Legionella in water distribution systems

Regular culturing of distribution system samples is the key to successful disinfection.

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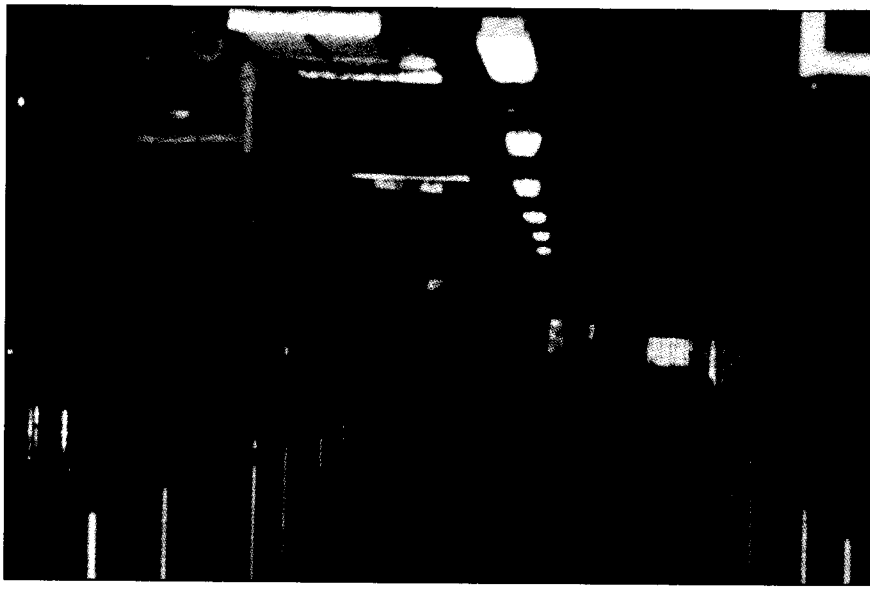
Water distribution systems are usually the source of *Legionella*, the bacterium that causes Legionnaires' disease. Water systems in hospitals, hotels, nursing homes, industrial plants, and homes have been linked to outbreaks of this disease.[1–3] Although early reports considered cooling towers to be an important reservoir for this pathogen, most of those reports were published before it was discovered that potable water could also be the source.[4] Since this discovery, attribution of cases of hospital-acquired Legionnaires' disease to cooling towers has dropped precipitously. For example, the British Communicable Disease Surveillance Centre reported that 19 consecutive hospital-associated outbreaks of Legionnaires' disease in the United Kingdom since 1981 were attributed to water distribution systems.[5] Surveys of hospital water systems show that 12–70 percent are colonized with *Legionella* (Table 1).

Legionnaires' disease arises from the presence of *Legionella* in water systems. *Legionella* can be found within biofilms throughout the entire water distribution system. Control measures such as copper–silver ionization, superheat-and-flush procedures, ultraviolet light, instantaneous heating systems, and hyperchlorination have been applied with variable success. Specific approaches, advantages, disadvantages, and costs of each method are reviewed. Many approaches commonly recommended by public health authorities have not been scientifically validated. Results from routine environmental surveillance cultures for *Legionella* are the critical component for rational decision-making.



Legionella can be found in low concentrations in lakes and rivers but can proliferate in distribution systems. Outbreaks of Legionnaires' disease have been linked to water systems in hospitals, industrial plants, and homes.

Conditions promoting the growth of Legionella in water systems

Low concentrations of *Legionella* can be found in natural aquatic bodies such as lakes and rivers. These low concentrations can be markedly amplified within distribution systems.[6] *Legionella* survives and grows within distribution systems partly because the chlorine residual is not sufficient to completely kill it. Large water distribution systems provide *Legionella* with optimal conditions for growth: warm temperatures (about 45–50°C), nutrients (such as sediments and biofilms), and commensal microorganisms.

Many approaches commonly recommended by public health authorities have not been scientifically validated.

