample, each state had both small and large plants. Therefore, we thought it would be more meaningful to compare small and large plants rather than compare plants based on population density criteria.

Table 5 shows the association of these factors with the knowledge level of operators. When we compared the responses of water plant operators who were mandated to fluoridate with

**TABLE 4**
**Fluoride Compounds Used**

| Compound | Total n (%) | Large Plants n (%) | Small Plants n (%) |
|---|---|---|---|
| Sodium fluoride (NaF)* | 148 (11.6) | 24 (5.0) | 124 (15.5) |
| Sodium fluorosilicate ($Na_2SiF_6$)* | 140 (10.9) | 97 (20.2) | 43 (5.4) |
| Fluorosilicic acid ($H_2SiF_6$)* | 969 (75.7) | 343 (71.5) | 626 (78.3) |
| Combination of compounds | 10 (0.8) | 10 (2.1) | 0 (0.0) |
| No response | 13 (1.0) | 6 (1.3) | 7 (0.9) |

*Significantly different between large and small water plants ($P<.05$).

**TABLE 5**
**Selected Factors Associated with Water Plant Operators' Knowledge of Optimal Fluoride Levels and Reported Ability to Maintain Fluoride Concentration within 0.1 mg/L of Optimal**

| | Correct Optimal Concentration n* (%) | Accurate Reasons for Choosing Level n (%) | Maintaining Fluoride Level within 0.1 mg/L n (%) |
|---|---|---|---|
| Fluoridation laws | | | |
| Mandatory | 329 (68.3)‡ | 301 (62.5)‡ | 122 (25.3) |
| Not mandatory | 481 (60.3) | 596 (74.7) | 209 (26.2) |
| Location of fluoridation program | | | |
| Health department | 557 (60.9)‡ | 637 (69.7)‡ | 251 (27.5) |
| Environmental unit† | 67 (67.7)‡ | 80 (80.8)‡ | 20 (20.2) |
| Environmental department | 186 (69.7)‡ | 180 (67.4)‡ | 60 (22.5) |
| Operator training | | | |
| Required | 63 (61.8) | 84 (82.4)‡ | 42 (41.2)‡ |
| Not required | 747 (63.4) | 813 (69.0) | 289 (24.5) |

*n=number of water plants.
†Environmental unit within state health department.
‡Significantly different ($P<.05$).

those who were not mandated, there were no clear-cut differences between the groups (Table 5). While those in mandatory states were significantly more knowledgeable about their correct optimal fluoride concentration (68.3% vs 60.3%, $z=2.92$, $P<.05$), they were significantly less likely to know why they chose that concentration (62.5% vs 74.7%, $z=-4.55$, $P<.05$) and reported no difference in their ability to maintain the fluoride level within 0.1 mg/L. On analyzing the impact of the location of the fluoridation program, again we noted no clear differences in knowledge levels among groups (Table 5). When the fluoridation program was located in the Environmental Department, the water plant operators were more likely to know the correct optimal fluoride concentration than those located in the Health Department (69.7% vs 60.9%, $z=2.69$, $P<.05$). However, for those programs in the Environment Unit in the Health Department, water plant operators were more likely to know the most accurate reasons for choosing that level than those located in the Health Department (80.8% vs 69.7%, $z=2.62$, $P<.05$) or Environment Department (80.8% vs 67.4%, $z=2.74$, $P<.05$). Operators in states that require fluoridation training (Massachusetts and Colorado) were significantly more likely than operators in other states to choose the most correct reasons (82.4% vs 69.0%, $z=3.33$, $P<.05$) and significantly more likely to be able to maintain the fluoride concentration to within 0.1 mg/L (41.2% vs 24.5%, $z=3.31$, $P<.05$).

## Discussion

The criteria set by CDC did not allow for a random selection of 12 states. Colorado was the only western state chosen because most western states have very little fluoridation. Utah has 3 percent, California has 15 percent, and Nevada only has 2 percent of its water supply fluoridated. Due to the first two guidelines set forth by CDC, not all states were part of the sampling frame. This was done to randomly select states with a greater number of water plants that fluoridate. While more efficient, it has in fact resulted in more of a convenience sample than a probability sample. Nevertheless, we consider the CDC methodology to be the most practical approach to sampling water plant operators who fluoridate US drinking water.

