DEVELOPMENT OF A SIMPLIFIED WATER FLUORIDATION TECHNIQUE FOR SMALL COMMUNITIES[1,2]

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Water fluoridation can effectively reduce the incidence of dental caries; but various factors, including importation and cost problems, have limited implementation of the measure in socioeconomically deprived regions. This article describes a simple fluoridation method developed in Brazil that gets around these problems. The method uses locally available fluorite (calcium fluoride) as a partial replacement for sand in the filter beds of standard water treatment plants

Introduction

The work reported here arose from two proven facts—the enormous magnitude of dental caries as a public health problem in many parts of the world and the ability of water fluoridation to effectively combat caries *(1-3)*. In Brazil (and many other areas as well) it is believed that spread of the practice of fluoridation is hampered to some extent by the need to import the products traditionally employed. Studies have shown that fluorite (calcium fluoride, CaF_2), a mineral that occurs in Brazil, can be used to fluoridate water as effectively as other fluoride salts *(1,2,4)*. However, for various reasons until now these technical findings relevant to Latin America have not created any real prospect of large-scale fluoridation.

To further explore the possibilities involved, several national and international agencies—The Water Supply and Sewerage Agency of Rio Grande do Norte (CAERN), the Public Health Secretariat of Rio Grande do Norte, the Federal University of Rio Grande do Norte (UFRN), PAHO/WHO, and UNICEF—launched a pilot project in 1972. The project sought to use crude fluorite as the basic material for fluoridating water in small communities. This article describes work done in connection with that project.

Background Considerations

The first studies relating to fluoridation of public water supplies stemmed from investigations of dental fluorosis conducted by Frederick McKay in the United States. As a result of his initial findings, McKay eventually came to associate a low prevalence of dental caries with consumption of drinking water containing significant amounts of fluoride at levels insufficient to cause fluorosis *(2,3)*.

Later, between 1932 and 1939, Dean and his coworkers in the United States Public Health Service conducted a study of fluoride levels in the public water supplies of some 21 cities. This study made it possible to determine the optimal level of fluoride in drinking water—a level in the area of 1.0 ppm that is affected somewhat by climate. Today over 120 million people around the world are benefiting from water fluoridation *(2,3)*.

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[2]The study reported here was conducted with the technical assistance of PAHO/WHO engineering consultants Guillermo Roviralta and Arturo Velásquez, as well as that of Mohandas Bhat, Visiting Professor of Dentistry at the Federal University of Rio Grande do Norte (UFRN) under a Project Hope/URFN agreement.

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Fluoridation in Brazil

Fluoridation was introduced into Brazil by the Foundation of Specialized Public Health Services (FSESP), which in 1953 set up a pilot project at a town named Baixo Guando in the state of Espirito Santo. In 1967, after fourteen years of fluoridation, results obtained by the FSESP showed that the incidence of dental caries had fallen about 66.6 per cent, thereby reaffirming the effectiveness of the measure *(1,2,4)*.

According to 1977 Ministry of Health data (Table 1), some 227 Brazilian cities and towns in 18 states are today using fluoridated public water *(4)*. It is also true, however, that a significant number of these communities use sodium fluosilicate or sodium fluoride as raw material; and since these salts must be obtained from Germany, Italy, or the United States, importation problems and lack of commitment by official agencies have caused interruption of fluoridation in many of these systems *(4,5)*.

Use of fluorite. Studies by Bellack and Mayer, conducted in the United States in 1956, showed that fluorite is soluble in an acid medium and in solutions of aluminum sulfate. This established the feasibility of using fluorite for water fluoridation *(1,6)*.

In Brazil, the FSESP conducted pioneering surveys on fluorite use with a view to devising alternative techniques as a solution to importation-related problems. Experiments conducted in 1963 at a town named Macaé in the state of Rio de Janeiro gave quite satisfactory results. In addition, it has been found that use of fluorite markedly reduces operating costs. Accordingly, since that time new or projected systems making preferential use of crushed fluorite have been designed and set up when technically feasible *(1,2,4,6)*.

Fluoridation in Rio Grande do Norte. In response to rising public demand that dental

Table 1. Data on water fluoridation in Brazil showing the number of cities and towns served and the size of the populations benefited, by state, in 1977.