Several factors seem to promote the survival and proliferation of *Legionella*. Temperature is a key factor in water distribution systems.[6] Water samples from tanks with temperatures of 50°C or less were significantly more likely to be positive for *Legionella*.[7–9] Electric heaters (versus gas or oil) were associated with contaminated domestic hot water systems.[10,11] Vertical tanks (i.e., those in which the height is greater than the width) were significantly more likely to be contaminated than horizontal tanks.[7] Furthermore, older tanks were also significantly associated with the presence of *L. pneumophila*,[7,8] perhaps because of the accumulation of scale and sediment in older systems. On the other hand, one of the largest outbreaks of Legionnaires' disease occurred in a new hospital at the Wadsworth Medical Center in Los Angeles, Calif.,[12] and *Legionella* colonized the water system of a newly constructed long-term care facility.[13] In 15 hospitals, higher concentrations of calcium and magnesium were associated with the presence of *L. pneumophila* in hot water tank samples.[7] Shock absorbers installed within water lines were a reservoir for *Legionella* in one hospital.[14]

Bacteria and protozoa also colonize pipe surfaces, some of which have been shown to promote *Legionella* replication.[15] *L. pneumophila* is known to infect amoebae, most notably *Hartmanella veriformis, Acanthamoeba* species, and ciliated protozoa.[16] *Legionella* and other microorganisms attach to surfaces and form biofilms on pipes and other materials throughout the water distribution system. *Legionella* can colonize plastics such as polyvinyl chloride, stainless steel, rubber, wood, and to a lesser degree copper in concentrations up to 10^5 cfu/cm^2.[6,17] Water-pressure changes that disturb the biofilm may dramatically increase the concentration of *Legionella*.[18] The biofilm can also interfere with disinfection directed at *Legionella* because bacteria within biofilms are more resistant to biocides and heat than freely suspended bacteria.[19] Some chemical disinfectants such as chlorine are even rendered inactive by the organic constituents of biofilms.[20] Following some disinfection procedures, *Legionella* within the biofilms then can reseed the water distribution systems.

Disinfection methods for Legionella

Copper–silver ionization. Copper and silver ions kill *L. pneumophila* in vitro[21,22] and in situ.[23] Copper and silver ions have also been shown to inhibit amoeba.[24] More than 30 hospitals in the United States are now using copper–silver ionization to control *Legionella* in their water distribution systems.[24–34]

Method. Ions are electrolytically generated from electrodes made of copper and silver. The manufacturer* recommends that copper and silver ion concentrations be maintained at 0.2–0.4 and 0.02–0.04 mg/L, respectively. These concentrations are well below the maximum contaminant levels specified

*LiquiTech, Willowbrook, Ill.

by the US Environmental Protection Agency for drinking water. Copper and silver concentrations should be monitored. Copper concentration can be estimated weekly by use of a sampling kit and verified monthly by atomic absorption spectroscopy. Samples of hot water used for assays should be clear, not turbid.

Advantages. Copper–silver systems are easily installed and maintained. Efficacy is not affected by higher water temperature, unlike chlorine and ultraviolet light. Oral consumption is limited because ions are added only to the hospital hot water recirculating lines. *Legionella* are killed rather than suppressed, which can minimize the possibility of recolonization.[22] Recolonization was delayed by six to twelve weeks even after the ionization system was shut down in one hospital.[23,34] Thus, the residual effect provides an added margin of safety (unlike hyperchlorination, in which *Legionella* can rapidly appear if the system malfunctions).

Disadvantages. Scale must be removed from the electrodes regularly to ensure best performance. Excessively high ion levels have turned water a blackish color and stained porcelain sinks lavender.[28] Elevated pH (≥ 8.0) reduces the effectiveness of copper–silver ions against *Legionella*.[35] Long-term treatment with copper and silver ions could theoretically result in the development of resistance to these ions.

Cost. The costs for installation of copper–silver ionization units range from $60,000 to $100,000 depending on the size of hospital. Annual maintenance cost, largely to replace electrodes, ranges from $1,500 to $4,000.

Thermal eradication (superheat-and-flush procedures). Raising the hot water temperature was the first method successfully used for disinfection.[36,37] The "superheat-and-flush" method can be used as an emergency procedure during an outbreak of Legionnaires' disease or intermittently to suppress widespread *Legionella* contamination.