While we concentrated our analysis on the difference between the 480 large and 800 small water treatment plants, other characteristics of the water plants also were studied. These other factors included location of the plant in a state with or without a mandatory fluoridation law, location of the water plant in a state that requires fluoridation training of its operators to one that does not, and the location of the fluoridation program within or outside the health department. The response rate from each state ranged from more than 40 percent to nearly 80 percent. The two states with the lowest response rates (Illinois and Texas) both had sample sizes of more than 100 water plant operators. The overall response rate of 54 percent is reasonably good when one considers the relatively low pay grade of water plant operators. Response bias with any survey of less than 100 percent response rate can be a problem; however, because of the similarity of fluoridation training, or the lack thereof, and relatively low pay grade of water plant operators, the concern may only be minimal.

In this study, over one-third of respondents were inaccurate in the most basic knowledge of fluoridation. Eleven percent of the water plant operators did not know the correct optimal fluoride concentration of their plant to within 0.1 mg/L. Nevertheless, fewer than 0.5 percent of operators reported an optimal concentration that was outside the control range established by their individual state environmental health program. These 0.5 percent of operators all worked at small water plants. The size of the water plant was significantly associated with how operators reported choosing the optimal concentration: operators at large water plants more often used the most accurate source of information in choosing their optimal fluoride concentration, while operators at small water plants often depended on inaccurate information.

Water plant operators must be able to maintain an optimal fluoride concentration. Optimally fluoridated tap water is a major factor in the declining prevalence of dental decay in the United States (9-13) and abroad (14-16). When the concentration is below optimal, the prevalence of dental caries may increase, especially in children. Studies have shown that in once-optimally fluoridated communities in which water fluoridation had been decreased to suboptimal levels or had been discontinued, the prevalence of dental decay increased (17-19). On the other hand, when the fluoride concentration is higher than optimal, fluorosis is more common (10,13,20-22). Although it is not considered to be a public health problem, fluorosis can be perceived as an esthetic concern by parents of children with fluorosis (23). Three-quarters of operators felt they could maintain fluoridation concentrations to within 0.2 mg/L of optimal, and nearly 95 percent acknowledged they could maintain concentrations to within 0.3 mg/L. These results indicate a problem in maintaining consistent fluoride levels in US water supplies. The problem was especially noticeable with operators at small water plants, who were significantly more likely than operators at large water plants to report being able to maintain the optimal levels at 0.2–0.3 mg/L.

The factors responsible for variations from optimal fluoride concentrations were predominantly main water flow variations (12.8%) and feeder problems (18.4%). In fact, equipment breakdown often can cause the eventual discontinuation of water fluoridation in a community because of the time and costs of the repairs. When equipment breaks down, it takes time to replace or repair it. It is not uncommon for the fluoridation equipment that breaks down to be out of service for several days. Also, repairing the equipment, if costly, can require the permission of other officials and may require changes in the city budget. This process may cause the equipment to not be repaired for several months. When we considered the combined problems, we determined that feeder problems or main water flow variation plus other factors were responsible for approximately 50 percent of the occurrences where operators could not maintain a consistent fluoride concentration in the drinking water. We found little difference between small and large water plants with regard to feeder problems or main water flow variations, but other factors were significantly more prevalent among small water plants.

Water plant operator training in water fluoridation may be an important factor in the variations from optimal fluoride concentration in the drinking water. Water plant operators in states that require fluoridation training were significantly more knowledgeable in choosing and maintaining the optimal fluoride concentration than the other 10 sample states without mandatory training (Table 5). However, one limitation in the analysis was due to differences in group sizes; i.e., 102 plants required training, while 1,178 do not require training.