State	No. of water systems fluoridated				Population benefited			
	With natural fluoride	With fluorite	With sodium fluosilicate	Total	With natural fluoride	With fluorite	With sodium fluosilicate	Total
Amazonas	–	2	–	2	–	485,113	–	485,113
Maranhão	–	1	–	1	–	20,251	–	20,251
Piauí	–	1	–	1	–	34,188	–	34,188
Ceará	–	2	–	2	–	28,000	–	28,000
Rio Grande do Norte	4	7	–	11	90,788	49,299	–	140,087
Pernambuco	–	4	–	4	–	26,800	–	26,800
Alagoas	–	–	17	17	–	–	219,610	219,610
Sergipe	–	1	–	1	–	20,265	–	20,265
Bahia	–	8	1	9	–	132,664	–	132,664
Espírito Santo	–	11	1	12	–	204,910	12,615	217,525
Rio de Janeiro	–	1	2	3	–	90,000	120,000	210,000
Minas Gerais	–	28	2	30	–	650,944	1,104,970	1,755,914
São Paulo	–	–	12	12	–	–	1,095,905	1,095,905
Paraná	–	3	7	10	–	59,830	1,097,000	1,156,830
Santa Catarina	–	8	–	8	–	171,928	–	171,928
Rio Grande do Sul	–	–	102	102	–	–	2,979,117	2,979,117
Federal District	–	–	1	1	–	–	700,000	700,000
Mato Grosso	–	1	–	1	–	10,563	–	10,563
Total	4	78	145	227	90,788	1,984,755	7,329,217	9,404,760

Source: FSESP.

health needs be met,[6] in 1972 the State Secretariat of Public Health of Rio Grande do Norte placed among its priority goals for 1972-1975 the development of a social and preventive dental health program. As a first step in this undertaking a committee was established that included representatives of the Secretariat for Public Health, CAERN, the dental school of the Federal University of Rio Grande do Norte, and the Superintendency for Development of the Northeast (SUDENE).

The committee's purpose was to seek out and assess ways the aim of improving dental health could be attained. After performance of appropriate studies, the committee concluded that the most efficient, viable, and rapid solution would be to fluoridate existing and future water supply systems. It was also proposed that specific programs be designed and implemented for administering fluorides by alternative methods in communities where water fluoridation was not possible.

On the basis of these committee findings, the Public Health Secretariat—in coordination with other institutions including CAERN, UFRN, SUDENE, PAHO/WHO, and UNICEF—undertook to fluoridate public water supplies in Rio Grande do Norte *(7)*. Local implementation of this project was assigned to a technical team consisting at the outset of a sanitary engineer, a water treatment expert, a dental health specialist, and a physician. This team subsequently received technical support from two PAHO consultants.[7]

It was known at the time that Rio Grande do Norte possessed plentiful natural fluorite deposits from which the mineral could be extracted cheaply. It was also clear that any fluoridation process used would need to be compatible with prevailing socioeconomic conditions. Therefore, the program's operating strategy was directed at finding a simple and economical way of fluoridating small community water supplies with fluorite *(7)*.

The Study Framework

Significant socioeconomic considerations included the following:

- Over 50 per cent of the population centers in the state of Rio Grande do Norte were small communities.
- The rate of dental caries was high, the purchasing power of the state's population was low, and the manpower available for dental care was insufficient.
- Existing legal statutes declared water fluoridation to be a public health measure worth implementing.
- Public health institutions had become aware that water fluoridation offers an effective and efficient way to reduce the incidence of dental caries.

In addition, a number of preliminary technical points needed to be considered. One of these was the previously mentioned fact that exploitable fluorite deposits were present in the state. Another was the prospect for obtaining optimum levels of water fluoridation with crude fluorite. Also, it was necessary to ascertain that conditions peculiar to the water supply systems would permit adequate development of the proposed fluoridation technique.

It was also noted that the state of Rio Grande do Norte has low annual rainfall levels, and most of this rainfall occurs during a few months of the year. These and other circumstances account for the fact that water in the existing aquifers generally has good physical and chemical properties for most of the year. This in turn eliminates the need for auxiliary water treatment with aluminum sulfate, thereby making fluoridation with crushed fluorite more difficult.

Besides these considerations, the project work was based on two conceptual assumptions. The first was that the efficiency and effectiveness of water fluoridation with crude fluorite would depend on the size of the fluorite particles, the void-to-particle ratio,[8] the

[6]This statement is based on personal communications between the authors and technical staff members of the Secretariat for Public Health of Rio Grande do Norte.

[7]Engineers Guillermo Roviralta and Arturo Velásquez.