Method. Hot water tank temperatures are elevated to 70°C, and then all water outlets, faucets, and showerheads are flushed for 30 min.[38] It is critical to document that the water temperature at the distal outlet reaches 60°C. If this temperature is not reached or if the duration of flushing is too brief, the procedure is likely to fail. The Centers for Disease Control Guidelines for Prevention of Nosocomial Pneumonia erroneously recommended flushing outlets for 5 min.[39] The duration of flush should be 30 min, not 5 min. A 5-min flush failed to eliminate *Legionella* at two hospitals; a 30-min flush was later successful.[40] *L. pneumophila* can recolonize within weeks to months after superheat-and-flush procedures. Because hot water systems that are maintained above 50°C are less likely to be recolonized by *Legionella*,[7,9–11] several hospitals maintained hot water temperatures at 60°C after using the superheat-and-flush procedure.[9,41]

Advantages. The superheat-and-flush method requires no special equipment, so it can be initiated expeditiously. Costs are minimal if personnel costs and overtime can be controlled.

Disadvantages. The superheat-and-flush procedure is time-consuming, and a large number of personnel are needed to monitor hot water temperatures and flushing times. Mixing valves and scald guards must be bypassed. Disinfection is only temporary, and recolonization of the system will occur within months.[42] Scalding can occur, although such incidents have not been reported by hospitals using this method.[43,44] Signs and newsletters have been effective at relaying information about the procedure.[45] However, several hospitals that do not alert patients or personnel have not reported scalding incidents.

egionella thrives in water distribution systems in part because the chlorine residual is not sufficient to completely kill it.

Cost. The superheat-and-flush method can be the least expensive control measures; personnel costs have been the greatest expense assocated with this method. For example, in one 500-bed hospital, the cost per superheat-and-flush episode was about $20,000.[25] In another 900-bed hospital, the cost in 1990 was $31,000.[43] Surprisingly, fuel and energy costs are reduced because at the higher temperature less hot water is used to maintain water at a comfortable temperature for bathing.[46]

Ultraviolet (UV) light. The efficacy of UV light has been demonstrated in vitro[47–50] and in vivo.[51–53] Continuous UV light treatment combined with filtration prevented *Legionella* from colonizing water fixtures that were near the point of use[52] in a single hospital ward housing renal transplant recipients.[53] UV light can also be used with chlorination to provide supplemental protection against *Legionella*.[54]

Method. UV light units are effective if installed near peripheral outlets such as showerheads and faucets. The water flows in one port of the hydraulic chamber and is sterilized by UV light generated by mercury lamps.

Advantages. UV light systems are easy to install and do not harm water or plumbing. Unlike copper–silver ionization and hyperchlorination procedures, the UV light procedure forms no disinfection by-products.

Legionella in hospital water distribution systems

Year	Site	Hospitals Surveyed	Positive for Legionella percent (number)	Identity of isolate	Reference
1985	Wales	40	70 (28)	*L. pneumophila*, serogroup 1	[illegible]
1987	Pennsylvania	15	60 (9)	*L. pneumophila* serogroups 1–6	
1992	Quebec	84	68 (57)	*L. pneumophila* serogroups 1–8, *L. longbeachae*, *L. micdadei*	6
1993	Scotland	17	12 (2)	*L. pneumophila* serogroups 1, [illegible] and [illegible]	[illegible]
1994	Nova Scotia	39	23 (9)	*L. pneumophila*, *L. longbeachae*	[illegible]

Disadvantages. UV light does not provide residual protection because *Legionella* will persist in biofilms where UV light cannot penetrate.[55] Thus, UV light is unsuitable as the only control measure for an entire hospital water system; a systemic disinfection method (such as superheat-and-flush procedures or hyperchlorination) is required for hospitalwide disinfection.[54,56] Water must be filtered to minimize the accumulation of scale on the quartz glass tubes, and the tubes must be cleaned regularly.

Cost. In 1996, four large (984.2 L/min [4.3 gps]) and two small (113.6 L/min [0.5 gps]) units* installed at a 500-bed hospital cost an estimated $50,000. A filtration system is an additional expense.

Instantaneous heating system. Instantaneous heating systems flash-heat water to a temperature >88°C and then blend the hot water with cold water to achieve the desired temperature. Two of two hospitals (100 percent) with instantaneous heating systems† were free of *Legionella* as opposed to nine of 13 hospitals (70 percent) with conventional water tank systems.[7] However, instantaneous heaters did not eradicate *Legionella* in three hospitals, presumably because *Legionella* in biofilms was not affected.[25]

Method. Such systems are most effective when installed as the original heating system in a new building. If an instantaneous heating system is to be installed in a hospital contaminated with *Legionella*, the entire system must be decontaminated after installation.