Presently, CDC is reasonably certain that operators are receiving very little fluoridation training. Colorado and Massachusetts are the only two states in the United States that have an ongoing training program, which consists of one-day training courses. CDC's definition of fluoridation training differs from that of most state drinking water programs. CDC recommends a minimum of one day (six-hour minimum) of training for fluoridation at least once a year. Almost all states have passed or will pass an operator certification program. State certification programs generally require fluoridation training for all operators of fluoridation systems. However, this training requirement is for a minimum of one hour per year, not one day per year, as CDC recommends. Most states that require fluoridation training, with the exception of Colorado and Massachusetts, have courses ranging from one to four hours in length.

A properly trained operator will know when the metering pump is the wrong size, when the chemical order is incorrect, how and when to test for fluoride properly, how to recognize variations in the fluoride level, and know how to immediately correct the variations. All water plant operators should receive start-up and annual training from the state drinking water engineers (24). The state engineers, in turn, should be trained in all aspects of water fluoridation, to include the public health benefits of water fluoridation and the role of water plant operators in providing those benefits (24). CDC recommends a full-time state fluoridation specialist or engineer (24).

A few water plant operators had questions on which fluoride chemical to use. The American Water Works Association sets standards for all chemicals used in water plants, including fluorides. All states require or urge all water plants to follow those standards (25-27). The fluoride compounds used in water fluoridation are the byproducts of the production of phosphate fertilizer. The byproduct is a weak solution of fluorosilicic acid, which is concentrated for use by the water supply industry. Both NaF and $Na_2SiF_6$ are salts precipitated from acid. Most very large water systems (e.g., New York City, Chicago, San Francisco, and Atlanta) use $H_2SiF_6$. Mid-size systems use either $H_2SiF_6$ or $Na_2SiF_6$, and small systems use either $H_2SiF_6$ or NaF. In large and mid-size water systems, the choice almost always is determined by economics. In small systems, the decision to use $H_2SiF_6$ or NaF depends on several factors. The state drinking water program may prefer the use of the acid compound ($H_2SiF_6$), but the small water plant operator may be somewhat leery of using the acid compound because the term "acid" may be interpreted as "toxic" by the lay public.

For water fluoridation to be effective, the fluoride level in the water system must be maintained consistently. The water treatment plant operator must know what the optimal fluoride level is and consistently maintain this level. This study has shown that while most, but not all, larger systems report maintaining the correct fluoride levels, many smaller systems are not. To correct this problem, it is recommended that CDC's training advice be followed: (1) the water plant operator should receive at least one day of training (six to eight hours) annually, (2) all state fluoridation specialists should attend CDC's basic fluoridation training course at least once a year and the advanced workshop at least once every three years, (3) trained state personnel should provide start-up training for all water plant operators for each new fluoridated water system, and (4) each state should employ at least one full-time state fluoridation specialist.

A major factor for the variations in fluoride levels is feeder problems or equipment breakdowns. This problem and the lack of state resources for training require money to correct. We recommend that the present CDC fluoridation grant program be expanded to assist the states in meeting these recommendations.