[8]The space between particles, expressed as an index.

water-granule contact time, and the flow rate of the system. The second assumption was that controlled imitation of the natural water fluoridation process could be accomplished efficiently and effectively at public water supply treatment facilities if established technical standards were maintained.

Materials and Methods

Laboratory tests were conducted in order to determine the best crude fluorite particle size for our purposes. This entailed construction of small-scale models where graded sizes of crude fluorite particles obtained from Rio Grande do Norte deposits could be tested. As Figures 1-3 indicate, the water fluoridated in these models was then subjected to chemical analysis, and the findings were plotted on curves correlating the contact time (in seconds) and fluoride content (in parts per million). In addition, these values were correlated with other variables—including the void-to-particle ratio, pH, water hardness, total alkalinity, and carbon dioxide. These latter correlations were made because of indications in the literature that acid or alkaline conditions could affect the fluoridation process.

The satisfactory results of these laboratory tests paved the way for implementation of the proposed fluoridation process at a number of treatment facilities serving existing water supply systems in Rio Grande do Norte. Accordingly, the following actions were carried out:

- Determination of the natural fluoride content of state public water supplies.
- Appraisal of the DMF (decayed, missing, and filled tooth) indexes prevailing among the schoolchild populations of places likely to be fluoridated.
- Assessment of existing water systems' suitability for fluoridation with crude fluorite.
- Selection of the systems to be fluoridated by the proposed method.
- Fluoridation of the chosen systems.

Figure 2. Relation between test water's F- content and its time of contact (in seconds) with fluorite particles having a diameter of 1 to 12 mm and a void-to-particle ratio of 0.43.

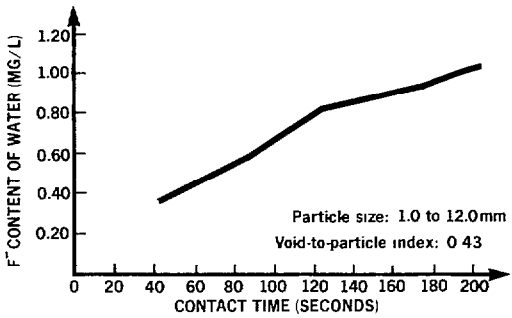


Figure 1. Relation between test water's F- content and its time of contact (in seconds) with fluorite particles having a diameter of 5 to 20 mm and a void-to-particle ratio of 0.48.

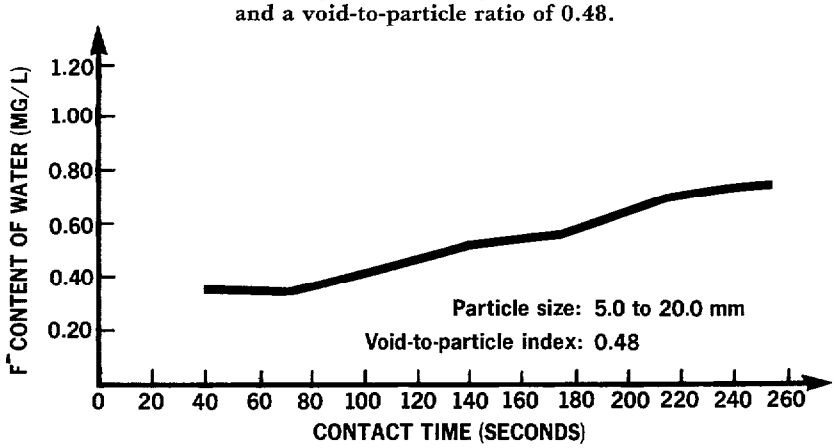
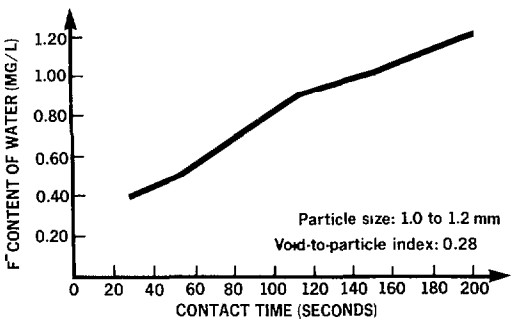


Figure 3. Relation between test water's F- content and its time of contact (in seconds) with fluorite particles having a diameter of 1.0 to 1.2 mm and a void-to-particle ratio of 0.28.