Advantages. These systems are more efficient and require less space than conventional hot water tanks. Large-volume water heaters, in which stratified water temperatures and sediment accumulations can support the growth of *Legionella*, are eliminated.

Disadvantages. Heat treatment is limited to the incoming hot water, and no residual protection is provided. Complete eradication of *Legionella* cannot be achieved unless hot water temperature at outlet sites exceeds 60°C. Furthermore, these heaters have difficulty providing the large volume of superheated water required to flush many outlets for 30 min, so that superheat-and-flush disinfection may not be feasible.

Cost. At a 330-bed hospital with three semi-instantaneous heaters, the average cost of each heating unit was $12,000–15,000 plus installation costs.[25]

Hyperchlorination. The residual level of chlorine in domestic water is usually <1.0 mg/L.[51,57,58] Initial suppression of *L. pneumophila* usually requires chlorine concentrations of 3–6 mg/L and subsequent maintenance concentrations of 2–4 mg/L. Continuous hyperchlorination has been used with variable success to control the growth of *L. pneumophila*.[12,43,59–62] Supplemental chlorination in the range of 2–6 mg/L has also been combined with the superheat-and-flush method.[43,63] In one hospital, *L. pneumophila* recolonized after shock (i.e., periodic) hyperchlorination two to five months after chlorine concentrations returned to baseline levels.[64]

Method. Two approaches have been applied: shock hyperchlorination and continuous hyperchlorination. During shock hyperchlorination a pulse of chlorine is injected into water to achieve a concentration of 20–50 mg/L throughout the system.[38,55] After 1–2 hours, the water is drained, and the system is mixed with incoming water so that the residual chlorine returns to 0.5–1 mg/L.

Continuous hyperchlorination is accomplished by continuous injection of calcium hypochlorite, sodium hypochlorite, chlorine dioxide, or gas chlorination.[38,65,66] Residual chlorine concentrations will fluctuate because of changes in incoming water quality, flow rates, and scavenging by system materials or indigenous biofilms. Engineering personnel need to be trained to monitor the residual chlorine concentration.

Combined shock and continuous chlorination was tested by adding 10 mg/L of chlorine to the water heaters for 30 min followed by systematic purging of the hot water system with cold water containing 1–1.5 mg/L of residual chlorine.[67] However, five to seven months of intermittent chlorination was required before *Legionella* was eradicated.

Advantages. Residual disinfectant is provided throughout the entire water distribution system.

Disadvantages. Chlorine is highly corrosive and damages pipes. Three years after chlorination at the University of Iowa hospital, the incidence of pipe leaks was 30 times the rate before chlorination.[68] Even after all hot water pipes were coated with a sodium silicate precipitate, one to three leaks per month continued to be noted.[68]

Chlorine may only suppress *Legionella* rather than kill it, and rarely can *Legionella* be eradicated by this

*Aquafine, Valencia, Calif.
†Leslie Controls, Tampa, Fla.

Methods recommended for controlling Legionella

Advisory Group	Hot Water Temperature: Storage Tank	Hot Water Temperature: Outlet	Cold Water Temperature	Minimize Stagnancy	Use Approved Plumbing Materials	Flush Faucets and Showerheads Periodically	Comment
Allegheny County Health Department[111]	60 ± 2.5°C	50–60°C	<20°C	Yes	NM*	NM	Remove sediment and sludge from water storage tank; clean and disinfect cold water storage tank annually
Harper[91]	>60°C	55–60°C	<20°C	Yes	NM	Yes	Maintain Cl_2 level at 1–2 mg/L
Hart & Makin[92]	NM	50°C	NM	Yes	Yes	Yes	Purge and chlorinate [illegible]
Department of Health, United Kingdom[90]	>60°C	>50°C	<20°C	Yes	Yes	NM	[illegible]
Chartered Institute of Building Service Engineers[93]	>55–60°C	>46°C	<20°C	Yes	Yes	Yes	NM
Health and Safety Commission[94]	NM	NM	NM	Yes	Yes	[illegible]	[illegible]
Health and Safety Executive[95]	>60°C	50°C	<20°C	Yes	[illegible]	[illegible]	[illegible]
Occupational Safety and Health Administration[96]	>60°C	>50°C	<20°C	Yes	NM	NM	[illegible]
Worksafe Western Australia[97]	>60°C	NM	NM	Yes	NM	Yes	[illegible]