## References

1. Centers for Disease Control and Prevention. Fluoridation census 1992. Atlanta, GA: US Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, 1993.
2. Horowitz HS. The effectiveness of community water fluoridation in the United States. J Public Health Dent 1996;56(Spec Iss):253-8.
3. Dean HT, Jay P, Arnold FA Jr, Elvove E. Domestic water and dental caries. II. A study of 2,832 white children aged 12-14 years of eight suburban Chicago communities, including L. acidophilus studies of 1,761 children. Public Health Rep 1941; 56:761-92.
4. Dean HT, Arnold FA Jr, Elvove E. Domestic water and dental caries. V. Additional studies of the relation of fluoride domestic waters to dental caries experience in 4,425 white children aged 12-14 years of 13 cities in 4 states. Public Health Rep 1942;57:1155-79.
5. Dean HT. Chronic endemic dental fluorosis (mottled enamel). J Am Med Assoc 1936;107:1269-72.
6. Galagan DJ, Lamson GG Jr. Climate and endemic dental fluorosis. Public Health Rep 1953;68:497-508.
7. Reeves TG. Water fluoridation—a manual for engineers and technicians, Atlanta, GA: US Department of Health and Human Services, Public Health Service, Centers for Disease Control, 1986.
8. Lalumandier JA, Jones JL. Fluoride concentrations in drinking water. J Am Water Works Assoc 1999;91:42-51.
9. Brunelle JA, Carlos JP. Changes in the prevalence of dental caries in US schoolchildren, 1961-1980. J Dent Res 1982; 61(Spec Iss):1346-51.
10. Driscoll WS, Heifetz SB, Horowitz HS, Kingman A, Meyers RJ, Zimmerman ER. Prevalence of dental caries and dental fluorosis in areas with negligible, optimal, and above-optimal fluoride concentrations in drinking water. J Am Dent Assoc 1986;113:29-33.
11. Brunelle JA, Carlos JP. Recent trends in the dental caries in US children and the effects of water fluoridation. J Dent Res 1990;69(Spec Iss):723-7.
12. Szpunar SM, Burt BA. Dental caries, fluorosis, and fluoride exposure in Michigan schoolchildren. J Dent Res 1988;67:802-6.
13. Jackson RD, Kelly SA, Katz BP, Hull JR, Stookey GK. Dental fluorosis and caries prevalence in children residing in communities with different levels of fluoride in the water. J Public Health Dent 1995; 55:79-84.
14. Ismail AI, Brodeur JM, Kavanagh M, Boisclair G, Tessier C, Picotte L. Prevalence of dental caries and dental fluorosis in students, 11-17 years of age, in fluoridated and nonfluoridated cities in Quebec. Caries Res 1990;24:290-7.
15. Riordan PJ. Dental caries and fluoride exposure in Western Australia. J Dent Res 1991;70:1029-34.
16. Ismail AI, Shoveller J, Langille D, MacInnis WA, McNally M. Should the drinking water of Truro, Nova Scotia, be fluoridated? Water fluoridation in the 1990s. Community Dent Oral Epidemiol 1993; 21:118-25.
17. Lemke CW, Doherty JM, Arra MC. Con-

trolled fluoridation: the dental effects of discontinuation in Antigo, Wisconsin. J Am Dent Assoc 1970;80:782-6.
18. Kunzel W. Effects of an interruption in water fluoridation on the caries prevalence of the primary and secondary dentition. Caries Res 1980;14:304-10.
19. Stephen KW, McCall DR, Tullis JI. Caries prevalence in northern Scotland before, and 5 years after, water defluoridation. Br Dent J 1987;163:324-6.
20. Driscoll WS, Heifetz SB, Horowitz HS, Kingman A, Meyers RJ, Zimmerman ER. Prevalence of dental caries and dental fluorosis in areas with optimal and above-optimal water fluoride concentrations. J Am Dent Assoc 1983;107:42-7.
21. Segreto VA, Camann D, Collins EM, Smith CT. A current study of mottled enamel in Texas. J Am Dent Assoc 1984; 108:56-9.
22. Butler WJ, Segreto VA, Collins E. Prevalence of dental mottling in school-aged lifetime residents of 16 Texas communities. Am J Public Health 1985;75:1408-12.
23. Lalumandier JA, Rozier RG. Parents' satisfaction with children's tooth color: fluorosis as a contributing factor. J Am Dent Assoc 1998;129:1000-6.
24. Centers for Disease Control and Prevention. Engineering and administrative recommendations for water fluoridation, 1995. MMWR Morbid Mortal Wkly Rep 1995;44(RR-12):1-41.
25. American Water Works Association. AWWA standard for sodium fluoride. ANSI/AWWA B 701-94. Denver, CO: American Water Works Association, 1994.
26. American Water Works Association. AWWA standard for sodium fluorosilicate. ANSI/AWWA B 702-94. Denver, CO: American Water Works Association, 1994.
27. American Water Works Association. AWWA standard for fluorosilicic acid. ANSI/AWWA B 703-94. Denver, CO: American Water Works Association, 1994.