The first action, that of determining natural fluoride concentrations, involved drawing water samples from sources in areas being considered for fluoridation and finding the natural fluoride content of those samples. These determinations were made by the Scott-Sanches method, using a Bellack still *(2,3, 8,9)*.

Since prevailing temperatures can influence the optimum level of fluoridation (because people in hot climates tend to drink more water), data on average maximum daily temperatures in the areas selected were obtained from reports of the *Departamento Nacional de Obras Contras as Secas* (DNOCS).

Schoolchild DMF indexes were determined in the towns of Acari, Angicos, Currais Novos, and Jardim do Seridó (Table 2) by examining the teeth of schoolchild population samples in those centers. (Angicos and Jardim do Seridó were among the five towns selected for inclusion in the crude fluorite fluoridation program; Acari and Currais Novos have been fluoridating their water with powdered fluorite.) The preliminary DMF data obtained, which are now being subjected to computer analysis, are to be compared with the results of later DMF surveys in these towns in order to determine the effect of the provided fluoridation in preventing caries.

The findings obtained from these various actions, together with the laboratory data, were used to decide which water treatment systems seemed most suitable for fluoridation with fluorite and how these should be fluoridated.

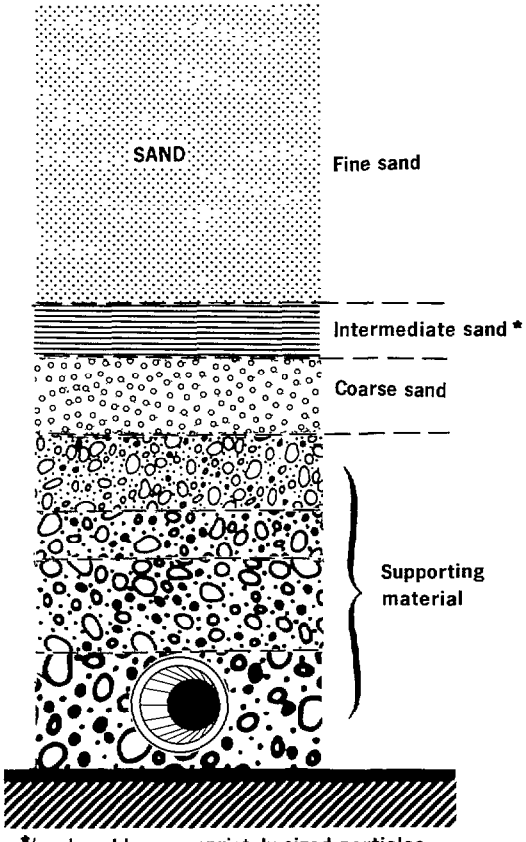
In particular, the laboratory research showed that the optimum-sized fluorite particles had a diameter comparable to that of intermediate-size sand particles in the middle sand bed of conventional water treatment plant filter systems (see Figure 4). For this reason, it was decided that the fluorite should be placed in this middle layer of the plants' filters. It was also felt that the fluoridation should be carried out at treatment plants using conventional water treatment systems, because this would provide the most extensive coverage and result in the maximum possible caries reduction in susceptible groups.

On the basis of the available information, the water supply systems of five Rio Grande do Norte communities (Angicos, Cruzeta,

Table 2. Baseline data (1975) on caries prevalences among schoolchildren 7-14 years old in four Rio Grande do Norte communities where the water was fluoridated with fluorite beginning in late 1974 or 1975 (see Table 3 for dates).

		Average number of teeth that were.							
Town or city	No of children examined	Sound	Carious, extraction not indicated	Carious, extraction indicated	Extracted	Filled	Total (average no. of erupted teeth)	DMF index	Natural F⁻ (mg/l) in water
Angicos	535	13.5	3.7	0.7	0.5	0.05	18.5	5.0	0.10
Jardim do Seridó	387	12.7	3.9	0.5	1.2	1.04	19.4	6.7	0.35
Acari	739	12.7	3.7	0.4	0.4	0.12	17.3	4.6	0.40
Currais Novos	984	12.0	3.6	0.5	0.6	0.5	17.3	5.3	0.40

Figure 4. Cross-section of a typical water treatment plant's filter showing the intermediate sand layer suitable for replacement with crude fluorite particles 1.0 to 1.2 mm in diameter.



*(replaced by appropriately sized particles of crude fluorite).