*NM—not mentioned

method.[65] Forty minutes were required to kill 99 percent of *L. pneumophila* in vitro at 0.1 mg/L of free chlorine; <1 min was required to kill 99 percent of *E. coli*.[69] If a chlorinator fails or malfunctions, *Legionella* can reemerge within days. Most hospitals using this method will still encounter sporadic cases of Legionnaires' disease.[67] The presence of *Legionella* within amoeba, which may be more resistant to chlorine, may theoretically allow *Legionella* to recolonize after chlorine levels drop.[70] Because chlorine has a limited ability to penetrate biofilms,[71] it is less effective against biofilm-associated microorganisms such as *Legionella*.

The reaction of chlorine with organic materials produces trihalomethanes, which are known carcinogens. Several studies have documented a higher estimated risk of cancer in those who consumed chlorinated water compared with controls. A meta-analysis of 10 case-control studies[72–81] and two cohort studies concluded that this risk was clinically significant.[82] The risk of acquiring cancer is presumably even higher if hyperchlorinated water is consumed. Finally, a higher rate of miscarriage in pregnant females has been linked to consumption of chlorinated water.[83]

Cost. Costs depend on the type of chlorinator, the number and capacity of chlorinators, and supplemental equipment. In 1993, the University of Iowa reported costs of $75,800 to install chlorinator injectors, $48,000 for consultant fees, and an annual operating cost of $7,000.[68] In an 800-bed hospital, the cost was $88,000 initially, plus $16,000 annually for maintenance. A hospital in Pittsburgh, Pa., found the costs of continuous hyperchlorination approached $150,000 for the first year.[25] Maintenance costs resulting from replacement of pipes were high. Silicate injection devices used to minimize corrosion cost $55,000 to install and $11,000 annually to operate in the University of Iowa hospital.[68]

Ozone. Ozone has proved effective in vitro and in model plumbing systems.[51] One hospital had equivocal results.[84] The authors do not know of any hospital that has installed such a system to control *Legionella*. The advantages and disadvantages of this system are discussed elsewhere.[85]

Redundancy as a disinfection approach. More than one disinfection approach may be used so that if one fails, another can serve as a backup.[54,86] Synergy has been documented in vitro between chlorine and either UV light or copper and silver ions. Thus, chlorination might be combined with other disinfection methods but at a lower concentration of chlorine than if used alone.[21,54,87,88] The authors recommend that an existing chlorination facility should not be dismantled even if it is replaced by other methods, because it may still be used for backup or as part of a synergistic disinfecting approach.

Unvalidated eradication methods

Some institutions attempted, without success, to eradicate *Legionella* from showers and faucets by immersing the contaminated showerheads and faucets in boiling water or chemical disinfectants. *Legionella* promptly recolonized after these fixtures were placed back on line. Automatic drain valves fitted to showers did not maintain a reduction in the number of *Legionella* in shower water.[89]

Most methods recommended by various advisory groups[90–97] to control *Legionella* have not been scientifically validated, and some methods are now known to be useless (Table 2). Virtually all advisory groups recommend good engineering practice and preventive maintenance,[89,91] despite the fact that *Legionella* colonization is unaffected by such practice. Hospitals that practiced preventive maintenance, including cleaning or flushing the hot water storage tank on a weekly to annual basis, were as likely to have systems contaminated with *Legionella* as those without such programs.[7] Even after "appropriate" engineering practices for preventing legionellosis were instituted in 17 hospitals in England and Wales, *Legionella* was recovered from 12 percent (two of 17) of the water systems.[98]

Some advisory groups have suggested that certain rubbers and plastics promote the growth of *Legionella* and thus should be avoided,[6,99–101] whereas other materials, such as thiuram-containing rubbers and copper, have been recommended because they inhibit it.[6,100] The National Water Council in the United Kingdom tests plumbing materials for their ability to support microbial growth and lists approved materials in a Water Fittings and Materials Directory.[102] In one London hospital, it was concluded that replacement of *Legionella*-contaminated rubber washers with a type approved by the National Water Council eradicated *Legionella* from persistently contaminated fittings.[103] Unfortunately, no controlled study compared approved replacement washers with the originally colonized washers, so this hypothesis remains unvalidated. The results in this London hospital were also confounded by simultaneous initiation of chlorination of the cold water and elevation of hot water temperatures (>55°C). In another hospital, changing washers did not eradicate *Legionella*.[104] Although these approved materials may not promote the growth of *Legionella*, biofilms will eventually develop on most plumbing materials. *Legionella* will even colonize biofilms on surfaces of copper, a substance known to inhibit *Legionella*'s growth.[6]

Bacteria within biofilms are more resistant to biocides and heat than are freely suspended bacteria.

Most advisory groups have suggested eliminating stagnation points in the water distribution systems. These areas are thought to serve as a breeding ground for *Legionella* that then reseeds the system. Although this recommendation appears to be reasonable, it is difficult to remove all dead ends, and experience has shown that doing so seems to have little bearing on *Legionella* colonization. Maintenance of cold water temperature below 20°C throughout the system has also been recommended without scientific validation.[90,91,93,95,96]

The one scientifically based recommendation is to keep hot water tank temperatures >60°C.[7,8,41,42,51,105–108] However, if the water system is already colonized, the entire system must first be disinfected. Even then, high water temperature only minimizes or delays *Legionella* recolonization.

Monitoring after disinfection

Routine periodic surveillance using environmental cultures is necessary, because mechanical failures and human error are to be expected. It is easy and inexpensive to isolate *Legionella* by culture on selective dye-containing media.[109] The average cost of environmental cultures for one year at six health-care centers was approximately $1,300 (range $350–$2,500).[110] The highest yield of *Legionella* requires use of buffered charcoal–yeast-extract selective media containing dyes, glycine, vancomycin, and polymyxin.[109] The highest concentration of *Legionella* will be found in the biofilm, not the flowing water collected from a peripheral outlet. Therefore, swabs should be used to sample distal fixtures. The authors recommend that environmental samples be cultured at two-month intervals in hospitals with documented hospital-acquired Legionnaires' disease, because recolonization could occur within weeks if the disinfection equipment malfunctions. Hospitals using hyperchlorination may need to culture samples at two-week intervals because *Legionella* are relatively chlorine-tolerant and recolonize rapidly if the system fails. If environmental cultures are positive, a hospital's physicians and infection control practitioners should be more suspicious of any case of pneumonia contracted by a patient.

Legionella is difficult to eliminate from a water distribution system by any disinfection method. Small pockets of *Legionella* may survive in protected niches but in numbers insufficient to cause infection. *Legionella* infections in one Pittsburgh hospital did not occur until the percentage of *Legionella*-positive sites exceeded 30 percent,[36] but other hospitals have recorded cases when a lower percentage of sites was positive.[110]

Because outbreaks of Legionnaires' disease have coincided with hospital construction,[18] environmental cultural surveillance and preventive measures should be intensified during construction projects that affect water lines or when the water supply is shut down and later repressurized.

Maintenance of mechanical disinfection methods such as copper–silver and UV light is an important, but underestimated, factor in long-term success.

Summary

Environmental cultural surveillance for *Legionella* is the foundation for a rational long-term approach to successful disinfection. The Allegheny County (Pa.) Health Department recommends that all hospitals culture once a year, even those without cases of Legionnaires' disease.[110,111] If any cultures are positive, specialized laboratory tests for *Legionella* diagnosis should be made available to the physicians in that hospital. If disinfection is to be instituted, baseline environmental information should be documented first so that the effectiveness of the disinfection measure can be evaluated. Culturing of samples collected from faucets, showerheads, and ice machines should be directed at high-risk patient areas such as intensive care units and transplant wards.[112]

The superheat-and-flush procedure can be used during an outbreak. Once the crisis is over, long-term solutions should be considered. The major change since the last review[38] of this topic is that copper–silver ionization has proved to be an efficacious and cost-effective method. However, before the purchase of any commercial system, a hospital should obtain evaluations from other hospitals using the same system.

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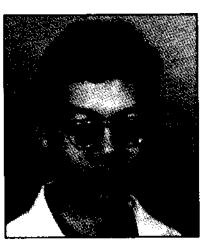

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