Jardim do Seridó, Pau dos Ferros, and Santana do Matos) were selected for fluoridation with crude fluorite (Table 3). Accordingly, a layer of crude fluorite was substituted for sand of comparable size in the intermediate (second) sand bed of each water treatment plant's filter system. The fluoride content of the emerging water was then controlled, and a mathematical formula for determining the volume of fluorite to be added to each system was applied.

Results

Preliminary Laboratory Findings

As Figures 1-3 show, the most suitable of the three particle size ranges tested was found to be the 1.0-1.2 mm range, which had a void-to-particle ratio of 0.28; that is, the tests showed that this particle size fluoridated a maximum quantity of water with the minimum volume of fluorite. Also, laboratory analyses of water fluoridated by this method in the laboratory and at the treatment plants showed that observed variations in the water's physical and chemical properties (with regard to pH, hardness, total alkalinity, and carbon dioxide content) did not interfere with the fluoridation process (Table 4).

Fluoridation Levels

The previously mentioned formula for determining the amount of fluorite needed, a formula which proved applicable in practice, treats the volume needed as a function of the void-to-particle ratio, the water flow rate, and the water-fluorite contact time. This formula is as follows:

$$Vf = \frac{Q \times T}{Iv}$$

where Vf is the volume of crushed fluorite to be used (in liters), Q is the water flow rate of the system (in liters per second), T is the water-fluorite contact time derived from experimental data (in seconds), and Iv is the void-to-particle ratio (determined by dividing the volume of water present by the volume of fluorite present).

Subsequent laboratory testing of fluoride ion levels in water samples from each water treatment plant over a five-year period showed that these levels held constant at 0.75 mg per liter.

The Fluoridation Process

In general, the simplicity of the described procedure (from the planning phase through

Table 3. Urban areas of Rio Grande do Norte providing water fluoridated with fluorite since 1975, by locale.

Town or city	Total urban population	Population supplied with water	Date fluoridation began	Form of fluorite used	Natural F- in water (mg/l)	Adjusted F- content of fluoridated water (mg/l)	Per capita cost per year (in cruzeiros)[a]
Acari	7,657	4,958	October 1974	Powder	0.40	0 75	0.15
Angicos	9,051	4,350	May 1975	Crushed stone	0 10	"	0.03
Cruzeta	3,851	2,966	June 1975	Crushed stone	0.30	"	0.03
Currais Novos	24,389	21,358	October 1974	Powder	0.40	"	0.15
Jardim do Seridó	5,422	4,390	February 1975	Crushed stone	0 35	"	0.06
Pau dos Ferros	12,917	9,752	March 1975	Crushed stone	0.25	"	0.03
Santana do Matos	3,298	1,515	July 1975	Crushed stone	0.35	"	0.06

[a]December 1975 exchange rate: US$1 00 = Cr 9.02.

Table 4. Chemical analysis of seven community water supplies fluoridated with fluorite by the Water Supply and Sewerage Agency of Rio Grande do Norte (CAERN), 1975.

Town or city	pH	Hardness (ppm)[a]	Total alkalinity (ppm)[b]	Carbon dioxide (ppm)	Adjusted F- content (ppm)
Acari	7.9	94.0	53.0	8.0	0.75
Angicos	7.9	148.0	98.0	3.0	0.75
Cruzeta	7 6	68.0	54.0	9.0	0 75
Currais Novos	7.9	94.0	53.0	8.0	0.75
Jardim do Seridó	7 6	56.0	30.0	3 0	0.75
Pau dos Ferros	7.8	64.0	59.0	3.0	0.75
Santana do Matos	7.9	112.0	79.0	2.0	0 75

[a]ppm of calcium carbonate and other constituents that contribute to water hardness
[b]ppm of substances that contribute to water alkalinity

the implementation phase) minimized the chances for human error or equipment problems that could interrupt the fluoridation process.

Operating costs were low because (aside from the fluorite) no special material, equipment, or other technical apparatus needed to be acquired or maintained. And, as Table 5 shows, in terms of overall costs this crude fluorite process proved more efficient than other fluoridation methods.

Also, the fact that the fluoride level in the output waters was maintained by this process over a five-year period shows that the useful service life of the crude fluorite added was similar to the service life (five to eight years under our conditions) of the sand bed it replaced.

Discussion and Conclusions

In general, Brazil's smaller communities are justly considered the neediest, and so governmental priority has been assigned to assisting them. This official priority reemphasizes the need to develop simplified fluoridation technologies suited to the socioeconomic conditions of these smaller communi-

Table 5. Annual per capita costs of fluoridation in Rio Grande do Norte communities using different raw materials, 1977.

Raw material utilized	Annual per capita cost (in cruzeiros)
Fluorite (as crushed stone)	0 04[a]
Fluorite (as powder)	0.15[a]
Sodium fluosilicate	2.40[b]
Sodium fluoride	2.59[b]

[a]Source of data Present study
[b]Source of data Grimplastch *(4)* December 1977 exchange rate: US$1 00 = Cr 15 95

ties. Such technologies should be inexpensive, should be easily applied, and should make use of locally available natural resources.

Within this context, crude fluorite's abundance and cheapness in Brazil makes it easy to use for fluoridating public water. Published official data show that deposits of this mineral have been found in the states of Rio Grande do Norte, Bahía, Minas Gerais, Paraíba, Pernambuco, Rio de Janeiro, and Santa Catarina *(11,12)*.

It is also felt that technical and operating problems with the conventional fluoridation processes now in use, together with difficulties involved in importing the basic materials these processes require, have become impediments to serving a larger proportion of the population, especially the residents of small communities *(5)*. Overall, of the 223 systems artificially fluoridated in the country as of 1977 (see Table 1), 145 were using imported sodium fluosilicate *(4)*. Substitution of naturally occurring fluorite for this fluosilicate, where appropriate, is in accord with the Government's high-priority policy of import substitution. Hence, it appears that there is excellent justification for the research done on fluoridating the water supplies of small communities with crude fluorite.

When this research began in 1975, Brazil's experience with crude fluorite in water supply systems was limited to a study done by the FSESP in the towns of Cachoeiro do Itapemirim and Jeronimo Monteiro. This study involved a pilot project in the first town and a full-scale program in the second *(1,4,6)*. The method used consisted of passing water through a bed of crushed rock (crude fluorite) at a rate that would place the desired level of fluoride (between 0.8 and 1.0 mg per liter) in the water.

Unfortunately, it appears that the final results of this FSESP study never found their way into the literature—so that there has been no way of analyzing those findings and comparing them to the results of the work described here. However, the very lack of information suggests either that the results were unsatisfactory or that the study could not be concluded for other reasons.

The present study was based on the hypothesis that crude fluorite could be used efficiently and effectively in water fluoridation processes if appropriate scientific criteria were developed and applied to those processes. The study has produced results confirming this hypothesis and has also developed a simplified water fluoridation technology that permits scientific criteria to be applied—by means of a mathematical formula theoretically derived and subsequently proven in practice. The efficiency of the procedure involved has been demonstrated by the results obtained, especially those results showing the method's comparatively low investment cost vis-a-vis the cost of other fluoridation processes now in use. The process was also found to be effective because of its simplicity, which tends to reduce the incidence of human and mechanical errors interfering with the fluoridation process.

As previously mentioned, the effectiveness of artificial fluoridation in reducing dental caries is well-recognized around the world. In the specific case of our study, no findings of this sort have yet been reported because the time elapsed is barely sufficient to start yielding meaningful results. However, the matter has not been neglected. Baseline data on the prevalence of dental caries in other fluoridated Brazilian communities have been gathered, and as of this writing an evaluation of our fluorite fluoridation program's impact on dental caries is underway.

SUMMARY

Water fluoridation studies have shown repeatedly that fluoridation can effectively reduce the incidence of dental caries. Nevertheless, various factors—including the need to import fluoride salts and the cost of fluoridation to poor communities—have hindered implementation of this worthwhile public health measure in many developing countries. The Brazilian study reported here evolved a method for overcoming these problems by fluoridating community water supplies with cheap and locally available fluorite (calcium fluoride).

In essence, the method involves replacing intermediate-size sand particles in the filter bed of a standard water treatment system with fluorite particles of comparable size. In 1975 five towns in the state of Rio Grande do Norte had their water supplies fluoridated by this method. The amount of fluorite added was sufficient to raise the fluoride level of the water supply to 0.75 parts per million, a level that was still being consistently maintained in all the towns five years later. The average cost of the crushed fluorite used for this purpose came out to around 0.04 cruzeiros per person per year.

Besides its effectiveness and low cost (no additional personnel or expensive pieces of equipment are required), the method has the advantage of being very simple—thereby reducing the chances for human or mechanical error. Overall, there seems good reason to conclude that this method could prove useful for fluoridating community water supplies in areas where fluorite is locally available, and where socioeconomic conditions dictate that costs must be kept down.

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